Emanuel von Zezschwitz, Daniel Buschek,
Axel Hösl, Henri Palleis, Hanna Scheider,
Tobias Stockinger, Simon Stusak, Sarah Tausch,
Andreas Butz and Heinrich Hussmann (Editors)

Human Computer Interaction in the Internet of Things Era

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University of Munich
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Emanuel von Zezschwitz, Daniel Buschek, Axel Hösl, Henri Palleis
Hanna Schneider, Tobias Stockinger, Simon Stusak, Sarah Tausch,
Andreas Butz and Heinrich Hussmann (Editors)

Human Computer Interaction in the Internet of Things Era

An overview of current trends, developments, and research in human-computer interaction

Preface

This report provides an overview of current applications and research trends in the field of human-computer interaction. It especially focuses on sensor-rich environments and interaction with smart devices. Various topics are discussed ranging from system security, big data, and persuasive technology to blended interaction.

During the summer term 2015, students from the Computer Science Department at the Ludwig-Maximilians-University in Munich did research on specific topics and analyzed various publications. This report comprises a selection of papers that resulted from the seminar.

Each chapter presents a survey of current trends, developments, and research with regard to the Internet of Things. Although the students' background is computer science, their work includes interdisciplinary viewpoints such as theories, methods, and findings from interaction design, ergonomics, hardware design and many more. Therefore, the report is targeted at anyone who is interested in the various facets of current topics in HCI.

Munich, September 2015

The Editors

Emanuel von Zezschwitz, Daniel Buschek, Axel Hösl, Henri Palleis,
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Blended Interaction: a method to analyse smart objects based on cognitive theories

Inga Brehm

Abstract—In the area of the Internet of Things more and more applications are emerging nowadays. How can we support the design process of those applications especially focused on the interaction? The integration of cognitive theories can help to better understand humans and use these findings in the design process.

The aim of this paper is to present the theory of blending as well as the framework of Blended Interaction and to transfer those concepts to the context of the Internet of Things. In the following I outline the cognitive background of blending or conceptual integration and present the underlying principles. I then specify the framework of Blended Interaction and provide the example of Affinity Table. The second part of this paper illustrates the basics of the Internet of Things with related application sectors. Finally, the example of Sifteo cubes is presented and analysed related to the concept of blending. The analysis shows that this application provides a well defined blend.

Index Terms—Blending, conceptual integration, Blended Interaction, embodied cognition, Internet of Things, smart objects

1 Introduction

In the era of the Internet of Things bridging the gap between the physical and the digital world plays an important role. But how can we develop intuitive to use interfaces or objects, taking into consideration the complexity and power of computational devices and simplicity of direct physical manipulation? To answer this question it is import to understand how humans learn and how human cognition works. We can then transfer this cognitive background to the area of interface design.

In this paper I will present the concept of blending [9], [5] and the framework of "Blended Interaction" [11]. I will then outline the background of the Internet of Things. Based on the assumption, that the theories can be beneficial in the context of the Internet of Things, I will finally analyse one example application.

2 Cognitive theory

This section deals with the cognitive background of blending and the explanation of a blend. In this context I will illustrate the terms embodied cognition, metaphor and mental space.

2.1 Embodied cognition

In cognitive science the term embodied cognition emphasises the importance of physical and social interaction for human reasoning [11, p.1141].

According to Gibbs [7, p.1-3/8] embodiment tries to explain the issue to what extend the body of a person influences situated cognition (for instance thinking and speaking). The way how human cognition is formed and how humans make sense of their environment depends to a great extend on embodied experience. For this reason exploration of the world via physical actions is important for children to enable learning and the formation of basic concepts.

Lakoff [13, p.3-4] states that this does not only mean that humans need a body to understand their environment but also that the form of reasoning is based on embodiment. "The same neural and cognitive mechanisms that allow us to perceive and move around also create our conceptual systems and modes of reason" [13, p.4]. Summarised three important discoveries of cognitive science are the following: "The mind is inherently embodied. Thought is mostly unconscious. Abstract concepts are largely metaphorical" [13, p.3].

2.2 Metaphor

Imaz and Benyon [9, p.37-40] claim, that the use of metaphors has advantages and disadvantages. Beneficial is, that they enable new methods for interaction based on previous knowledge, even though they can also be misunderstood. They define metaphors related to the comprehension in literature without the poetic associations but as a conceptual means. Via a metaphor existing mental schemata can be projected to another context. For the definition of the term, the concept of a domain plays an important role.

"A domain is a coherent sphere of activity observed and described at some level of abstraction" [9, p.37]. There are abstract domains (love) and concrete domains (maternal love, the Titanic). Abstract domain are more general and less specific than the concrete ones. One domain is used to define another domain.

To illustrate the term Imaz and Benyon provide the example of the metaphor "Love is a journey" [9, p.38], in which travelling is the source and love the target domain. In this metaphor different projections occur. Two lovers are associated with travelling companions with a shared travelling destination. As soon as a mapping has taken place the metaphor can be used in a broader sense. Lakoff[12, p.207]] names the situation of being stuck with someone as an example.

2.3 Mental Space

Metaphors and other terms can be seen as instructions for the creation of mental spaces [9, p.40]. Mental spaces are fragmentary cognitive structures that are formed when thinking and talking "allowing a fine-grained partitioning of our discourse and knowledge structures" [4, p.11]. They are characterised as different domains and support the understanding of the environment [4, p.34]. Imaz and Benyon [9, p.40-41] explain, that mental spaces have different sources namely background experience, cognitive models, observed actions as well as conversations. Connectors can mediate in between different mental domains by creating relations among aspects of different spaces, resulting in a network of connections.

2.4 Blends/ conceptual integration

According to Imaz and Benyon [9, p.43] a blend or conceptual integration is created by combining two input spaces into a third one. The structure of the blend is dependent on the two input spaces but also forms a new structure itself. Fauconnier and Turner [5, p.39-42] explain how the process of blending works based on the riddle of a Buddhist monk. In the morning the monk climbs up a hill, makes a break to meditate and walks down again another morning. The aim is

- *Inga Brehm is studying Human-Computer-Interaction at the University of Munich, Germany, E-mail: Inga.Brehm@campus.lmu.de*
- *This research paper was written for the Media Informatics Advanced Seminar ' Human Computer Interaction in the Internet of Things Era', 2015*

to find out, if there exists a location where the monk is located at the same time of the day on both journeys. To solve the riddle, one can imagine the monk walking up and down the same day and meeting himself a certain point on his way. This way of dealing with the riddle arises the question how one could reach the answer and be certain that it is correct, although such an encounter in reality is not possible. The explanation lies in the way human sense making works. For the human reasoning it is not relevant that this situation cannot take place but that it is generally possible for two people to meet. Human imagination allows blending these two separate journeys into one, where an encounter is possible.

Imaz and Benyon [9, p.43] describe blending as a composition of three intermediate steps. In the beginning relations and aspects of the two input domains are connected via a cross-space mapping *(see figure 1)*. Based on the example of the monk the two different journeys are the input spaces and the cross-space mapping refers to the "mountain, moving individual, day and motion" [5, p.41].

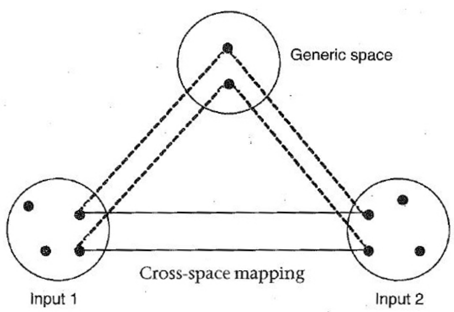

Fig. 1. Cross-space mapping and Generic Space [9, p.44]

Then a generic space *(see figure 1)* is created by projecting the shared aspects from the cross-space mapping into one space [9, p.44]. The generic space of the riddle contains: " a moving individual and his position, a path linking foot and summit of the mountain, a day of travel, and motion in an unspecified direction" [5, p.41].

In the end the blend *(see figure 2)* comes into existence through a partial projection of elements of the two input spaces. The blend is not only structured by the input spaces, but has its own new structure [9, p.44]. In the monk story the blended space contains both journeys with their dynamic (different positions at different times of the day) intact [5, p.41].

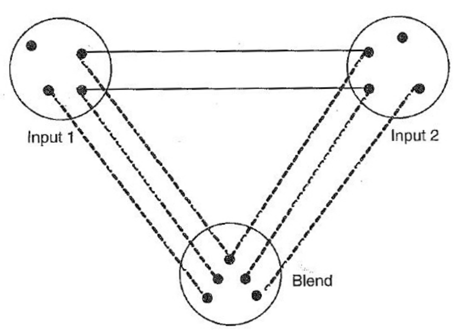

Fig. 2. Blend (or blended space) [9, p.45]

Imaz and Benyon [9, p.44-45] list composition, completion and elaboration as the three central principles of blending. Composition is about the creation of new relationships, that were not existent in the initial inputs. Completion enables the perception of blended structures as one construct via already acquired knowledge. In addition via elaboration the blend can be further development, expanded and specified.

2.5 Desktop metaphor as a blend

Imaz and Benyon [9, p.50-54] name the desktop metaphor as an example for a blend, which is the result of joining office objects with computer commands like copy and paste. The origins of the desktop metaphor lie in the Xerox Star and the idea of building on familiar concepts, in order to facilitate the understanding of computers. Since the beginnings of the desktop interface, it has evolved up to now and developed to a large blend. When dealing with the desktop interface it is common knowledge, that for instance a window (as well as the other objects) on the screen is not the same as a window in real live.

The term metaphor derives from the fact that the desktop interface builds on the initial metaphor, in which most of the common office tasks have maintained as actions for the interface (for example opening and closing of folders). The executed actions resemble those of an office job and no thought needs to be spent on the related computer commands. In the metaphor the operation system is presented as an office desktop. However, when analysed further it becomes apparent that the desktop interface is a blend that builds on this office metaphor. There exist actions like using a double click to open a folder, that have no equivalent in neither of the two input spaces, giving the desktop interface a new structure of its own.

2.6 Blending: Methods and Principles

Imaz and Benyon [9, p.106-111] mention two different types of principles for blending. Constitutive principles are the main principles, which describe the activity and make a distinction related to other actions by establishing rules. There are three constitutive principles as defined before: Composition, Completion, Elaboration. Whereas constitutive principles define rules for the process of blending and mental spaces, governing principles (or guiding principles) communicate strategies to make the development of blending more effective. Both types of principles provide limitation by implying what will not happen, but cannot be used to predict the final outcome.

An important aspect of using these principles for blending is to develop blends at a level of abstraction that humans can understand focused on the key features without any unneeded details.

There are different principles of governing. Often it is not possible to fulfill all of those concepts at the same time, but they can be used to help to make good design related decisions. If two principles conflict, the more important concept has to be figured out. In the following sections the different principles of blending are summarised based on Imaz and Benyons findings [9, p.50-54].

2.6.1 Compression

A blend consists of a compression of relations between the different input spaces. It is recommended to choose the aspects of the space more related to human understanding to project to the blend. In the blend only the important elements and states should be noticeable. For example the trash can icon in the desktop metaphor has two states. It can be empty, when no element is contained or full, when one or more elements are in it. No intermediate states for the different amounts of items exist, because they are not needed in the desktop context.

2.6.2 Topology

The topology describes the composition of items. Two different types are available: inner- and outer-space topology. The inner-space is related to connections inside one input space, whereas the outer-space describes relations among different input spaces. Diverse ways of projecting topologies to the blend can be applied. When dealing with the desktop interface the inner office topology has been lost by putting the trash can on the desktop, which is usually located underneath the desk.

2.6.3 Integration

Human cognition uses integration. Integration is about the creation of a blend that is perceived as a unit, where the manipulation takes place in context to the whole concept. The blend should be perceived as uniform, not as assembled from different parts. In that way it is easier to be used by humans and easier to remember. Integration can be reached through pattern completion, web and unpacking.

Pattern completion refers to the systematic use of available background knowledge to complete the blend, for instance using the office frame of the desktop metaphor in context of another interface in order to add additional functions.

Web deals with establishing backward connections from the blend to original input domains. Despite that the focus lies on the blend and not the initial input spaces, those connections should be experienceable for humans to facilitate understanding.

The unpacking principle states, that it should be understandable, how the blend was constructed and deconstruction should be possible. An important aspect to simplify this process is the existence of appropriate connections in between input spaces.

2.6.4 Relevance and Recursion

A blend should not contain unneeded items, if an aspect is not related, it should be disposed. The principle of recursion refers to the possibility of reusing one blend as an input for another blend and in this way reaching a degree of compression.

2.7 The folder blend

Based on the example of the folder blend *(see figure 3)* Imaz and Benyon [9, p.114-117] specify, how a blend is created between an input device like the mouse and a graphical user interface. This example consists of two blends. The first blend (manipulation blend) is created by the combination of the input space of the mouse and the input space of manual actions. This results in three new actions in the blend. A click is composed of pressing and releasing the mouse button and is used for selection. Two clicks equal a double click associated with the open action. A drag can be used to move something by pressing the mouse button and moving the device. Finally a drop is executed to stop a drag action by releasing the mouse button.

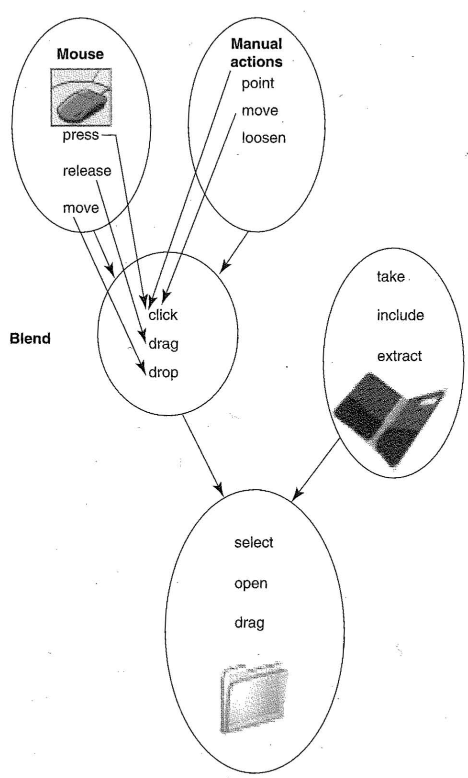

Fig. 3. The folder blend [9, p.117]

Based on the governing principle of recursion, which says that a blend can be used as input for another blend, the manipulation blend is combined with a physical folder to produce the folder blend. The result of the folder blend is the folder icon and several actions, that can be executed on this digital representation. A folder can be selected with a click and opened with a double click on the icon. Moreover, digital folders can be moved by dragging and elements can be put into the folder by dropping them onto it.

3 Blended Interaction

The term "Blended Interaction" is introduced by Jetter et al. [11] based on the before mention cognitive theory as a framework to explain why an interface is perceived as "natural" or not. For humans easy to use and learn interfaces can be created by understanding the designing environment and developing interaction methods considering conceptual integration. The framework is designed for explanatory use in post-"Windows Icons Menu Pointer" collaborative environments.

In the following I will illustrate the usefulness of blending in Human Computer Interaction and outline the framework Blended Interaction as well as its components.

3.1 Blending in Human Computer Interaction

Based on the PACT framework [3] according to that Human Computer Interaction is composed of four main parts, Benyon and Imaz [9, p.103-104] characterise Human Computer Interaction as a blend. The four key aspects are: people, activities, contexts and technologies *(see figure 4)*. The aim is to integrate those four elements.

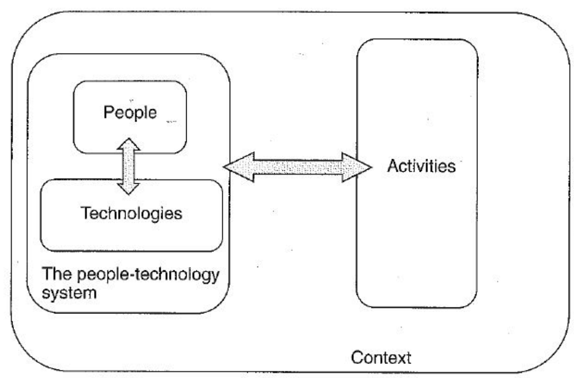

Fig. 4. People, activities, contexts and technologies framework [9, p.104]

The blend in Human Computer Interaction is situated between people, activities and context on the one hand, as well as technology on the other hand. Technology needs to be instructed as series of actions, whereas human activities are aimed at reaching human goals. A main issue in the area of Human Computer Interaction is to compensate the tension between those two aspects.

Jetter et al. [11, p.1144-1145] illustrate, that the experiences we make in the real world differ from those we make in the digital worlds. The task of the designer is to blend the two worlds without losing the familiarity of physical and the computational power of the digital world. User interfaces do not need to be designed as realistic as possible as long as they share certain aspects of the real world based on which conceptual blending can happen. A problem, which can occur when creating interfaces is, that mental space of designers and users can be different. Therefore, it is important to develop interaction based on a general space that most people have in common like image schemas [8], the interpretation of affordances by Norman [19, p.219] and the four themes of reality [10], [11, p.1144-1145]. In the following those three concepts are further specified.

For Hurtienne and Israel [8, p.128/130] intuitivity in interaction is based on applying pre-existing knowledge without being consciously aware of it. Pre-existing knowledge can be innate or sensorimotor knowledge. Innate knowledge is specified by the genes or before birth. Sensorimotor knowledge is obtained at an early state of childhood and includes image schemata and affordances. Image schemata represent abstract elements that humans use to reason about the environment. They consist of patterns that repeatedly appear in embodied interactions. An example is the container schema, which is defined by an inside and an outside part separated by a border. Based on this schema an hour glass can be classified as two containers filled with a substance and joined by a link.

According to Norman affordances are a "result from the mental interpretation of things, based on our past knowledge and experience applied to our perception of the things about us" [19, p.219].

Jacob et al. [10, 201-203] introduce the framework "The four themes of reality-based interaction". It consists of four areas, describing pre-existing knowledge humans have in common based on their experiences with reality.

- The first theme is *navïve physics* which implies that humans have an idea about physical rules in their environment like gravity or friction.
- In addition there is *body awareness & skills* stating that humans are aware of their own bodies and able to control its motion.
- *Environment awareness & skills* underlines the common awareness of the surrounding and the ability to understand depth cues and orient oneself.
- Last but not least *social awareness & skills* describe capability to identify other people and to communicate.

Jetter et al. [p.1146-1147][11] explain that not only concepts from physical world can be blended to the digital world, but blending works the other way round as well. There exist digital concepts, that have become integrated into everyday actions to such an extent, so that they have become common knowledge (established blends) and can be used as base for new blends. When interacting, all learned concepts, no matter if from the real or digital world, are applied by users. For instance two finger pinching as well as undo are concepts from the digital realm most people are familiar with. That way even seemingly unnatural interaction concepts can be perceived as natural ones, if they are based on already known approaches.

Another important aspect to take into consideration is the trade-off between power and reality when designing user interfaces. In other words, it is necessary to find a balance between powerful and complex, yet difficult to use interfaces, as well as less powerful but easier used interfaces based on direct manipulation. Blended Interaction can help to bridge this gap.

3.2 The four design domains of Blended Interaction

Jetter et al. [11, p.1148-1150] explain that Blended Interaction is based on what has been classified as basic elements of human thinking and experience by Human Computer Interaction and cognitive science. Those basic aspects play an important role for the design process. The framework is based on four components *(see figure 5)*. Blended Interaction combines reality with computational power. The reality aspect is based on concepts "that we as humans share due to the similarities of our bodies, our early upbringing, and our sensorimotor experiences of the world" [11, p.1156]. Related to the aim of the interaction the trade-off between reality and power has to be considered. To provide a structure and to support the design process Jetter et al. introduce four domains of design [11, p.1148-1150]. In the following those domains are illustrated.

- *Individual interaction* is the manipulation executed by a single person. This type of interaction builds the foundation for group-based collaborative actions. Means for input apart from the common desktop interaction could be an interactive pen or tangible interaction.

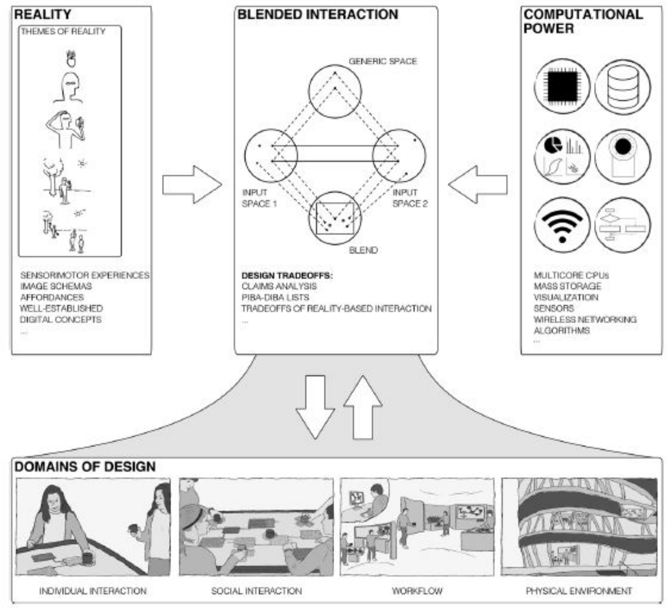

Fig. 5. The Blended Interaction framework [11, p.1149]

- For *social interaction* the actions of groups have to be coordinated. The established methods of communication between individuals have to be analysed in order to in-cooperate those in the design process. By this means collaboration supported and interferences with the gestures used for interaction can be avoided.
- A *workflow* can give structure to an interaction, but can also limit opportunities. The appropriate degree of freedom has to be chosen depending on the context and aim of the interaction. It has to be considered, how the user can be supported best in his tasks and actions.
- Finally the *physical environment* plays an important role for interaction. The existing space influences the level of freedom in the design process. The layout and content of the area have to be considered as well as ambient signals like light and sound. It is crucial to prevent a conflict between composition of the interface and common ways of cooperation in an environment. Depending on the space it can be beneficial to include knowledge from other domains for instance architecture.

3.3 Example: Affinity Table

Fig. 6. Non-digital affinity diagramming and affinity table [11, p.1152]

Based on the Affinity Table *(see figure 6)* Jetter et al. explain how the framework Blended interaction can be applied [11, p.1151]. Affinity Table [6] is an interactive group-based multi touch table to support affinity diagramming". The table is combined with a vertical display and tangible objects like digital pen and paper.

Affinity Diagramming is a method to support the design process in small groups. Originally the workflow is guided by non-digital materials like whiteboard, pens and sticky notes. As a result a spatially grouped arrangement of ideas is produced.

Jetter et al. [11, p.1151-1155] developed the Affinity Table to blend the originally non digital method off affinity diagramming with computational power. They started their design process with an analysis of the interaction of the physical method and used the design domains of Blended Interaction to guide the development as outlined in the following paragraphs.

The *physical environment* of Affinity Tables consists of a touch table and a vertical screen to resemble the initial composition of the non-digital version. According to Jetter et al. the layout coupled with objects like sticky notes support is fitting for collaborative and individual work (for example sorting elements or writing notes). Using digital elements compared to non digital objects provides the possibility of saving and restoring constellations quickly, without wasting the space or time needed when working without computational power.

The objective in the domain *social interaction and communication* is to enhance collaboration. Since Jetter et al. observed that sticky notes often appeared to be too small and not always visible for every group member, they decided to add the “focus token”. This physical token allows to focus specified areas by placing it on the table and display them on the vertical display. A turning motion zooms in or out of the selection. The focus token incorporates blends from different input domains and allows in this manner an easy interaction with the application. Firstly, the person in control over the token is in charge of the process. The idea of passing an object around to allow the current owner to execute a specific action, is a concept most people are familiar with. The concrete appearance of a token can vary, but the general concept is known across cultures and ages. Moreover, if located on the table, the focus token prevents forgetting, that a specific system state is enabled. Finally, because the token is shaped as a round turnable knob for increasing or decreasing values, as used in many everyday products, the use is largely self explaining.

The *workflow* of affinity diagramming is based on four stages: the individual generation of ideas, the sharing and presentation as well as the reflection and sorting of ideas within the whole group. Jetter et al. designed the underlying interaction techniques by blending the manipulation tasks of the non digital method with computational power and by considering the four themes of reality. The tables offers personal an collaborative work spaces. The used sticky notes, created with digital pen and paper, have a hybrid shape. They exist in physical form in the personal space but can be digitalised and transferred to the general workspace via placement on the table. Changes in the note, which take place later on, are synchronised in the digital space. The digital transfer of a note enables new functions (like more efficient sorting and movement), which could not be executed with the traditional ones.

Organising and clustering of the available information is based on several blends. The digital representations of notes can be manipulated (for example dragging and rotating) via multi-touch gestures. In that way, based on familiar concepts, quicker learning is enabled. Clustering is supported by aspects illustrated in the theme of naïve physics. Snapping mechanisms, resembling magnetism allow easier grouping.

In addition the search function enables a related image search by dragging notes to a specified region on the table. Acoording to Jetter et al. searching mechanisms are digital concepts are nowadays sufficient established and a new approach would be confusing for users.

Affinity Table enables *individual interaction* by providing each person which their own material (pen and paper) instead of sharing the same input devices. Thereby disruption of the interaction process can be avoided. No user has to wait for another participant to finish their actions before being able to execute personal actions.

4 Blended Interaction and the Internet of Things

Generally speaking the concept of the Internet of Things can be considered as a large blend. Smart Objects and applications usually incorporate aspects from the physical and digital world. In the following I will explain the terms Internet of Things as well as smart objects and outline different application sectors. Furthermore, I will transfer the concepts of blending and Blended Interaction to the Internet of Things. Finally, I will analyse the blend of Sifteo cubes as an example application in the context of smart objects.

4.1 Theoretical foundations of the Internet of Things

The term Internet of Things is not easy to specify. It incorporates a broad spectrum of movements. Its roots lie in the concept of Ubiquitous Computing [14, p.242]. Ubiquitous Computing, introduced by Mark Weiser [21], is based on the idea of seamless integration of computers into the environment. In contrast to virtual reality, where an alternate world is created digitally, the computer moves to the real world invisibly included into everyday objects. The vision does not stop at the point, where computational devices become portable. The computer moves to the background enabling new possibilities of interaction without device related restrictions. Ambient Intelligence [18, p.1500], which is based on the idea of Ubiquitous Computing, also bears a resemblance to the notion of the Internet of Things. The key aim of Ambient Intelligence is to computationally enhance the environment, facilitating interaction especially focused on humans needs and well being [1, p.244].

Mattern and Floerkemeier [14, p.242] describe, that the concept of the Internet of Things is based on the estimation, that developments in microelectronics, communication and information technology will continue to increase. This causes a growing integration of technology into objects, which bring new potential for interaction. These smart objects can be interconnected and possess the power to interact with each other or with humans .

The term Internet of Things describes on the one hand the network of smart objects with the help of internet technology and on the other hand the necessary technologies to help making the vision reality [18, p.1497].

Mattern and Floerkemeier [14, p.244] list the following different technological developments, which make the closer coupling of digital as well as physical world possible and can be seen as characteristics for smart objects.

- *Communication and cooperation*: Objects are connected with the internet or with each other and can evaluate data.
- *Addressability and identification*: Every object can be addressed within a network and can be uniquely identified.
- *Sensing*: Sensors integrated into objects, enable data collecting about the environment. This data can be saved, processed or transferred.
- *Actuation*: Actuators included into objects, allow to affect their surrounding (for example converting electronic input into movement).
- *Embedded information processing*: Objects contain a microprocessor and the capacity to store data
- *Localisation*: Smart Objects are aware of their own position in the environment or their location can be identified.
- *User interfaces*: Smart Objects possess a direct or indirect interface via which the user can manipulate them or access their data. For instance indirect interaction could take place via a smartphone.

The use of Internet of Things technology can be beneficial for various scenarios. Miorandi et al. [18, p.1509-1511] and Bandyopadhyay and Sen [2, p.22] define the following application areas in the context of the Internet of Things.

In *smart homes or smart buildings* the Internet of Things can be used to diminish the power consumption (like water or electricity) or to make live more comfortable for the inhabitants. Sensors can be used to monitor the energy used in the building and to identify the needs of the residents and react accordingly (for example turning the lights on/off).

The area of *smart cities and transportation* deals with efficiently managing the cities infrastructure. New technology could help to better control traffic. The inclusion of cars within the city monitoring system might enable improved traffic jam prevention and checking of traffic violations. In addition, parking space or pollution detection could be possible.

The aim of *environmental monitoring* is to detect natural phenomena as rainfall or temperature. The biggest challenge in this sector is to combine many sensors as well as to analyse and process the recorded data in real-time. Environmental monitoring can be located in place, which are difficult to reach for humans like the ocean or an volcano. Such systems can be used to warn, when emergencies or catastrophes are occurring or likely to happen.

Internet of Things technologies in *health-care* can support assisted living. Patients can be monitored at home without the need of going to a hospital and medical data can be submitted to specialists located in another place. In this manner, critical conditions are more likely to be detected in time. Self tracking is another health related aspect. This allows people to record their own activities and exercises. Based on those recording, methods to enhance health can be suggested by smart devices.

In *smart business or inventory and product management* technologies to track an identify articles are already in use. Nevertheless, there is still room for improvement. Technologies to make processes more flexible can be designed and the use of bio-sensors could help giving information about the condition of goods (for example temperature or appearance of bacteria).

In *security and surveillance* the Internet of Things technologies can help to make performance more efficient. Suspiciously acting people could be identified via the analysis of the environment. Moreover, devices could be designed less visible and distracting.

The sector of *media and entertainment* can allow to transmit user location based news related to present media devices. Marking places with tags can help to transfer additional information or be used as means for communication.

4.2 The Internet of Things as a blend

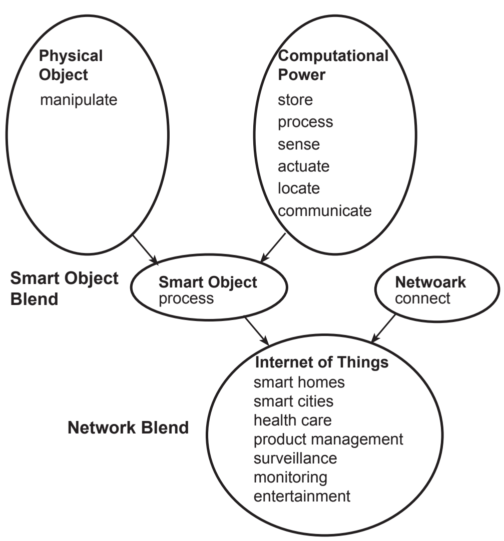

Fig. 7. The Internet of Things as a blend

Based on the earlier mentioned literature the Internet of Things can be seen as a blend *(see figure 7)*. The combination of a physical object with computational power like storage and communication capabilities results in the blend of an smart object. Many smart objects can be blended together. The result is the Internet of Things with its own emergent structure and different application areas.

4.3 Sifteo cubes as a blend

In the following I will analyse the smart object blend further based on the example of Sifteo cubes. Sifteo cubes [17] *(see figure 8)*, based on Siftables [16], are block shaped quadratic objects, which contain a coloured touch display. The cubes can be manipulated by motion and are wirelessly connected. Each block includes infra-red sensors, a battery and an accelerometer. One cube can sense other cubes in its close surrounding and its motion on a surface as well as being picked up or shaken.

Fig. 8. Sifteo Cubes [17, p.1018]

The blocks satisfy most of the characteristics for smart objects. The wireless connection with each other and the internet enables *communication and cooperation* with other cubes. When connected, cubes can be *addressed and identified* explicitly. They include different sensors and can therefore *sense* each other and movement. Integrated microchips allow *embedded information processing*. In relation to the other cubes, a cube can *localise* its position and orientation in the room. A *user interface* is provided via the included touch screen and the motion gestures, that can be executed.

The cubes can be categorised as an application in the media and entertainment sector. Their purpose is the interaction with information and media and playing games in single or multi-player mode. Available games are for instance learning games, where the cube contain words, numbers or letters. When used in groups, each participant is in charge of one or more cubes. To advance in the game the player have to collaborate and use their individual cubes together.

Sifteo allows different types of gestures for interaction [15]. Tilting the cubes can be used for regulating aspects as sound or pouring colour from one cube to another. Two or more objects can be grouped or connected by a placing them next to each other. Shaking cubes triggers a change in the represented information.

4.3.1 Sifteo cubes: the chroma shuffle blend

Sifteo can be used in many contexts and there are different applications available. In my analysis I will focus on Chroma Shuffle *(see figure 8)*, a game composed of coloured dots which are gravity sensitive [20]. The game is formed through several blends *(see figure 9)*.

A Sifteo cube in itself is a blend, which is the result of the combination of a building block with computational power and a touch screen. The touch screen is situated on top of the cube and on the four sides of the cube connection points are located. Each cube can be used as a container for different types of elements.

In the manipulation blend the input space of the cube as a container of elements and the input space of manual actions are connected. This

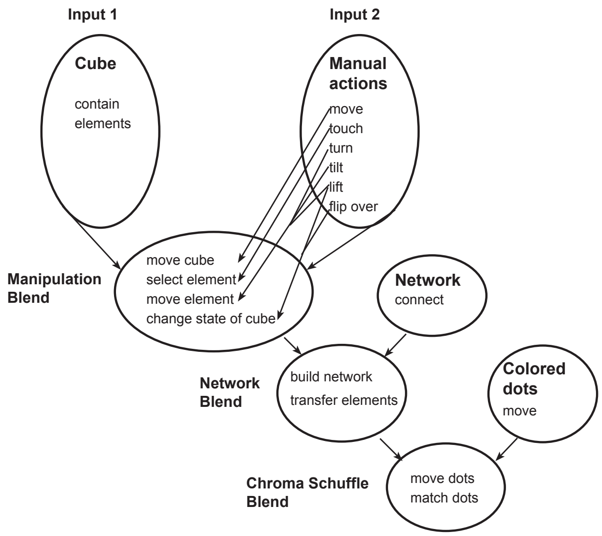

Fig. 9. The chroma shuffle blend

blend allows different ways to interact with a cube. A cube can be moved. Single elements within a cube can be selected by touching the screen. Elements can be moved by turning, tilting or lifting the cube as well as by a combination of the three actions. The state of a cube can be changed by lifting and flipping it over, in a way that the touch screen is facing the ground.

Based on the governing principle of recursion the manipulation blend is used as an input for a new blend. Together with the input space of a network the network blend is formed. A network is composed of points, which are connected by paths. Two or more cubes can be joined by grabbing them and moving them towards each other as well as turning them to the desired connection point. Via this connection the transfer of elements is possible.

Finally, the Chroma Shuffle blend is the result of the combination of the network blend and the input space of coloured dots. This dots can be distinguished by their colour as well as an incorporated symbol and react to gravity. In the chroma shuffles game this new input domain adds the functionality of moving and matching dots. The aim of the game is to match dots with the same colour on different cubes by connecting those. Matched dots are vanishing, leaving blank space on the related cubes and the player gets points accordingly. Within a cube completely filled by dots moving elements is not possible, but when a cube includes blank space elements can be moved by the manual actions of turning, tilting and lifting. As the dots react to gravity, they always move to the side of the cube facing ground. A cube can be completely refilled with dots by the manual actions for a state change.

4.3.2 Sifteo cubes: principles of blending

In the following I will analyse the Chroma Shuffle blend related to the constitutive and governing principles of blending, that are incorporated in the Chroma Shuffle blend.

The composition of the blend ist based on the perception of the cubes as containers with elements. The elements in the containers can be moved and containers can be connected with each other. Based on the principle of completion follows the possibility to transfer elements from one container into the other. Finally the elaboration of the blend allows to use the cubes in the context of different applications like the Chroma Shuffle game.

Sifteo deals with different aspects of *compression*. There are just two connection states two cubes are either connected or not connected. A state for a partial connections does not exist. One cube can at most be connected to four other cubes. Elements stay within the boundaries of the cubes. They can move between connected cubes but cannot leave the cubes.

The *topology* of Sifteo has two levels. On the one hand we have the two dimensional layout within the cubes, in which the elements can move and which can be extended by the connection of cubes. On the other hand we have the three dimensional world, where the interaction and manipulation of the cubes takes place.

The success of the *integration* of the blend is dependent on understanding the mapping between the two different levels of the topology. Based on how objects in containers are reacting to three dimensional movement, the behaviour of elements in the context of Sifteo can be comprehended and predicted. Object manipulation is a concept humans learn in their early childhood and is therefore easily understandable for most people. Consequently the interaction is perceived as continuous action, instead of a series of independent activities.

As outlined in the previous paragraph the Sifteo blend includes multiple layers of *recursion*.

4.3.3 Sifteo cubes: four domains of design

In the following I apply the four domains of design of Blended Interaction to the Sifteo Interface.

The *Individual interaction* with the cubes can be executed with both hands simultaneously or separately. Cubes can be manipulated as specified in section *4.3*.

Examining Sifteo related to the *social interaction and communication*, it becomes apparent, that not all the applications are primarily designed for group interaction [17, p.1017]. Nevertheless single player games can be played collaboratively by splitting cubes between different players and using them together. It appears to me, that the game set-up in this context might not be optimal for every game and highly depends on the environment as well as the number of players. Because the cubes are small and in some games have a special orientation, the content is not recognisable from every angle. Apart from this aspect the collaborative aspect is supported rather well by the shape of the cubes as different units. There is no interference through other gestures or group communication with the interaction.

When analysing Sifteo related to the *workflow*, it is highly dependent on the application. Chroma shuffle has no ordered set of actions but is structured by the goal of getting points by removing matching dots.

The *physical environment* in which Sifteo can be executed is variable. It can be used on any flat surface, where there is enough space for the amount of blocks present.

To summarise the analysis of Sifteo and Chroma Shuffles related to the principles of blending and the four domains of design, the blends in this context appear to me to work successfully. The interaction with the cubes is easily understandable. Learning it does not require a lot of time, because it is self explaining and intuitive.

5 Conclusion

In the scope of this paper, I have presented the theories of blending and Blended Interaction and their cognitive origins. I believe, that, as stated in the before introduced literature, taking into account how humans form mental models and reason about the world, is an important aspect to consider, when developing interfaces. If successfully integrated, the use of those interfaces is easier to learn for humans.

Generally speaking, I found the principles of blending and the framework Blended Interaction helpful for analysing Sifteo and can imagine that the integration of this framework into the designing process can be generally useful for the development of smart objects. When dealing with the Blended Interactions framework, it has to be considered, that it is targeted at collaborative interaction. However, I feel that it might also be beneficial to be taken into account for the design process of individual interaction, if leaving out the design domain of social interaction and communication.

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Revealing the Invisible - Information Visualization in the Internet of Things Era

Benjamin Fritzsche

Abstract—The Internet of Things (IoT) enables us to collect undreamed quantities of data no matter where and when. However, to be useful for humans further processing is necessary. To allow an interaction between the IoT and the user, the in the background collected information have to be made visible in an appropriate way. With technologies like smartphones, tablets, desktop environments or 3D printing the same information can be visualized in many different ways. The knowledge how to display information on different output-devices based on it's purpose is one of the most important aspects of developing a useful display visualization in the IoT era. The purpose of this paper is to get an overview about the state of the art in IoT, typical application areas and visualizations who either exceed in terms of usability and aesthetics or define new out of the box approaches. The focus is on the diversity of visualizations and design decisions, based on goals and technologies (e.g. sensors). This paper shows that virtual displays evolve from standard information tables to user behaviour changing and evoking feedback visualizations. The way the user receives useful information is flexible and there are even a few physical feedback prototypes experimenting with it.

Index Terms—internet of things, sensors, information visualisation

1 Introduction

The urge of the human being to get wisdom and insight is insatiable. We live in a century where we collect an overwhelming amount of data and information every single day. With the internet of things and wireless sensor networks (WSN) we managed to get to an even higher level.

However, with all this data at hand we should pay attention to the Invisibility dilemma [22]: We have got all that tiny sensors and accumulators hidden in places where they are not recognized any more. They collect information, but we have to find a way to make the data provided by them visible or all that information will be lost and overhead is created.

By collecting all these information for us humans, we have to take responsibility how these information are further processed and visualized. These steps are thematically discussed by information visualization (infovis), which is *"interested in how visualizations can be used to convey objective information about the data itself and yield factual insights about this data"* [17]. As we are speaking of the information visualization in the IoT we have to transfer the infovis paradigm into the IoT. The mayor point of this work is to find, analyze and describe visualizations that provide insight or a mayor benefit from data generated by a network of communicating and sensing objects.

As these two themes - IoT and infovis - collide we have to rethink about certain mayor factors and questions:

Information Visualization perspective. As already mentioned above the term visualization is just restricted by the factor that it should provide insight or a mayor benefit. So we have to search for different visualization approaches in the fields of both virtual and physical displays. We also have to measure information related themes like information density, efficiency and effectiveness. As the visualization is displayed for the user, the visualization should be usable and aesthetic according to usability standards. But in the end an information could be perfect displayed and still not changing anything. So we have to consider if an information is indeed usable and - in the best case - invokes a certain user behaviour based on that information. For example 32% body fat displayed in the correct format possesses the ability to invoke the reaction in the user to be more sportive. Visualized in a bad way it is discouraging and insulting, resulting in anger and helplessness.

Internet of Things perspective. If we speak about visualization of information provided by the IoT, we have to give an overview about the Internet of Things and current applications. As we speak about Applications the need of a categorization arises, because the IoT is used in several different environments. We should be clear about the differences in the amounts of data and sensor types in different application areas. So a categorization of application areas would provide an overview which is the basis of the sorting of existing applications.

This paper provides an overview about existing IoT application areas and example applications who either did a great job visualizing all necessary information or tried new visualization approaches.

The rest of the paper is structured as follows. First we start with the IoT definition part, get to the layer structure and analyze an existing framework. After that we get to the technological enablers, middleware and the important application layer. Next we need to move from the application layer to a good visualization and examine in the information visualization section different visualization approaches and the differences between virtual and physical visualizations. After that there is a brief overview about existing IoT domains and use cases. The main part of this paper is about the examination of three different applications, their technology and visualizations used. The discussion section focus on the comparison of those applications and the conclusion gives some advices how to develop a good visualization in an IoT context.

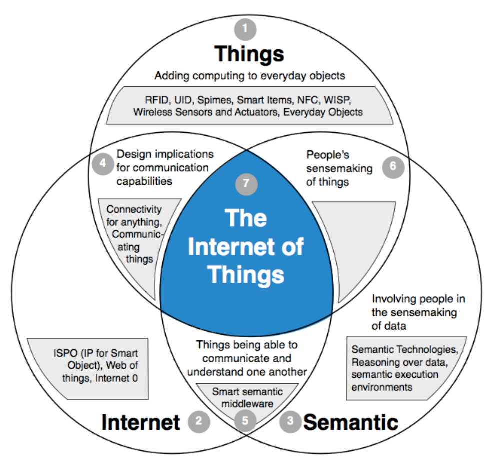

Fig. 1. Framework about the 3 IoT perspectives [20].

- *Benjamin Fritzsche is studying Media Informatics at the University of Munich, Germany, E-mail: B.Fritzsche@campus.lmu.de*
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2 Overview

First we start with the subsection Internet of Things. In this section we shortly define the IoT and explain the enabling technologies and the layer structure behind it. The main focus is on the different sensor types and functionalities. After that we give a short review about Information Visualization as an important part of our paper.

2.1 Internet of Things

The Internet of Things section is split into the definition part, the layer structure, the framework and the enabling technologies. The sensors have its own section outside the enabling technologies section because they have a major role in the visualization process.

2.1.1 Definitions

The Internet of Things has a lot of different definitions. Atzori et al. define these 'things' as RFID tags, sensors or mobile phones that interact, communicate and cooperate with each other to achieve goals [3]. Although this definition is quite simple and easy to remember, it lacks some IoT specific information. Miorandi et al. [25] enhance it and achieve a more complex definition:

"Interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications. This is achieved by seamless large scale sensing, data analytics and information representation using cutting edge ubiquitous sensing and cloud computing."

It should be mentioned that privacy, trust, security and resource management are also issues that are important in the IoT but are not covered in this work.

Combining these two definitions gets us to a layer structure of the main layers the IoT builds upon:

2.1.2 Layer structure

The technological layer or hardware layer consists of the technological enablers, like RFID tags, Wireless Sensor Networks (WSN), actuators and other sensors. This hardware provides the basic functionalities: (a) identification and information storage (RFID), (b) information collection (WSN), (c) information processing (embedded processing) and (d) communication, control and actuation [4].

The middleware layer operates bidirectional between the technological and the application layer as an interface. In the last couple of years the IoT followed the service oriented architecture (SOA) approach, which simplified the IoT development and made applications out of well-defined components [4]. It's responsibilities are the device and information management, data filtering and aggregation, semantic analysis and access control [4].

The application layer consisting of all different kinds of IoT applications. There are a lot of different application areas in the IoT: Healthcare, Logistics, Transportation, Aeronautics, Smart Home and many more. We go into more detail about this in section 3.

2.1.3 Framework

Figure 1 shows the work from Atzori et al. [3] that visualizes the IoT as a framework. There are many similarities to the layer structure, but it is less a categorization than a framework which supports the development of IoT applications.

In the word *Internet of things* the first term is network oriented and the second one object oriented. On top of these two perspectives there is a third one come into play: The semantic-oriented perspective [3]. This framework was further improved by Koreshoff et al. [20] *(see figure 1)*. Their focus is on the human centred perspective of the internet of things and how applications could be build using this framework as a tool to understand and develop an IoT application.

The *things oriented category* contains the physical components - the hardware and electronics - that build the IoT. Radio Frequency Identification (RFID), wireless sensors and actuators, Near Field Communication (NFC) and spime - an object that can be tracked through time and space and that is sustainable, enhanceable and identifiable. Smart items belong to these category too, as they provide wireless communication, memory, elaboration capabilities and an autonomous and proactive behaviour.

The *network or internet oriented vision* focuses primly on protocols and languages which is not that important in case of HCIor to understand the approach of our paper. That is why we do not go into any further details into this area. Just note, that this approach is about connectivity and communication between objects.

The *semantic vision* is all about the reasoning over data and semantic technologies, how information could be represented, stored, interconnected, searched or organized to make sense out of data.

The intersection of the semantic and the object oriented perspectives are the main focus of this paper: How do people make sense out of data displayed to them? How should these data be displayed to make it easier for the user to get insights out of it? Before we can discuss these questions we have to take a look at the enabling technologies, to get a better understanding how the IoT actually works.

2.1.4 Enabling technologies

The first IoT was made out of two components: Radio Frequency Identification (RFID) and a Wireless Sensor Network (WSN).

The RFID is a cheap chip of a small size with an antenna, which communicates wireless in low or ultra high frequencies. They help in automatic identification of anything they are attached to acting as an electronic barcode [12]. Passive RFID chips don't have an on-board power supply and are powered by radio signals emitted by their RFID readers. This kind of RFID chip is most often used in the logistics and supply chain section. Semi-passive RFID chips do have a power supply who is powering the microchip while the radio is powered by the transmission signal by the reader. In active RFID chips - which are the most expensive - the battery powers the transmission signals as well [3].

The wireless sensor network connects a number of sensor and/or actuator nodes into a network through wireless communication and integrates this network into a higher level system through a network gateway [28]. It consists of multiple sensor nodes, who communicate their sensing results - location, temperature or movements - to a sink (special node) [3]. The sensor nodes are normally lightweight, inexpensive, easy to deploy and maintain, but the capability and functionality are limited by resources. The sensor node is made up of a power supply, a processing unit, a communication unit and a sensing unit. These factors enable sensor networks made out of thousands sensors that collect, process and analyze valuable information. Because of this energy efficiency, scalability, reliability and robustness are the main issues in wireless sensor networks.

2.1.5 Sensors

A sensor is an object performing a sensing task: Gather information about an object or a process, including the occurrence of events. A sensor is technically an transducer who transforms physical signals to electrical energy. Sensors link the physical with the digital world by capturing and revealing real-world phenomena and converting these into a form that can be processed, stored, and acted upon [7]. If you put a lot of them into different machines or places, the benefits are huge. From smart home to improved logistics to new security. Sensor networks sometimes include actuators, which manipulate the real physical world, like a motor who switches the state of the water boiler. Table 1 shows the most common sensors used to sense a physical property. We use a sensor for our application when we need to get information about that physical property in a special context. You have to difference active and passive sensors. Active sensors have an external power supply, passive sensors don't. They receive their energy from the source, for example an passive infrared sensor. Sensors can further be categorized into resistive, capacitive, inductive and piezoelectric sensor types [7].

In the last years a couple of new kind of sensors were developed. They are single-sensing units that are used in smart home environments. These sensors use the fact that most of the things we use in everyday life create their own unique signature. The goal of these sensors is to sense these signatures to achieve equal sensing results with far less overhead. These new kind of sensors will be discussed in the following.

Hydrosense. The idea behind this new kind of Sensor is to make the complex and high-cost in home sensing with multiple sensors easier and simple. The outcome is Hydrosense, a low-cost, easy to install and use water-pressure Sensor [11]. He can identify individual water fixture points based on their unique pressure waves. Due to this achievement in sensor history it is possible to analyze the water usage of a single household with just a single sensor attached to the base water pipeline. He recognizes where, when and how much water is consumed by - for example - a flushing toilet in the 2. floor. Accuracies between 76% and 98% [10]. Furthermore it is possible to detect activities with this system [8].

It should be mentioned that there are other single-point-sensing devices for different fields: *HVAC* - Sensing of Human Movements with a single sensing device in home through air pressure and event-detection with an accuracy of 75% - 80% [29], *ElectriSense* - a single-sensor approach detecting and categorizing electronical switch mode power supplied (SMPS) devices with an accuracy of 93,82% [14] and *GasSense* - another low-cost, single-point sensing approach, this time to identify and measure the gas used up to its source with a 95,2% accuracy [14]. With these sensors it is possible to build a smart environment with a handful of sensors.

Table 1. Classification and examples of sensors [7].

Type	Examples
Temperature	Thermistors, thermocouples
Pressure	Pressure gauges, barometers, ionization gauges
Optical	Photodiodes, phototransistors, infrared sensors, CCD sensors
Acoustic	Piezoelectric resonators, microphones
Mechanical	Strain gauges, tactile sensors, capacitive diaphragms, piezoresistive cells
Motion, vibration	Accelerometers, gyroscopes, photo sensors
Flow	Anemometers, mass air flow sensors
Position	GPS, ultrasound-based sensors, infrared-based sensors, inclinometers
Electromagnetic	Hall-effect sensors, magnetometers
Chemical	pH sensors, electrochemical sensors, infrared gas sensors
Humidity	Capacitive and resistive sensors, hygrometers, MEMS-based humidity sensors
Radiation	Ionization detectors, GeigerMueller counters

2.2 Information Visualization

Information Visualization is a necessary part of most IoT applications, because it is the communication interface between the user and IoT application who makes the information of the environment visible [25]. Without a visualization there would be an invisibility dilemma [22] - hidden sensors that collect data without analyzing or displaying it - resulting in a waste of information and energy. The purpose of Information Visualization to get insight. In combination with the Internet of Things it provides insight into the environment. We have to find possibilities to detect events and visualize vast amounts of raw and modelled data in a way the user can benefit from. The end user needs a - in terms of usability - good, intuitive and visual attractive visualization to benefit from the IoT [31]. Additionally, Consolvo et al. state [6] that visualizations can turn from pure data representations to motivating and behaviour changing presentations. She suggest certain design strategies that should be considered creating behaviour changing technologies.

A simple way to do that is to represent real-world objects (RWO) as virtual objects (VO), who should be addressable, accessible and provide a description of their nature, status and capabilities towards both other VOs and users through a visual representation [5]. These representations can be either a physical or virtual user interfaces. Virtual displays such as smart phones, tablets or desktop environments are most common because they are established and customizable. They *"are able to accommodate heterogeneous and dynamic datasets, and support powerful interactive exploration tools like dynamic filtering and search"* [17].

Bousard et al. describe in their paper [5] the use cases and advantages of these three display types. Smart phones provide a small interactive screen and are mobile, which make them suitable for short interactions at home or outside. The visualization should be appropriate to the small screen. Tablets have a larger touchable screen then smart phones, are mobile, but still have less interaction capabilities then the desktop environments. Due to the fact that tablets are most used at home (where the user has more time) [30], the visualization should be more detailed, providing more feedback (i.e. graphs, lists). The most detailed visualization should be on desktop environments. They have the largest space and the interaction device is typically a mouse. Generally the 10 usability heuristics by Nielsen who state general principles for User Interface Design (i.e. visibility of system status or match between system and the real world) are a good way to start [16].

All of these devices follow one simple rule: The visualization comes logical after the virtual device who displays the information. The visualization is customized due to the space of the screen, the data provided by the sensor network and many other factors. In physical devices on the other hand the physical display is created on base of a visualization approach. In the last couple of years physical visualizations became more advanced due to the evolution of 3D printing and shape shifting displays. Ambient displays do have their own heuristics [24] which are similar to the existing ones created by Nielsen.

It should be mentioned that material representations can offer many opportunities. Jansen et al. conducted a study where they compared physical to virtual visualizations [17]. Against the hypothesis the physical display of a 3D bar chart visualization outperformed the virtual 3D visualization on the screen in terms of information retrieval and usability. The ability to touch and rotate an object is a remarkable cognitive aid. In combination with the higher resolution provided by the human eye the interaction is simple and the data of this visualization can be easier extracted because of the physical features.

However, there is more than one possibility to build a physical display: Vande Moere et al. [34] categorizes five different forms of physical displays, each one of them providing advantages and disadvantages for different applications (Ambient Display, Pixel Sculpture, Object Augmentation, Wearable Visualization and Data sculptures). The tempescope is an example for an ambient weather display. It does provide a new and refreshing visualization as the weather is displayed in a glass-cube with rain or smoke, but it lacks detailed information (e.g. temperature according to the time of the day) [18].

In conclusion 3D physical display are worth considering, when they are designed for a specific task.

There are no guidelines how IoT applications in general should be displayed. Because of that we analyze existing application areas and show some example applications in order to demonstrate what are good, bad and new visualization approaches whether they are virtual or physical.

3 Application Areas

In the IoT context there are a lot of different applications, in different fields with different sensors used. There are a lot of possibilities how to sort all these applications. Some factors are:

- The number of wireless sensors used (one to thousands)
- The number of people involved (a single person, a group, a community,...)

- The scale of the environment (person-centric, home-centric, city, country, world)
- the physical property measured (temperature, motion, ...) or what kind of sensor is used (accelerometer, gyroscope)

The application areas are categorized in relation to previous works [3, 15, 25, 4, 2]. Due to the wide field of application areas this work does not claim to be complete.

3.1 Transportation and Logistics

There are many different areas in the transportation and logistics section. Transportation is the act or process of moving people or things from one place to another. Car-to-car, car-to-infrastructure communication and sensors (i.e. video, sonar, radar, inductive loops or magnetometers) are already used to achieve *traffic control* and *intelligent transportation systems* in the automotive branch [36]. Traffic-jams can be nipped in the bud and travelling times can be reduced while providing higher safety. Sensors in transportation units (cars, trains,) and roads provide important information for collision avoidance systems, monitoring of dangerous materials or road traffic patterns (*assisted driving*).

Each step of the *supply chain* (design, material purchase, production, transport, storage, distribution, sale, services) can be tracked and enhanced with RFID tags [23]. It makes supply chain management much more efficient and effective. It provides insight into each step in the chain, giving real time access to both the customer and the company. It is possible to determine a transportation unit and the status of goods, the delivery time, delays or faults. The IoT is able to provide the *aerospace and aviation* industry with significantly safety improvements. For example the aircraft parts can be accessed by sensors and RFID tags, who reveal information about themselves. This lowers the maintenance time and raises the support quality when the actual status can be read this quick to reveal suspected unapproved parts. The assembly-line work in the *manufacturing industry* could be improved as well [33].

Augmented maps equipped with tags provide additional information about specific places like hotels, restaurants or monuments. The user can now browse with a smart phone (with NFC reader) and all events related to the area of interest to the user can be automatically displayed. The user can now refine his query or select or deselect places which are not of interest. It is also possible to display the information with augmented reality into the world or on the map.

3.2 Environment Monitoring

One example of environment monitoring is the *monitoring of perishable goods* in all states (harvesting, production, transport, storage, consumption) to accomplish an efficiency food supply chain. Temperature and humidity are monitored to assure quality. Monitoring of large buildings (*structural health monitoring*) like bridges or pipelines with sensors is very important for maintenance and security [32]. Sensor types can be ultrasonic, thermal, X-ray, magnetic or optical imaging techniques. There are many places on our earth who are either *difficult to reach or dangerous*. We need to get information from environments with volcano activity to support the population [35], monitor oceans to provide feedback about fish swarms and pollution or monitor mountains with the danger of avalanches. Even glacial monitoring to measure indicators of the global warming are possible applications.

The identification of herds and numbers to prevention and control animal diseases, the real time detection of animals in case of contagious outbreaks and certification of health status are a few mayor points in the *agriculture monitoring*.

3.3 Health Care

Health Care is one of the biggest industries with many specialised applications. *Identification* and *Tracking* of an object or a person in motion (mostly babies) is a huge safety enhancement. Information about the patient ID reduces complexity, incidents, prevents mismatching and ensures accurate medical records. The inventory can be tracked for monitoring, use, maintenance, before/after an operation and to avoid thefts and loose of important instruments. The automation of *data collection* reduces process time and organisation efforts [21].

Pulse oxygen saturation sensors (haemoglobin, oxygen and heart rate), blood pressure sensors, electrocardiogram, electromyographic (muscle activity), temperature, respiration, blood-flow and blood oxygen level sensors are very *special sensors* centred on patients/ diagnostics, used in health care to track the patients conditions and provide in combination with a *Wireless patient monitoring system* real-time patient health information. With the use of RFID and mobile technologies it is possible to display these information where they are needed and lower the chances of faults due to wrong medication, when the information about the patient are always present [26]. Most health sensors are *body centric* and are used to accomplish *independent living* at home.

3.4 Insurance Industry

The IoT helps insurance companies to better *estimate and manage* their risk. It enables new possibilities like *personal insurance rates*, based on global, local and personal data. User can place sensors in their cars, to track their location and movement patterns, to (a) lower their own rating and (b) help the insurance company to get more accurate data. These information can be used to generate *innovative offerings* based on detailed personal information. IoT even helps in cases of loss or damage with a more assisting customer support.

3.5 Smart environment

Smart environment is about all the places we live, work, train and spent our time. Much work has been done to accomplish *smart homes*. Connected things inside home provide a lot of useful information [22]. They provide insight into energy consumption, daily life patterns and security issues. Ambient mirrors for example can reflect the user behaviour [27]. In *smart homes and offices* energy can be saved by switching off electricity when not needed and the room heating can be adapted based on preferences or the weather.

Smart gymnasiums have individual training profiles on the chip which are loaded into the training machine with personal setting predefined. The data can be used for training analysis to show muscular strengths and weaknesses. Health parameters can be displayed during training, to help users with high blood pressure or injuries to watch over their body. New smart sport devices can be designed with integrated sensors to get more accurate data [22].

Smart museums can differentiate climate conditions, based on historical periods or visitor counts.

3.6 Personal and social domain

RFID tags attached to users could enable a whole new level of *social networking*. The RFID tags generate events when people meet at places like restaurants or the university. In combination with a twitter like IoT network it is possible that these things can post automatic updates about the position and activities of the user. These information can further be used to communicate with other users or to write a digital diary. The access to these information should be restricted because they provide a detailed overview about the behaviour pattern of the user. Another example is the *protection of assets*. The IoT can help finding objects in cases of loss. The owner gets a Notification when objects are moved away from their natural environment.

4 How to reveal the invisible

Unfortunately the most IoT applications don't focus on the HCI side (e.g. usability, a efficient interaction or the development of a visualization), but instead they focus on all steps made in the development of the IoT application. In the following sections there are three approaches from different application areas in terms of sensors and visualizations used. The first section describes an approach to visualize heart data into 3D printed artifacts. After that there is a single-sensing water pressure sensor who visualizes the information on a tablet for economic feedback. The last section describes two different solutions for a energy consumption visualization.

4.1 The Visualization of Physical Activity through 3D Printed Material Artifacts

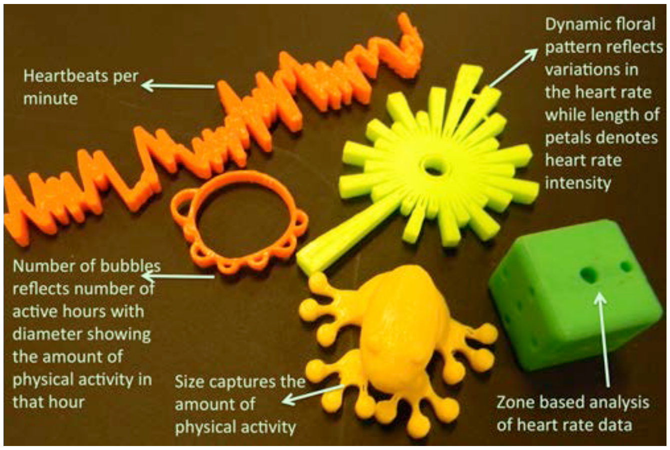

Fig. 2. Five material representations of physical activity, each depicting a different aspect of physical activity [19].

Khot et al. [19] studied a new approach representing physical activity with 3D printed martial artifacts. They used the SmartAtoms 3D modelling and printing system to display the heart rate of the user. The participant first performs his exercises which are recorded. The model is created after the pattern of the heart rate and printed with a 3D printer. These types of physical display solutions should encourage the user to do more sport and be more active.

There were several important aspects to consider in the creation of the physical display in the healthcare area.

Turn physical activity into data. The important aspect here is their visualization approach. First of all they made s statement: They wanted to measure the physical activity. After that they tried to find a variable which were best suited to represent the physical activity as a whole. The authors decided to take the heart rate as an indicator for physical activity performance and health progress. After talking to experts the authors subdivided the heart rate output into individual patterns. The heart rate was subdivided into six zones each providing insight into different aspects about the physical activity. This paper is a very good example of typical visualization steps: 1) What should be visualized 2) how should it be visualized and 3) determine the most important variables.

After the determination of the data aspects they had to consider *aspect of the material representation.* There are a few factors that have an impact on the acceptance and successfulness of an material representation. According to Consolvo et al. [6] the representation should be abstract, aesthetic and include aspects of the recorded heart rate. Additionally they should not care any personal information, so that the display can be made public, should be unique and should cause a positive enhancement for doing physical activity. The consideration of those aspects is a more or less theoretical step, but necessary. All these aspects have to be considered when developing a material representation which represents physical activity.

Fabrication models. Under consideration of the restrictions of 3D printing five models were designed *(see figure 2)*. The *Graph* maps the recorded heart beat per minute to an XY space. The *Flower* represents variations in the heart rate and different heart rate intensities. The amount of physical activity done at the day is represented by the size of the *Frog*. The *Dice* represents the time spent in each of the six heart beat zones on all six sides. The *Ring* displays the amount of active hours at that day in form of bubbles around the ring which sizes are determined by the heart rate at that time. The time to print one of these models ranged from 10 to 35 minutes. These five models are abstract physical displays that represent certain aspects of the heart beat and fulfil the requirements stated in the segment before.

A study were conducted in six households to test the new visualization approaches. In each of them the SmartAtoms system was installed and the participants printed their objects by themselves. They were enthusiastic at the beginning, but that positive feeling faded over the time of the study as the process of printing became a habit. It seems that the process of 3D printing, which is required to build a physical artifact, is a major disadvantage of physical displays, because it is not part of the visualization itself but part of the process to make one. It would be best to print the models automatically in future works. Furthermore the interest in the 3D models seemed to stay the same and in some cases increased over time, which shows that the visualization is more interesting then the 3D printing process.

Interestingly not all 3D artifacts were equal popular (the frog got the most attention) and there were many different interactions recorded (e.g. frogs were sorted by their size or flowers were put into vases). This shows that further research is need to analyze the effect of 3D artifacts in case of appearance and human interaction.

The advantage of these physical representations over virtual displays was the fact, that the participants could touch and interact with it. The heart rate evolved to something personal and engaged the user to be more active. The ability to show these representations others helped too and made them more special. The physical activity of all participants increased over time. That showed that physical displays do have their value at least in a health feedback system.

4.2 The Visualization Approach of an Economic-Water-Feedback-Display

Froehlich et al. [9] did an online Survey Study with 651 persons and an in-home interview in ten households to test two kinds of new economic feedback display systems who visualize the water consumption. This work belongs to the area of smart home, economic feedback and energy monitoring.

First of all they implemented a single-point sensing system that can measure the water usage of individual fixtures: Hydrosense. It can collect all kinds of different data, what, where and when water is used. Based on that system they were able to collect a lot of data. To display the information the authors decided to use a virtual display. They used a tablet with an estimated 11 inch LED Display, large enough to support a wide range of visualizations, portable, lightweight and easy to use with a capacitive touch screen. It combines the strengths of a virtual display with the usability of a tablet.

After the determination of the output device three main scientific questions arose: *(1)* How the information about the water consumption should be visualized in the most useful way. *(2)* What aspects of the data is the user interested in. *(3)* What user behaviour could be invoked by different visualizations.

To answer these questions there are two sets of displays. The first set consist of display visualizations with isolated *design dimensions*: Data granularity, time granularity, comparison and measurement unit. The second set tried to provoke certain behaviour in the participants like cooperation or blame, caused by its visualization.

In the following we will separate in three main categories. First we analyze *simple visualizations* which have one dimension, are rather simple and are based on the design dimensions. After that we take a look at *complex visualizations* with one or multiple dimensions and the last category includes visualizations that try to *invoke user behaviour*. The work of these authors is more complex then the other two, because the authors analyzed multiple different visualization themes.

4.2.1 Simple Visualizations

In the following the simple visualizations are categorized into the mayor points bar graph design, data granularity, time granularity, comparison and measurement unit. The goal is to show the differences between certain visualization aspects, what is important and what not.

Bar graph design. A bar graph design was used because it could be changed along one dimension. 64% of asked participants liked it the most of all visualization approaches, because it is easy to understand, aesthetic and a comparison is possible. It is most intuitive and functional. This is a very important aspect, because it shows the benefits

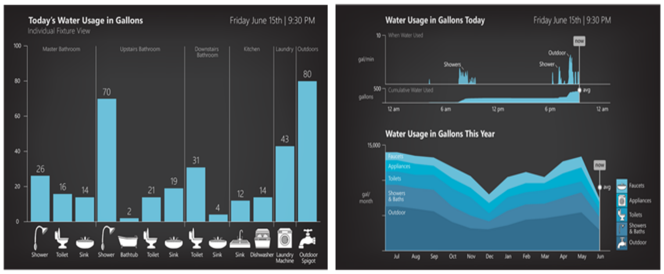

Fig. 3. WaterSense Visualization. *Left:* Bargraph showing the information about individual fixture points. *Right:* The time series visualization shows trends over time [9].

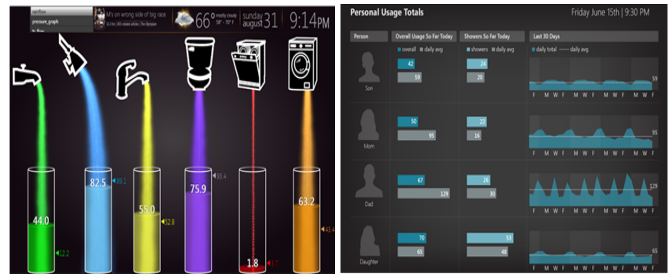

Fig. 4. WaterSense Visualization. *Left:* The Rainflow Visualization. *Right:* The per-occupant Design. [9]

of the bar graph design and it seems very likely to adapt this design to other areas as well.

Data granularity (from simple to complex). Most participants (54%) preferred the *individual fixture* visualization *(see figure 3 left))*(e.g. toilet at the end of the floor), because they were able to see leaks and individual water usage for reduction efforts. The *fixture category* (e.g. all toilets) were useful too, when the participants don't want to see everything in detail, but still wanted some functionality. The participants were very happy about the *hot/cold breakdown* where the water usage of both types was shown. 91% wanted it in such a economic feedback system, because it provides insight in the differences between hot-cold water usage and energy costs.

Although the highest granularity on fixture level is preferred the most, visualization should be able to give information on different granularity levels. Recommendations how to reduce water usage should be implemented too.

Time Granularity represents different time states (day, week, month) and can be seen as a trade-off between small updates (day) and general usage patterns. 64% of participants wanted access to all 3 kinds of visualizations, because each one provides different feedback, insight in patterns and actions. It should be easy for users to analyze different time granularities.

Comparison. Displayed in a common two bar visualization, that provokes changes in action and has an influence on behaviour. This could be both in positive or negative manner. Both the comparison target, but also the visualization are important. You have to categorize in three types *self-comparison* - daily average vs. current usage of fixture type -, *goal-comparison* - comparison to external or self-set goals - and *self-comparison to other households*. All comparison types are well accepted and should be included in the display. User control is important, thus many participants wanted to set their goals by themselves.

The *measurement unit* is not just about the understandability, but also about motivation (finding a visualization that is motivating *and* understandable). There are three different measurement units: *volume based* (liter), *flow-rate*(liters per minute) and *costs* (dollar/euro). For 71% both liters and costs were useful. Sometimes you can't see the value of both, because water is really cheap in most countries, so cost display could be an anti motivator. Additionally water reaches such high values in normal households that it is hard to understand, but in a hot/cold cost comparison it makes sense. Regardless, a visualization should include both.

4.2.2 Complex Visualizations

Complex visualizations try to take the next step in the area of Infvis. The goal is to provoke responses through visualizations. There is no agreement about the perfect display, because there are a lot of different personalities, genders and generations even in the same household. Therefore multiple options for display informations should be provided. In the following we describe five approaches that dealt with the thematic of a complex visualization.

The *time series visualization* is one of the most complex visualizations as it reveals trends over time *(see figure 3 right))*. *Time over day* (with peaks in the morning, dinner and bedtime), *day over week*(with peaks in the weekend, because of the free time) and *season* (with peaks in the summer). The Participants liked seeing long term temporal patterns and reduction efforts.

A *Spatial layout* was designed to show the rooms, which provided feedback how much water was consumed in which room. It is easier to read and understand what rooms consume how much water.

The *per-occupant* visualization was created to analyze the themes blame, competition, accountability and privacy *(see figure 4 right))*. It shows which person consumes who much water. This personal information resulted in a lot of controversial. There are two sides: From the side of the water consumption it is a valuable information and helps reducing the water usage. From a household and human perspective it creates a atmosphere of competition and blame instead of cooperation. There is the wish to reduce the water consumption, but not with an family full of anger as a result. This shows that a simple visualization is able to invoke reactions and emotions.

The *Aquatic ecosystem* is an abstract display, who visualizes the water usage with a fishtank view and aquatic life. It is far less data centric and focuses on water saving and displays them when goals are met (more fishes/ vegetation). Many parents were afraid that their kids would stop washing themselves in the hope that the number of fish increases.

The *Rainflow* design is similar to the bargraph, but the information are displayed in a more fun way: Water from the different fixtures flows into containers at the bottom *(see figure 4 left))*. When too much water is used the water is overflowing. Similar to the aquatic ecosystem, the visualization resulted in actions who were not intended. The flow of the water was displayed that well, that especially children consumed more water to see it overflow. This is an example of an visualization that invokes the wrong behaviour. It is important to mention that the design goal and the actual impact could differ and it is the responsibility of the designer team to test the user reactions.

4.2.3 Invoke User Behaviour

Competition and cooperation were addressed by the per-occupant and aquatic eco-system design. It is very polarizing. Some thought of it as some kind of gaming experience. Those who disliked it just doesn't want to create a competitive environment, where everyone is against each other. The best solution is to make it an optional visualization. It is okay to encourage competition against other (not present in person) households and try to strength the household cooperation.

Accountability and blame were realized through the per-occupant and spatial view visualization. Both were polarizing, some liked the possibility to see usage responsibilities. Other dislike it, because the possibility to account someone for their usage can turn into blame and conflicts.

The aquatic ecosystem and the rainflow visualization were used to experiment with *playfulness and functionality.* They are more playful, and provide less utility and information. They seem to be excellent at creating interest, fun and engagement. But they don't have as much functionality as the bar graph. Rainflow could provoke behaviour in children that's contra-intuitive because they like the water flowing. It is important to make the Visualization not look more interesting with increased consumption.

Privacy and the display placement. Water usage can reveal activity patterns and routines (when someone is / is not at home). There should be different security levels, so that not everything is visible by everyone. The displays are in most cases located in public places with a lot of traffic - kitchen or hallway - where everyone walking by is able to see the information. The placement is an important part, because it restricts who can see the display and who don't. When guests come over, the eco-system would be perfect as a screen server not revealing any private information.

All in all there are multiple aspects important to consider when developing simple visualizations, complex visualizations or the invoking of user behaviour. Each one of them has it's own purpose and all three together cover a wide range of information and possible questions that might arise.

4.3 Energy Consumption represented by Physical and Virtual Visualizations

Guinard et al. [13] designed and implemented a Web of Things application making real-world objects accessible over HTTP. In this context they attached sensors to electronic devices, so they can measure their consumption. These information are further transported to a smart gateway. This gateway includes a web server, control and monitoring functionalities. On top of that the authors presented two different mashups: A *physical-virtual mashup* in form of a standard web-interface and a *physical-physical mashup* - a physical display or ambient device, that displays the current energy consumption of a room in a form of a adaptive light.

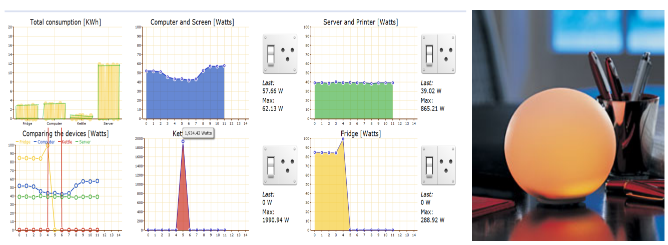

Fig. 5. *Left:* The web user interface for the embedded devices. *Right:* An example of an ambient light orb display [13].

Energy Visualizer. It is a priority of many households to save unnecessary costs. One way to achieve that is to minimize the energy consumption. The energy visualizer is a web user interface *(see figure 5 left)* who enables the user to identify and regulate the energy consumption of the attached devices. They display was designed to be easily accessible, attractive and dynamic - displaying real-time data instead of snapshots. The four graphs on the right side of the screen display the consumption of different devices. Additionally there are toggle buttons to switch them on and off. The two on the left side monitor the total consumption and a comparison of all attached devices. The graphs are redrawn every ten seconds.

The line graphs are a standard way to visualize this kind of data. The different devices can be compared both individually and all together. The possibility to switch the devices on and off with a simple mouse click has the potential to save the most energy in this setup, because a click is simple and fast. The biggest problem of this visualization is that it does not scale very well with an increasing number of devices. There is a lot of unused space and it takes too much time to compare different devices. The bar graph on the upper left side on the other hand is easy and quick to understand. The time line on the lower left side shows a progress, but gets confusing with too much lines represented. All in all this visualization is not the best approach to display IoT data in that kind of way.

Ambient Meter. The physical display prototype changes its color to display the level of the current energy consumption of the room it is temporarily placed in. The feature is that is can be transported to any other room and it automatically changes to color it is placed in. The color ranges from light green (not much energy is consumed) over yellow to red (much energy is consumed).

This physical display *(see figure 5 right)* translates the energy consumption in a room to a color. It is intuitive that a low energy consumption is represented by green (cold, low, calm) and high consumption by red (danger, attention, aggressive). The advantage of this approach is that the user receives very limited information (between low and high) on a visual level. It's omnipresent, an eye-catcher and invokes feelings and the behaviour to try to save energy, more than a graph does. The disadvantage is obviously a great loss of information about the current situation and certain devices. It does provide feedback, but does not support the user to change the current state. A small integrated display could combine the strengths of both physical and virtual display [1].

5 Discussion

In the following there is a discussion about the applications introduced in section four and their visualization approaches.

In all three works the visualization played a crucial part. There are many possibilities how to visualize information depending on the questions you want to answer or the actions you want to invoke in the user. All applications used different sensors and visualizations according to their needs.

The smart economic water feedback display examined many different visualizations, some just displaying data in form of graphs and other tried to invoke certain behaviour to take information visualization to the next step. They showed that it is important to sense and collect as much information as possible, but to visualize only one certain aspect at a time. Their study demonstrated that users want to switch between different granularity levels of information, from a very detailed level to just an overview. In comparison to the Energy Visualizer who used line graphs, bar graphs are one of the best options in terms of readability and usability when it comes to the visualization of pure data. Additionally they were able to create visualizations who invoked that kind of user behaviour they were created for. But they also showed that visualization should not be supporting behaviour that is against that what they are supposed to support.

Applications who try to invoke behaviour are hard to design and - even if well designed - could fail in their task, if the users have negative concerns. They are risky and don't provide a stable outcome and because of that bar graphs are a much saver option, easier to implement and provide insight. However, physical displays provide the power of touch and interaction on a different level then virtual displays. They are able to enhance uninteresting topics and make them 'feelable'.

All in all virtual visualizations are - at the moment - better suited for several visualization tasks in multiple IoT areas. They building up on already existing output devices like tablets or desktop environments, making it easier to develop an application for it. Additionally there are a lot of guidelines and visualization patterns that help creating a useful visualization. Physical displays can provide a benefit, but require a lot of work to accomplish that (in comparison to virtual displays). To make physical displays more appealing there has to be put a lot of effort into the creation of physical displays (e.g. speeding up the 3D printing) and interaction modalities. In the near future the enhancement of touchable shape shifting displays could make physical displays a considerable alternative visualization approach.

6 Conclusion

This paper provides an overview about existing IoT applications and their visualization approaches in different contexts. There are many ways to make good visualizations for IoT applications if you keep a few factors in mind. Try to collect only as much information as you need in order to fulfil the purpose of your IoT application. Virtual devices are powerful to display different granularities of information of different aspects one at a time. Bar graphs are simple visualizations and one of the best in terms of readability, usability and scalability. Visualizations who try to invoke certain behaviour are not only hard to design, but also have a high chance of failure or to get misinterpreted by the user. Ambient Physical devices are fun and provide a greater user experience, but this effect decreases over time and they are very limited in the amount of information which can be displayed and updated. Other physical displays like 3D sculptures can achieve higher results in information retrieval, but need time to build and cannot be updated. Tangible and reconfigurable user interfaces who provide the information density of virtual displays combined with the touch experience of physical devices could accomplish new visualizations. Future research has to be put into the development of new output devices and visualizations and the examination of behaviour changing visualizations.

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Smart Camera Motion via Interconnected Drones

John-Louis Gao

Abstract— The availability of commercial camera drones and their rise in popularity have opened up many new possibilities for filmmakers. But with increasingly sophisticated tools, the need for support in controlling them is increasing as well. The concept of interconnected drones could provide help by simplifying workflows and actively assisting the operators. To achieve this goal, we seek inspiration in another domain where networked vehicles offer benefits and a technological foundation already exists, car to car communication. First we provide a summary of current technologies and efforts for both areas, before analysing the differences and similarities. Finally, we transfer use cases on camera drones which would simplify filming and discuss their feasibility and problems. In conclusion, while some applications and technologies are directly transferable and would be instantly beneficial, the specific requirements of different user groups pose further challenges to research.

Index Terms—UAVs, car-to-x communication, vehicular networks, camera drones, camera motion

1 Introduction

Over the past few years, unmanned aerial vehicles (UAVs), often called 'drones' in the mainstream, have downright exploded in popularity among hobbyists and professional filmmakers. What was once a technology available to the military only is now allowing enthusiasts to produce aerial shots that were unattainable or impossible before. But handling them is still a demanding task, with injuries and monetary loss on the horizon should something go wrong. In the search for solutions to make drone operation safer and easier, while also opening up even more possibilities we look towards another vehicle where new technology has spawned concepts to achieve the same goals, the car.

With the wider adaption of wireless LAN technology in the last decades, manufacturers and governmental agencies alike have pondered how to use it to make our journeys safer. The result is the idea of car-to-car (C2C) communication, the concept of vehicles sharing information to warn drivers about safety hazards we would not have recognised with any of our own senses. And due to similarities in many areas, it is worthwhile to think about a possible transfer of concepts and the resulting consequences.

The rest of this paper is structured as follows: in section 2 we introduce the concept of C2C communication, discuss possible use cases, challenges to overcome and the current state of research. Similarly, section 3 discusses UAVs in general as well as the current progress in research and the market of camera drones specifically. In Section 4 we discuss possible applications of C2C communication concepts on camera drones and their implications. Finally in section 5 we summarise our findings and provide an outlook on possible future concepts and research.

2 Car-to-car communication

2.1 Overview

While the assistance systems of modern cars already provide the driver with external information gathered from other cars, for example about traffic jams on the planned route, they are preprocessed and distributed by a central provider, mostly the manufacturer of the car. Car-to-Car (C2C) communication describes the exchange of information among close-by vehicles over an ad-hoc wireless network, whereas in Car-to-infrastructure (C2I) communication the car communicates with fixed roadside infrastructure such as traffic lights. They can distribute additional information as well as act as a central hub for the wireless network. The main goal of this technology is to assist drivers in critical situations, where information might be missed because of driver distraction or missing visual cues.

Research into C2C communications initially began in 2003, but its origins can be traced back to the 1990s [15]. Recent developments such as the rise of wireless networking and increase in processing power, as well as intensified research into projects such as autonomous cars have brought us closer than ever to the idea becoming reality.

But while the possibility of cars communicating opens up a new world of opportunities and applications, there are still problems to be addressed before the introduction to the general market.

2.2 Technical background

The design of a fitting communication standard for C2C communication poses a challenge due to the unique requirements. It has to deal with a constantly changing network topology, allow their construction 'ad-hoc', that is without a central coordinator controlling the access of the medium, while still being able to reliably provide potentially critical data in short amounts of time. Additional constraints are the desired range, the bandwidth available as well as scalability. Use cases defined by the Vehicle Safety Communications consortium suggest a maximum latency of 100 ms, minimum range of 150 m while cars broadcast messages with a frequency of 10 messages per second [4].

Currently, the most commonly assumed standard for dedicated short-range communications (DSRC) is IEEE 802.11p "Wireless Access in Vehicular Environment" (WAVE) [1], an amendment to the IEEE 802.11 standard, also known as wireless LAN. As of 2012, 802.11p has been incorporated into the 802.11 standard [2]. It covers the PHY and MAC layers in the OSI model. Figure 1 gives an overview of the different standards and their position in the model. Additionally, the IEEE 1609 family of standards define upper layer functions, such as "the architecture, communications model, protocols, security mechanisms, network services, multichannel operation" [40] and others.

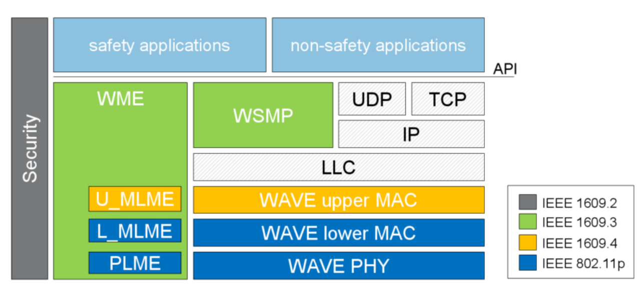

Fig. 1. DSRC standards and communication stack [19]

• *John-Louis Gao is studying Human-Computer-Interaction at the University of Munich, Germany, E-mail: j.gao@campus.lmu.de*
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802.11p is based on 802.11a and shares similarities in the “MAC layer, frequency band, and modulation” [32], while other aspects have been modified for its new field of application. They include reducing the channel bandwidth from 20 MHz to 10 MHz in order to minimise the spreading delay [6], which in turn halves the maximum data rate to 27 Mbps, as well as defining fixed applications for the channels. Additionally, the need for a Independent Basic Service Set (IBSS) as in traditional 802.11 has been substituted by introducing a separate BSS called WAVE BSS (WBBS), which “has fixed identifiers and transmits beacons on demand. A beacon contains the essential information to establish a communication, as well as the list of services offered by the group, eliminating the authentication process” [36].

Teixeira et al. have conducted a series of real-life experiments evaluating 802.11p. In their setup, one car is stationary while the other drives past it at varying speeds. Their results have shown that the average association time lies around 1.035 ± 0.0024 s. They also conducted experiments comparing different frame sizes and movement speeds, measuring the bit rate, delay, jitter and loss rate. For speeds of 20 km/h and 40 km/h, “the average bit rate was around 1 Mbps for 150 byte frames, 3 Mbps for 500 byte frames and 8 Mbps for 1460 byte frames.” [36]. These bit rates may be too low for multimedia applications like audio or video streaming, but are more than sufficient for safety applications. They conclude that 500 byte frames obtained the best performance “although the bit rate for 1460 byte frames was higher, the behaviour for 500 bytes was less variable”.

Additional experiments by Lin et al. have shown that 802.11p is more robust against packet loss in V2I communications, even in nonline of sight environments. Their highest recorded loss rate was 2.68%, while the worst case for 802.11a was 11.1% [23].

Architecturally, the C2C communication system is broken up into the following three individual components. The C2C-CC Car-to-car communication consortium (C2C-CC, an union of mostly European car manufacturers and components suppliers) defines a minimum set of functionalities that these have to fulfil in its manifesto[5].

- The *On-Board Unit* (OBU) is responsible for C2C and C2I communications and based on IEEE 802.11p. It is used “to send, receive and forward safety-related data in the ad-hoc domain.” It can also be equipped with additional network devices for non-safety communications. It also provides these communication services to Application Units

- An *Application Unit* (AU) is “an in-vehicle entity and runs applications that can utilise the OBU’s communication capabilities.” The C2C-CC does not differentiate whether it is a dedicated device, integrated in existing, stationary ones, for example the navigation system or even a nomadic device such as a mobile phone.

- A *Road-Side Unit* (RSU) is a device in a fixed location and “equipped with at least a network device for short range wireless communications”. It’s main functions are to extend the range of an ad-hoc network, as well as providing safety functions. Additionally it could be connected to the internet to transmit information to a central datacenter or even provide internet connectivity to OBUs.

Whilst the means by which the data is transported seem relatively set in stone with prototypes and field tests already making use of them [15], the type of data is still up for discussion. Obviously, different applications require different information. The C2C-CC defines position data, acquired via Global Positioning System (GPS), vehicle speed and driving direction as required. Additional parameters can be obtained from different sensors in the car, for example brake power, rain wipers, ABS and ESP status. The consortium does not specify how the OBU accesses them, and does not yet define a protocol for exchanging them.

Today, many now cars already come equipped with a central computer, controlling and monitoring various sensors, navigation data, the entertainment system and others. It seems obvious, that it could be the entry point to integrate an additional C2C module.

2.3 Use cases

The C2C-CC defines three categories to organise possible use cases [5]. They are:

- Safety
- Traffic Efficiency
- Infotainment and Others

The use of C2C communication to increase **safety** for passengers is the most important application, since it could drastically reduce the number of traffic related accidents. The United States Secretary of Transportation Anthony Foxx has been quoted, saying that “V2V [vehicle-to-vehicle communication] has the potential to help drivers avoid 70 to 80 percent of crashes that involve unimpaired drivers” [22]. The C2C-CC specifies three possible use cases [5]:

Cooperative forward collision warning aims at reducing the amount of rear-end collisions. Here, vehicles “share relevant information such as position, speed and heading”. Vehicles monitor the actions of their drivers and warn them if a critical proximity is detected. Figure 2 shows a model of this use case, with the relevant information propagating over multiple cars.

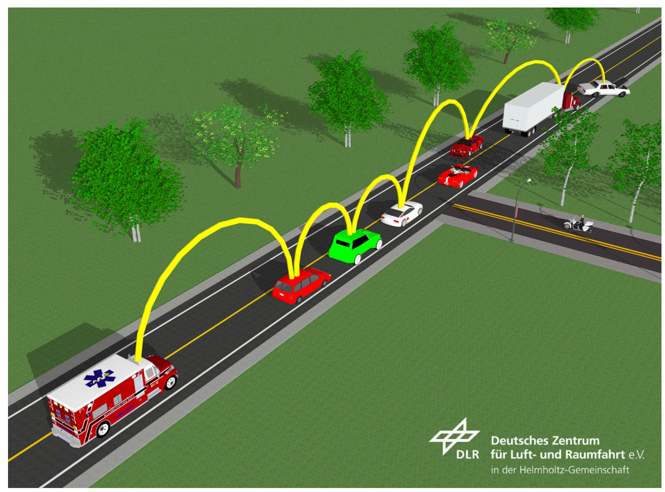

Fig. 2. Visualisation of ’cooperative forward collision warning’ use case [31]

Pre-crash sensing/warning occurs, if the system detects that an unavoidable crash is imminent. The vehicles exchange more detailed information to enable optimised usage of “actuators such as air bags, motorised seat belt pre-tensioners, and extendable bumpers”

Hazardous location V2V notification describes the exchange of information about road conditions among vehicles. It is sourced from the OBUs. For instance, activation of the Electronic Stability Program can indicate slippery road conditions. Other vehicles in range of the V2V system can prepare themselves and warn the driver. Because of the range limitation, it is possible for the information to ”die out” before it reaches another vehicle. Solutions to this problem would be either a RSU that stores the information and broadcasts it to vehicles entering its range using V2I communication, or to relay it via a network with longer range, for example UMTS.

Cooperative adaptive cruise control is an use case mentioned by Röckl et al. [31]. It expands the capabilities of current cruise control systems, which measure the distance to cars ahead using radar or lasers. Its advantage lies in the smaller delay between initiating the speed change and the following car recognising it. Using C2C technology, the car ahead can transmit the cause of the change in speed, instead of waiting for the following to recognise it.

Use cases falling under the **traffic efficiency** category aim at minimising disruptions to the flow of traffic, thereby reducing delays and providing shorter travel times for drivers as well as economic benefits for them and road operators.

One application would be the *green light optimal speed advisory* mentioned by the C2C-CC. It assists drivers in making use of traffic lights that allow continuous traffic flow over multiple intersections, commonly known as ”green wave”. Here, the traffic lights themselves inform approaching vehicles how many seconds the green light is away, or how many are left in the current phase.

Infotainment and others captures the remaining use cases that do not fit in the other categories. They do not provide direct safety benefits but can improve the comfort of passengers. For example, *point of interest notifications* allow local businesses to advertise their services to nearby vehicles. This allows them to reach a target audience more likely to visit them while the driver can access dynamically updated information like opening hours or prices.

2.4 Challenges

The main challenge in the introduction of cars capable of communicating among themselves, is the fact that in order to be useful, there has to be a certain percentage of cars that support C2C communication in circulation.

This goal is particularly hard to achieve, since cars generally have a comparatively long average lifespan. According to the European Automobile Manufacturers Association, the average age of a car in the EU 2011 was 8.6 years, with more than a third older than 10 years [10]. The C2C-CC estimates that even if every new care were to be equipped with a C2C system from a certain date onward, it would take “about one and a half years to reach 10% penetration in the field” and “more than 6 years to reach 50%” [5]. It also spawns another hurdle in that the system will be hard to sell, since customers would not be inclined to spend money for a system that does not or only occasionally works. Possible solutions to this ”chicken and egg problem” are making it attractive to drivers using features that do not require a high penetration rate among cars [37], such as applications that communicate with road-side units. Also, reducing costs by sharing components with other systems in the car as well as subsidising the cost could increase the number of supported vehicles.

Assuming that a sufficient propagation has been achieved, the problem of over-reliance will sooner or later arise. Drivers will get used to the warnings the system provides and assume that the contrary holds true as well, for instance in the collision warning use case that a collision is not imminent just because the C2C system does not send a warning. This may be caused by different factors such as technical failures. It lulls the driver into a false sense of security and may negate the positive effect the C2C system provides. This paradox has been a topic in other fields of automation, such as production lines or safety precautions on aircraft [3, 27]. While scientific studies covering this topic with a focus on the use cases enabled by C2C communications are rare, it will certainly be hotly debated once the infrastructure and systems are commercially available. Similar discussions developed in the past for other safety features, such as daytime running lights [21].

Another focus of research are the underlying issues regarding security and privacy. Especially in environments where potential lives are at stake, it is critically important that received information can be verified for authenticity and integrity, meaning it was sent from a trusted source and has not been tampered with during transmission. In other networks, for example the internet, these goals are achieved using a so called public key infrastructure (PKI). In a PKI, “certificate authorities (CAs) sign bindings between public keys and node identifiers; these bindings are called certificates.” [16]. Entities that trust this CA can store its public key and then verify their certificates. Simply applying this concept on cars opens up other issues. For one, it increases the overhead of messages transmitted and therefore the load on the network, as well as the hardware that has to verify every incoming message, which depending on the density could exceed thousands per second. Also, individual certificates contrast strongly with the goal of anonymity and privacy. They “can be treated as a pseudonym of a vehicle ” [17] and would allow attackers and governmental agencies to uniquely identify them and possibly their owners. Possible solutions to these problems like other authentication processes are actively discussed and researched [24].

2.5 Current situation

At the time of writing, no C2C system is commercially available yet. Various manufacturers have demonstrated prototypes, but only in closed areas and with small numbers of vehicles. While efforts to norm the communications are in place, none of the consortia have yet finalised them. Furthermore, there are separate consortia in Europe, the United States and Japan, all working on their own ones. To complicate the situation even more, the three regions differ in the systems used for DSRC as well. While the U.S. adhere to the IEEE 802.11p and 1609 family of standards, the specification by the European Telecommunications Standards Institute (ETSI) called ITS-G5 is based on 802.11p, but differs “mainly in the higher layers” [34]. Also the allocated frequency bands for the use of intelligent transport systems differ as well. The FCC “allocated 75 MHz in the 5.9 GHz band for DSRC” in 1999 [36], 5.875 to 5.905 GHz to be exact, while the bands defined by the ETSI range from 5.855 to 5.905 GHz depending on the application. Finally the distribution of functions among the bands also differs.

On the technical side, the implementation of C2C hardware and software seems easier than ever. More and more cars come with powerful infotainment systems as standard which offer sufficient amounts of processing power. Also, manufacturers equip their vehicles with WiFi, allowing passengers to stream content from smartphones or laptops to the infotainment system, or even access the internet using an integrated SIM card and mobile radio. A potential C2C system could make use of the existing hardware, lowering the cost for the buyer.

Between competing standards and technical challenges, it might seem like C2C technology is still far away from entering the market. But with the current research interest in autonomous cars as well as the potential safety benefits of C2C communication, manufacturers and governments alike are pushing for faster deployment. In a statement from May 2015, U.S. Secretary of Transportation Anthony Foxx announced that the Department of Transportation “is accelerating [their] timetable on a proposed V2V rule that would require vehicle-to-vehicle equipment [...] in all new vehicles”, adding that “it is critical that technologies like V2V make it onto our roadways as soon as possible” [12].

3 UNMANNED AERIAL VEHICLES (UAVS)

3.1 Overview

UAVs are defined by the U.S. Department of Defense as “powered aerial vehicles sustained in flight by aerodynamic lift over most of their flight path and guided without an on-board crew. They may be expendable or recoverable and can fly autonomously or piloted remotely” [38]. In the past, research, development and usage have mostly been conducted by the military. Contrary to popular belief, the usage of UAVs is not a recent technological innovation. It “pre-dates human-piloted flight” [44]. Records show the usage “as early as the 1849 aerial bombardment of Venice using balloons” [43]. The combination of UAVs and cameras for surveillance usage was explored “as soon as suitable photographic apparatus were developed” [44]. Records show the use of remotely triggered cameras aboard kites in the 1898 Spanish-American War [14]. Watts et al. conclude that “throughout the history of military aviation, development of unmanned aircraft has continued apace, with developments in human-piloted flight often inspiring (or being inspired by) new unmanned aircraft technology” [44].

Due to the range of possible applications, UAVs differ greatly in properties such as size, endurance, capabilities and payload. The classification of civilian UAVs has generally followed military descriptions, grouping them mostly by range. The camera drones covered in this paper, as well as commercially available drones in general mostly belong in the Micro / Nano Air Vehicles (MAV / NAV) group, with few higher end models reaching into the Low Altitude, Short-Endurance (LASE) class. The higher tiers shown in figure 3 are mostly reserved for the military due to high costs as well as regulatory issues. UAVs belonging to these categories are similar to regular airplanes in size

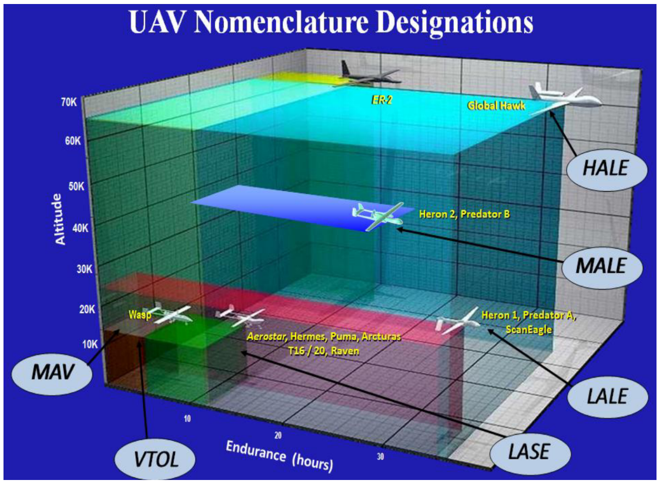

Fig. 3. Classification of UAVs [28]

and build and are generally fixed wing constructions, powered by fuel and require runways to take off and land.

Civilian UAVs that became popular in recent years on the other hand are mostly so called multicopters. They consist of propellers mounted at fixed positions on a fixed frame and are powered using batteries. Unlike helicopters, they are mounted facing in the same direction and have a fixed pitch. Compared to similarly sized helicopters, this setup reduces maintenance cost and workload [29]. They are generally flown within line-of-sight and controlled using a remote.

Multicopters offer inherent advantages over fixed-wing aircraft and helicopters which simplify flying and assist filming. The most significant is the support of a *hover state*. Fixed wing aircraft always require air moving over its wings to stay airborne. This limitation alone is enough to exclude them from being used as camera drones which require maximum mobility and agility. It should be noted however that most surveillance drones are fixed-wing aircraft, because the necessity for longer range prevails. The hover state also covers part of the use cases where helicopters are typically deployed.

The use of electricity as energy source instead of fuel leads to *less vibrations* and therefore a more stable flight. Also, it further simplifies the build since there is no need to worry about fuel pipes and tanks. It also minimises the chance of a total loss after a crash, since there are no flammable liquids on the drone. Finally, while the electrical motors are not exactly quiet, they still emit less noise and no exhaust gasses, making them somewhat less distracting.

Lastly, many components used in multicopters are sourced from remote controlled helicopters and are mostly cheaper as well as readily available. Although off-the-shelf solutions are offered by many companies, some users mix and match components in order to customise their UAVs to their specific needs. This *flexibility* opens up room for experimentation and keeps costs for repairs and maintenance down.

3.2 Current technology

In order to build a multicopter capable of flight, the following components are needed:

- frame
- motors, propellers and electronic speed controllers (ESC)
- battery
- flight controller
- radio receiver

The *frame* holds the components together and should ideally be as light as possible to maximise flight time as well as stiff enough to endure potential crashes without breaking. Typical materials used are aluminium, plastics and on higher end models carbon fibre composites.

The *motors* used in multicopters are usually brushless since they offer a better power-to-weight ratio and do not heat up as quickly as their brushed counterparts. [25] As mentioned before, they are generally mounted facing in the same direction and motors next to each other spin in different directions to avoid the multicopter spinning around its yaw axis. The amount of motors necessary depends on the desired use case. While bicopters with only two propellers are possible, they are very sensitive to weight distribution and hard to fly. Tricopters need a servo to tilt one motor in order to provide yaw capability, can only carry a light payload and provide no redundancy should one of the rotors fail. The most common configuration features four motors and offers a good compromise between stability, lift and cost. Professional camera drones frequently feature six or eight rotors, allowing for heavier payloads and more redundancy. Propellers face the same requirements as frames. They should be light to respond quickly to changes in rotation speed and stiff to prolong their usage time. It should be no surprise then that they are typically manufactured from the same materials. The ESC is responsible for converting the signal from the flight controller and the attached batteries to deliver the power necessary to drive the motor at the correct speed.

Batteries provide power for motors and controllers. The most commonly used type for multicopters are lithium polymer batteries which offer good power density, high discharge currents and a friendly discharge voltage curve.

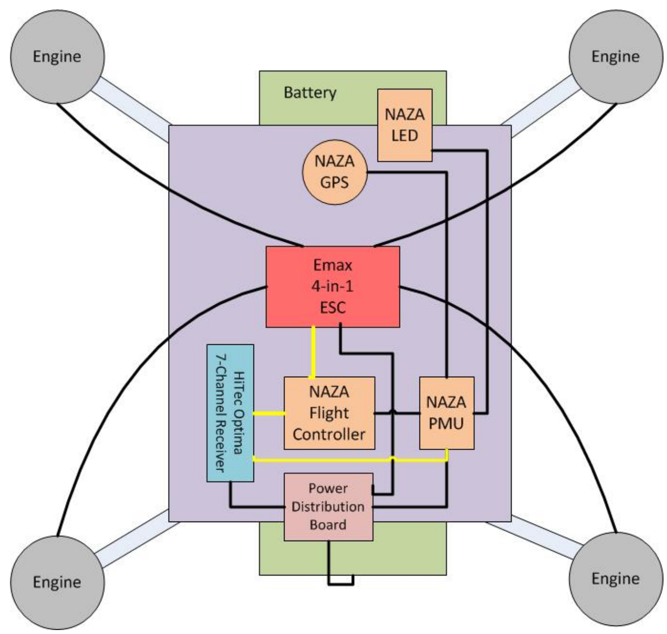

Fig. 4. Schematic of a simple quadcopter [13]

A *flight controller* is a microcontroller responsible for processing the inputs of the operator and sensors on bord and controlling the speed of the rotors based on them. In order to determine its position and movement, it contains at least a 3-axis gyroscope and accelerometer. These sensors are referred to as inertia measurement unit (IMU). Sophisticated models can automatically level out the multicopter when no inputs are available and support additional sensors to improve accuracy such as GPS for positional information and sonar for more accurate altitude measurements and collision avoidance. Some manufacturers make use of them by offering functions such as automatic return when radio contact has been lost or the batteries run low, as well as supporting the following of pre-programmed flight routes.1

Finally the *radio receiver* receives the control inputs made by a transmitter and relays them to the flight controller. These systems are the same as the ones used for RC helicopters and mostly transmit in the 2.4 GHz spectrum. The corresponding transmitters mostly use two sticks to input controls, with the four axes mapped to elevator, rudder, throttle and aileron respectively. The amount of channels a receiver has to support depends on whether additional signals such as controls for a gimbal have to be transmitted as well.

The type of *camera* mounted on the UAV differs depending on the price range. Cheaper multicopters come with integrated cameras mounted directly on the frame, recording to a flash card and offer no image stabilisation. Mid-level off-the-shelf products mount their cameras on a brushless 3-axis gimbal, which use the IMU to react to movements of the drone and counteract them by rotating the camera in the opposite direction. They offer impressive results, challenging the steadycam while being easier and cheaper to operate. High-end multicopters use gimbals that offer mounts for external cameras. They can range from small action cameras like GoPros[1], mirrorless and DSLR cameras with interchangeable lenses up to professional ones used in movie production like the RED EPIC[2]. The orientation of the gimbal and camera can be remotely adjusted, allowing tilts and pans independently from the movement of the drone. Some can also control the zoom and focus of a mounted lens. In order to alleviate the framing of subjects, some systems offer a way to transmit live video from the camera to a monitor, generally via WiFi or other protocols in the 2.4 GHz band. Since the camera operation is relatively complex, it is generally handled by a second person allowing the pilot to concentrate on the drone movement alone. This setup requires a well-rehearsed team to correctly execute a choreographed movement.

Figure 5 shows an example of a professional camera drone made by DJI. It features 8 propellers, a maximum takeoff weight of 11 kg and uses a Canon 5D Mark 3 DSLR mounted on a 3-axis gimbal to capture the video. It's maximum flight time amounts to 15 minutes in optimal conditions (hovering without direction changes). Figure 4 shows a schematic of a similar build, using components of DJI's NAZA family.

Depending on the make and model, these multicopters can reach speeds up to 100 km/h, as well as heights and ranges of up to 5 km. Generally speaking, these specifications make multicopters an adequate alternative to other systems used to capture aerial footage like helicopters, spidercams or cablecams while being more affordable and flexible to set up and also supporting tracking shots which are usually filmed using steadycams, dollys or cranes.

3.3 Challenges

The technical challenges in the field of camera drones mostly concern the short flight time and other limitations set by the need for heavy batteries. Battery-powered UAVs have flight times around 60 minutes at maximum, depending on the amount of battery-packs and additional payload carried. Professional camera drones only manage around 20 minutes due to the weight of high quality lenses and camera bodies. This rules out the usage of UAVs for many applications such as live-broadcasts of events and puts more pressure on the execution of pre-planned shots. While the battery-packs are interchangeable on most drones, the flight still has to be interrupted. Though until a more effective solution to store electrical energy is found, it is still the best compromise. Possible solutions such as using a combustion engine as range-extender or powering propellers in addition to the brushless electrical motors are still in the prototype stage and not ready for the mass market [30] . But with more development time and more capable gimbals to counteract the vibrations of fuel-powered propellers, a hybrid approach could pose as a useful replacement.

Due to their quick rise in popularity in the recent years, the laws and regulations concerning UAVs are still lagging behind their capabilities. The recreational use of drones generally falls under the same regulations as other model aircraft. The details differ from country to country, though they place similar limitations. Firstly, UAVs must be flown in line-of-sight at all times. Second, the height is limited to around 100 m in order to avoid interference with manned aircraft. Also there is a maximum weight limit placed at around 25 kg. Finally, there are restrictions in place to prohibit entering critical airspaces, such as airports, governmental buildings and big crowds. In recent years, governmental agencies such as the FAA have proposed new regulations specifically tailored to recreational usage of UAVs [11]. Potential commercial users on the other hand currently have to request a license and register their aircraft with the agency in order to fly.

Independently from the risks they pose towards other aircraft, there are also risks for users and bystanders in the vicinity of the drone. The motors rotate at multiple thousand revolutions per minute and can cause serious cuts and injuries when coming in contact with humans. Additionally, the size and weight of a UAV flying at high speed poses a threat should it crash due to pilot error or technical problems. The availability of ready-to-fly drones for everyone combined with inexperienced pilots has lead to multiple accidents in recent years [20]. This raises the question if a pilot certification should be mandatory in the future. In its proposal, the FAA suggests a minimum age of 17 as well as passing "an initial aeronautical knowledge test at an FAA-approved knowledge testing centre" and "a recurrent aeronautical knowledge test every 24 months" in order to be allowed to operate an UAV [11]. Considering the dangers and the fast development and distribution of drone technology, we can assume that governmental regulation is on the horizon to eliminate grey areas.

4 Application of C2C concepts on UAVs

4.1 Analysis of problem domain

Fig. 5. Example of a professional camera drone [8]

The similarities in the two domains might not be obvious at first, but they share enough of them for us to think about the possibility of transferring applications. For one, both cars and drones are currently sold with a plethora of wireless communications hardware on-board but do not make use of them in order to communicate among themselves yet. Secondly, the technical requirements and limitations for this communication are very similar as well. They require a similar range, move at similar speeds and prefer very short delays to increase safety and support other applications.

While a generally accepted standard for exchanging data in the C2C domain exists in IEEE 802.11p, no such protocol for interconnected drones is in place yet. Past efforts and research in interconnected UAVs are mostly focused on military ones and more concerned with longer range communications than the comparatively short ones required for camera drones. Various network technologies have been explored for usage among swarms of UAVs and between UAVs and ground stations, including 802.11a [6], 802.16e WiMAX and 3G cellular networks [9] as well as Bluetooth [7]. Each of these differ in range, data rate, energy requirements and price. WiMAX was originally intended to offer broadband access to remote places via stationary connections. It was designed with long range and low delays in mind, while still offering good data rates. But due advances in cellular networks such as Long-Term Evolution 4G offering higher data rates and the increasing range and speed of WiFi, the usage of WiMAX has

[1] http://www.gopro.com/
[2] http://www.red.com/products/epic

decreased to the point of obscurity [42]. Bluetooth is a very energy efficient and popular standard for close-range communications, but does not offer enough data throughput and range for our application in interconnected drones.WiFi seemingly offers the best compromise between our desired properties. Especially with the modifications made in 802.11p, it fulfils all our requirements regarding range, data rate and delay. However at the time of writing, no research or performance measurements for the usage with drones exist. Yanmaz et al. have performed measurements using 802.11a however, showing a throughput of 10 Mbps at a distance of 500 m is possible [46].

The goals of interconnected camera drones are not as focused on the safety aspect as C2C communication, since they do not carry passengers. As shown in section 3.3 however, it should still be addressed, since their operation is still dangerous. The main focus lies on supporting filmmakers in achieving their desired shot, whether they are professionals or amateurs. This divide in the user group will have consequences we must consider. Just like with other technology, there is a discrepancy between the ease of use and amount of manual control between the target audience. Normal users will expect more autonomy because they do not have the personnel, equipment or expertise of professionals, though professionals can benefit from more autonomous flying as well. However, it sets high requirements for the precision of sensor data and processing power, both of which ca not be realised yet without compromises in other areas. For example the “Flying Machine Arena” [26] by Lupashin et al. demonstrates a space in which multiple UAVs execute impressive feats together, such as catching and throwing objects in a net spanned between them. The individual movements however are not calculated by the UAVs themselves, but by an external PC that merely sends control commands to them. It also requires an array of up to 13 cameras plus markers on all UAVs and objects to precisely track their location. They claim that each installation “took 4-6 h to set up from shipped containers and 4 h to break down back to a packed form.”, which makes this system far too intricate for use by typical users. It may however be feasible for locations where filming via camera drone is frequently necessary, such as stadiums or movie sets. Without additional technology, UAVs have to rely on civilian GPS for positioning, which may not be accurate enough.

4.2 Use cases

The first use case we will discuss is *cooperative collision avoidance*. As mentioned before, while camera drones do not carry passengers, they are still a potential hazard to humans, not to mention their cost and the cost of the equipment they carry can easily exceed thousands of euros. Some flight controllers already support obstacle detection via technologies such as ultrasound or 3D cameras. Interconnected drones could enable the detection of imminent collisions and warn the pilot or even autonomously avoid it, similar to the cooperative forward collision warning use case in C2C communication. This use case would require the transfer of position and movement data, including the altitude among the drones. This added dimension increases the computational difficulty and therefore requires more processing power.

The pre-crash sensing/warning use case can also be extended to the drone’s surrounding environment. It could be mapped into a digital model that could be transmitted between UAVs to extend its vision further, just like in C2C communication. This system could also implement the safety measures proposed by the C2C-CC. Similar to the measures aimed at protecting the driver, the system could try to minimise the damage and possible injuries to bystanders by slowing down the rotors to avoid cuts or orienting the multicopter in a way the camera does not get hit, should an unavoidable crash be imminent.

Another range of applications could make use of the continuous broadcast of position and direction when combined with data stemming from the mounted camera. Given an OBU that is powerful enough, each drone could build a three-dimensional model of the current location and perspectives of nearby drones. This way, they could *avoid entering others frames*, again either by warning the pilot or autonomously. The application would require the additional information such as the focal length and orientation of the camera. Building and maintaining this model as well as predicting possible collisions with frames of other cameras is a demanding computational task, although it could be combined with the collision avoidance use case.

The final use case is the *automatic tracking of subjects*. Here, one or more drones follow a previously determined target in a set distance while keeping it in the frame. This use case could make the usage easier for both hobbyists and professionals alike. The first group gets a system that does not require a dedicated operator, the latter profit from the easier setup and recording of multiple camera angles. This use case is conceptually similar to the adaptive cruise control in C2C communication. In both domains, the goal is to avoid collisions, while also easing the job of operating the vehicle. Among the differences we have to consider when applying it on drones are the fact that cars generally move on roads, which makes the movement more predictable than a subject that can move freely in all three dimensions, as well as a difference in distances.

4.3 Discussion

The introduction of interconnected drones to the civilian market seems very possible, with current products already featuring a plethora of networking and sensing solutions. Just like in cars, the low prices for hardware have lowered the barrier of entry to the point where even the cheapest models make use of WiFi, Bluetooth and others. These technologies are mostly used to realise one-to-one communications, mostly between the UAV and a ground station. They cover use cases regarding the control of drone and camera, as well as transferring data such as a live video feed. This shows that while the technical requirements for interconnected drones are mostly fulfilled, there is no generally accepted standard for communication yet. In this section, we will discuss the requirements and feasibility of the use cases introduced previously.

The issue of collision avoidance has always existed in the world of aviation, with the first collision on record occurring in 1910, only seven years after the Wright brothers first took off in a motorised aircraft [41]. The inherent danger of mid air collisions has lead to the introduction of air traffic control. Electronic traffic collision avoidance systems (TCAS) have emerged during the late 1990s and are currently mandatory under regulations of the International Civil Aviation Organization for all aircraft with a maximum take-off mass of over 5,7 t or authorised to carry more than 19 passengers [18].

TCAS and other similar systems such as FLARM[3] operate by requesting data from the transponders of nearby aircraft, including their speed, direction, climb-/sinkrate and height to build a model and predict possible collisions. Should one be detected, the system warns the pilots and in the case of TCAS orders one of them to climb and the other to descend immediately.

The direct transfer of these systems to UAVs is problematic for several reasons. First, they are designed for larger aircraft which are less agile and move in more predictable patterns. Rapid changes in movement speed and direction will require frequent broadcasts to update others systems. The positioning is provided via GPS, which only guarantees an accuracy of 7,8 m [39]. To predict collisions, a more precise method of positioning will be necessary. Second, they add significant weight and require energy to function, resources that are both limited on camera drones. Finally, the computation of flight paths requires additional processing power for either the flight controller or another computer.

The switch to 802.11p to broadcast flight data could reduce the power consumption, whilst flight controllers continue evolving. The increasing popularity and power of small single board computers such as the Raspberry Pi[4] could make them feasible replacements. Even if the addition of processing power were not possible, modern standalone systems like the PowerFLARM Portable (see Figure 6) weigh in at a mere 150 g and are small enough to be carried on a drone.

It seems that the most problematic challenge is the issue of precise positioning. In the Flying Machine Arena [26] mentioned earlier, an array of cameras in conjunction with markers on the drones is used.

[3] `http://flarm.com/`

[4] `https://www.raspberrypi.org/`

Fig. 6. Commercial collision avoidance device (PowerFLARM Portable) [33]

The limitations to this approach are the limited transportability and additional cost. Still, in some situations it might be sensible to adopt this idea, for example in areas where camera drones will be used extensively, such as movie studios or stadiums. Other projects aim at improving GPS accuracy using improved algorithms and multiple receivers. An example would be the Piksi by Swift Navigation[5], which uses two GPS receivers to achieve accuracies of up to 2 cm.

The use case of camera drones avoiding entering others frames sets similar requirements. In addition to the flight data, information about the state of the camera has to be broadcasted as well. The computation of a three-dimensional model tracking the line of sight of surrounding drones can be performed in addition to the flight paths.

To track the movement of a subject, a method of localising it will be necessary. Early prototypes by Wenzel et. al used infrared LEDs and required the subject to wear a special hat [45]. Today's commercial products mostly use a small tracking device that wirelessly communicates with the drone via Wi-Fi or Bluetooth that can be worn as an armband. Popular examples are the Lily drone[6] or Hexo+[7]. A limiting aspect is the absence of a collision avoidance system for detecting obstacles, meaning that both can only be used in open spaces. Also, they are designed as completely autonomous solutions, meaning there is no way to manually control either the direction or the camera. This may be sufficient for casual users, in order to appeal to professionals however, manual control is a necessity. For example, the automatic following can eliminate the need for a dedicated pilot, while a camera operator would still be able to frame shots. Additional information about the flight path can assist him in planning ahead. Concepts to avoid collisions with obstacles revolve around sensing the environment using ultrasound or infrared light. Prototypes have been built using commercially available systems such as Intel's RealSense[8] ore the Microsoft Kinect[9].

A second approach is to track the subject using the images produced by the cameras. For example, Tarhan and Altu describe a system using a catadioptric camera to detect movement [35]. The Shift by Perceptive Labs[10] is a add-on kit for commercial drones that targets a professional audience. It contains a camera and processor that allow for selecting any arbitrary subject to track as well as multiple subjects, while still allowing manual intervention into controlling the drone or gimbal. It tackles the need for processing power in order to perform image recognition by supplying its own processor. In Figure 7 an example scenario is shown where the camera is controlled by the Shift system, following the boarder while the drone movement is controlled by an operator.

Fig. 7. Example usage scenario of the Shift system [33]

To summarise, the problems in realising these concepts can be boiled down to three general issues. First, the increased amount of processing power needed to evaluate the information gained from own sensors and received from other drones. With increasingly powerful mobile platforms and the popularity of miniature computers such as the Raspberry Pi, this factor might not be relevant anymore in the near future. Second, the necessary hardware will add weight and cost compared to existing platforms. Similarly to C2C communication, it could be reduced by making use of existing, built-in radio technology or combining the function of the flight controller with the new computer, replacing the existing PCB. Additional sensors however will negatively impact the maximum payload and battery life. Lastly, the suitability of 802.11p or similar standards has not been shown yet, and differences in network topology and routing could make additional changes necessary.

5 Conclusion

In this paper we gave an overview of car-to-car communication and camera drone technology. We gave information about the histories, technical backgrounds, challenges and the current state of both, then discussed the possibility of transferring concepts from the former to the latter.

While C2C technology has not been introduced to the general market yet, the wide availability of underlying hardware as well as the significant safety benefits it provides have lead to increased efforts to do so by manufacturers and governments alike. Compared to the established and heavily regulated cars, drones are a very young technology. With every year, they offer more and more functions to make the usage easier and safer. The concepts of C2C could fuel these innovations even more and while not fully fleshed out yet, their benefits can be the next step to help drone technology unfold its full potential.

To summarise, the general transfer of C2C concepts in the domain of camera drones can offer advantages for amateurs and professional filmmakers alike. Despite the similarities in requirements and environments, the existing 802.11p standard will probably need adaptation to the topology of UAV networks in order to perform at its fullest. With technology relentlessly pushing forward, the use cases here and many more will probably be realisable in just a few years time. Until then, further research is required to make the most of drone technology.

[5] http://swiftnav.com/piksi.html
[6] https://www.lily.camera/
[7] https://hexoplus.com/
[8] https://www.intel.com/content/www/us/en/architecture-and-technology/realsense-overview.html
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The Handling of Big Data in the Quantified Self Movement

Philipp Hauptmann

Abstract— The continuing rise of modern sensors faciliates the tracking of self-concerning data. Based on a review of related literature, this research paper examines the handling of the resulting data masses that are gathered in the Quantified Self tracking process. It identifies challenges and investigates suggested solutions. A special focus is on the tools, that the self tracker uses to analyze and explore his data. These tools that are used in the traditional Big Data analysis are introduced and compared to tools used for the analysis in the Quantified Self. Finally, I discuss reasons for the Quantified Selfer's drowning in collected data and give design recommendations for personal information analysis tools.

Index Terms—Internet of Things, Quantified Self, Big Data, Analysis, Exploration

1 Introduction

Since the human being is curious by nature, he wants to bring order, understanding and control to the environment which surrounds him [25]. Classical self-tracking has been practiced for centuries. In fact, the first record about an individual tracking quantitative numbers of himself, Sanctorius of Padua, was held back in the 16th century [25]. Looking at the more recent past, self-monitoring was an area of research in behavioral psychology since the 1970s [14]. While Sanctorius of Padua used to track his body weight and food intake via pen, ink and paper, modern sensors allow us to collect various kinds of digital data for constantly decreasing costs [25]. Additionally, these sensors become more and more powerful: an up-to-date heart rate monitor, for example, collects up to 250 samples per second [25]. Today's technology faciliates the tracking of enough data to pull conclusions for the quality of our lives. One of the current main challenges in self-tracking is how to handle the emerging large amounts of collected data [13].

2 The Quantified Self Movement

The term Quantified Self describes "any individual engaged in the self-tracking of any kind of biological, physical, behavioral or environmental information"[25]. With today's low-cost sensors, you don't have to be a health professional anymore to track quantified self data. Anyone has access to tracking devices, [27] even the sensors in current smartphones can track different types of data [11]. In general, the devices range from manual data collection with pen and paper over fitness trackers like Fitbit to luxury smart watches [12]. These devices allow to track data automatically.

In 2008, American WIRED editor Kevin Kelly formed the still growing "Quantified Self Movement". The core of this movement are, regularly, worldwide held "meet ups", where members and interested people discuss their self-tracking experiences [25]. Figure 1 shows the rapid growth of their community between the years 2010 and 2011. The Quantified Self guideline "self knowledge through numbers" is not just about collecting as much data from oneself as possible. Rather it is the attempt to get to know yourself better with the intention to improve your life [14].

Thereby the Quantified Self Movement differentiates between the individual and community [11]. Basically, self-tracking is a n=1 experiment, where the sample size of a trial is being generated of only one individual [21]. The Quantified Self community offers a platform, where individual selftracking experiences can be shared worldwide through meet ups, blog posts or conferences. Their web site serves as a repository for people to get information and share experiences about self tracking [14]. This possibility to share their data to people around them or over the internet is developing an even larger "group data" pool of the community [25], even though conventional data management tools already despair of the tracked data amount by an individual [13]. This is already the first challenge that comes with the large amount of collected data.

- *Philipp Hauptmann is studying Media Informatics at the University of Munich, Germany, E-mail: philipp.hauptmann@campus.lmu.de*

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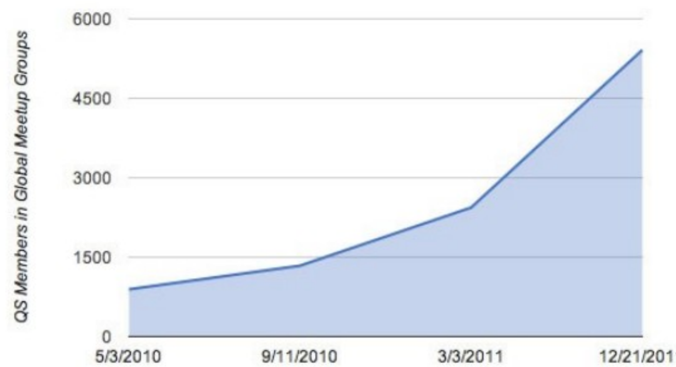

Fig. 1. Growth of the Quantified Self meet up members between 2010 and 2011 [1]

3 Big Data in the quantified self context

These data sets which can't be computed with traditional data tools are generally called "Big Data" [19]. As this term is a rather young phenomenon in data science, it still is far from general knowledge. In 2013, more than half of the interviewed persons in Germany didn't know the definition [6]. In fact, there is not only one definiton, but several similar approaches to describe this phenomenon. One approach by Merv Adrian defines the term as "Big data exceeds the reach of commonly used hardware environments and software tools to capture, manage, and process it within a tolerable elapsed time for its user population" [8]. The Big Data in the Quantified Self Movement consists of the collected data from several tracking tools. That amount of tracking data is growing rapidly, because many sensors and devices produce many data. For example, the Internet of Things, where the Quantified Self counts to, will be the main part of worldwide Big Data by 2030 [13]. The mobile sensors' traffic of 2012 were almost ten times higher than the whole internet traffic in 2000 [23]. These numbers illustrate the recent growth of collected data size.

But it is not just that the increasing amount of data sets made it difficult to manage them. Also, it has totally changed the way of doing experiments. The traditional way consisted of scientists to decide which values they want to collect and how they would analyze them. Now, with the possibility of collecting large data sets, everything is being tracked and the analyzing is done via pattern recognition in the resulting data [24]. This approach is called ”data dredging” [24] and follows the statement that ”patterns can emerge from that data before we understand why they are here” [26].

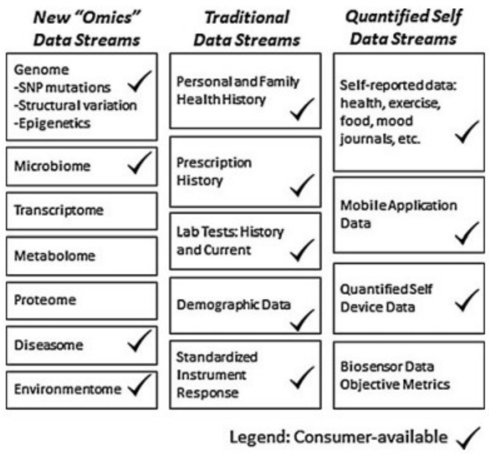

Fig. 2. Data streams that produce Big Data [25]

Figure 2 shows the three groups of health data streams: the traditional medical data (like blood sugar, blood pressure or heart rate), the omics (like genome sequences) and the quantified self data (like sleep hours, fitness activities). Even if they may not seem to conform the Big Data term at first glance, these data streams offer three features of the Big Data Paradigm [13]. First, the many different sources that produce masses of data. Second, the generated data is mostly unstructured and heterogeneous. And finally the tracked data is only useful for the individual after it has been analyzed.

Big Data offers several opportunities to work with in the Quantified Self movement. As machine learning algorithms are taking profit of large data sets, they can work more efficient. For example in image recognition algorithms, before the software is able to ”recognize” images, it has to be fed by masses of images. In Quantified Self, the tracked data could be used to get a better understanding of biophysical phenomena in general. Additionally, with Quantified Self Big Data, new tiers of health norms could be articulated. The guideline that eight hours of sleep are ideal for adults could be reviewed with greater granularity. Another potential benefit of working with Big Data in the Quantified Self, respectively health sector is the opportunity to set up a passive collection of these available data sets, which would act as an early warning system. Anytime certain biophysical behaviours would shift outside the normal variability, it would alert the tracker [25].

After pointing out, that the Quantified Self, and life sciences at itself, have entered the area of Big Data, and that we can take benefit of it, we take a look at the resulting challenges in each step of the process from tracking numbers to provide useful information for the Quantified Self tracker.

4 Challenges of Quantified Self's Big Data

The process of how the tracked data arrives as information to the Quantified Self individual splits in three parts. Each of them is currently confronted with different challenges. Besides the data pipeline, from collection over processing/analyzing to exploration and being visualized to the individual, important challenges in the sector of sharing and resulting from that in the privacy of the tracked data have to be mentioned. In Figure 3 I created an illustration of the connection between the five terms whose challenges are going to be investigated.

4.1 Data Collection

Masses of big data are already generated[13], even though fully automated tracking of all values is not possible yet [25]. It does seem likely, that one device isn't enough to store and compute these various data streams. The current approach to solve this problem is the displacement of the data away from local devices into the cloud. The resulting advantages are obvious: more storage and processing power [16]. Since the cloud services don't solve the problem with the handling of unstructured and heterogeneous data, the long-term goal in the collection process is developing algorithms for efficient compression of the raw data on the one hand. On the other hand it is desirable, that the tracked data gets translated automatically into reasonably aggregated data [25]. These steps would facilitate the data processing procedure.

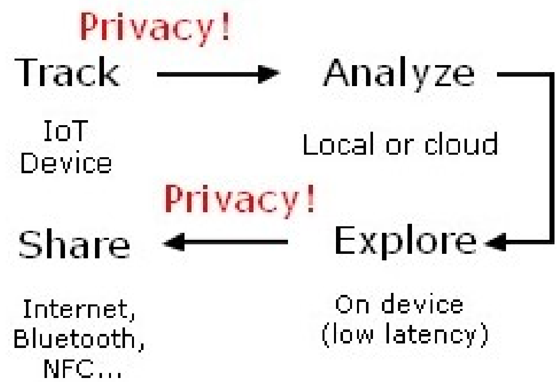

Fig. 3. Illustration of the QS data pipeline (by me)

Another challenge is the fact that several sensors simultaneously collect different values of the same individual [25]. Resulting in a large amount of raw and unstructured data sets [9]. The official Quantified Self web site currently lists over 500 tools and devices that help you tracking your life [1]. As we have this high number of sensors, more precisely different sources, these raw data sets are also heterogeneous which complicates the integration of the data [9] (Figure 4).

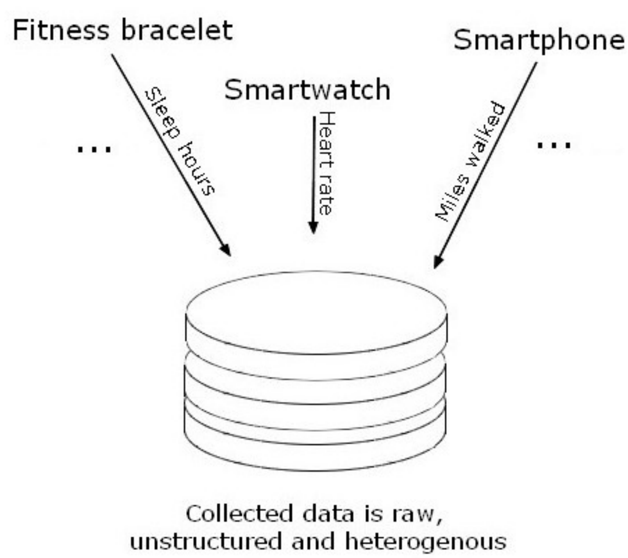

Fig. 4. Examplary illustration of the collection process (by me)

4.2 Data Analysis

Although the hardware and tools for computing digital data have improved the last years as well, the processing of data has fallen behind the collection of it [13]. In other words, more data is being collected than can be calculated. That can be seen as a challenge in the Quantified Self context, as one of the near future goals is to allow real-time processing resulting in instant feedback to the self tracker, which will be detailed out below.

The main reason for the complexity to process is the high dimensionality and massive sample size of the collected data, where traditional statistical methods are inapplicable. Also large data sets show three features which impede the analysis in particular: noise accumulation, spurious correlation and the incidental endogeneity [15].

The ”accumulation of noise” in big data sets describes the phenomenon, that most of the tracked data is not valuable [15]. For illustration: if you track your heart rate over several days, most of the time you will receive normal values but only the few abnormal values, that could be warning signals, are of interest. A big part of the tracked data is therefore unnecessary to explore and seems to be a waste to store. But these files have to be kept in order to investigate and validate the data sets. One approach for solving this problem is to store the data compressed and the development of new algorithms that could process these compressed files efficiently [25]. The search within compressed files could reduce one of the main challengegs of Big Data, the huge amount of storage needed.

”Spurious correlation” is the occurrence of fake relations between variables in data sets. The high dimensions can cause high sample correlations between normally uncorrelated variables. This is especially dangerous in the above mentioned technique of data dredging, the search for patterns in data sets. While in traditional data sets these minor spurious correlation can be detected relatively easily, the sheer size of the amount of wrong correlations in Big Data sets can mislead to think about real correlations [15]. As David Leinweber, a computer and financial scientist, found a strong correlation between the S&P500 stock index and the butter production in Bangladesh,[18] such a similarly arbitrary correlation could also occur in the Quantified Self context, with Big Data making it more likely to appear misleadingly.

The third feature of large data analysis is the occurrence of incidental endogeneity. That describes the phenomenon of a correlation between a measured variable and a value from noise. The difference to the spurious correlation is, that these correlations really exist, but, due to the high dimensionality, are being linked incorrectly [15].

Besides these unique phenomenons occurring in Big Data analysis, there are some challenges for the used hard- and software as well. Computing a continuosly growing amount of large data, carries the risk of high computational costs and hardware requirements [15]. While one approach for the solution is the displacement into the cloud, the focus challenge is to develop algorithms which minimize the instability when working with masses of heterogeneous data. In this case, traditional solutions and algorithms have to be reconsidered.

Databases like MySQL and Postgres show a lack of scalability compared to large sets like in Big Data. Platforms and algorithms like MapReduce and Hadoop, who distribute their data on several servers (see Figure 5), do scale up to these masses, but they are mainly used for processing blocks of replicated, disk-based data and therefore inappropriate for low-latency responses like needed in the Big Data context [19]. The future goal in the processing of the Big Data generated by Quantified Self tracking is not only the development of algorithms that guarantee stability and efficiency but primarily the analysis of the collected input in real-time [15]. As the tracked data constantly changes, it needs to be computed and returned with a very short delay [25].

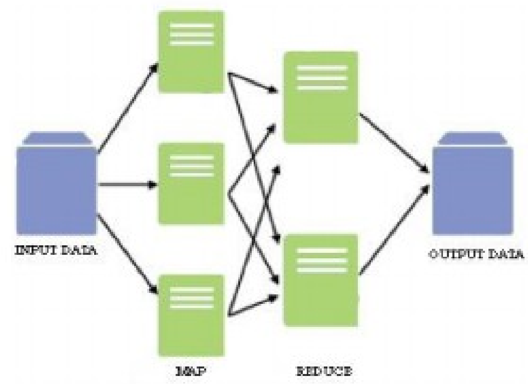

Fig. 5. Architecture of distributed servers with Hadoop and MapReduce [26]

4.3 Data exploration

The top three motivations for people to track things of their life are at first to improve their life by getting to know themselves better with their data. Second, to improve other areas of their life like feelings and senses, to be more mindful everyday. The third motivation is to find new life experiences by exploring things to track [14]. Like the Quantified Self slogan sums it up very well, the ”self-knowledge through numbers” is the self tracker's main motivation. The fact that people think in stories and not in numbers, is another indication of what people expect from exploring their tracked data. Compare Figure 6, how participants of a study from Choe et. al. explored their tracked data bei building customized visualizations [14].

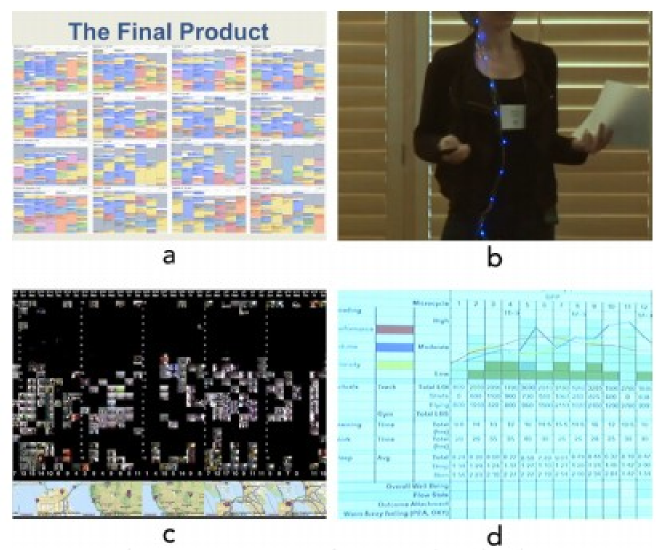

Fig. 6. Custom visualizations of users exploring their data [14]

As one participant of the study mentioned above has noted, the biggest challenge for the data exploration consists of the lack of the user's exploration knowledge: ”it's not that we lack the information[...] The obstacle is that we don't have the proper tools to interpret the significance of our data”. As we are going to examine in chapter 5.2, the tools actually do exist, but they can't be used by unsophisticated users.

4.4 Data sharing

The basic idea of the Quantified Self movement is being part of a community. While currently only experiences of the self trackers are being shared at their regular meet ups, the intention exists to create public online databases where anyone can share their digital collected data and compare it with others [25]. These emerging Big Data sets could facilitate the research process, like the public genome databases in genomics did before [25]. Big Data scientists could take a leading role in both developing new models to support Quantified Self data sharing features and also defining open-access database resources and privacy standards for how personal data could be used in the future [25]. But there are some challenges as well.

The question to be asked would be the copyright of self-tracked data. Am I the owner for the data I tracked? Do I own the data of my food intake? Or does the copyright move to the database's owner once it has been contributed? The World Economic Forum has suggested that personal data should become a new asset class [22]. In addition to these ethical, or rather legal, issues a technical challenge appears as well. It is like the variety of data sources from the individual tracking resulting in heterogenous data masses, but on another level. Many sources from different devices and trackers would come together. So the future goal regarding the sharing of self tracked data is to model a single data standard for all contributors [25].

4.5 Data privacy

Where data is being shared, potential points of contact for criminals occur. Securing the gathered data is one of the key challenges of the Quantified Self [10]. Since the main goal of self trackers is to collect as many self data as possible and best manage it all together in one tool or device, the combination of a person's health, behavioral and environmental data represents an attractive target for cyber-criminals [25]. With these data stolen, crimes like identity theft, stalking or misuse in general are thinkable. As self-tracking services are running on mobile devices, they can be compared with conventional mobile services or apps. Hence they share the same security issues. In general, three stages of points of attack do exist, that need to be secured: on the device, while transmission and, when shared, in the cloud storage.

The security risks on the device are, at first, that your tracking device gets stolen. If you use your smart phone for your daily trackings, you maybe set up a password protection to prevent the thief to get easy access on your tracked data. In contrast to smartphones, devices that are only used to track specific data, don't offer much protection for the physical theft of the device. Besides this physical theft, digital data stored locally on your device can be stolen by malware. Another attacking point exists while transmitting your data. Either if you sync it with your data stored in the cloud or share it with other trackers via Bluetooth, WiFi or NFC. Risks like traffic sniffing, man-in-the-middle-attacks or redirecting your data to non-confidential servers exist.

While the previous targets mainly involve the risk of getting data of single individuals stolen, the cloud storage contains data of all users of this software or device. Attacks like brute-force logins or Denial of Service attacks are only two of them. Here lies the responsibility mostly with the service provider [10].

5 Tools for working with Big Data

After pointing out the current challenges that come along with generating Big Data through self tracking, we now take a look at the analysis and exploration tools that are used in traditional Big Data context. Hereby, the term "traditional" has to be treated with caution, as Big Data itself is a young phenomenon in data science [17]. These tools will be compared with those that are used in the Quantified Self context, to understand, how the self tracker's way of dealing with his Big Data can be improved. As it is common in current end user tools, the presented softwares below combine functions to analyze and explore Big Data.

5.1 Traditional Big Data Analysis Tools

A study conducted by the data science corporation KDNuggets in 2012 asked 798 professionals which Big Data analysis tools they had been using in the past 12 months [7]. The top five answers almost entirely consisted of open source statistical software tools, Excel was the only commercial product of them. With 30,7%, the allegedly most used tool was the open source software R, which is a language especially made for statistical computing and graphics (see Figure 7) [2]. Excel was ranked second, with 29.8% of the participants using it. It is not only the sole commercial product ranked in this study, but also the most popular for users who are not into professional statistical analysis. The other three tools are, similar to R, statistical data mining softwares that allow to analyze, explore and visualize the data sets.

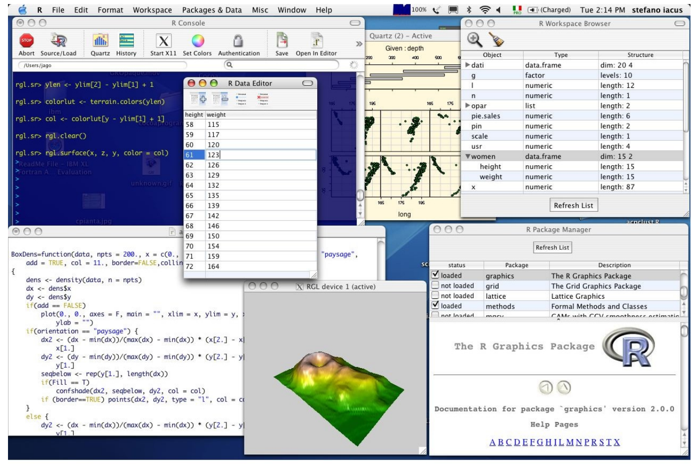

Fig. 7. Screenshot of the most popular statistical tool R [2]

5.2 Tools used in Quantified Self

In contrast to the study of KDNuggets, Chloe et. al. conducted a study regarding the tools being used by self trackers in 2014 [14]. It is noticeable, that even if the participants of their study largely consisted of data analysts and computer scientists only 4% used the statistical tools that are popular in traditional big data science (see above). None of the participants used explicit exploration tools like Tableau. Instead, most of them either used single spreadsheets without statistical functions (44%) or built their own software (35%). 39% relied on commercial cloud services or including software of their hardware tracking device (see example in fig. 8).

As today's low-cost wearables allow the Quantified Self to move into the general public [25], the average self tracker doesn't have to own expert coding skills anymore. Therefore, the vast majority of self trackers relies on pen, paper, spreadsheets and the software which is given them by commercial developers. Thereby many self trackers are unhappy with those commercial softwares. The fewest of them offer a single tool for tracking and exploring data and they don't allow self-experimentation by the request of the self tracker [14].

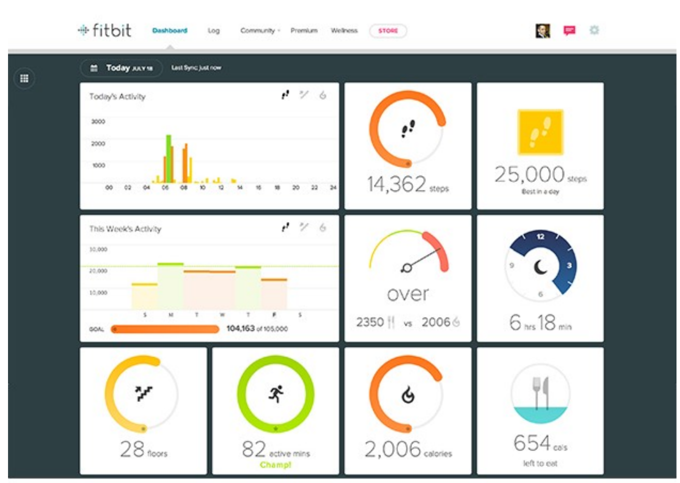

Fig. 8. Dashboard of a commercial product (Fitbit)[3]

5.3 Comparison and findings

After the established tools have been presented, we can take a look at Table 1 where the respective most used tools of traditional Big Data analysis and those in the Quantified Self context (according to the studies of KDNuggets and Choe et. al.) are set against each other. It has to be mentioned, that in the according questionnaire, giving multiple answers has been possible, so that the sum of the percentage values is above 100%.

Traditional Big Data	**Quantified Self**
R (30.7%)	Spreadsheet (44%)
Excel (29.8%)	Commercial Software (39%)
Rapidminer (26.7%)	Custom Software (35%)
KNMINE (21.8%)	Open Source Platform (8%)
Weka/Pentaho (14.8%)	Statistical Software (4%)

Table 1. Tools used in traditional Big Data compared with the Quantified Self context

Particularly noticeable is the fact, that all the tools used for the conventional Big Data issues are statistical tools, which offer powerful operations to manipulate and visualize large data sets. In contrast, in the Quantified Self, only 4% of the participants used software that allow such statistical operations. The question that comes up is: why is there such an enormous difference in the popularity of statistical tools, although both conducted studies dealt with Big Data? One approach to answer that question is, that the participants of KDNuggets' study were professionals who have been dealing with data science issues on a daily bases.[7] In contrast Choe's user group consisted of self trackers, that, even though most of them had a technical background, were no data or statistical experts [14]. From that it might be concluded, that you have to be a sophisticated user of statistical tools to attain desired information out of Big Data with tools that exist today.

Leading to another approach to answer the question, that these existing tools simply are inappropriate for the average self tracker. If you compare figures seven and eight, you can see at first glance, that there are big differences in the user interface and usability between a commercial Quantified Self product's dashboard and the Interface of the statistical tool R. This results in a inhibition treshold that could keep unsophisticated users from acquiring skills in those software tools.

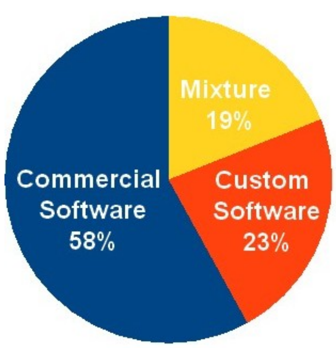

Fig. 9. Distribution of software types used in Quantified Self context built on study results of Choe et.al. [14] (pie chart made by me)

In addition to the low usage of statistical tools the percentage values in the Quantified Self context reveal, that besides spreadsheets, the most used softwares are commercial ones (Figure 8). That could be explained with the fact, that most of the hardware device vendors don't make their tracked data open source. They want you to use their device and to explore the collected data with the tools that they offer you. A major disadvantage of this approach will be listed in the discussion chapter.

Now that we compared traditional Big Data tools with them who are used by self trackers, the subjective quote from the participant which has been cited earlier (they may not have the right tools to interpret their collected data) can be seen in another context: the right tools do exist, but it seems much more likely that the users show a lack of skills to use them properly.

6 Discussion

Since it has been pointed out above, that features like sensors, which track their data fully automated and algorithms, which process the collected data in real-time are not available yet, today's Quantified Self individuals may still be able to handle their collected data with pen, paper and simple spreadsheets. But as soon as the amount of data is too large to process manually, most of them can't handle these sets of Big Data by themselves: the examined study of Chloe et. al. revealed, that the average self tracker has no experience in using statistical softwares, which would be appropriate and necessary regarding to these masses of data [14].

This lack of knowledge enforces them to rely on the software and hardware products from commercial vendors. A major disadvantage in doing so, is that you also totally rely on how they interpret your data. For example, you own a fitness tracker from a commercial vendor and you want to track your nights sleep and the according resting pulse rates to get to know yourself better. Now what it does, is monitoring your sleep phases and visualizing them for you. Imagine you suffer from cardiovascular disease symptoms and don't know it. Your device tracked these data which could have been evaluated by other health devices, but you bought your device primarily for monitoring your sleep phases. This example points out, that, up to this day, the main responsibility, concerning not only data evaluation and exploration processes but also data privacy, lies with the commercial hardware and software vendors.

Taking a look at areas of the Quantified Self, where Big Data already exists the field of the genomics does occur. Single human genome sequences can take up to several hundred gigabytes of disk space [20]. In that context solutions are needed more urgent than for the average self tracker. By tracking the daily food or walked miles, the usual self tracker doesn't come in touch with the real Big Data most of the time. The daily trackings are limited to n=1 and as long as there are no public databases available to share everything you have tracked with others, the amount of data remains clear arranged [21]. But the rise of sensors will force the data growth and in the near future, Big Data will become a still bigger matter.

Once the self trackers do get confronted with such large data sets, they fail to analyze and explore their data. However, the self tracker has to make it clear for himself, what he expects from exploring his tracked data. If he bought a tracking device to record his daily running session, commercial products will do the task. But if he wants to discover, for example, potential correlations between his heart rate and GPS coordinates he visited, the functions of commercial products are getting pushed to their limits. In this case, an approach for the near future solution would address the Quantified Selfers to acquire skills in statistical exploration and visualization tools like R. But in the mid-term future the developers and vendors can't come past to offer tools, that are more user-adapted and easy to handle for unsophisticated users.

Nonetheless, they should offer a wide range of equipment to manipulate the data. An useful feature could be the possibility to set every tracked variable in correlation to each other.

In addition, the algorithms of these tools should be more robust with handling the large Big Data sets.

An approach for the exploration and visualization of the data could be, that the software not only represents the collected data as numbers, but rather set them in the context of stories. As current commercial tools like the management software from Fitbit[3] try to visualize their tracked data with bar charts instead of numbers, this is a beginning but still expandable.

Another important aspect is the possibility of connecting all your devices to one tool. Resulting that you only need that one tool to organize all your Quantified Self data. In fact, apps like Myfitnesspal already allow to import data streams from other popular apps like Fitbit or Runkeeper [4], but only to compute your daily calory consumption.

The ideas that could improve the handling of the Quantified Self individual with their tracked data, are summarized below in Table 2.

Features that good QS data exploration tools should contain
Able to be used by statistical unsophisticated users
Offer wide range of operations to manipulate data
Present the data visual appealing
Single standard to share data among different devices
Real-Time analysis of tracked data)
Real-Time visualization/instant feedback of tracked data
One software/platform for all QS devices

Table 2. Requirements that new data exploration tools should meet

Another interesting approach is an upcoming project announced by Google. As a platform for the Internet of Things, Project Brillo promises to be able to connect all your IoT devices to share and use data among themselves [5]. Not only would it move the Quantified Self, respectively the Internet of Thing in general, into the wider audience. It would also offer new solution approaches for above introduced Big Data challenges like dealing with the heterogeneity through collecting your data or defining a single standard for the sharing of data. Considering that the goal in data collection is, to fully automate the collection process, the really Big Data is yet about to come.

Since the current data computation is limping far behind the collection already, Tim Harford's quote about Big Data in general can be applied to the Quantified Self Movement as well: "Big Data has arrived, but big insights have not" [17].

7 Conclusion

With the rise of the Internet of Things, Big Data is becoming a more and more important topic in today's life. In the Quantified Self this results in both positive and negative effects.

In this paper I reviewed related literature and gained insights of the occurence of large data sets in the Quantified Self Movement. I specified the main challenges of working with Big Data and listed approaches and future goals for solving these issues. By comparing conventional Big Data tools and those who are currently used in the Quantified Self context, I pointed out, that the last ones are unsuitable for an efficient and user-friendly handling of the gathered data. Approaches for the improvement are given in the discussion section.

As both terms, Quantified Self and Big Data, are rather young terms in the digital universe, the existence of certain challenges are completely normal. To improve the handling with these data masses, Quantified Selfers should realize that they are confronted with Big Data and not hesitate to work together closely with Big Data experts.

Thereby a field for future research could be to find ways that might faciliate conquering the existing gap between these two digital areas.

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Can you Trust your Fridge? Privacy and Security Challenges in the Internet of Things Era

Lara Hirschbeck

Abstract— In this paper I discuss the privacy and security challenges present in the *Internet of Things*. At first, I will give an overview over some aspects of IoT, especially in which parts of our lives we already deal with sensors, RFID tags and other data-collecting items. Then, I will show concrete challenges concerning privacy and security in ubiquitous computing related communication induced by the factors previously mentioned. I will also explore other identification tags, such as QR-codes, sensors, such as cameras, and network communication and data storage with this in view. This will be followed by introducing already existing according solutions and approaches in literature. Here I take a look on the technical, the educational and the legal side, as well. After that, I discuss and evaluate what already has been done to increase security in terms of a digitally connected world. And finally, I also want to point out some challenges, which have to be solved in the future and how things could be handled by individuals.

Index Terms—Internet of Things, Security, Privacy, Smart Home

1 Introduction

In today's digital world data is collected, used and stored everywhere. A few famous examples for this are facebook, Yahoo! and Google among other big enterprises. They provide obviously free services, but need to earn money, too. This is accomplished by advertisement placement depending on the users preferences found out with collected data. A facebook user who just posted something about his new car will probably get more advertisements about car tires than another user, who just posted about his hiking vacation. The reason for this is, that advertising space is explicitly sold to companies which want to place their products. But in general, there is a possibility, that user data is sold, too. In how far this is indeed done can be experienced when someone participates in a raffle via an e-mail address which is not used very much and after a certain amount of time it get spammed. This is a rather harmless situation for an experienced user, since if one does not click on links embedded in those e-mails, the only trouble consists of deleting them. For a user with less know-how, however, if he clicks the included links, he is endangered to infect his computer with a computer virus, for example.

A different situation can be explored in smart homes. Apart from name, address and phone number, there is a lot of other data, which can be collected with a variety of sensors and tag readers. This leads "*from the Internet of Computers to the Internet of Things*" [25]. The Internet of Things (IoT) includes a greater spectrum of connected items than Ubiquitous Computing (UC). While UC only references to self-computing devices like smartphones, tablets and portable game devices, IoT also reaches out for far more items. For example, there are items like pulse measuring wrist bands which do communicate with your smartphone, which in turn builds up the connection to the Internet *(see Figure 1)*. But all kinds of other sensors, such as some reacting on movement, weight or infrared light, and also cameras are included in the IoT, too. A concept involving a large variety of sensors is proposed by Suryadevara et al. [38]. Their goal is to be able to forecast the behavior of elderly people living alone and in case of a deviation between the calculation and the reality, a care person could check for them. Another wide range of possibilities is given with radio frequency identification (RFID) tags. A common example here is the use for theft security and inventory management at companies like Saturn and Walmart [45]. RFID tags are rather inexpensive, but chips working via radio frequency are also included in biometric passports and identity cards. When storing a lot of very sensitive data, it is important that only authorized personal can get access to it.

With this paper, I give a survey over privacy and security challenges in IoT and present solutions already existing and being in development. The first part of the paper gives an overview over the Internet of Things and lists examples of existing practical applications. In the second part, I show privacy and security challenges in IoT communication beginning with the process of collecting data, ending with data transfer and storage. Then some possible solutions for the different kinds and areas of those challenges are presented. The presented solutions I will evaluate finally and discuss what has been written in literature.

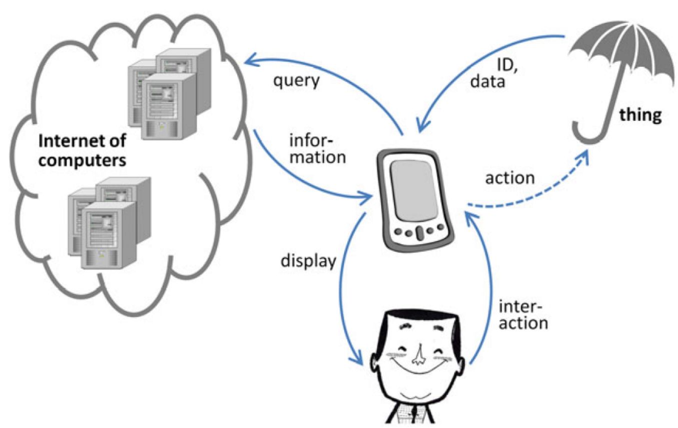

Fig. 1. The smartphone as a link between the Internet of Computers and the Internet of Things [25]

2 The Many Dimensions of IoT

From 2000 till 2014 the worlds internet usage has grown for 741 percent according to Miniwatts [26]. This includes not only the use of computers but also of smartphones, tablets and many other devices which do not seem to need an internet connection, at first sight. Some of these devices work as readers and connectors for rather small items or *things* which are then building up the *Internet of Things*. According to Santucci [37, p.2], the first occurrence of the term "Internet of Things" was at a presentation of the Proctor & Gamble Company by Kevin Ashton in 1998: "*Adding radio-frequency identification and other sensors to everyday objects will create an Internet of Things, and*

- *Lara Hirschbeck is studying Media Informatics at the University of Munich, Germany, E-mail: L.Hirschbeck@campus.lmu.de*
- *This research paper was written for the Media Informatics Advanced Seminar 'Human Computer Interaction in the Internet of Things Era', 2015*

Fig. 2. Left to right: Apple Watch [2]; German biometric passport [6]; GE's smart refrigerator "Chill Hub" interior with USB ports and "Milky Weigh", a mobile milk jug monitoring system [13]

lay the foundations of a new age of machine perception." The IoT is an evolution of the *Internet of Computers*, which only included rather bi-directional communication and computation on all participating devices. This means smartphones and tablets communicating on a basis of WiFi, Bluetooth and ZigBee. Essential for the IoT are a few more characteristics as described by Mattern et al. [25]:

- *Communication and cooperation*
- *Addressability*
- *Identification*
- *Sensing*
- *Actuation*
- *Embedded information processing*
- *Localization*
- *User Interfaces*

Taking these buzzwords as reference, categories like surveillance, resource use optimization and identification can be identified as the main fields of application for IoT.

2.1 Surveillance

Surveillance in some cases has a negative connotation leading to the impression that George Orwell's "*BIG BROTHER IS WATCHING YOU*" [31, p.20]. The appearance of the implementation proposed by Suryadevara et al. [38] is very similar to this dystopia, but has another intention. They describe a prototype for an apartment monitoring the wellness of elderly people. To accomplish this, sensors in all kinds of items are integrated. Electronic devices like microwave, heater, toaster and TV collect data when used. But also non-electronic furniture such as bed and chair are equipped with pressure sensors, so the daily routine of a person can be followed. The main components of this system are a Wireless Sensor Network (WSN) and intelligent home monitoring software. WSN is relevant for communicating data to the central part of system and the monitoring software evaluates sensor collected data and is needed for detecting changes in peoples behavior. Changes in behavior can hint at psychological problems such as depression or at cases of emergency. If needed, automatically a care person can be informed by the system to come by to look after the senior.

An approach less oriented on direct usefulness is given by so called lifeloggers. History - even in form of stories and fairy tales - was always important for humanity. How were the pyramids in old Egypt build? How did the Romans transport water from the Alps to Rome? We know much about these things from archaeological discoveries and written records. In 1939 a time capsule was buried [28] and some people began to think how future people can get a glimpse of their daily life in the past [1]. With technical progress of cameras and computers since the early eighties, also based on research on wearables of Steve Mann [23], the idea of documenting someones life with those gadgets came up. Mann himself also invoked the lifelogging community, also known as gloggers, where he even participated himself equipped with a wearable camera allowing users on the internet to see things he was seeing and a wearable display in which he could receive messages from the users. Others followed his example by installing webcams in their homes, like Jennifer Ringley's JenniCam on jennicam.com being online from 1996 to 2003 [8]. In the age of 20, Ringley went online with her website and broadcasted her daily life in an uncensored way. She was home most of the day, this is why her concept worked so well. At the beginning the service was totally for free, later paid membership entitled for an image refresh every minute, while free transmission only supplied a new shot every 15 minutes.

Not only cameras and displays were made wearable, but also new kinds of sensors came up, which could communicate with smartphones and therefore with the internet. Already in 1998 Nintendo released a kind of Tamagotchi with the ability to count steps [11]. With this pedometer it was possible for the user of this item to earn additional currency which could be used for the care of the digital animal. Still, there was no communication between any devices, but with the follow up item Pokéwalker, this changed. The Pokéwalker was delivered with Pokémon SoulSilver/HeartGold and provided the ability to count steps and communicated via Infrared with the Nintendo DS, where the game state was saved and you could use your earned steps [29]. In 2012, the product category of smartwatches came up [39]. This found its latest high with the release of the Apple Watch in April 2015 *(see Figure 2)*. All versions of this item contain an accelerometer, a gyroscope, a heart rate sensor and a barometer [2]. To use all of its abilities it relies on a WiFi connected iPhone, which again gives access to the internet and via Applications (Apps) on this device, it is possible to archive user's data and achievements in sports and even to share those with friends and/or a whole community.

2.2 Resource use optimization

In the area of smart homes the so called "Chill-Hub" from General Electrics is already available [13]. This is a refrigerator equipped with USB slots, WiFi and a control software for iOS. Accessories can be developed by everyone and printed with a 3D printer. The intention is, to create a community and to share plans and ideas for equipment. Even if a customer has no 3D printer by himself, he can order the favored accessory from a website. Already available is the scale "Milky Weigh", where a milk jug can be placed and over the software it is possible to see, how much milk there still is *(see Figure 2)*.

A prototype of a smart oven is described by Li et al. [21]. Their goal is to help people in an household with better nutrition. For each family member the individual energy level, age, weight, height and diseases can be stored and every cooked recipe is stored for the respective cooking person. Then an individual report is generated considering standard nutrient values and the estimated energy requirement for this person. Communicating with a smart fridge, it can also propose recipes containing groceries stored in the fridge.

A fridge with these abilities is described by partly the same team members [22]. It extends the abilities of the oven with generating and updating the store list by scanning food and storing its information. Thereof it is able to generate a shopping list and warnings when food is going to expire. Also calculations of body mass index and related nutrition suggestions based on stored information and medical records of the family's members are made. Like the oven, the fridge features a control panel providing the user all available information. With his prototype which prevents the loss of uneaten food, Rouillard's approach is very similar [35]. Instead of an rigidly mounted display on the fridge, the whole idea is based only on a smart computer system, using the ability of today's smartphones to read bar codes and respective access to an online database for further information. Because of the lack of identifying a concrete item with bar code, the expiration date has to be added either via speech or keyboard input. When food is close to expiration, the user gets an according reminder on his smartphone.

2.3 Identification

In the field of IoT, there already are possibilities to identify a certain item and store a rather great amount of data. Radio-frequency identification provides these abilities. RFID is currently embedded in tags, placed on store items allowing an easier inventory management system for stores and even help at preventing and recognizing theft, for example at Walmart and the German electronic retailers Media Markt and Saturn.

With the biometric passport, also people can be identified via items taking part in the IoT *(see Figure 2)*. On its RFID chip, biometric data is stored digitally additionally to information like name, address and other details printed on the passport in an analog way. The German *Electronic Health Card* stores information about the health insurance provider, validity period of the card and personal information about the patient, like name, address, date of birth, sex, health insurance number and also medical data if the patient has agreed to it [14]. RFID chips are also available as implants for animals, leading to many pets like dogs and cats being marked. In 2004 there was even a short time trend where humans could get those chips when attending parties in certain European clubs [4].

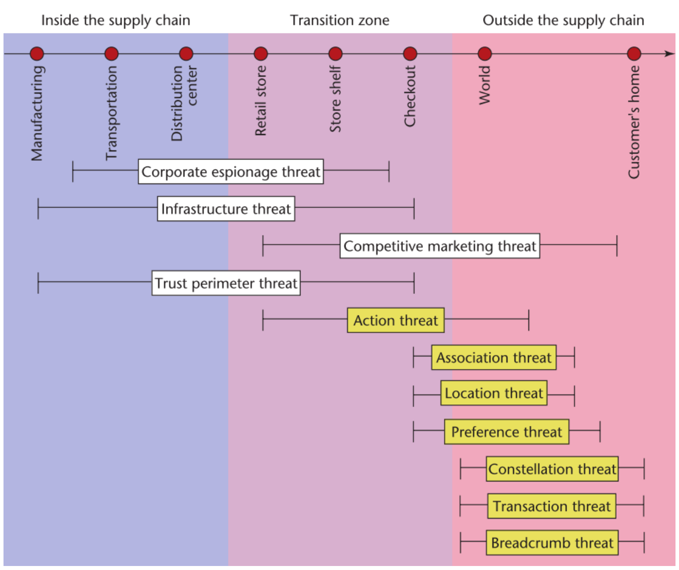

Fig. 3. Threats within the electronic product code chain; White labels indicate corporate data security threats; yellow labels indicate personal privacy threats [12]

3 Privacy and Security Challenges in IoT Communication

With so many kinds of communication and implementation in IoT, various problems are arising on different levels of communicating, storing and gathering of data. In the following, I want to give an overview over the main challenges of IoT.

It has to be differentiated between privacy and security. Information is privacy related if it is collected on a free access base. This means, every technical involved part works correctly without any malfunctioning and collects data via sensors or other input devices. Problems here can arise, when private data gets collected and exchanged with third parties without peoples control or even their respective knowledge about further usage of their data.

Security, on the contrary, describes data protection against unauthorized access. Security issues can happen on every level of the communication line from the step of collecting data, to the forwarding system like WiFi and fiberglass and finally on the data storage system. Assaults on these levels are often initiated by hackers and are, for example, industry espionage related. Garfinkel et al. [12] developed a an overview, where threats in the electronic product code chain can arise (*see Figure 3*). Those threats can also be adopted to other forms of technology within IoT.

3.1 RFID

The quote, where IoT was mentioned for the first time, already referenced RFID as a main form of identifying things [37]. RFID is a generic term for a collection of different standards, all based on radio-frequency communication [12]. This leads to the following properties: they work wireless, tags can be read without a line of sight and there is a variability how close the RFID tag has to be to the reader to be read. For example if the tag has an additional power source, it can be read from within 100 meters [34]. But most less expensive passive tags can be read from within two meters. Therefore, following threats in view of RFID were identified by Garfinkel et al. [12].

3.1.1 Corporate Data Security Threats

Corporate espionage threats - The supply chain based on RFID tags can be tracked by competitors, if an agent is in place for scanning individual objects. By identifying individual chips it is possible to recreate the concrete route of a tag and therefore of the individual product including secret company processes.

Competitive marketing threat - Unauthorized competitors can gain information of consumer preferences.

Infrastructure threat - Companies depending on RFID are easily endangered by Denial-of-Service attacks through jamming radio frequencies.

3.1.2 Personal Privacy Threats

Action threat - “Smart shelves” in shops register articles via RFID and recognize when high value objects suddenly disappear. Some manufacturers suggested registration of accumulated events to several individual objects might indicate that the respective customer is planning to shoplift, although the possibility that the article just has been dropped to the ground is given, too.

Association threat - By purchasing an item tagged with RFID the customers identity can be associated with an individual object (a unique aspirin package) rather than with a group of objects (an aspirin package).

Location threat - Covered readers at specific locations can monitor unique tags and locations of people can be revealed if the monitoring agency knows the association between a unique tag and this individual person. Also the position of the tagged item can be unveiled to unauthorized persons.

Preference threat - Apart from the manufacturer of the tagged item via RFID also the respective product type and the item’s unique identity are revealed. Competitors in producing and selling similar items can easily gain information about customers’ preferences at a low cost. This can also be used by thieves targeting their victims based on the respective values of the carried tagged items. Therefore this is also a *value threat*.

Constellation threat - Tags form a unique shadow or *constellation* around individuals. The respective person can be tracked by adversaries without knowledge of concrete identity.

Transaction threat - When tags are moved from one constellation to another, it is possible to infer a transaction between individuals associated with these respective constellations.

Breadcrumb threat - When people buy tagged items, the tags identities are associated with the persons identities at company databases. If those items get lost or stolen, the discarded items are still associated with the original owner's identities. A third person can then carry this item and, for example, commit a crime and the first suspect for this crime would be the original owner.

3.1.3 Cloning Threat

By cloning RFID tags, it is possible to use associated information to perform different kinds of crimes. For example car keys using RFID chips can get stolen easier, RFID related payment systems can be misused and all kinds of identity theft can take place.

3.2 Optical Identification

Optical Identification is connected by the need of sight contact for reading a respective mark. This leads to a reduced flexibility concerning the usage of the tag but also increases the security. There are different types of optical identification tags, also known as bar codes. The most common bar codes are the linear EAN-13, used in worldwide retail and the two-dimensional QR-Code, the most scanned bar code with smartphones.

EAN-13 provides different amounts of numbers but only enough for identifying a group of products and also no redundancy of data is included. With QR-Codes it is possible to store alpha-numeric information like web-addresses or short sentences. If you want to store a longer message in the code it is at the cost of redundancy, which provides a certain amount of readability, even when parts of the code are destroyed. The highest amount of information, which can be stored, is about 23,630 bits, depending if only numbers, alpha-numeric or other characters are encoded.

3.2.1 Corporate Data Security Threats

Corporate data security threats are very limited, because apart from the company and product group connected with the number behind an EAN-13 code, nothing is derivable. Apart from this, a potential attacker would not only need to have sight contact, but also need to come very close with the respective reader.

The usage of QR-codes in companies is often more marketing related. It is common to add QR-codes to billboards including links to web-pages, giving further information about the advertised product and the company itself. Also links to smartphone related apps are possible. This way an interested potential customer is not in need to memorize data for a long time or is forced to enter a sometimes long web-address manually, while he can take his smartphone and scan the code as easy as taking a picture with his camera.

3.2.2 Personal Privacy Threats

Association threat - By purchasing a bar code tagged item, a customer can be associated with a kind of product, but not with a certain item, because of the lack of an item ID. The amount of threat is similar to only be seen by purchasing an item. The threats can arise, by combining the purchase of bar code tagged items with electronic paying systems as RFID based paying system, ec card or credit cards, because this way, a customers identity can again be associated with an item.

Preference threat - If it is possible to gain a glance of the carried products of a customer, for a thief – not necessarily with a bar code tag reader, simple eye sight contact would be enough – this can lead to a preference of the product's carrier as a potential victim.

In conclusion, there is to say, that most personal privacy threats are very limited, compared to RFID tagged items, due to the necessity of sight contact for scanning.

3.2.3 Cloning Threat

Cloning bar codes is very easy as a simple photo copying machine would be needed or even the content of the encoded information would be enough to generate a bar code including the same message. One possibility might be the use of an allegedly correct bar code on counterfeited products to fake reliability. The threat coming from this is rather limited, as the encoded message is not security relevant on itself.

Another practice is, to place a faked QR-Code on top of the true one of original advertisement poster, only with wrong information or misleading to a counterfeited website, used for phishing [41].

3.3 Further Sensors

There are many kinds of sensors in IoT. There are, for example, infrared sensors, pressure sensors and cameras often attached on common places, but also sensors combined with wearables containing accelerometers, heart rate sensors, gyroscopes and barometers. It has be differentiated between sensors watching over personal space and sensors in public space, although similar risks and threats arise, particularly for private persons.

3.3.1 Corporate Data Security Threats

A potential corporate data security threat arises, when companies use for example secretly attached cameras for industry espionage on competitors. This can be extended to all kinds of other sensors which might be useful to gain information on this level.

3.3.2 Personal Privacy Threats

Association threat - Surveillance cameras on public places save pictures from individuals who can easily be identified, for example via face recognition software. Weight data collected with pressure sensors [38] can be associated, too.

Location threat - Cameras in public places take pictures for safety increasing purposes and are able to tell who was there at a certain time.

Most of the personal privacy threads cannot be clearly foreseen today. But for example for health insurance companies it would give a better base to know about the concrete health state of their clients [30]. This could be achieved by receiving collected data via the already mentioned wearables. The collected data then provides information about health risks, chronic illnesses or stress. First steps have already been done by American employers rewarding their insured staff as part of so-called corporate-wellness programs [30]. Data are respectively collected by sensors like fitness trackers. For a person living very healthy and exercising on a daily basis, it might be very comfortable to have to pay less. But those who are not able to reach those excellent values will be the ones who suffer. Today, health insurance companies make their calculations depending on information about age, gender and other risk factors like sports, but the more information is collected the higher will be the pressure on everyone, even on those who are already "good", because they could be "very good".

3.4 Network Communication and Storage

The threats in the area of network communication and storage are more security related, instead of privacy oriented. That is, because respective data is already collected and at this point is only forwarded or *communicated*, and stored [12] (*see Figure 3*).

Trust Perimeter Threat - As described by Garfinkel et al., this is describing the threats, that arise when data is shared with other corporations and stored on external servers [12]. This might lead to the possibility of unauthorized accesses. But transferred to the example of a smart home, especially the fridge, this also shows characteristics of a personal privacy threat. If data usually is stored and processed on servers in the users home environment and only specific messages are forwarded to central corporation servers, through security breaches, either intentionally executed by hackers or unintentionally caused by system updates for example, also the personal privacy can be violated.

In the German weekly magazine DER SPIEGEL 20/2015, Frank Dohmen wrote, that hack attacks even on private networks have increased [7]. Germany, according to Dohmen is attacked up to 15 million times per month. And they are getting more and more with the increasing amount of digital devices like refrigerators, television sets or roboters connected to the internet, said Telekom's head of security Thomas Tschersich. The main targets seem to be WiFi networks with routers with security loopholes in their software, over which the hacker gains access to smartphones, tablets and other devices logged into the WiFi.

3.5 User Interfaces and Human Computer Interaction

As devices with screens are used to create connections between the "things" and the internet, it is necessary to take a look at those, too (*see Figure 1*). The most common examples in this area are probably smartphones, tablets and common personal computers. As personal computers are more often placed in very private spaces, their potential risks are more likely security based and therefore rather associated with *Network Communication and Storage* in the next subsection. However, people carry smartphones and tablets with them all the time and use those at very public places, too. There are many information stored on someones smartphone, such as passwords, and other access data to websites or even bank accounts [16]. Apart from the risk of losing those devices or those getting stolen, there is still a risk of simple shoulder surfing, although according to Harbach et al. this problem in their study was only relevant in 11 out of 3410 sampled situations. Nonetheless, this is possibility has to be considered and leads to both, security and privacy threats, as relevant data can be spied out while inputting those.

In 2011, Samsung presented a new feature for smart refrigerators at the CES 2011 [36]. They had developed the RF4289, a fridge including a display and some apps. One of those apps granted access to *Twitter*. Apart from this being rather unconventional, which lead even to a *meme*, referring to the intention behind this, I think, it can also lead to some security issues. For example, every visitor who goes into the kitchen would easily gain access to the Twitter account and could *tweet* in the original owners name and worse. For those cases, it is necessary, to have appropriate security systems, too.

4 SOLUTIONS FOR INCREASED PRIVACY AND SECURITY

In this section different kinds of approaches for increasing privacy and security in IoT, will be presented. First, I will show some possibilities in the technical area. After that, I will point out some ideas for increasing user awareness for privacy threats and last I will list some legal approaches which influence both technology and user awareness.

4.1 Technological Approaches

There are a lot of different approaches within the technical section of IoT. Here, an overview of secure communication standards, particularly of RFID systems will be given.

4.1.1 RFID

Especially for RFID exist several strategies for increasing security and privacy [32].

Tag Killing and Sleeping - When an item is purchased, the respective RFID tag should be killed [18] or at least go to sleep [32]. The disadvantage of a killed tag would be, that it cannot be reactivated anymore. So, it is proposed by Pateriya et al. that a tag put to sleep however could be reactivated when respective functions would be needed. The killing is initiated by a unique 8-bit password, which causes a fuse on the tag when received. This is already done in supermarkets, after paying the resulting total. Then the check-out system sends out those "kill codes" for the just purchased items and the customer can neither be scanned as a theft nor can any of the other personal privacy threads happen.

Tag Blocking - A so-called *blocker tag* acts as a protector of private zones by simulating all kinds of other RFID tags [20]. It acts as a passive jamming system and creates a zone around it, in which scanning of electronic tags is impossible. With the use of specific properties of RFID, it is even possible to block just selective tags. This approach unfortunately can also be used for denial-of-service attacks against companies, for example.

Tag Soft Blocking - Involving software or firmware at readers side, the use of a soft blocking tag only signals, that other RFID tags carried within a zone should not be read. This leads to a more voluntarily based option and solely works on privacy, not security. Those tags just express the privacy preferences of their owner to RFID readers, it cannot be checked without any effort, if those are violated.

Tag Relabeling - A modifiable tag is overridden with a new unique ID, while the tag itself stays in place [15] for reuse. A possible use could be for library books, where with each lending out the same book gets another ID, only recorded by the library's administrative software. For secretly acting attackers or all kinds of "spies" it would be difficult to identify the respective match of the tag ID to the respective book.

Tag Re-encrypting - Re-encryption takes a fixed message, or in this case an ID, which always stays the same, and just varies the encryption overlay. One example might be the use of an cryptography approach, with help of a key-pair, consisting of a private and a public key [19]. As this approach originally was meant for RFID-enabled banknotes, the private key would be held at an appropriate law enforcement agency. The RFID tag itself carries a unique identifier, which is encrypted with the public identifier to a new message, which is finally emitted by the tag and visible for readers. As this would not be enough, because the new message would still be a unique identifier, the approach includes then to re-encrypt the underlying plain-text periodically, using the public key and the algebraic properties of the *ElGamal cryptosystem*. Only the law enforcement agency would be able to decrypt the underlying identifier involving the respective private key.

Tag minimalist encrypting - This approach is in general similar to the *re-encrypting* approach [17]. But it involves no active re-encryption on the side of the tag. The idea is that the tag emits a different synonym from a set of identifiers every time it is requested. Only the underlying authorized software knows all synonyms of the respective ID. To prevent attackers from just requesting all synonyms by approaching the tag multiple times, it is proposed, that the tag can only be accessed after a rather long refreshing rate. Also, the respective synonyms can be refreshed by the system via the readers. This would help preventing industry espionage.

4.1.2 Secure Communication Standards

All security implementations on the first link of the Internet of Things chain are worth nothing, if further levels lack totally on security. Because then, hackers get a good chance for attacking and security breaches would be usual. Therefore, some already common, non-theless still effective technical solutions in communication and data storage are shown, in the further. But it is also evaluated, why some are not as practically as they might seem at the first glance.

Transport Layer Security (TLS) - TLS, also known with the older versions' name *Secure Sockets Layer* (SSL), establishes a secure connection between a client and a server. It involves a handshaking procedure in which client and server agree on various parameters. As for each request to the *Object Naming Service* (ONS), the identifying system behind RFID based on the *Domain Name System* (DNS), a new TLS connection would be necessary to establish, this would lead to an enormous overhead of data exchange [44].

Hypertext Transfer Protocol Secure (HTTPS) - HTTPS is already in use for secure connections between clients and servers. HTTPS works similar to the not secure *Hypertext Transfer Protocol* (HTTP), but with an included handshake over TLS. The Mozilla community announced recently, that they plan to fade out any support for HTTP for security reasons [33].

Virtual Private Networks (VPN) - Over a public network, VPN uses tunneling to extend a private network. It creates virtual point-to-point connections with every participant, including the mutual promises to act confidential and to have integrity. This makes it very limited in use with third parties beyond the borders of the VPN [44].

DNS Security Extensions (DNSSEC) - Through DNSSEC a security aspect is added to DNS, while it was missing in the first place. Every message created within DNSSEC protected zones are signed with public-key cryptography, which guarantees the origins authenticity and the integrity of delivered information. While it is backwards compatible to DNS, to make sure every record on the ONS is correct, it would be necessary for the entire Internet community to adopt this new system [44].

Onion Routing - Onion routing is a routing system based on multiple layers of encryption. On its way through a network of multiple onion routers, on each router just one layer is "peeled of" of the encryption layers. This leads to a higher anonymity in communication as each router only knows his direct descendant and ascendant, but neither the complete route, nor the origin or the destination of the message. But performance issues may arise, as onion routing increases latency [44].

4.1.3 Secure Data Storage

Most security mechanisms in databases are implemented directly in databases. These are further developed access systems such as discretionary and mandatory access control models and role-based access control models [5].

Private Information Retrieval (PIR) protocol is used for giving an information to a requester, but without revealing the requested item. There are some implementation existent, but, according to Weber [44], performance issues and problems of scalability and key-management within a global system, such as the ONS, would arise, leading to impracticability of this method within the ONS. Whereas for other uses on smaller databases acting within a restricted community it might still work. This refers particularly to databases of companies hosting information on contents of customers fridges. This also leads to an increase of privacy, as it conceals otherwise available information about the requester.

Another solution not necessarily practical for every consumer and provider of devices would be to host databases within the users own network. This would prevent direct visibility of user data and a potential hacker would need to gain access to many different databases instead of one big database hosted on one central server. Disadvantages are, that the respective user would need to administrate his own complete system including a respective server. But with progress in technology, a local server already or in the near future could be made small enough to store and process a sufficient amount of data.

4.1.4 Secure User Interface Access

To make user interface access more secure, there have been approaches since the first mobile phones came up. Personal Identification Number (PIN) and drawing patterns are the most common examples at the moment for smartphones and tablets. The problem with those is, that some people do not use them according to the complexity and preventing them from a fast access to the device. Apple has made a step forward to this direction with embedding the Touch ID, finger print scanner to their iPhone 5s and newer models of smartphones and tablets, too [3]. This finger print scanner works relatively fast compared to the PIN or drawing patterns, but the difficulty here is, to minimize the error rate of falsely accepted and falsely rejected users, as the used parameters of the finger prints have to be discretized from the system and the respective sensor.

Another alternative is given from von Zezschwitz et al. with their SwiPIN [42]. Their system is based on the regular PIN number block, but instead of tapping the numbers, which is easily observable, they coded the numbers with swipe gestures (*up*, *down*, *left*, *right*, *tap*). For encoding a set of ten digits, they partitioned the screen in two different areas, where the swipes have to be performed. The swipe directions were marked on the numbers with black arrows, where no arrow meant, that a tap had to be performed. As the swipe encoding changes after each input, the security against shoulder surfing is increased. An observer would have to memorize the respective encoding for each number and connect it with the performed gesture. This is very complex and would not usually fit in the human short-term memory.

4.1.5 Repelling Attackers

As potential hackers are always looking for deprecated systems or insufficiently secured routers, an already used method of the *Telekom* for repelling attackers are so-called *honey pots* [7]. Those are rather cheap devices pretending to be computers with an old Windows OS, a web-server or a simple smartphone, for example. The idea behind this is, that the hacker would choose those items as targets, while another software behind the pretended deprecated operating system collects data of the respective attacker, such as used IP address and keyboard commands used within the attack. The collected data is then evaluated by experts. Until today there are about 200 of those tiny computers, worth between 50 and 180 Euro, hidden in networks all over the world. Future goals of Telekom are to hide more honey pots and that also its customers will be able to use those as an early-warning system, that their network has become a target to hackers.

4.2 User Awareness

As collected user data is per se often very sensitive, it is important to make the user aware when and where his own data are exchanged [24] (*see Figure 4*). To get a better view, the sight on IoT can be divided in two dimensions. First, the *functional scope*, defining the operational mode, ranging from self-contained to infra-structured. Second, the *spatial scope*, defining the operating space, ranging from private to public. Therefore a connected vending machine in public would require much less the consent from a customer to communicate with the respective network, as a home surveillance system collecting information about every residents move, meal or fridge's content. This could be requested every time a new data exchange is executed, as it is already done with some identification cards as the eID on current German identity cards [40] or also with the German Electronic Health Card [14].

4.3 Legal Approaches

To provide a basis against potential data abuse, always the legislative is in demand. Since particularly the RFID system, with its information carrying tag, a reader and a further forwarding system to sometimes even third parties, makes up a special constellation, it is not simple to get this in consent with the German telecommunications act (TKG), for example [27]. The main part in the area of RFID is only affected by §89 TKG, which is, in general, about prohibition of eavesdropping within amateur radio.

On May 12, 2009, the European Commission took further steps and gave out proposals, how the governments of the member states

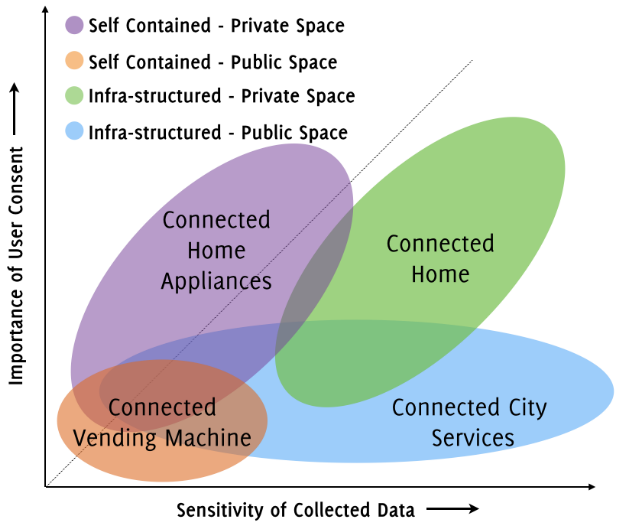

Fig. 4. View of consent within IoT [24]

of the EU should proceed concerning RFID tags and that they need to talk on a par with their respective residents and companies [10]. Moreover, about one month later, on June 18, 2009 they published even "*Internet of Things - An action plan for Europe*" [9]. Here, the European Commission expressed the opinion that developments in the field of IoT should not be left to the private sector and other world regions. Therefore, this document included 14 lines of actions and addressed topics such as object naming and the assigning authority, addressing mechanism and information storage, the security and also the legal framework at the respective member states.

Of course, the best way for the producer and consumer to follow is self-regulation by the device and service offering party. Unfortunately, mostly, this only takes place, when the pressure coming from customers is sufficient [43]. But for this, civil society has to be informed accordingly.

5 Discussion

With the increasing progress of the Internet of Things, there are many threats we must face as a civilization at the beginning of 21st century. Particularly, privacy and security threats wont vanish, but rather increase with more and more sensors carried with us. As long as we have to add sensor bearing devices additionally to our standard mobile phone, like the Apple Watch needs dedicated smartphones, it seems, users are more aware of the sensors. But probably some day we wont need anymore subsidiary sensors, or we wont need an additional smartphone.

Nonetheless, we wont need as much different devices and so we wont be aware of them as much either. The awareness itself helps people to gauge if they need some features or not. Of course, a person who does sportive activities on a regular basis, will be more interested in his own achievements and probably wants to share those with a community. Activities are tracked automatically, but if you want to add information about your meals, it gets a bit more difficult. If you only eat oven-ready meal it is easy just to scan the respective bar code. But cooking by yourself leads to difficult calculations on calories, especially if you have fresh ingredients such as salad, fruit and vegetables from the market without any tagging. This does not necessarily make your live easier. And so I can imagine, that there might be a large group of people, who are quitting this system very fast and therefore protect their private space in some way.

The system with scanning the bar code is also done with the prototype of the smart fridge [22], although they want to improve their system with an RFID reader. In general, this would lead to an easier detection system for the customer. But a necessary requirement for this system would be the presence of RFID tags on groceries, which are even at a cost of about 0.05 Euro each too expensive to be added to items sold at a price 1.50 Euro each. It is questionable if discounters would risk a general increase of prices as it would bring no direct value or at least only a very small value to their resource management systems. Even shop lifting would be negligible in this system, as the value of a single stolen item in this price range is not relevant.

Another situation is given by already existing private networks, where every smartphone, TV and computer is communicating, particularly via WiFi. An example is given by "Ben's Smartphone" [7]. In this case one of the Telekom's honey pots simulated a smartphone and could record an attack from a hacker from China. It took him only two minutes to unlock the smartphone connected over WiFi, tree further minutes and he had changed access privileges and could see all information stored on the phone, such as address book, passwords, E-mail and pictures. There are two possibilities for attackers to use this information. Firstly, they can use them directly by gaining further access to already installed bank software and transfer money to their account, for example. Secondly, they can use the gained information for blackmailing their victims with compromising pictures, for instance. Those are cases, where the rightful user of the network can do a few limited things, such as updating every installed software on every device on a regular basis or deactivating WiFi, when not needed. But this again requires the user to be informed properly and some known security breaches are not even fixed by the respective companies, as some devices are simply are too old to be profitable, if support would still be provided.

It is good, that legislative instances, such as the European commission, give suggestions and define standards to keep their respective inhabitants secure and countries on an up-to-date state, concerning technological developments. But the real difficulties lie within reality. To secure people's privacy or, at least, to solve cases, such as cyber crimes, it would be necessary to store large amounts of data over a long time, to be able to recognize and to solve the respective crimes. But according to Germany's current law, network operators have to delete data leading to identification of attackers, like IP-addresses within seven days. This is not as bad, as it might sound at first, as it leads to increased privacy of customers and prevents possible abuse of data. It is a thin line between harm and benefit within the area of data collection and storage.

6 Conclusion

The more information is collected, the more security and privacy breaches are possible. Each user has to decide for himself, if and which of his private data shall be collected. For some people it might be a gain to collect information about their groceries for nutrition reasons. Those could be allergic or diabetic persons, for example. Also for other applications, such as resource use optimization, it might be useful to have an appropriate tracking system.

The important point is, that every participant needs to inform himself, which risks he is willing to take to get digital advantages. This might be easier for companies, which can have their own security experts than for private ever-day users. Eventually, for every fix or solution, there is still the possibility of further and even new created loop-holes, threatening privacy and security of the IoT's users.

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Persuasive Technology inside Smart Homes

Daniel Kolb

Abstract— As the current designs of smart homes and the common idea of smart homes are highly divergent, I present exemplary works on the widespread field of persuasive technology. Furthermore I discuss differences and similarities in recent design approaches by comparing their fundamental advantages and disadvantages as well as their suitability for future or current smart homes. The design approaches were categorized by their way of displaying information as ambient or data-driven devices. The device's method of evoking a certain behavior within the user allows for further subcategories; a mere hint equals an implicit prompt while a detailed description of a procedure corresponds to an explicit prompt. Moreover this paper investigates the respective user studies including the soundness of the intended behavior change support. This paper functions as an introduction to persuasive technology inside smart homes and a summarization of recent developments and findings in this field of research.

Index Terms—Smart Home, persuasive technology, eco-feedback, behavioral change support, HCI

1 Introduction

While traveling by subway I read an article in the German magazine DER SPIEGEL about security risks of smart phones in homes with interconnected appliances[3]. The person next to me took a glance at the report and started a discussion with his acquaintance concerning the increase of embedded computing systems in things that usually don't need a computer to operate, especially fridges. A smart home of interconnected devices seemed to result in computers taking charge of one's life. For instance, the aforementioned fridge would decide to deny access to its interior food to the user, based on some dietary algorithms. The conversation ended with both rejecting smart homes as options in their future life.

These two conversational partners can be seen as representatives of a common perception of smart devices: Augmenting household appliances with computers is on par with installing HAL 9000 or SKYNET in one's home. A type of Ubiquitous Computing which doesn't implement Calm Computing (or a grim variant thereof) is mostly unheard of. Unlike Calm Computing, Persuasive Technology integrates the user in every decision made [21]. This paper aims to deliver an overview of said technology, a categorization of designs of recent prototypes and comparison between those categories.

2 Persuasive Technology inside Smart Homes

B. Fogg defines Persuasive Technology as devices or applications which are designed to influence its user's attitude and support behavioral change by convincing them or by functioning as social actors, though never coercing the user into doing something they don't want to do. [4]. This approach contrasts with Mark Weiser's vision of calm technology as necessary way of interaction with the ever increasing amount of digital interconnected technology surrounding [23]. Calm technology minimizes the amount of user interaction by keeping information in the user's periphery, enriching and easing life by transferring tasks from the user to computers. Only when required does the information shift towards the center of the user's attention. Persuasive technology on the other hand aims to keep the user engaged in the interaction as an integral part of the decision-making process. Instead of letting computers decide on the user's behalf, the user will be presented with relevant facts, options or consequences to options, leaving the user in charge. It calls the user's attention to issues they would otherwise not perceive and supports them in reaching a qualified decision, which could even mean that the user ignores said issue in case they don't deem it relevant.

A most critical application of technology, be it calm technology or persuasive technology, is within one's own four walls. The increasing permeation of technology coupled with the ability of devices to interact and share data with each other entails many opportunities to enhance the lives of the inhabitants, though care should be taken to not overwhelm them with the sheer amount of data. The Internet of Things has led to many new computers acting and interacting within one's home as part of common household appliances, a number that will likely increase over the next few years. Implementing calm technology in such a smart home would result in a mostly self-governed house which manages most duties (energy consumption, security, cleaning...) and hiding those processes from the user. A smart home utilizing persuasive technology would rather prompt the residents to do those tasks, for example by informing the user that closing a certain window would decrease heating costs [9]. Additionally the enhanced home would display knowledge, relying on human curiosity to engage the user and let them figure out which behavior changes would be beneficial.

As a matter of fact, the subject of eco-feedback technology enjoys much attention as field of application of persuasive technology [5, 20]. Additionally some research facilities have been constructing or repurposing houses as smart-home-laboratories for the sole purpose of studying the application persuasive technology prototypes and their effect on people [10].

3 Ambient Feedback

The idea behind ambient feedback is to display information that the user can analyze easily at a glance, to present little, but highly relevant data (see figure 1). It should always show the required information, yet at the same time the display mustn't come to the fore when implemented in the household. Therefore the challenge to designing ambient feedback devices lies in the selection and interpretation of data to display to the user as well as the choice of data presentation so the device fits seamlessly into daily routines instead of disturbing them. This field of research originated in calm computing and resembles a hybrid form of persuasive technology, being subtle yet dependent on human interaction.

- *Daniel Kolb is studying Media Informatics at the University of Munich, Germany, E-mail: daniel.kolb@campus.lmu.de*
- *This research paper was written for the Media Informatics Advanced Seminar ' Human Computer Interaction in the Internet of Things Era', 2015*

Fig. 1. Examples of ambient persuasive technology (line by line from left to right): Infotropism [8], Power-Aware Cord [6], Water Bot [1], Elements of Consumption [16].

Given the multitude of critical design choices, prototypes for ambient feedback are highly reliant on user studies to verify their effectivity. As the data conveyed is all but highly detailed, the display might not be right out intuitive and the user may be in need of an initial introduction or a period of familiarization. Also the user needs to deduce the intended behavioral modification, since the delivered feedback contains no explicit suggestions, conveying implicit recommendations instead. This gives the user more power over the decision and options, even making ignoring the issue easier.

3.1 Infotropism

Developed in 2004 at the Carnegie-Mellon-University, PA, Infotropism uses two light sources to manipulate a plant's growing direction to represent a needle gauge [8]. In their user study the authors placed a waste bin to the right of the prototype and a recycling bin to the left. Inserting trash on either side caused the corresponding lamp to "feed" the plant, which accordingly grew towards the lamp that was triggered more often. Additionally they built a robotic variant of the plant and placed it in the same environment: two bins and two lamps on either side to fulfill the same task as the living plant.

The study's duration of two weeks is too short to measure statistically significant data on behavior change, unfortunately. Nonetheless the authors revealed several other findings. The study implies that the robotic plant as much influence on the users than the real plant. Furthermore the context of the application suits the design and increases awareness: Using living nature (or a facsimile thereof) to increase awareness for nature. The device seems to have had caused an increase in recycling, though this effect might have been short-lived.

However, the bold design shows flaws. Concerning the plant's health, throwing trash into the waste bin does not differ from throwing it into the recycling bin. Both support the plant's growth. A user might be even tempted to distribute waste equally so the plant grows straight. Besides the plant does not grow indefinitely, which means that the whole display would have to be reset in regular intervals. Apart from that a plant-device would easily fit into a smart home, next to other potted plants. The data displayed does not have to be limited to waste disposal and could be extended to other home-related ecological issues in need of monitoring, for example aggregated plant health.

3.2 Power-Aware Cord

The American magazine TIME listed this simplistic Swedish design as one of its "50 best inventions of 2010" [2]. The prototype corresponds to a common power cord upgraded with three luminescent wires, which light up when energy flows from the socket outlet to appliances connected to the power-aware cord [6]. The magnitude of energy consumption is displayed twofold; higher Watts result in brighter light and pulses of higher frequency. It enables the user to either monitor an appliance's energy usage over a period of time or to compare different appliances and their respective energy usage states - on, off or stand by. Furthermore it can be utilized to elicit awareness for energy consumption: An opaque cable connecting an appliance which is in stand-by mode to a socket uses more energy than the calm "display" implies.

As the prototype featured loose contacts at the time of testing, the authors chose the Wizard of Oz method to keep testers out of harms way. This means that no user interacted with the Power-Aware Cord directly nor was it installed and surveyed at their homes. The user study showed that the design was easy to grasp, with most test persons expressing their willingness to use said device at home. Their main concern was that the light emitted at higher power consumption was perceived as irritating and intrusive, especially interrupting their sleep at night. The authors also remarked the obvious drawback, as the display itself increases energy consumption to display electricity, even though it ought to decrease energy consumption. However, this increase is rather small compared to the other appliances' own wastage.

3.3 Waterbot

A further subdomain of persuasive eco-feedback technology is reducing (unnecessary) water consumption. To help decrease water cost and water wastage a team at the Massachusetts Institute of Technology developed an enhanced water tap, which reminds its user of their aggregated water usage and rewards them for closing the tap [1]. The design features two illuminated bar graphs: One displaying the total amount of time the tap has been open during the current washing session next to a second graph representing the household average. Consequently the display of current usage fills visibly fast while the tap is in use. Upon closing the tap and thereby ceasing using water an acoustic reward in the form of a pleasant chime is played. Continued good saving behavior by the user is rewarded with random patterns of illumination of the water, thereby reinforcing behavior modification and keeping the user engaged and interested. The display of the household specific average water usage enables the user to compare their behavior to others. This application of social proof amplifies the intended behavior change.

The authors conducted two separate studies to evaluate the design and its intuitive comprehensibleness on the one hand and the influence on the user's behavior on the other hand. The design study showed that the two bar graphs' meaning was easily understandable by the uninformed test group. On the contrary some of the more sophisticated features and modes were not recognized, signifying the need for an introduction or explanation of these features. The second survey lasted two months measuring the acclimatization and possible weariness of the users. The results show that the test group grew accustomed to the device and suffered no interference in their usual tasks.

The lack of tracking of water usage data, however, makes it impossible to prove whether the device has the intended effect on user behavior: a decrease in water wastage. Additionally for the user to collect their reward for continued good behavior they have to open the tap, possibly even for longer than necessary so the water illumination can be enjoyed. Some test persons wished for more variation among the rewards as the seven jingles implemented in the prototype were not enough to last for the whole study duration. Further research would be necessary to evaluate how users could be kept rewarded and interested by means of acoustic and visual feedback over a longer period of time.

The prototype featured an integration of another - though non-persuasive - device invented by the authors, the HeatSink. The HeatSink furthers the goal of reduced water wastage and proves that the WaterBot could be fused with other designs for increased effect.

3.4 Elements of Consumption

Combining the purposes of reducing electricity consumption and reducing water consumption, Elements of Consumption, which was developed in 2011 in British Columbia, Canada, is used to monitor and display the usage of electricity, water and natural gas [16]. Each type of consumption is represented by a specifically colored fluid which mark the pathing of artificial life organisms. These organisms are otherwise invisible with their pathing dependent of the resource they represent. The device includes measuring gadgets integrated into the home to gather the required usage data. A computer compares current usage to the average of previous days and induces according behavior of the artificial life: higher consumption generates more organisms, resulting in a brighter, more colorful display; less consumption causes a part of the respective organisms to "die", leading to a calmer display. These visuals can be shown on different screens within the smart home, for example as screen saver, a tablet app or an animated framed picture.

The authors are currently working on the development of said display variant as an independent canvas, in order for user studies to take place. Therefore there are no data on the effect of this design on user behavior and acceptance within homes, especially on a long term basis. A potential drawback could be a user's possible emotional attachment to the artificial organisms, provided he is informed regarding the origin of the fluids, as energy efficient behavior leads to starvation and death of these organisms.

4 Data-driven Feedback

Since many applications need to deliver more information for a more in-depth perspective, appliances of the data-driven kind chose to trade subtlety of prompts for a broader display of - partially raw - detailed data. Consequently this approach oftentimes requires more attention and more dedicated interaction from the user. Its advantages lie in enabling a deeper understanding and quantification of processes within the smart home so the user can easily comprehend the benefits of a certain behavior change, thereby persuading them by using logic and factual numbers. Furthermore the ability to present more data facilitates displaying scores of other users for the current user to compare to, making social comparison easier by incorporating social networks.

However, the increase of data results in a major drawback. When not currently interacting the user the displays are usually not even within the user's periphery. Further steps need to be taken to catch the their attention, while a continued interest in the application by the user demands even more motivation from the device. A possible solution relies on a user's smart phone to remind and prompt the user to interact with the actual appliance. Such memos must be used carefully as being too intrusive has adverse consequences on the user's behavior instead of the intended behavior change. Overall the designs need not overdo the amount of data presented, as data irrelevant to the particular user simply lessens their interest. An integration of the appliance into a social network bears the risk of deterring certain users who oppose having their personal data published to others.

4.1 Implicit Prompts

Unlike ambient feedback devices, data-driven devices have the possibility to rely on one of two different ways to display a course of action for the user to take. Implicit prompts work similarly to ambient displays, as they display facts (albeit in a more detailed manner, see figure 2), requiring the user themself to deduce the behavior modification. These facts may consist of aggregated data, historical data, which makes it easier for the user to identify the consequences of their behavior and extrapolated data, which serves to display direct consequences of a possible action taken by the user. Thereby the user can chose their own goal and their own method - one of probably many - to reach it. This may include temporally ignoring an issue. Similar challenges as with ambient displays persist, as both feature interpreted data. So the design has to take the most suitable way of choosing, interpreting and displaying said information.

4.1.1 WattBot

This application exclusive to Apple devices focuses on energy usage, aggregated over the current month and partitioned by individual circuits within the house [18]. It features a bar chart with each bar representing the kilowatt hours consumed by the respective appliances in descending order. Thereby energy consumption is doubly encoded by bar length and bar color with the color spectrum ranging from green, resembling little energy usage, to red, which equals high consumption. Additionally appliances currently consuming energy have their bar pulsing with a frequency which matches the degree of consumption, emulating an electricity meter. The usage data per circuit can be collected by installing electricity measuring devices at the circuit breakers. The design provides an incentive for users to investigate and identify those appliances which use an unnecessary or even excessive amounts of energy. By replacing these inefficient household appliances or shutting off devices on a regular basis the user would be able to conserve energy and save money.

Fig. 2. Examples of data-driven persuasive technology utilizing implicit prompts (line by line from left to right): WattBot [18], EnergyWiz [19]. Bottom: Watt's Watts [11].

The reliance on smart phones, especially on such an expensive kind, proves to be a serious hurdle [18], as users are not willing to spend hundreds of Euros on a device that displays information, which could just as easily be represented on any computer. Consequently the authors are working on a web application. The user study found that the users wish for the application to save and display previous data so they can compare the current consumption of a specific circuit to the previous consumption. This is especially the case if the user modified the circuit to hopefully decrease energy wastage. The ability to compare values would serve as reinforcement of the users behavior by displaying positive consequences to their actions.

4.1.2 EnergyWiz

Instead of targeting individual appliances, like the WattBot does, the smart phone app EnergyWiz focuses on the whole energy consumption of households and aims to motivate the user to decrease their usage by three different means of persuasion [19]. Firstly the monitored consumption is put in a quantified perspective, as pollution and monetary costs are direct consequences of the user's household usage. This appeals to diverse user groups as money saving and a pro-environment attitude serve as independent motivators. Secondly the user is able to compare their power consumption to previous entries to make the effect of their changed behavior easier perceivable. Lastly the application offers a social comparison system, likening the user's household to the neighborhood's upper and lower bound as well as the allowing the user to challenge their peers via an existing social network. This helps to keep the user interested over a longer period of time while also visualizing precise goals. The user is able to identify the amount of energy consumption to be reduced to close in on the the more efficient usage values of neighbors or friends. The certainty of having a relatively "better" household could then help support efficient behavior.

The user study found that the social comparison is biggest problem area. Depending on the heterogeneity of the neighborhood an efficient household with more inhabitants is likely to have a higher absolute power consumption than an inefficient neighbor who lives alone and therefore uses less appliances. In addition several study participants said they were unwilling to utilize the challenge option if none of their friends used the app and would therefore be not challangeable. Moreover there is a risk of users who realize that they are among the more efficient households to treat this realization as justification of their previous behavior and don't improve or even cut back on their consumption reduction measures. Ultimately the concerns on having personal energy consumption data being displayed to other people also serves as restraint.

4.1.3 Watt's Watts

Combining the two approaches above, this design enables the user to monitor individual appliances as well as compare their energy consumption to their neighbors', their peers' and past self's [11]. The user is presented with his aggregated energy usage aggregated per day in form of a bar chart. Additionally horizontal lines showing the average usage of their peers as well as their neighbors are drawn into the histogram. The color of the bars further encodes the user's own consumption compared to their neighbors' with green bars standing for 80% or less of the average, yellow signifying a usage between 80% and 120% and red denoting a day when the household used more energy than 1.2 times the average. By allowing the user to enter two time frames, one with a certain appliance in use and one with the same appliance switched off, the software is able to give the user an approximation regarding the power draw of a chosen device. On top of that a direct reward/penalization system extends the incentives of this application. Efficient behavior means that energy was saved, which in turn results on a smaller energy bill. Via a link in the application the user can study a list of things he can buy for his accumulated points, all of which can directly be purchased. Likewise inefficient behavior increases the power cost and therefore decreases the score - potentially past zero.

The user study conducted by the authors featured over 100 participants divided in three different study groups and ran for six weeks. It focused mainly on correlations between usage of certain parts of the app and energy consumption as well as continued overall app usage. It is one of the few scientific papers I found to deliver statistically significant data regarding behavior modification caused by the respective proposed design. The authors found that users who reduced their consumption also used the software twice as much as those who did not change their inefficient behavior. Concerning incentives for a regular app usage the study's result showed that rewards and historical comparison were very effective while social comparison and monitoring individual appliances had little influence. Penalization on the other hand even discouraged the users from further usage of the app.

4.2 Explicit Prompts

The final design category for persuasive technology is made up of appliances providing detailed and clear messages, which aim to give the user a precise sequence of actions for them to adhere to or ignore (see figure 3). To maximize the effectiveness of these just-in-time prompts, the design should make use of Intille's 5 rules [10]. Of all design categories, this one requires the most attention and interaction by the user. With full sentences at their disposal, data-driven appliances utilizing explicit prompts can take on the role of social actors in their interaction with the user.

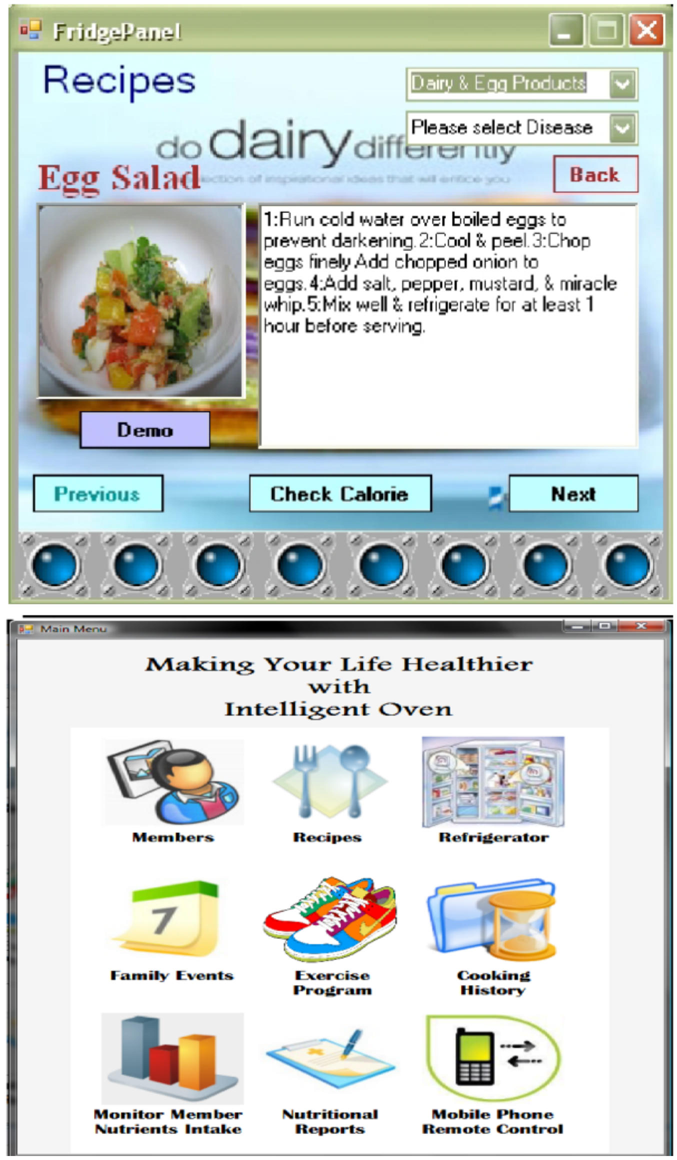

Fig. 3. Examples of data-driven persuasive technology utilizing explicit prompts (top to bottom): Smart Fridge [15], Intelligent Oven [14].

4.2.1 Tampa Smart Home for Veterans with traumatic brain injury

Moving on from eco-feedback and to a different kind of smart home, a Florida-based research team is working on augmenting the *James A. Haley Veterans Hospital* in Tampa, Florida [12, 22]. The proposed Tampa Smart Home specializes in rehabilitating veterans who suffered traumatic brain injury. In order to help users who are suffering from cognitive and memory handicaps readapt to daily life and routines the facility teaches behavior sequences by means of multiple detailed well-phrased prompts, each representing an individual step of the sequence. On successful execution the patient is rewarded with a positive message acknowledging his feat. Over time parts of the prompts will fade until removed entirely so the displayed information ultimately serves merely as cue instead of instruction. This requires a high degree of surveillance of the patient to track their location, current activity and progress on the active task. A multitude of sensors on all kinds of appliances monitor the patient's interaction while a wrist-worn device transmits the patient's location. An array of LCDs is responsible for the relay of the instructional prompts to the user, though only the LCD nearest to the user is respectively chosen. As those displays may not be in the patient's field of view for an indeterminate amount of time the aforementioned wrist-worn tracker is enhanced with means of drawing the user's attention, for example by using auditory or vibrotactile signals [13]. The multitude of collected data also helps the clinicians in identifying symptoms, tracing the patients, monitoring recovery progress and delivering an individually tailored treatment. Upon sufficient improvement of the patient's abilities and their release from the hospital they would ideally be transferred to their own augmented smart homes, which would feature a similar setup as the hospital to continue supporting the veterans. The collected data, especially the current state of the prompts, would be transmitted to their homes so the behavioral aid could continue where it left off in the hospital. Inversely the smart home could provide its own data on the user to the hospital staff for them to continue monitoring their patients therapy and to be able to intervene in case of a relapse.

At the time of writing the smart home is still in the process of being set up with specialized devices being designed and built. Therefore there are no data on the (lasting) success of behavior modification caused by this design. Given the immense amount of surveillance of the patients, at least partial refusal by some users would be likely. However, the authors found that, while this reservations was initially present, it dissipated and most of the patients voluntarily agreed to their tracking.

4.2.2 Smart Fridge

This design for a smart fridge takes a more conservative approach to smart home implementations by augmenting a kitchen appliance with the ability to display various details and suggestions based on data gathered by the machine's sensors [15]. Utilizing groceries equipped with Radio-frequency Identification (RFID) tags the fridge is able to maintain a database, which not only keeps track of the physical inventory but also monitors data concerning the respective item, for example date of expiry, nutritional values and ingredients. If an item's expiration date comes close the fridge will inform the user that the item is about to go bad. A fridge-mounted LCD would then recommend using the item to the smart home's inhabitant. The item database would further be used to help the user in preparing a shopping list. Additionally the fridge would collect user-specific data, like height, weight, dietary restrictions and health problems, to support the user in his choice of cooking ingredients. Additionally the tracked health data would display the increase of the user's health due to the usage of the application. Finally combining both the item database and the user database the appliance would be able to suggest recipes based on the groceries available in the fridge and the nutritional data and suitability of the respective ingredients matching the user's preferences and requirements.

As this design is a mere proposal of an implementation with only the GUI being present it is currently impossible to test a fully functional prototype. Accordingly it lacks a user study regarding the usability and acceptability of the smart fridge as well as a statistically significant collection of data concerning the modification of the user's behavior including potential health improvements. Upon thorough implementation further steps can or need to be taken: Instead of RFID tags, groceries feature bar codes, which contain far less information, limited to the product line instead of the unique item. This could be compensated by including cameras to read the written date of expiry and scales. The addition of further interconnected smart appliances within the same smart home would be beneficial as the data required by the fridge and the data generated by the fridge match the data required or generated by other devices well. A smart scale in the bathroom could inform the fridge on the current weight and weight changes of the home's inhabitants while the smart fridge would complement a smart cooking station by informing the oven about the ingredients which are about to be used.

4.2.3 Intelligent Oven

This led the same team of researchers to develop an intelligent oven which would be able to communicate and share data with the fridge [14]. Transferring some of the functions from the fridge to the cooking zone the intelligent oven's main functionality is using its built in visual display to provide the user with matching recipes, albeit more thoroughly than the fridge. Again this kitchen appliance collects user-specific data concerning the health of the consumers, especially allergies, Body-Mass-Index and nutritional deficiencies. The oven can request the list of available groceries from the smart fridge and combine the data into suitable recipes. The oven's added abilities include computing the shopping list for an intended meal by comparing the items needed with the items readily available in the fridge, automatic cooking, creating a history of cooked meals and a more detailed monitoring of the health of the inhabitants of the smart home. This includes proposing an exercise plan to burn the exact amount of calories provided by the cooked recipe. Accordingly the display of the user's tracked progress towards their desired weight serves as an incentive.

This design features similar problems as the smart fridge, as it currently consists only of a GUI, lacking a usability study, a functional prototype and a user study on behavior change of the very same prototype. Furthermore without an existing functional smart fridge the intelligent oven loses several of its features. Again this smart appliance would benefit greatly from an already existing internet of other smart devices.

5 Discussion

As we can see the most important difference for the user between ambient and data-driven designs lies in the *time invested* vs. *information received* trade-off. It is evidently possible to display water consumption and incentivize a reduction of the very same in such a way that its interaction doesn't demand dedicated concentration or time by the user. On the other hand encoding and displaying a cooking recipe ambiently such that a user is able to understand and perceive by glimpsing at the appliance for a very short time might be a futile project. Data-driven designs appear to be more intrusive in a smart home inhabitant's day-to-day routine compared to ambient designs, although they are unsurpassable when presenting detailed information is important. Therefore I propose a guideline on persuasive technology appliances; a smart home appliance should be designed to such an extent that its intrusiveness is kept to a minimum; otherwise a smart home of data-driven designs, each requiring the user's exclusive attention would prove overwhelming and detrimental to the user. Thus said appliance should be as data-driven as needed and as ambient as possible. Since ambient designs always present implicit prompts (see figure 4), as explicit prompts require a deeper, more engaged and hence more time-consuming interaction by the user, a need for a display of explicit procedures proves just one of the possibilities in which ambient designs can not be applied. The situation is similar with explicit and implicit recommendations. Implicit prompts can easily be applied to quantifiable, comparable data. When the circumstances require a detailed description of the intended user behavior, for example when the appliance represents a social actor, explicit prompts are indispensable. In cases which require only partial user interaction, like appliances which continue to work when the user is absent, a mixture of calm technology and persuasive technology is quite possible. When the user is at home the device would rely on the user's decision and behave persuasive and switches to a calm mode when the user leaves for work.

Out of the ten design examples of persuasive technology inside smart homes, which I described above, only five conducted at least one user study. Of the five proposed designs with corresponding user study but one was accompanied by a serious survey of behavior change correlating with usage of the design with the remaining four focusing only on user interaction and the appeal of the presentation. It is self-evident that evaluating the design of the user interface is important for an appliance to be comfortable to use, though without data to back up the claim of effectively improving the user's behavior, especially

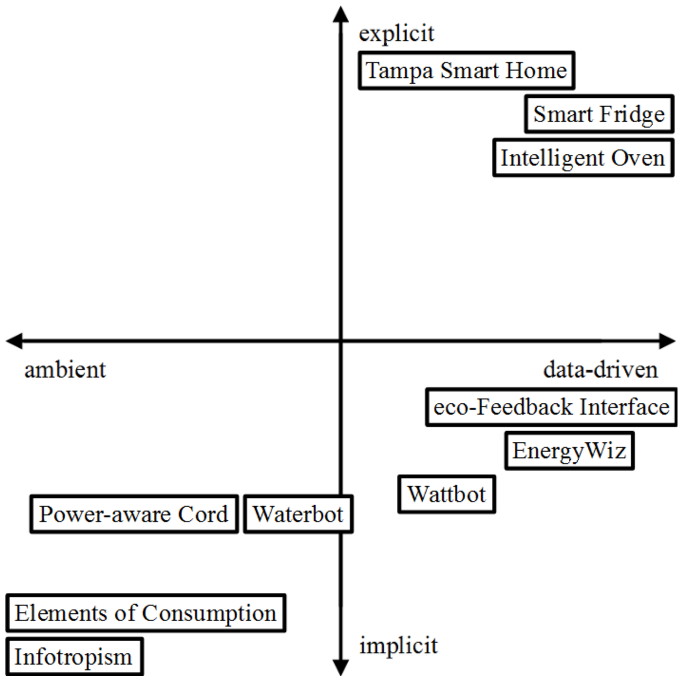

Fig. 4. Classification of persuasive technology designs

whether this improvement is just a short term change or a lasting effect, remains but a claim. This lack of evidence is oftentimes pointed out by the authors themselves, arguing that they are about to build a fully functional prototype for further testing. A division of the design process into individual prototyping phases with subsequent design evaluation by tests and user studies is indeed a proven approach to designing [17]. Under this perspective the authors deliver a novel design based on previous scientifically proven findings and general design guidelines to solve a given problem within a current or future smart home. As prototyping and evaluating their proposed appliances is a costly - financially and temporally - undertaking the authors chose to evaluate low-resolution prototypes to prove the benefits of the idea and gather user input. Positive testing results would then facilitate earning funding for the development a more sophisticated prototype and a broader user study with sufficient participants to reach statistically significant results. However, few of the presented designs, which by the time of this writing are three to eleven years old, seem to enter the next iteration. Some teams, like the group behind Infotropism, never intended to develop their prototype further and instead aimed to evaluate a daring new kind of display, so that other researchers can build upon their results. While some designs gathered funding and are actively in development, for example the Tampa Smart Home, which is backed by the U.S. government, most are rarely heard of ever again.

6 Conclusion

A review of 95 research papers exploring persuasive technology conducted in 2014 showed that more than 90% delivered positive or at least partially positive results [7]. These findings affirm that persuasive technology is effective - at least from a general perspective. The very same paper criticized the lackluster quality of the studies in question. Ranging from too small samples, too small durations to the complete absence of control groups, the validity of the results often did not meet scientific standards. While researching for this paper I could observe the very same discovery. With only one out of the ten designs analyzed in this paper delivering a thorough scientific study I can concur with Hamari, Koivisto and Pakkanen. To further scientific progress in this field of research by separating the most effective design approaches from the ineffective propositions, future research papers presenting a novel design should by all means conduct sound user studies to verify the intended benefit of the design; a flood of User Interfaces without proof of functionality or follow-up prototypes is unnecessary with individual papers being shortly forgotten.

However, instead of discouraging further research I rather encourage further work to follow the lead of the decent design propositions in building and repeatedly evaluating prototypes of increasing resolution and fidelity. This is especially important if the inclined developer desires to transcend scientific journals and devise a smart appliance that will be mass-produced and installed in future homes. Additionally the recent rise of promising research on gamification [7] deserves to be considered to be included or even fused with current aspects of persuasive technology to further improve behavior modifying devices.

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Designing Smart Interactions for Smart Objects

Mai-Anh Nguyen

Abstract— This paper deals with the interaction design of smart objects. The steady increase in the number of smart objects in our daily lives, results in an equally growing number of different interaction designs. To analyse them, first of all the extensive term 'Smart Object' has to be classified. For this, comparable interaction designs have to be found. After the classification, the interaction designs of one specific group will be analyzed and current examples of smart objects presented. Also, research of alternative interaction designs will be discussed. What is the impact on human computer interaction if the smart object or the computer disappears? What will the interaction design look like? Is it possible to define a general interaction design for all smart objects? All these questions will be adressed and discussed.

Index Terms—Smart Objects, Interaction Design, Classification, Human Computer Interaction

1 Introduction

In todays society the topic 'Internet of Things' and, therefore, also our smart objects have become an increasing issue. Hardly anyone does not have any smart objects around him in his home or environment. In 1991 Weiser[39] already had the vision that humans would not notice the digital tools around them anymore because they have become everyday things with which we interact unconsciously. To take just one small example, most of our smartphones give us feedback with a small LED light in the front. It could be a message they received or a missed call. With different colors it also provides more information on which type of message it is. For example, green could be a new chat message in WhatsApp, a popular texting application, and blue a new message on Facebook. This functionality gets habitual for us over time and we do not have to think about it anymore. An interesting aspect of this phenomenon is to take a closer look at the interaction design of our smart objects. Dix et al. define interaction design as: "Interaction design is about how the artifact produced is going to affect the way people work: the design of interventions." [10]. How do we interact with them and in what different ways can we communicate with them? This paper focuses on the different types of the interaction designs and compares some examples to each other. Before we can analyze the interaction designs it is necessary to clarify and classify the large term 'Smart Object'. This paper rests on this classification because it will extract one of these classified groups to limit the scope of this work.

The following section is required for the classification. First of all it will give an overview of existing definitions of smart objects and it will summarize the main important aspects of the different definitions. Another point of section 2 will also be an overview of the different types of interaction designs. It points out the dimension of this work and is, next to the classification, another important basis for the analysis of the interaction designs. Section 3 firstly contains the classification of smart objects. Afterwards, examples for different interaction designs will be shown and analyzed in relation to the prior chosen category of the classification. It will also discuss possible types of future interaction designs. Section 4 gives a short summary of the key aspects of this paper.

2 Foundations

First of all, it is important to determine a definition of a smart object which this paper is working with. There are many definitions and all of them have a basic technical definition of a smart object. In the following section the core definition of a smart object will be pointed out. Afterwards an overview of possible different types of interaction designs will be shown.

2.1 Smart Objects

Many papers have already been published about the technical characteristics of smart objects. All of them define smart objects as objects in our environment with integrated digital functions which can be identified and communicated with. In [27], Mattern et al. described all functional conditions for smart objects which are essential for the concept of the Internet of Things: communication and cooperation (UMTS, GSM, Wi-Fi, Bluetooth, ZigBee, etc.), addressability, identification (RFID, NFC), sensors (collecting information from the environment), effectors (the function gives the object the ability to have an effect on the environment), embedded information processing, localization and interface. Lopez et al. defined the I-S-A-D-N model for the properties of smart objects [26]: identity and data, sensing, actuation, decision and networking. With the combination of these letters Lopez measures how smart an object is. For example, an ISDN-smart object is "smarter" than an IS-smart object. The research paper [17] from Hernandez et al. deals with the topic of a classification model for smart objects with regard to their capabilities (see figure 1). It also considers different definitions from literature and is based on several existing concepts for classifying smart objects, especially from Lopez et al. [26]. In this paper Hernandez's definition of a smart object will be used: "A smart object is a physical object with enhanced digital capabilities including, at least, identification, communication, retention and energy-harvesting. Smart objects are derived from non-smart objects and maintain these objects' original essence. Smart objects are a type of smart things and include not only devices but regular objects."

The classification model grades smart objects in their technical capabilities. The following gives a brief description of the classification model. Table 1 below lists all capabilities for every level in detail. A smart object in Level 1, the essential level, has a minimum of capabilities. It implies the core capabilities as digital identification, communication, retention and energy harvesting. For example, companies integrate RFID-chips in their products to improve their logistics sector. The products can be scanned and located easily with the goal to manage the delivery or product order faster. Level 2, the networked level, includes the ability for the smart objects especially to make a connection to the Internet. Programming and processing capabilities are also included in the second level. Level 3, the enhanced level, gives the smart object the possibility to get and give feedback to the environment with the sensing und actuating capabilities. The data can also be protected in this level. Level 4, the aware level, includes more sensitive data from the human, environment and from itself. Data of temperature or emotional state from the user [1] will be collected and the smart object is able to react to it. For example, a vehicle with lights is able to turn the lights on because the sensors provide the in-

- *Mai-Anh Nguyen is studying Media Informatics at the University of Munich, Germany, E-mail: Mai.Anh.Nguyen@campus.lmu.de*
- *This research paper was written for the Media Informatics Advanced Seminar ' Human Computer Interaction in the Internet of Things Era', 2015*

[1] In this paper the term user is used for all genders

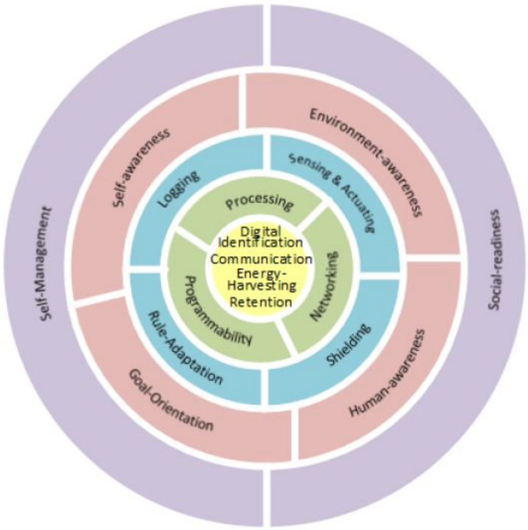


Fig. 1. Smart Object Capabilities [17]

Table 1. Smart Object Capability Level

	Capabilites
Level 1 (Essential)	Digital Identification, Communication, Retention, Energy-harvesting
Level 2 (Networked)	Networking, Processing, Programming
Level 3 (Enhanced)	Logging, Sensing and Acutuating, Shielding, Rule-adaption
Level 4 (Aware)	Self-awareness, Environment-awareness Human-awareness, Goal-Orientation
Level 5 (IoT Complete)	Social-readiness, Self-management

formation of poor lighting conditions. Another example is the eCall in cars. The European Parliament decided to make the eCall obligatory in European cars starting in 2018. If there is an accident, the car checks its own state and knows how serious the accident is and is able to call an ambulance [12]. The last level 5, named IoT Complete, is the most highly developed technology for a smart object. It has all features to simulate a human brain. It learns from the environment and it makes decisions autonomously. The behavior of the smart object is very close to the human behavior with the capabilities social-readiness and self-management.

Another perspective to classify smart objects is to look for application in their smart environment or smart space. In [14, 16, 26] some groups are listed, for example Smart Water, Smart Farm, Smart Agriculture, Traffic Management, etc. In the paper [38], an abstract overview of possible applications for smart objects is shown. It covers the entire field of the environment space where a smart object can be used (see figure2).

These two aspects, the technical classification and the application classification, are the orientation and basis for the specific classification of this paper. As it was mentioned before, to compare interaction designs of smart objects to each other, it is necessary to compare smart objects with the same level of capabilities. To limit the range of the smart objects it is useful to choose one area of the smart environment.

The next step is to summarize the different environment interactions

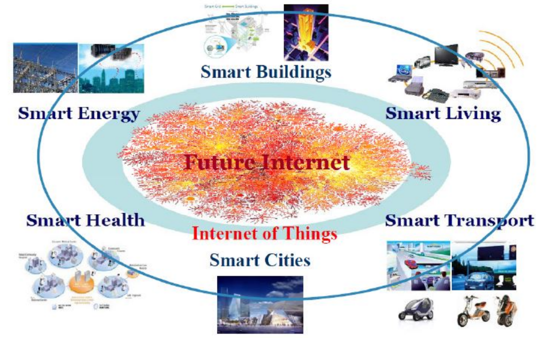


Fig. 2. Smart Environments [38]

the user has at his disposal. This section is helpful to later characterize and analyze the interaction designs.

2.2 Environment Interaction

The user has many ways to interact with a smart object. To give an abstract overview, three general types of relation between humans and computers will be pointed out in the following:

- Strictly tool-based: Humans use the 'tool' consciously. Without users no action of the smart object would be triggered. The smart object just supports the human in his actions. Example: The user wants to switch all the lights in the house off. An application on a smartphone gives the user the opportunity to control the lights.
- Automation: Smart object decides and reacts automatically. It does not necessarily require the initiation by the user. Example: The shutters of the building are controlled by sun sensors. If the sun is shining at a specific angle, the shutters are put down.
- Proactivity: Initiation is entirely caused by the environment. It is the next level of assisted living. In this interaction model the user puts the most trust in smart objects. The smart object has the ability to take data from the environment and make own decisions. Example: The software 'J.A.R.V.I.S' in the movie Iron Man represents the idea of this interaction model. It simulates a human with self-learning capabilities and the user interacts and communicates with the software as if it was also human.

The different interaction types should be considered because the interaction designs depends on them. A smart object with a strictly tool-based interaction type needs a different interaction design as with a proactive interaction model. It should be mentioned that the interaction models are linked to the classification model of Hernandez [17]. It can be concluded that the strictly tool-based interaction model includes smart objects with the capability level 1 to level 3. The automation interaction model has smart objects with Level 4 and the proactivity interaction model includes smart objects with the capability level 5. A conclusion of these dependencies is that the level or grade of the 'smartness' of the object invokes a different interaction model which is related to the interaction design.

Another important aspect for the interaction is the difference between an implicit and explicit interaction [23]. Implicit Human Computer Interaction (iHCI) was defined by Riva et al. [33] as follows:

- "iHCI is the interaction of a human with the environment and with artefacts which is aimed to accomplish a goal. Within this process the system acquires implicit input from the user and may present implicit output to the user."
- "Implicit input are actions and behaviour of humans, which are done to achieve a goal and are not primarily regarded as interaction with a computer, but captured, recognized and interpreted by a computer system as input."

- ”Output of a computer that is not directly related to an explicit input and which is seamlessly integrated with the environment and the task of the user.”

To give an example for an implicit interaction: Some people use an electric toothbrush to clean their teeth. During the usage the smart toothbrush receives implicit data from the user, for example pressure, and if the pressure is too strong the toothbrush can self-regulate for a healthier usage. The user does not need a direct communication with the smart object, the communication works in the background. In contrast an explicit interaction means that the user is completely aware of the smart object he uses. Riva et al. explains that the explicit interaction requires a direct communication between the human and the smart object during the whole time of the interaction. Another simple example of the strictly tool-based interaction is switching light on and off where the user needs to interact with an interface of the smart object. In figure 3 the dependencies of these terms are illustrated. The automation can be both explicit and implicit.

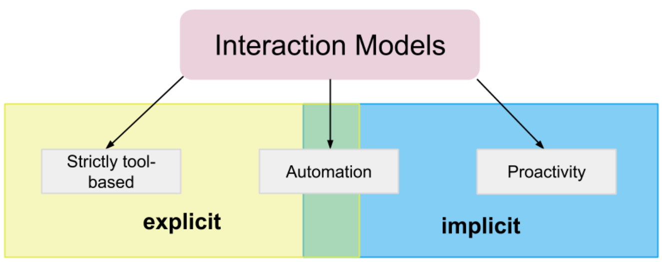


Fig. 3. Relation of Human Computer Interaction

The next step is to define the different types of the interaction design. In [22] it is mentioned that there are three different modalities of human computer interaction (HCI). The visual-based, audio-based and the sensor-based HCI. The visual-based HCI concerns itself for example with gesture recognition, body movement tracking, facial expression analysis or gaze detection. The audio-based HCI includes research areas such as speaker recognition, speech recognition, musical interaction and others. The sensor-based HCI deals with physical interaction devices we already use almost every day, for example mouse and keyboard, haptic sensors, joysticks, pressure sensors or pen-based interaction. It can also be sensors for taste/smell or for motion tracking. The system of an interface can be multimodal and is able to combine the three modalities. The modalities are based on the five human senses hearing, touching, smelling, speaking and seeing.

With this knowledge of the definitions a classification of smart objects for our analysis of interaction designs can be created.

3 Classification of Smart Objects

The classification which is needed for this paper results from the presented classification methods from the former section. To limit the field of smart objects it should be classified in regard to the smart environment [38]. Smart Living, also known as Smart Home, will be chosen for further analysis. This sector has developed considerably over the past few years and countless smart products already exist on the market. As already shown in the previous chapter the interaction models are connected with the capabilities of a smart object. To compare the interaction designs it is recommended to include the technical aspect for the classification. If we compare smart objects with capability level 1 and level 5, the interaction designs have to be different because the goal or intention of the smart object is entirely different. The former serves only as a tool for the user and needs to be initiated by him. The other ’smarter’ object does not necessarily need an initiation by the user, it can be trained or programmed for independent thinking. If we combine the two aspects, the technical view and the application view, we get a two dimensional classification. One axis represents the capability levels and the other axis the groups of the smart environment. To demonstrate the classification it will be given to each capability level with the focus on the Smart Living group. Examples:

Table 2. Classification

	Smart Living
Level 1	Smart Key
Level 2	Light Control
Level 3	Smart Plate
Level 4	Smart Air Conditioner
Level 5	Smart Fridge

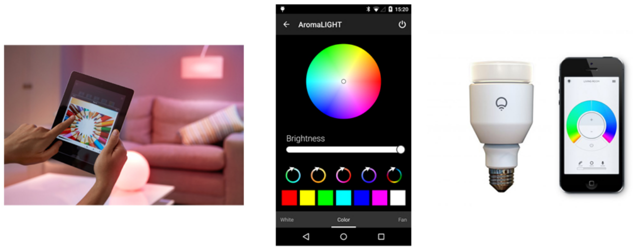
- Smart key: A smart key has an RFID tag integrated. It can identify itself wherever it is. Users can track the location of the key on applications.
- Light Control: The lights in the room are linked to a device with a wireless connection. The user can control the brightness and color of the lights.
- Smart Plate: The plate is sensing what kind of food is on it and sends the information to a cloud where the user can retrieve the data from his eating behavior.
- Smart Air Conditioner: The air conditioner senses the temperature of the room or scans the number of the people in the room to automatically regulate the right temperature.
- Smart Fridge: The fridge registers every product and learns from the owner which product or food he prefers. When it notices missing food which the owner always had in the fridge, it orders the product on the internet and informs the owner. All intelligent functions can be customized to the user.

Table 2 shows the classification with the examples. Now we can compare smart objects which are used in the same application environment and consider the different technical capabilities. For the analysis three specific application fields of Smart Living are selected. These application fields are Smart Lighting, Smart Kitchen and Smart Security. For each of these topics some examples for interaction designs will be given in the next sections. Each of them will be analyzed according to the classification model of this paper and according to the type of interaction model it is used in the examples.

3.1 Smart Lighting

Smart Lighting gives the possibility to control all the lights in the house or building with one device. Many solutions for this use case are the usage of applications on smartphones to interact with the smart objects. Figure 4 shows only a sample of the smart objects for smart lighting which are current innovations. But it represents the most frequent interaction designs for this special user application. The user explicitly controls the lights on the given interface on the tablet or smartphone. To compare the three smart products the capability level and interaction model will be defined.

Philips Hue [31], awoX [3] and LIFX [25] work with smart LED lights which are connected via wireless technologies such as Bluetooth, ZigBee or WiFi. With the app on the smartphone the user can control the smart lights, for example switch all the lights off or change the color or brightness. All three examples have the capability level of three (Enhanced). The smart objects receive commands from the user and give feedback on the current state. In all three cases the interaction between the user and the smart objects is explicit and strictly



Philips Hue awoX LIFX

Fig. 4. Three examples for Smart Lighting [6, 30, 32]

tool-based. It has to be initiated by the user in order to communicate with the smart object. A different way of interaction design was also presented by the fluid interface research group of the MIT MediaLab [18]. Augmented Reality (AR) is used as an interface for the interactions. It replaces the normal interface on the smart object or a static interface on a screen with a fluid interaction design. The user holds the smartphone/tablet in front of the smart object and a virtual user interface shows up. To connect more smart lights or smart objects the user can draw a virtual line from one smart object to the other on the smartphone/tablet. This concept merges the real world with the virtual world [11]. It shows an alternative way to interact with the smart objects. With the use of AR complex functionalities can be visualized if there is not enough space on the user interface of the physical device. It has the same classification as the three examples. The interaction is strictly tool-based and the user is aware of the use of the smart object.

All presented examples for Smart Lighting require a smartphone or tablet. The familiar physical form of the lights remains and the digital technology for the interaction is implemented on an external device. For the simple function to switch the lights on or off those type of realizations are not necessary. In some scenarios it takes more time for the user to start the application on the smartphone than to operate the light switch. On the other hand, for other, more complex functionalities such as changing color or brightness, a user interface is needed for specific control. The difference in the interaction design between the applications on smartphones and the fluid user interface with AR is that the fluid user interface enhances the existing everyday things in our environment with new technical properties. In this case the user holds the smartphone or tablet to the light switch and a virtual menu is displayed for changing color. In this way the traditional form and function of the light switch is kept. This represents one solution on how to transform an everyday thing into a smart object. The paper ”Designing Smart Living objects” [7] states that ”the digital enhancement should consider the object’s traditional function and interaction, and avoid any conflicts between its digital enhancement and traditional use”. The fluid interface satisfies these criteria. The other applications replace the role of the light switch in form as an on/off slide button. Both interaction designs have advantages and disadvantages. For example, for physically handicapped persons the application on smartphones are the better choice. It is possible to control the lights with the smartphone in any location. With the fluid interface they have to be in the vincinity of the trackable object. An advantage of the fluid interface is the strong visual connection between the everday things and the digital functionalities. It can help the user to understand the enhanced digital functions in a different way because, it directly shows a virtual interface on the real physical object. As we can see, the ’right’ interaction design for this use case is hard to determine because it depends on the needs of the user.

3.2 Smart Kitchen

The next three smart objects have a broader scope. But the interaction design for kitchen applications is the same in most cases, usually embedded in the existing objects. The role of smart objects in kitchens is to assist the user. Compared to other application, here the digital functions generally run in the background and assist the user in specific tasks without distracting.

Gorenje iChef [15], a smart oven, is equipped with an internet connection and a touch display. It is possible to search for recipes on the internet and the oven will adjust the required settings automatically depending on the choice. Also, a notification will be sent to the user’s smartphone if the cooking time is finished. This means that the smart oven is classified under the capability level four (Aware), because it has the capability of self-awareness. The user interacts with the oven primarily in an explicit way and the user still takes the initiative. There are some implicit interactions between the smart oven and the human if, for example, the oven sends a notification to the smartphone.

Jenn-Air LG Smart Fridge Whirlpool

Fig. 5. Three examples for Smart Kitchen [5, 28, 36]

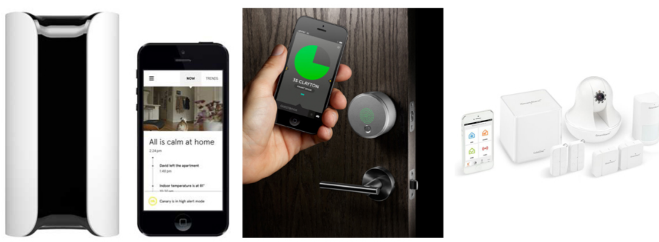
The LG Smart Refrigerator [28] has similar technological capabilities as the smart oven and can be classified in the same way. The fridge is able to connect with the internet and smartphones. It can automatically order food if the inventory of the fridge is low by sending a list of the missing items to the smartphone of the user. It is also able to adjust the settings on the oven if a recipe is chosen from the fridge computer and both smart objects are connected. The interaction between the user and the smart fridge is explicit as well as implicit and also strictly tool-based as well as automatic (this is an example of an interaction model which represents the overlap in figure 3). The user is still aware of the digital functions on the fridge but the fridge can also work in the background by checking the stock of the fridge automatically.

The interaction between the user and the smart objects needs a touchable interface in these examples. All the interaction where the user wants to initiate interaction is based on the integrated screen of the smart object or on the smartphone/tablet. It concentrates on the sensor-based HCI architecture. What the future kitchen might look like is shown in figure 5 with the prototype of ”whirpool” which was presented at the CES 2015 [5]. The cooktop is a touchable interactive surface. The interface is projected on the cooktop and the user interface adapts to the use case. It also supports social media and offers the user all relevant information needed for cooking. The combination of the virtual interface with real objects was already prototyped with the DigitalDesk from Wellner [41]. All the digital functionalities are integrated in our everyday things and assist the user in his specific tasks. This concept gives an alternative to the embedded touchscreens from the previously mentioned examples. The interaction gets more implicit than explicit because the tool is moved more into the background. According to the kitchen scenario it could be a good way to integrate the enhanced digital functionalities into our environment without changing the traditional use of our everday things. It is similar to the fluid interface, which was presented in the prior section. The one works with handheld displays and the other one with projection-based displays. For the interaction with smart objects the projection-based display is better suited in the kitchen scenario. Smart objects should not interrupt the user’s tasks by its interaction design.

3.3 Smart Security

Smart Security makes high demands on the technical capabilities of its smart objects. It has to give the user a feeling of safety and trust. The smart objects, therefore, have to be at least at level 3 to ensure the privacy of the user’s data. The interaction design plays an important role for these aspects. For the following three examples of Smart Security, the smartphone was chosen as an interaction tool (see figure 6). The use case is an entirely different one from Smart Kitchen because the active usage of the smart objects will be needed if the user is not at home.

Canary [4] and the iSmart [21] observe the home with cameras and motion detectors. August (Smart Lock) [2] is only for controlling the front door. All three smart products provide an alert function. Sensor-based technology collects the data from the environment and sends the user information to the smartphone. For example, if there are unusual movements in the house the motion sensors which are connected with the smart security system send a notification to the user. iSmart makes the user a proposal to call the police. The decision will remain in the hands of the user. The three products can be classified by the capability level 4 (Aware). In all three examples, the interaction between the user and smart objects are a mixed form of implicit and explicit interaction because the smart objects need the property of automation but the main control still lies with the user.



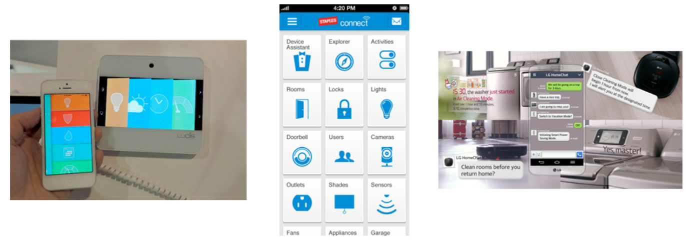
Canary August iSmart

Fig. 6. Three examples for Smart Security [9, 13, 37]

Multiple research papers exist [19, 29, 43, 44, 45] which study and discuss the issue of face recognition integrated in smart environments and smart homes. For example, [19, 43, 45] presents an alternative concept of Smart Lock with the help of a facial recognition system. The camera detects the face of the person on the doorstep who wants to enter the building. If the person is authorized, the door will open automatically. The system can also send an authorized person a message to their smartphone if an unauthorized person wants to enter. The interaction is completely implicit and represents a smart object or smart system which behaves proactive and has some characteristics for the highest capability level (IoT Complete). It takes own decision with the data of the environment and needs no operation of the human to initiate an instruction. Nevertheless, it should be mentioned that some systems which are based on facial recognition still fail in some cases, for example if the person wears a hat or a sunglasses [43]. Another idea is to combine voice identification with facial detection [42] to increase the security and make the smart system multimodal (visual-based and audio-based). If we enhance this combined security concept with functions such as social-readiness and self-management, we can talk about a full smart object of level 5. With a connection to social media, the smart cameras could recognize with the data if the person on the front door is a friend, relative or a stranger. It learns from the social environment of the user and makes the decision after interpretation of the data. For a high intelligent system the computers require many personal data of the user which is a critical issue for the data security.

However, nowadays the smartphone is the dominating interaction tool for Smart Living and enables the human to control his home. Even if the technology is so matured that it can take over the control, the question is how humans are prepared for it. An example for a smart system which has the capability to control all smart objects in the smart home can be seen in the products for Smart Automation (see figure 7).

The examples ranges from the capability level 4 to level 5. Some of them have the ability to learn from experienced situations (for example when to dim the light after learning the user's sleeping habits). The 'smartest' system of them is the LGHomeChat [24]. It could simulate a human brain behavior. The concept of this smart system could be working as a full automatic system. The user only has to tell the system that he will come home and the smart system activates other smart objects (for example, starting the washing machine or activates the vacuum).



Lucis Staples LGHomeChat

Fig. 7. Three examples for Smart Automation [8, 34, 35]

There are endless more examples for smart living. This paper gives only a little impression of our smart objects and their interaction designs. The analysis yields that the interaction between the user and the smart object is applied through interfaces/screens on our smartphones or tablets. From the presented research on different smart objects with different capability levels, the question rises whether there is a relationship between the grade of the capability of a smart object and the type of interaction design. The smarter an object is equipped, the less explicit interaction is needed between the user and computer. More and more the computer fades into the background. Weiser considered that computers should not be the focus of our lives [40]. But if the computer should be invisible and the interaction should not be in focus, how can the interaction design be structured? Some solutions were presented in the prior sections as research projects and prototypes. They show us what the future interaction design might look like. Another example is a wearable device with sensors that can detect different muscle movements of the user. The user can use it as a mouse device. Presentations or also computer games can be controlled with this device. The connection is based on Bluetooth. The capability level of this smart object is not very high. Nevertheless, the interaction has the intention to be implicit. After learning the different gestures of the hand, the user can control the device intuitively and without thinking too much about the MYO armband [20]. It contradicts the notion that smart objects with a high capability level imply an implicit interaction. Google ATAP's (Google's Advanced Technology and Projects) project Jacquard [1] is one of the newest invention for screen-less design (see figure 8). The developed sensor-based technology is so small that it can be integrated into clothes. Designers can make the touchable area on the cloth visible or completely invisible. With a touch on a specific place of the jeans or jacket the user can accept a phonecall.

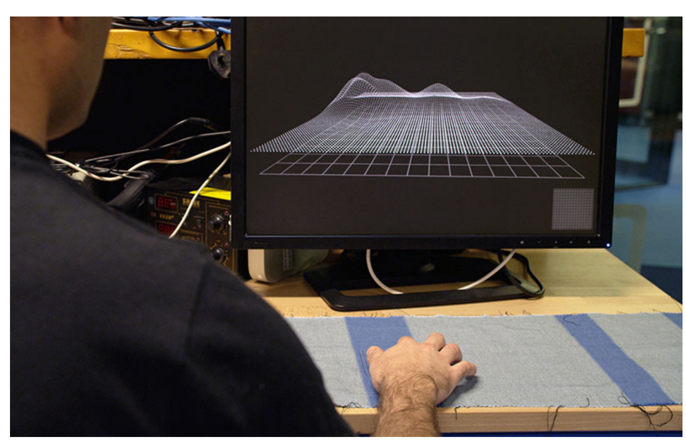


Fig. 8. Jacquard represents interactive clothes [1]

The next point this discussion wants to deal with is the question whether there is a solution to generalize the interaction design for smart objects. This paper already demonstrated that there are multiple factors which are related to the decision how to design the interaction between humans and computers. The goal of the human for a certain task is the orientation for how the interaction should be designed. It was mentioned before that the user who wants to use smart devices in the kitchen has other requirements than someone who wants to control the house if he is not at home. It also plays an essential role if the smart object is embedded in an existing object or not. If the intention is that the user should not interact explicitly with the smart object, the technology will be hidden and becomes invisible. In this paper we defined three possible types of interaction a smart object can have, strictly tool-based, automating or proactive. Now there are already two aspects which makes it difficult to find a general interaction design. The certain goal of the human task and the role of the smart object. A solution could be an adaptable interaction design with multimodal HCI which notices the needs of the user and gives him the right type of interaction. To give an example, assuming the car, home and phone are connected as one smart object. The system of the smart object always knows where the user is. In the house the smart object, for example, has voice control as interaction design and uses any connected display in the house for visualization, depending where the user is. By entering the car the system primarily uses voice control for interaction. If the intelligent system locates the user in a library it activates the mute mode on the smartphone. This is just an example how the problem about a general interaction design could be solved.

4 Conclusion

In this paper current and future smart interaction designs were shown of the application field Smart Living. This category was subdivided into smaller application topics to more easily compare the smart objects to each other. The analysis according to their interaction shows that the interaction design can be implemented in different ways. Firstly, it can be strictly separated from the smart object in the form of applications on smartphones and tablets. The second way is to embed the interaction design into the smart object in the form of integrated touchscreens or computer augmented environments. The third way is to make the interface invisible in form of natural interactions such as gesture, gaze or voice detection. For every use case a suitable interaction design has to be found. Research gives us some insight into the interaction possibilities in the future. From the technical aspect computers have the ability to collect sensitive data, for example facial expressions, sleep or eating habits, social media data, and so on. Computers have approaches to simulate human behaviors and the user is able to interact with the smart objects as with another human. This is a possible direction in which the future trend of interaction design could go. The main critical aspects rest on data privacy and the human's attitude to give a maximum amount of trust over the computer's control.

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Can you Trust your Fridge? Privacy and Security Challenges in the Internet of Things Era

Martin Reiss

Abstract— Since the arrival of the Internet of Things (IoT) we saw the rise of many new applications that help users manage their daily life, monitor their health or consume social media. This all is supported by the devices that enabled the IoT in the first place. These devices however, do not provide sufficient security to the kind of data they process, namely sensitive user data. In this paper, we discuss the vulnerabilites that threaten the users' security, privacy and even safety. We present an overlook of solutions to these vulnerabilites in the domain of hardware and software, like frameworks and models, and how encryption and secure protocols can be used to fix these issues technically. Further concerns include privacy and how transparency and awareness thereof need to be improved largely. Finally, we look into securing measurements from the view of human computer interaction (HCI), including authentication and biometrics.

Index Terms—IoT, HCI, Security, Safety, Privacy

1 Introduction

In recent years, a wide array of new smart devices and gadgets as well as technically updated everyday objects like fridges emerged that are interconnected. They collect data about their environment, possibly process it and transmit it further, ultimately feeding back into that environment. The application areas range from smart homes to health and well being and many of the devices operate in the background (see figure 1), without any user interaction needed in order to trigger their action. The sheer scale of such devices and the fact, that they are interconnected lead to the term Internet of Things (IoT) [11].

Most commonly the "things" are used in two domains[11]: homecentric and personcentric. In the homecentric domain, devices collect data about the environment at a user's home, like heating and lighting, and are therefore designed to be installed there permanently and not moved with user. The devices might be strongly interconnected, for example if one sensor detects an open entrance door, the light might turn on and the heating off. In the personcentric domain, devices are attached to a user to track his behavior and log data about his body. Other emerging domains are work-, family-, leisure- or transitcentric [11]. With the help of this data, users find support for saving energy, gain insight into aspects of their health that are otherwise hard to determine and make everyday life tasks easier.

While the benefits for users are numerous, however, these devices are currently not to be considered secure [23]. Due to constraints on budget and technical aspects of IoT devices, authentication and crypto mechanisms may be implemented poorly [25]. This leads to a range of security, safety and privacy issues. In this paper, we identify the exact issues and present solutions [3].

The rest of this work is organized as follows: In the next section, we take a look at common security vulnerabilities in the IoT and why they are potentially dangerous for users. In section 3, we present technical solutions ranging from frameworks and models to solutions found in related domains to improve security and privacy. Following that, we discuss what the field of Human Computer Interaction (HCI) can contribute to improve security and specifically authentication. The fifth section critically reviews the solutions presented in sections three and four and gives an forecast. The concluding section wraps the essential findings of this work up.

- *Martin Reiss is studying Human Computer Interaction at the University of Munich, Germany, E-mail: martin.reiss@campus.lmu.de*

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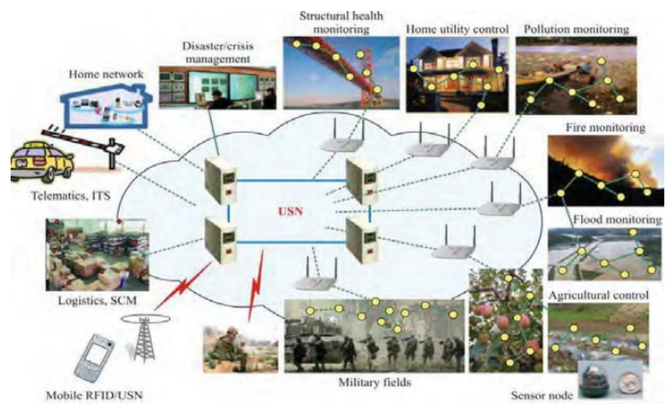

Fig. 1. The many application areas of IoT devices [14].

2 Security issues in the Internet of Things

In this section we take a quick look at typical characteristics of IoT devices that give rise to security vulnerabilities. As any computer system, IoT devices are as well affected by attacks on their integrity, confidentiality and availability. But because of some of their properties, this threat might be even larger here: The scale of the IoT is in the order of billions of devices communicating and transmitting data [10]. This opens up a big space for attacks. Furthermore, the heterogeneity of the different devices adds to the complexity of the IoT and adds an additional layer of vulnerability [25].

Unfortunately, the typical IoT device faces a number of restrictions. The hardware including the CPU is comparably weak, which makes the execution of complex encryption algorithms infeasible. Also, power supply can be problematic since many devices run on battery. And since such devices are produced on tight budget, cryptography is not a topmost priority. The devices will communicate with much more powerful entities over network connections. For this to work, the crypto mechanisms have to be optimal in that they need to be as simple as possible without decreasing the level of security. For example, a standard like the advanced encryption standard (AES) works on most devices, but not for the ones based on radio-frequency identification (RFID) [18].

But what makes these threats critical is not their technical vulnerability, but the fact that the data these devices process and transmit is highly sensitive. From personal data like food preferences, statistics about media consumption up to medical data of the glucose level in a user's blood, just about every aspect of everyday life can be tracked.

The implications of having systems compromised are therefore reaching beyond the privacy of data and go as far as threatening the physical safety [21].

Furthermore, as devices evolved, the way user interact with them also changed, but not in a beneficial way: authentication in the IoT is a problem, since the standard username and password paradigm is not applicable on small screens and does not fit into the vision of seamlessly working smart ”things”. For example, the fridge in a family kitchen should be open during the day, but lock over night for everyone but the adults in the family [18]. In this situation, they do not want to type in a password, especially not on a small screen on a fridge door. Here we need new technology like biometrics to do the job. But also, the privacy of users' data is at a stake. Users might feel overwhelmed with the number of providers that store their data. These concerns will be discussed here as well.

Generally speaking, the main challenges are resilience, authentication, access control and privacy [23]. Whenever the system is under attack and components are failing, the system must not collapse all together. Operations on data and executing of commands must be authenticated in order to prevent misuse. The access to data must be controllable, that means that the user is able to decide who can use what parts of his data. And finally privacy is fulfilled when no attacker can draw clues on a user's information by observing a system's behavior.

3 Improving security by technical means

In this section, we discuss technical solutions to secure the IoT. To gain insight into this, we first need to understand the overall architecture of the IoT, which consists of six layers [14]. The sensors, actuators and similar make up the bottom layer. They might be stand alone devices or embedded in cars for instance. The next layer is the gateway through which they communicate to other objects or access the network to send data. Layed upon this layer is the access layer, which are fixed infrastructures such as WiFi. Some devices may bypass the gateway layer and communicate directly through the access layer. Next is the globally connected transmission layer, which in most cases is the internet. It connects the access networks globally. The fifth layer is the service layer, where the data is stored, processed and can be accessed. This is for example the manufacturers server or a middleware of a third party. The layer on top of it all is the application layer, where information is presented through interfaces in a way that humans can process and understand it [14].

In the next subsection we introduce the security concepts used in the IoT and see why exactly they are insecure. Following that, we take a look at frameworks and architectures that tackle these problems. Finally, we examine the lessons learned from embedded systems and see if we can transfer them to the IoT.

3.1 Currently used cryptosystems and models

Here, we want to take a closer look at the cryptosystems currently used in IoT devices. We evaluate the common encryption schemes and authentication protocols. The IoT suffers from similar issues as the traditional Internet and wireless systems, such as jamming, spoofing, replay, and eavesdropping [22]. The solutions presented here touch upon these issues.

Devices are generally connected to network in only two ways: either to a local network, for example via WiFi at home or at a company, or to the Internet via public network. In local networks, devices usually communicate to each other within the network only and thus the focus is on authenticating for access to the network and prevent eavesdropping on transmitted data. In this scenario, the authentication in most cases is a simple password mechanism that also prevents eavesdropping. Given a strong enough password, the communication is sufficiently secure [25].

If devices are communicating with a remote system however, the security requirements extend to integrity and confidentiality of the transmitted data, that means the crypto mechanism has to ensure that the data was never read or modified by third parties. Here, the authentication will usually work with an ID and password pair that will authenticate an entity for every transmission. Alternatively, authentication can be ensured by the exchange of short-lived security tokens. The advantage of this approach is that a token allows for a session, as opposed to authenticating an entity for every single call. Even more mechanisms exist, but are somewhat less popular and are therefore not touched on here [25].

After the successful initiation, data will be transmitted over network. The alternatives are as follows [23]: Virtual Private Networks (VPN) are formally promising, since they promise confidentiality and integrity to all the participants. However, they have to be established between the partners explicitly and are insufficiently dynamic for the requirements of IoT. Transport Layer Security (TLS) and Secure Sockets Layer (SSL) which is commonly used as a trust structure in the internet provides confidentiality and integrity. The downside here is, that as a part of the protocol each connection will be established by verifying certificates and negotiating a secret, which leads to overhead that does not scale well with the number of devices in the IoT. DNS Security Extensions (DNSSEC) is secure in that it provides authenticity and integrity like TLS/SSL, but cuts down a part of the overhead by using public-key encryption. While still ensuring backward compatibility, it unfolds its full potential only if a significant fraction of communication parties embrace it. Onion Routing is, at first glance, a excellent solution, since it adds anonymity to the many encryption layers. So not only is it hard for attackers to decrypt messages, but they cannot know both source and destination of the message and are therefore incapable of deriving semantics by merely observing. Unfortunately, Onion Routing is impractical for the IoT, since the performance would not scale up to the demands. And finally, Private Information Retrieval (PIR) systems are to be mentioned here for completeness, but are not considered, since the performance and scalability make them impractical as well [23].

Out of all the alternatives, TLS and SSL is the most practical and in fact currently used the most [18]. The protocol largely depends on the encryption algorithm. Since IoT devices are tight on computational resources, an efficient algorithm is mandatory. Encryption algorithms for lightweight systems are already available with many more in various stages of development [18]. A recent block cipher called CLEFIA was developed by Sony and released in 2010. It supports keys of 128, 192 or 256-bit length and can be implemented in hardware and software. Its efficient design makes it a candidate for constrained devices, like the ones used in the IoT.

A problem however is the key excahnge. For previously known devices, symmetric keys are feasible. Asymmetric keys on the other hand will require the device to behave as a client [18], which cannot be expected from a number of the constrained devices. The biggest problem is the negotiation of keys between previously unknown devices. Given the highly dynamic nature of the IoT, this is concern that needs to be addressed with care.

3.2 Dedicated security frameworks and models

Many frameworks and architectures have been proposed to improve the security. But first, we discuss and identify the privacy and security requirements. For one, we need to be able to determine which part of the data we must encrypt. Next, we should be able to control who has access to what parts of the data. The difficultiy for this requirement arises in the face of the heterogeneity and dynamic nature of the IoT [2].

To overcome this problem, an analysis gives insight into the degree of controllability, resiliency and scalability of the network. Such analysis can be done by modelling a network, say a subnetwork of strongly connected devices, as a graph G with devices as the set of vertices V and the connections as the set of edges E, so that G = (V, E). Each of the vertices has properties attached to them that describe the technical specifics of this node, like its processor and memory. The edge between nodes is described by properties as well indicating the quality of connection between the two, for instance the bandwidth [21]. On the assumption that all edges e are bidirectional and all vertices v are allowed to have a degree larger than one, meaning a vetrex can be connected to multiple vertices, we can analyse the graph to determine three things: first, how well the network can persist in a dynamic environment while responding to control commands for individual nodes. Second, to what degree the network will be able to recover after components failed, due to error or after a malicious attack. This is crucial in that it indicates whetever the devices are interdependent in a way that makes perfectly fine working components fail as soon as other parts go wrong, i.e. a domino effect occurs. And lastly, we can describe if devices encrypt and authenticate information so that data and commands are treated with confidentiality and integrity [21]. Going back to our desire to quanitfy the controllability, resiliency and scalability of the network, we can derive three numbers that respectively describe them as

- the probabilty of messages reaching its correct destination,
- the fraction of connections (or edges) to fail to make the network not working as expected,
- and the operational constancy, combined with the previous two, to indicate how large and connected the network can be while remaining reliable [21].

IoT devices provide a lot of service to people with a medical condition like chronic diseases such as diabetes and arthritis, which are best treated with self-care. To support that self-care, many smart devices bring help and benefits to users. But at the same time, they are very critical from a security point of view, because of the data they work on [20].

In order to make the IoT successful in eHealth, Abie et al. [1] proposed an adaptive security framework. It is capable of preventing and reacting to known threats and to learn about and adapt to unknown threats. At the core, this model predicts the risk of threats and estimates the benefits of defending against them. Moreover, the system will adapt dynamically to changes in the network at run-time.

The key component is the risk management which identifies and predicts problems, analyzes their impact, schedules actions in order to fix them and reduces the risk exposure. It relies on components like the monitoring of the context and status of devices and the analysis model for this monitoring data in order to discover threats and estimate further actions based on the findings. Further components are a decision making model, which provides the means to take actions for whatever the analysis may have concluded. If for example, a vulnerability was discovered and found to be risky enough, the decision making model will find the best solution to protect the system from harm. After a decision was made and the solution was implemented, the framework evaluates and validates if the purpose was met and the security is restored [1].

While we took a look at security issues and solutions for them, we now want to focus on privacy. While somewhat related to security, there are a few important distinctions to be pointed out here. As we have seen up to this point, securing data means to protect it from unwarranted access of third parties. Privacy addresses a user's control over the generation, usage and disclousre of their data [12]. Therefore, privacy builds upon security, since data has to be truly secure before privacy concerns can be brought to the table. But privacy is crucial for applications in the IoT, since there are multiple stakeholders to data and the relationship amongst them needs to be clearly defined, as the question of ownership of the data illustrates. The privacy framework by Kotz et al. [12] provides a number of recommended properties to a system that will make for reasonable privacy if implemented. It is developed for systems in eHealth, but can argubly applied to other domains as well. A few important key concepts shall be discussed in the following:

- Users shall be provided with information transparency about what data is collected for what purpose and where it is stored. This helps users to feel in charge about their data and raises trust in the system.
- The data with the highest detail level possible as well as historical records must be accessible to the user. Furthermore, data needs to be added, modified for correction or deleted if requested by the user. Again, this gives the power over data into the user's hands.
- Users must be able to limit what data is generated about them and who will be able to access it.
- The provider must ensure accuracy, completeness and authenticity of data. In order to guarantee a certain quality, these conditions must be held by providers.

These conceptual properties must be implemented in a technical solution as completely as possible to provide privacy to a user. Furthermore, the framework states the need for usability amongst others, which is our main concern in section 4.

3.3 Approaches from related domains

Embedded systems are in some ways similar to IoT devices: they face the same constrains, but are expected to deliver reliably. For instance, the memory is as small as necessary to keep costs down. Thus software must be as efficent as possible, which often leads to the choice of C as the programming language. And indeed, since C is a lightweight language, programs can be efficent. But on the other hand, C is inherently unsafe, which makes it all more critical in the context of the IoT [22]. Here we see what we can take from the lessons learned in embedded systems. For one, many smart devices are used in public which means they are exposed to physical attack or manipulation, for example as sensors might be destroyed. As shown by Kanuparthi et al. [10], Physical Unclonable Functions (PUF) can help fix a large number of issues. In the example of sensors, we can implement sensor PUFs, that will have the following properties [10]:

- A sensor PUF takes a challenge and a sensed quantity to produce a response. If challenge and quanitity are the same, the response will be the same.
- No challenge-quantity-response triple leaks information about other triples.
- Sensor PUFs, like all PUFs, are not predictable regarding their output.

These properties allow for checking a sensor's credibility regulary and protect from tampering. Furthermore, PUFs can provide and challenge identification, because their ability to provide unique IDs. By using randomly chosen challenge-response pairs, which are unique for every ID, commands from fake, malicious enitities are neutralized [10].

If however, components are compromised and malicious software runs on them, we still want to be able to detect this. In order to do so, it is advised to use hardware performance counters (HPC), which are started by the operating systems and monitor software that is executed on this system. Through different metrics, HPCs help to verify the software's integrity and uncover malicious use. The downside with this approach is the high number of false positives a HPC might produce. Another approach in detecting compromised components would be to send notifications or verifications to the user everytime a device is about to send data. This way, the user will help, for example by being suspicious because he was not expecting any data to be send in the first place and will check deeper on his devices [10].

Now that we discussed how to secure individual devices, we conclude by taking a broder look at the problem. A way to do this is by thinking about the IoT as a distributed system. Clearly, the way devices can be closely connected, related and dependent carries many traits of distributed systems. With the help of Control Flow Graphs (CFG), programs can be analysed for possible vulnerabilities. The graph is constructed by modelling each instruction in the program as a node. If an instruction can be reached from another one, the nodes will be connected by an directed edge. In this simple setup, possible vulnerabilities can be already flagged by observing variable inputs that originate externally. Such input can cause buffer overflows if not checked properly and are easily exploited [22]. While powerful, CFGs often report false positives since runtime information is missing in static code analysis. This issues is fixed in Dependence Graphs (DG), which help the CFGs that model the instruction flow to additionally model the data flow of variables in the program. The limits of this kind of analysis is a distributed process, which we find in the IoT [22].

For this purpose, Distributed Control Flow Graphs (DCFG) were developed. In this model, each pair of individual instances is described as a subgraph using the regular CFG. Whenever they may communicate, an edge is added. That means that each instance can be analysed by itself but also in the big picture of the system as a whole [22]. The edges in DCFGs are directed to distinguish if a CFG sends or receives data. This is important for the overall analysis, since a message that is tampered with over the network, the instance that sent it is not vulnerable to this particular point, but the instance receiving has to validate the incoming message for confidentiality and integrity. In an analogous fashion, Distributed Dependence Graph (DDG) describe the data flow over distributed programs. Just like in a DCFG, a DDG contains pairs of DGs and incoming and outgoing edges to describe their relationship. This allows for buffer overflow analysis over multiple computing instances in the distributed system [22].

4 Improving security through HCI

For this section, we turn to countermeasures from the point of view of HCI. This discussion is worth having, because a strong cryptosystem will fail if it is not used correctly. When users do not understand a system fully, they might try to subvert its mechanisms in order to complete their actual task [15]. This way, the cryptosystem might break and vulnerabilites are exposed. Different techniques to avoid this are discussed in the following.

Before we delve into the security improvements that HCI can bring to the IoT, an overlook over how user actually use the devices is due. Amongst the most popular areas are sleep, body, fitness and weight, which coincide with the quantified self movement. Usually, users will interact with these devices by wearing them or indirectly through a dedicated smartphone app. The latter one makes sense, because user carry their phones with them frequently. Additionally, phones have larger screens and greater computation power, which not only extends the battery life of "things", but also allows for improved usability [11].

In many cases, the data collected by the devices can be consumed by the user, again, through their phone, making the smartphone the interface between user and data and the "things" the logging and transmitting focus [11]. For the remaining section, the usage of smartphones as a authentication token will be a recuring theme but not limited to that.

4.1 The gap between usability and securtiy

Usability and security are somewhat opposed to one another, resulting in an inversely proportional relationship [4]. This means, the securer a system, the less usable it is. For one, security is not an explicit goal in an interaction and in some cases is even in oppositon to it. Second, users do not necessarily enjoy to read about risk and threats, since the abstractness of the field can be unsettling for users [24]. And lastly, systems are expected and trusted to just work and perform tasks as desired [5]. It is worth noting, that the continuum between security and usability is not perfectly spanned: If a system is not usable, it cannot be secure, making a certain degree of usability a precondition for any secure system [4].

However, the paradigm of designing easy to use interfaces first and applying security afterwards proofed to be troublesome: Badly implemented security systems will lead to users subverting them, as seen with usage of smartphones [15]. And this comes back to users not understanding the risk or being biased in such a way that they believe they are not at risk at all [15]. But as much as security measures should happen in the background, out of sight for the user, at some point it is inevitable to inculde the user in the process. It is important to communicate the risk of the action at hand appropriately in these situations. At the same time, the system's security measures should not limit the user with requirements that are not feasible. To bypass this, system designers can motivate users to take security measures seriously. To do this, the designers can use the fact, that we do not value gain and loss equally and inform the user of potential negative consequences for not taking care of security [24].

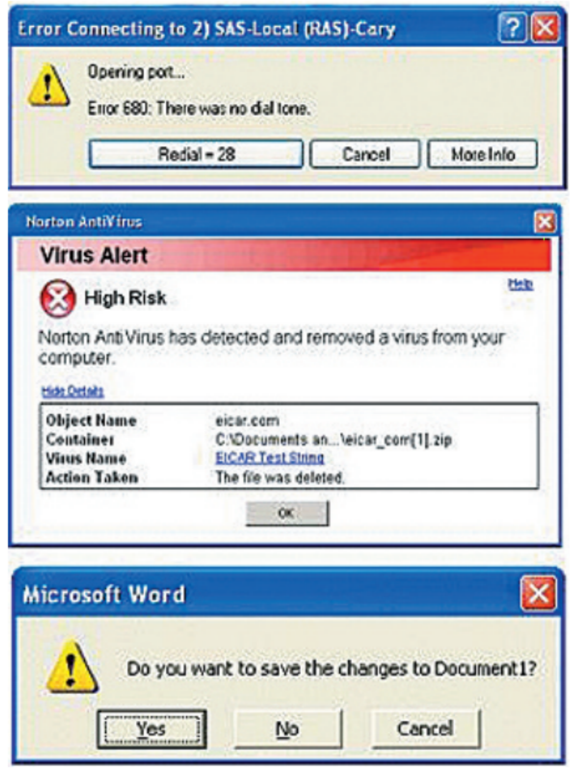

Fig. 2. Security related notifications need to be visibly distinct from other system promts in order to communicate the risk at hand [24].

4.2 The perception of risk

To improve security by HCI, we need to understand how users perceive risk and security. As it turns out, users will take steps towards secure interaction if they understand the costs it asks from them and know about the benefits in return. Importantly, users need to learn the risk of using a certain system as well as possible for it to be accepted. The problem is that users judge risk by affect rather than reasoning about it in a statistical or mathematical fashion [13]. The biggest risk posed at users is aimed at their authentication in a system. Essentially, attackers will try to do this in two ways, by either observing or stealing. Observing can take place by physically observing the users authentication actions, for instance while shoulder surfing, or technically by man in the middle attacks. Stealing authentication information can be done by, again, physically stealing the device or by extracting cached passwords. Since passwords, and especially strong passwords, are not easy to enter on small devices like smartphones, many users allow the device to cache them [13]. If the device is stolen, the passwords are very likely to be, too.

For instance, passwords that are required to be of a certain pattern, can make a system unusable if too complex. The bottom line is, that users need to understand risk and shall not have a hard time in the authentication process. But there are some psychological fallacies that make this harder than one might think. For one, individuals do not think they are at risk, but others are. This is even enhanced by the following pattern: whenever users increase their security measures, they also increase the riskiness of their actions [24]. Additionally, security is an abstract concept, that users do not necessarily understand fully. After all, it has no visible effect and users benefit by not suffering from attacks. Concretely, there are no direct rewards the user would notice

[24]. On the other hand, when a user's system is comrpomised, the user will not notice in most cases, since the consequences are visible after days or weeks. So the feedback for user's actions is delayed, which makes it hard for them to learn [24].

With that in mind, we discuss how HCI can improve authentication, which is a crucial part of system security. And following, we look into various techniques that will help raising awareness of security and privacy for untrained users.

4.3 Authentification in the IoT

Security based interactions need to meet expectations of fast interaction, otherwise they will not be accepted by users. One of the central security barriers is the authentication barrier. It protects the parts of the system that should be visible only to a specific user or user group and stop unwarrented users to access these parts. This barrier will inherently require the user to take a specific action, like typing in a password, that costs some load [9]. In the case of passwords that load is to memorize multiple password for different applications and entering them correctly, which can be cumbersome on small devices. Another common authentication scheme in the IoT is to authenticate with a hardware token [6]. This token can be an RFID chip that the user keeps with him and will use to authenticate with a device he intends to use. Such tokens can be lost or stolen and will need to be revoked [6].

In recent years, biometrics proved to be a promising way to authenticate users reliably. Instead of depending on the user's knowledge or the possesion of some token, human physiological or behavioural characteristics are used to prove one's identify. Uniquely, it not only authenticates users, but even more strongly identifies them as human [16]. This makes it harder for attackers to breach the authentication machanism. Furthermore, one cannot change his fingerprint or pass it to another person, like he could with credentials or tokens. Attackers can not steal biometric features, like they could with passwords [16]. But most importantly in the context of the IoT is that they cannot be forgotten by users and are easier for users to input into a system as opposed to typing in a passphrase.

There are a few disadvanteges to this approach, but the most relevant to our discussion are the following: there are possible performance issues, which is ever more so relevant in the low resource world of IoT. Another known weakness is the false acceptance rate, which is largely dependent on what characteristics are actually measured and what the accuracy of the device sensoring them is. And finally, while biometric features are unique and cannot be stolen, system can be tricked in feeding them data looking like freshly sensed biometric data [16].

As an example of an biometric authentication process, that is applicable in the IoT, we look at Heart-to-Heart (H2H) here and see if the disadvantages can be migitated to an acceptable degree [19]. Contained on Implantable Medical Devices (IMD) is medical data about patients that, if read by doctors in an emergency, can save lives. So this data has to be accessible quickly without a complicated, easy failing authentication process, but on the other hand shall not be easily accessible to attackers. To achieve this, a medical instrument acting as a special reader is placed on the skin of the patient and then can gain access to the data. For the authentication the IMD will read the patient's electrocardiogram (ECG) as does the reader. The reader then sends its measurement to the IMD and if they are equal or within an acceptance range, the reader will be provided access [19]. The IMD does not have to be a pacemaker, since the ECG can be measured elsewhere in the body. Also, due to the restriction of the reader to touch the skin in a significant way, this approach makes sure that the patient trusts and agrees with the access to his data since he needs to allow skin contact, which means his privacy is secured. With respect to the disadvantages, we see that this specifically designed device pair devides the work load and relies on a biometric feature specific enough and easy measurable enough. The false acceptance rate is migitaed by allowing a reasonable range for the measurement. And attacks that try to fake data will fail because the IMD is to be trusted, since it is an implant that was put into the user's body during surgery. And the reader can only authenticate by sending a correct measurement and has to be trusted by the patient before he can contact their skin.

4.4 Raising privacy awareness

Now that the user is logged in safely, he needs to be able to perform tasks securely. Of course, this depends largely on the system he operates and its crypto mechanisms, but there are still some open questions that need to be dealt with. For example, users must have as much freedom as possible, but how should a system communicate that the task the user is about to perform might lead to the system being compromised?

With a short discussion on how users perceive risk and security, we take a look at how to raise awareness of their own privacy when using devices. The most obvious strategy is to educate and train user in security behavior. In fact, it is necessary for users to understand the key concepts of security as a starting point [15]. But clearly, there is a lot more that can be done.

As touched upon earlier, security behaviour can be supported by motivating users to take respective actions [24]. This motivation can be enforced by rewarding users for their behavior. Such reward can be granted by positively visualizing a secturity system running and working. In a desktop setup, this would usually be done by issuing notifications of the detection and removal of malicious software. Such notifications need to be clearly distinguished from other system alert and notifications by the use of color or icons [24] (see figure 2). In the context of "things", we need to take a different approach, since we do not have large screens at our disposal and users might not look at them very often. On Android devices for example, users have to confirm various permissions for an app in order to be installed. Google's Play Store groups the permissions in three groups according to their riskiness as normal, dangerous or signature permissions. Normal permissions, like reading data on the phone, can interfere with the user's intended use, but ultimately are not security leaks. Dangerous permissions, like using network access, might be used for malicious purposes. The last group are not accessible for reuglar apps. Upon installation, the user will be presented a screen that shows only the dangerous permissions, while normal ones can be seen only in an advanced view. This dialog filters out unimportant information and emphasizes potential threats towards the user's privacy [7].

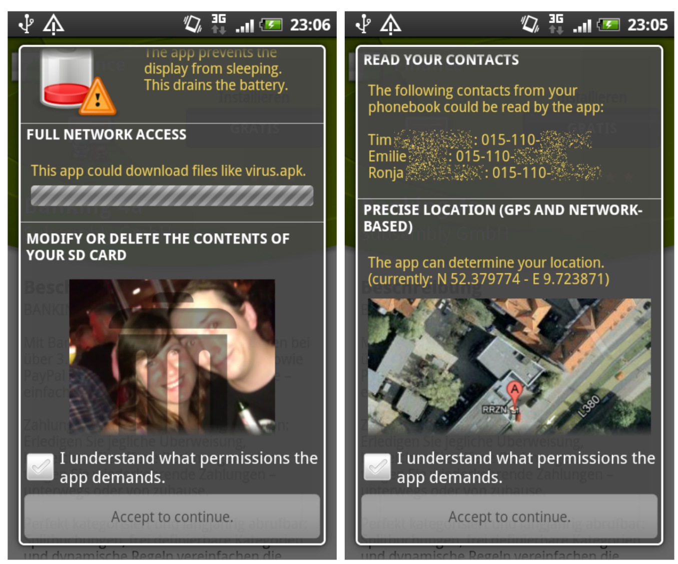

Fig. 3. The risk of granting certain permissions is visualized by showing example threats [8].

However, the prompt appears after the user already pressed the installation button. At this point, the user already made a decision and is unlikely to reconsider by merely looking at the permission screen. Also, users will rarely check back on what permissions which apps are

Vulnerability	Countermeasures: Technical (Hardware and software)	Countermeasures: Human computer interaction
Device	PUFs	X
Cryptanalysis (Eavesdropping, MITM)	Cryptosystems, secure frameworks	X
Privacy	Framework	Education, privacy awareness
Authentication	Secure auth scheme	Biometrics

Fig. 4. This matrix summarizes the issues and their solutions. The left column lists the issues while the middle and right column show technical and HCI solutions, respectively.

granted and uninstall afterwards, so we can assume that once a malicious app was installed the system is compromised [7]. Furthermore, many of the permission descriptions are abstract and users might not take into account all the concrete implications of a given permission [7]. As suggested in a study by Hettig et al. [8], visualizing example threats for a given app will make users reconsider the installation (see figure 3). For instance, if an app asks for the permission to access the contact data saved on the phone, the visualization will show some of the contact data and communicate with a prompt, that the app will be able to use this information. If the app asks for access to the user's pictures, the visualization will show a random picture from the phone and again prompt that the app will be able to use this image. Participants in this study showed to be more reluctant to install an app using this method as opposed to the traditional method [24]. In a nutshell, the visualization successfully raised the user's awareness towards security.

Concluding this section, we want to look at an conceptual approach to privacy. Translucent security focuses on threat assesment and assumes that user do not enjoy dealing with security systems at all. On these assumptions, it formulates five guidelines in order to combine security with usability. Of these five, we want to discuss the first two, since they precisely address the discussion here. First, the system defaults are as restrictive as possible and are subsequently lossened up where feasible. Second, the system should allow to change the security properties in a simple manner, but will inform the user about the risks and threats that will rise because of that. This way, the user has all the freedom he desires and is aware of the security and privacy status of the system. With a strong emphasis on integrating users in the design loop as early as possible, while still allowing freedom of action whenever desired, this concept combines secure system design with usability [5].

5 Discussion

With the great variety of tools presented here, we can now discuss how to reach a Internet of Things in which users can enjoy the benefits without having to worry about their security, privacy and safety. Figure 4 shows a matrix of which problem can be solved by technical means and which ones by HCI.

First of all, it should be clear that the devices can no longer be produced with security weak hardware components. With the help of Physical Unclonable Functions, the "things" will be secure against attacks on their confidentiality and integrity on the level of hardware. On a software level, ideally we would agree on a cryptosystem as a standard shared and implemented by every manufacturer of "things". But this seems not as easy and the reasons are multilayered. The number of devices is in the order of billions, which are inherently heterogenous in terms of operating systems, energy sources, size, functionality and employed protocols. Furthermore, they are produced by a great number of manufacturers and controlled by them and the individual users [14]. This certainly has implications for any discussion about a cryptosystem standard. At the core of every cryptosystem is a encryption algorithm. As lightweight as it might be, there are still some prerequisites for the system running it. Before we can agree upon one, we need to know what the lower bound for hardware capacities are, especially those of the CPU and memory.

On the next layer, we want to be able to transmit the data captured on the devices, preferably over network, to be stored on a server and be accessible to user in a human readalbe fashion. In order to make sure that the data, even if encrypted, is not tampered with when transmitted, it must be send over a secure connection. TLS/SSL are providing just that, although it is currently believed that it will not scale to the IoT, since it is computational intense due to the establishing of a connection which includes exchanging a key for the underlying encryption [18]. However, we can see a few strategies to migitate that problem. One would be buffer data until a certain threshold is exceeded and finally flush the buffer and send the collected data at once. Depending on the size of the memory, with this strategy devices will have to connect only a handful of times a day. In some uses cases, this might not be desired however, because the data is expected to be send instantaneously.

Ideally, an institution like the National Institute of Standards and Technology (NIST) would publish a standard that the industry implements. To enforce the standard, especially in health applications, a subnetwork of devices can be analysed beforehand by using a model as descirbed by Stepanova et al. [21] to check if the prerequisites are fullfilled by all the participating entities. If no such standard is defined from outside the industry, then it could still emerge from inside the industry. Once a powerful enough company pushes a product into the market, they can set a standard in terms of hardware and software and enforce it by its popularity. One example that might just do that is Google's Project Brillo and Weave.[1][2] Brillo is an operationg system designed for IoT devices and based on Android, allowing for

[1]Monica Alleven. With Brillo and Weave, Google introduces yet another fragment to the Internet of Things. http://www.fiercewireless.com/tech/story/brillo-and-weave-google-introduces-yet-another-fragment-internet-things/2015-06-01 (accessed on 21 June 2015)

[2]Project Brillo. https://developers.google.com/brillo/ (accessed on 21 June 2015)

hardware with minimum capacities and scaling up almost arbitrarily. While it is designed to support weak hardware, there will be a lower bound still, which defines a solution to the aforementioned problem. Weave is the protocol that devices are able to communicate with, may it be with other devices, a smartphone or the cloud. This communication layer will guarantee compatibility among all devices. This also has the potential to define a crypto mechanisms sufficiently secure to protect confidentiality and integrity. While it's still too early to tell, Google certainly has the power to enforce it as a standard, but it also depends on whether the industry will accept it as such.

Once the data is stored on a remote system or server, we have to be concerned with the privacy of that data. The user must be in charge of it and must be able to decide who can see what part of. In the light of interconnectivity, this becomes especially crucial. It's likely that other devices may want to access this data and it will be processed for the usage of other people. For example, a fridge might report the contents daily to the company's servers, as well as energy consumption statistics. On the way home from work, the car will remind the user to stop at a supermarket to pick up groceries. While the car's manufacturer can request that data, the energy provider shall not be able to do so, but should be able to see the energy consumption reports. As discussed above, there are many privacy frameworks of which one is described here and if implemented correctly, they will provide users with the appropriate privacy. Let us not forget that this issue is not to be underestimated, since the data is sensitive and user cannot effort to be comrpomised in such a way. A great paradigm for the health domain would be the principle of least privilege. Meaning each entity in a system is granted the smallest set of privileges and rights to complete its task [17]. Not only, will it protect the data from security attacks, but also from accidentally granted access rights to sensitive data. An example from the is the glucose level in a user's blood: While the family doctor should be able to request information about it, the user's dentist does not need to know about it and should have no access to it.

Once these measures are taken and the system is up and running securely, users then need to be able to draw use of the data collected about them and their environment. As discussed above, the main issue here is the trade-off between usability and security. Truely secure user interfaces are hard to use for many users due to their technical-centred nature. On the other hand, perfectly usable interfaces might not secure, since security was not a main focus in the design process. Notice however that this trade-off collapses at one end: If a user interface is not usable at all, because user will not understand it, it cannot be considered secure as well. As a consequence, manufacturers utilize user interfaces that are usable but not necessarily secure against some attacks. But there is a lot of potential for improvement: system designers need to take a user centered approach. Ideally, with as few steps as needed to keep the motivation high and not to subvert the system in any way.

The authentication in the context of IoT involves three options: using a secret, like passwords and keys, a token or biometric features. Above we discussed why the standard password authentication is not sufficient anymore in the IoT, namely because of display and interaction restrictions. One way to bridge this problem however is to use the user's omnipresent smartphone as a means to enter credentials. Another approach would be to use RFIDs or electronic passports as authentication tokens [18]. Biometrics have the advantage of being easy to understand and therefore have potentially better usability as opposed to traditional authentication [18][16]. However, there are a number of disadvantages to this approach. To tackle these, technologies like H2H developed a process that migitates them. Similary, other biometric authentication surely can be extended to overcome these limitations. For example, IoT devices could read a feature and use a backend or service to do the matching. A notification could be send to the user's smartphone app asking for confirmation and making the authentication a two step approach. It is very important with this approach to have a secure channel when transmitting to the backend, since it is not acceptable for fingerprint data to be compromised, because a fingerprint can not be replaced like a regular token can. Furthermore, both token and biometric based authentication can be enhanced by combining them with password credentials. These are commonly refered to as "what I have & what I know" and "what I am & what I know", respectively [18].

Finally we discussed privacy concerns and presented solutions from the technical point of view and showed how users can subtley informed about these issues. Nonetheless, systems should set security and privacy defaults for user that are as restrictive as possible at first. After users learn and are educated towards a profound understanding of their privacy, they will learn how to change settings to be less restrictive. But since they understand the risk they can take over responsibility and there is no reason why they should not be in charge at this point.

From a HCI point of view, this concern can be tackled by raising privacy awareness with the use of visualizations. Potential threats as well as positive feedback about the system status should be promted to users in a way that makes them easily identifiable as such. Along with occasional explanatory messages, this can help users to learn about privacy and gives them a sense of understanding. This way, it will become a more concrete measurement and get controllable for users, ultimately empowering them.

6 Conclusion

In this paper, we pointed out security and privacy issues in the context of the IoT and discussed solutions from a technical point of view as well as from the perspective of HCI. It is critical to implement these solutions as soon as possible, because the growing importance these devices play makes their vulnerabilites that much more threatening not only to the security and privacy, but also to the users' safety. From a technical standpoint, a hardware standard needs to emerge and exisiting protocols like TLS need to be adopted by all parts involved. Furthermore, privacy needs to be transparent to the users and controllable in a easy fashion.

The vision of the Internet of Things is to support users in many different areas of everyday life. In order to make this vision beneficial for the users and the industry, we need to tackle the issues as soon as possible. In the end, we might trust our fridge after all.

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Health and Everyday Life: The Potential of Self-Monitoring in Managing the Own Health

Anna Rieder

Abstract— This paper aims to give direction on how self-monitoring in everyday life can support the user's health. In a first step I will describe current approaches which make use of self-monitoring and the interdependency of health and everyday life. Those approaches include motivating a behavioural change, integrating health routines in everyday life and providing the patient's real-life data to health professionals. In a second step I will discuss the question if those approaches are empowering users in managing their health. The overall result is that the potential of self-monitoring doesn't lie in quantifying the isolated body. The true potential lies in in the user building knowledge and self-awareness out of his interactions with the environment and the effects on his health.

Index Terms—Self-Monitoring, Personal Informatics, Everyday Life, mHealth, Behavioural Change, Self-Regulation, Health-Management, Patient-Compliance

1 Introduction

Changes in society create new challenges for the health sector. Those changes include an ageing population [1], an increasing number of people suffering from chronic diseases [2], a shortage of medical service in remote and rural areas [3] and more and more people having to help themselves as they don't live together with family members [4]. How can ubiquitous sensing systems and mobile networks provide a base for new applications to meet these challenges?

Health is shaped and influenced by our environment and our everyday life's routines and approaches [5] and the other way around health is affecting our everyday life. To deal with handicaps, to improve the medical conditions, infirmity, diseases or the lack of well-being, people seek for help. They consult medical experts, they undergo therapy, change their lifestyle or use special assistance. Examples for measures are medication taking, doing sport, doing medical check-ups, meditating or being on a special diet. Those health routines are part of everyday life.

Modern technology can support health measures. On the one hand they support ill people in their everyday lives, on the other hand they help health professionals to diagnose the right disease or to set up and monitor the individual therapy. For a long time high technology in the health sector remained reserved to professionals. However in the last years smart devices, such as mobile phones, became more and more technically mature. Monitoring functions, ubiquitous sensing and computing, visual, auditive and tactile feedback, sensors, voice or gesture recognition are now accessible to a broad audience. The devices are smart, mobile, connected to the internet and affordable. Data about the user's behaviour, location, body functions or social interaction can be collected, can be put into context and can also be transferred to others. Those features can be accessed by simply using a mobile phone, a wearable or ambient device.

This explosive availability of user related data opens up new prospects in healthcare and gives a different perspective on the patient's role. Currently the patient plays a passive role in the own healthcare. Self-determination over the own body is handed over to health professionals in order to give them the scope to improve the health condition. Monitoring vital functions, giving injections, taking blood samples, discussing a diagnose, prescribing and performing therapy, those and other measures on the patients body are in the authority of health professionals.

The aim of this paper is to investigate the potential of ubiquitous sensing to promote health and to discuss if these new possibilities are empowering the user to have a self-determined role in managing the own health. This paper presents an overview of different approaches to motivate and support users to live a healthy life and illustrates current trends and concepts in the health sector using the increasing amount of data related to the user's daily routines.

2 Health & Wellbeing Technology in daily life

Health and everyday life are interdependent. Everyday behaviour has an impact on health, which is highlighted by the 2012 figures of the WHO on the death causes worldwide. 52 percent of all deaths resulted from non-transmissible diseases (NCDs) such as cancer, cardiovascular or respiratory diseases and diabetes *(see figure 1)* [6]. The World-Health-Organisation names the four main risk factors for these diseases, which are smoking, abusive consumption of alcohol, physical inactivity and an unhealthy diet [7]. Those risk factors are behavioural, they depend on the everyday routines and behaviour. This figure is an indication that a sustainable change of unhealthy habits is a key to prevent and manage diseases.

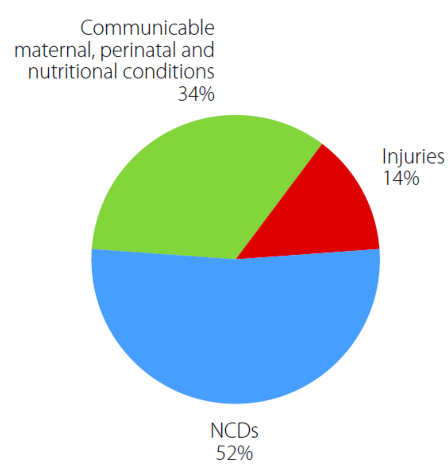

Fig. 1. "Proportion of global deaths under the age of 70 years, by cause of death, comparable estimates, 2012" [6].

- *Anna Rieder is studying Media Informatics at the University of Munich, Germany, E-mail: anna.rieder@campus.lmu.de*
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However taking care of the own body and managing health is part of everyday life and as everyday life can be complex, chaotic or stressful, health routines might fall on the wayside. Research shows that up to 50 percent of all patients do not regularly take their prescribed medication, which is putting their therapy at risk [8][9][10]. In physiotherapy, where patients often have to follow a training regime at home, similar proportions of patients seem to be non-compliant [11]. Irregular use of oral contraceptive pills is estimated to be the reason for approximately 20 percent of the annual unintended pregnancies in the United States [12]. These examples show that there are problems to integrate healthcare measures in people's daily life.

Modern technology is hoped to meet this discrepancy of integrating health and everyday life. As functions and capabilities of mobile devices are getting more and more powerful and users increasingly share and collect personal data, this personal data allows to draw conclusions about the user's behaviour and daily life. Users track their condition by while doing sport [13] or sleeping [14], they publish their current location on Facebook [15] and share private pictures over the internet [16]. This information about the user's everyday life reflects aspects of daily routines which are, as previously shown, closely interconnected to the own health.

When we look at the interdependency of health and everyday life as illustrated in *figure 2* two starting points for health and well-being technology can be derived: Promotion of a behavioural change and support of a smooth incorporation of health measures and daily life. Examples in the following sections will illustrate current trends in HCI which focus on these two concepts.

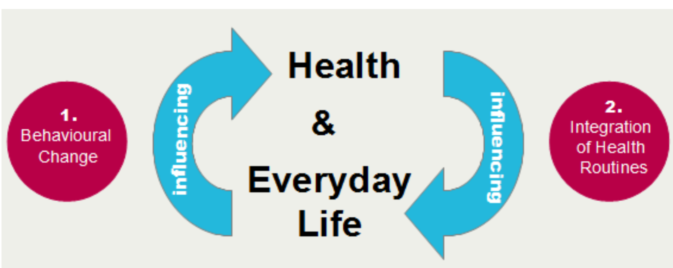

Fig. 2. Health and everyday life are interdependent. HCI Applications using personal information gained by pervasive sensing have two starting points to improve the user's health: motivating a healthy behaviour and incorporating health routines in daily life. (Source: Illustration by the author)

2.1 Behavioural change

In 2014 Apple announced its new health hub to be included in iOS 8. This hub brings together the health related information logged and used by health applications installed on the phone. The interface shows how qualities like weight or heart rate are developing over time [17]. Other applications share this approach of measuring health related data and presenting it to the user. There are applications tracking the user's behaviour from different domains like nutrition and weight [18], sleep [14] or fitness [13]. Wearable devices are supporting the collection of behaviour related data by being seaming-less integrated in the user's everyday life. They are sensing, sending, receiving, computing or visualising information without having the user to interrupt his activities. A basic concept of the applications described before is to collect user related data, such as the heart rate, the distance walked a day or the number of phone calls, and present this information to the user. How can this approach motivate the user to engage in a healthy lifestyle?

Mobile devices and pervasive systems allow the logging of the user's past either automatically or by journalling. This data can act as reference for providing real-time feedback to the user which allows the evaluation of the current state. Real-time data can be compared to past states, to trends and to goals. Self-reflection is enhancing awareness of current routines [19] and this insight can help to change behaviour [20][21]. According to Bandura human behaviour is motivated by self-regulation which comes in three subfunctions: self-monitoring, judging the behaviour in relation with own standards, which are partly derived from the reaction of the environment, and affective self-reaction [21].

Personal informatics systems help users to collect huge amounts of data and to interpret the data to see pattern and trends in their behaviour and current state. Li et al. defined this approach of using computing technology for collecting personal data and reflecting on it "personal informatics" [22]. An example for pattern recognition is the visualisation of telephone bills that are monthly increasing. The visualisation gives the user the chance to gain insight and to change the phoning habits or look for a new provider. In the domain of health there are various apps from regulating emotions [23][24][25] to monitoring physical condition and activity [26] [27] *(see figure 3)*.

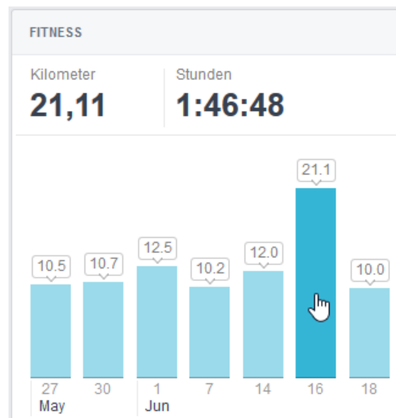

Fig. 3. Recognising pattern: This graphic visualises the user's past behaviour. It is a screen of a fitness application [13] where the user gets an overview about past performance. Recognising patterns in the performance enables reflection on behaviour. (Source: Screenshot by the author)

Isaacs et. al. tested if technology mediated reflection can have a positive effect on the emotional state. They built an Android application for capturing events and reflecting on them later. The user writes a note and optionally adds further media to capture an event and rates the own happiness on a scale from 1 to 9. Every day the application automatically shows three randomly selected memory notes and asks the user to reflect and re-rate them. When compared to a control group, whose member also saw the notes but couldn't re-rate them, they found that participants conveyed deeper emotions in their reflections and they used the application to see positive aspects of initially negative events. The participants improved their well-being by putting the past feelings into perspective, by understanding why they feel, what they feel and by seeing patterns in their emotional experiences [28].

The Quantified Self Community applies the concept of personal informatics by following the motto of gaining self-knowledge by numbers. This online community with about 50.000 registered members worldwide [29] promotes self-tracking of the body and of personal behaviour. One basic idea is to regulate behaviour on the base of this rational information. Unwanted behaviour such as not drinking enough water can be recognised and therefore be changed. Reflecting on collected personal data is a base to set and pursue goals. An example is the Accupedo application. When using the application the user sets a goal how many steps he wants to walk a day [30]. By tracking his activity the user sees the progress overtime which can motivate him to further pursue his goal *(see figure 4)*.

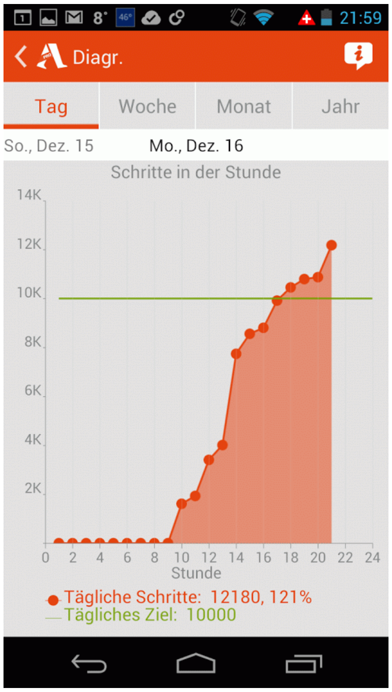

Fig. 4. Setting goals: The user set the goal of 1000 steps to walk a day. The diagram visualises his progress related to his goal, which is visualized by the green line. (Source: Screenshot of the Accupedo App)

Integrating a social dimension can be further motivating to engage in health promoting routines. Activity trackers often are linked to social networks where users can present their performance to an audience [13]. Getting positive feedback of friends can reinforce the user in his activities *(see figure 5)*.

Suh. et. al. show an interesting approach how the social dimension can be used to monitor the development of babies. This is needed to early detect developmental delays. In their work they developed an interactive system where parents logged their babie's accomplished milestones. Twitter messages were regularly sent to remind parents to check if their babies already can fulfil certain tasks. The twitter message included a milestone id, for example: "Does your baby flip light switches off and on? #baby2621". The parents could answer privately or publicly in a certain syntax which the @babysteps system could parse. For example: "#yes #Adam can do a push-up when he's on his tummy! #baby2325" [31]. The parents also had access to a accompanying website, where they saw an overview of already sent responses to developmental goals which gave them an overview about the progress. Suh et. al. tested their system by conducting a real world study with 14 parents of young children. The overall result of the study was that the participants felt more engaged to check if their kids fulfilled the goals. They liked that they could include the tests in the daily routines, as the already were Twitter user, they liked the overview on the companion website and some enjoyed interaction between participants [31].

2.2 Integration of health routines in daily life

Besides motivating users to engage in a healthy lifestyle another approach is to support users to integrate healthcare routines in their daily lives. In the hospital an ill person is in the role of a patient. While staying there the focus is on recovery. However when back

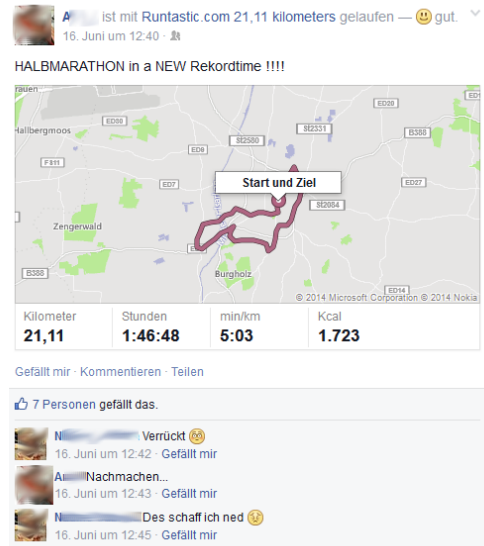

Fig. 5. Maintaining a positive self-image: A user of the activity tracker Runtastic shows his pride about his performance by sharing it on Facebook. Facebook friends backup this emotion by commenting positively about it. (Source: Screenshot by the author, names are anonymised)

home the patient's roles are much more diverse. The person might identify as a mother, a carpenter, a pupil or a businessman rather than as a patient. Healthcare routines now have to compete with everyday life activities like driving a car or sharing a funny story with friends. In this section approaches will be presented how healthcare routines can be integrated smoothly into daily life and how health professionals can support patients at home by using logged information about their behaviour.

2.2.1 Routine Assistance

As for medication taking people tend to forget to take their medicine which puts the effectiveness of therapies at risk. Stawarz et. al. evaluated current medication reminder which are available at Google Playstore and found that most just offer a reminding function, similar to an alarm clock, which triggers an alert at a predefined time. They propose that applications should move on from being passive alerts to providing smart routine assistance by considering the habitual nature of medication taking [32].

In an online survey conducted with 971 participants they explored the strategies of women to remember oral contraception. They found that nearly half of the participants forgot to take the pill at least once a month, 75% of them reported about taking it too late. The main reason for forgetting were changes in daily routines or being busy and distracted. Women who included the medication taking in their daily routines were less likely to forget the pill. The researchers propose that applications should consider the individual routine to make the task of taking medication a habit [32].

They proposed following design requirements to combine medication taking with existing routines:

- The user should be asked to specify or select a routine which is suited to trigger medication taking [32]. Examples are eating breakfast or going to work by car.
- A backup notification reminds the user to take the medication if routines changed. When forgetting to take the medication too often, the application asks the user to select another routine to combine with the task of medication taking [32].

- As there is the danger that users forget if they have already taken the medication, a post-completion backup should be provided for the user to check former intakes [32]. This is needed as the nature of routines is regular repetition of similar events which makes them difficult to distinguish and remember.

Lee et. al. take a similar approach. They also follow the strategy of encouraging the user to include medication-taking in a daily routine and they also see simple medication taking reminders as a disruption of current routines. In contrast to the application which reminds the user before medication taking, they introduce a ambient device which gives near real-time feedback after the task. The real-time feedback should support the user to develop own routines through self-regulation. A pillbox was augmented with sensors to track if the medication has been taken and if it has been taken on time *(see figure 6)*. On a tablet pc realtime-feedback was displayed if the current medication and the medication before had already been taken *(see figure 7)*. In a 10 month study with 12 participants they evaluated if the medication-taking behaviour improved when getting real-time feedback via the tablet pc. They found that correctness, promptness and time of day variance improved significantly, adherence also increase but without statistical significance. After the first six months the feedback display was removed while the medication-taking was continued to be tracked by the pill-box. The result was that the performance of the medication dropped back again. The researchers explanation was that the established routines of medication-taking didn't remain because the looking for feedback on the tablet was part of the routine [33].

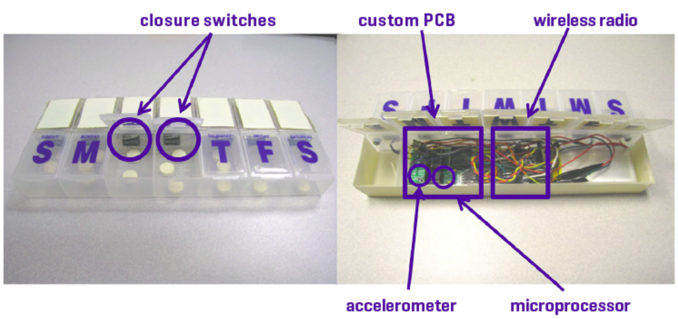

Fig. 6. Tracking human behaviour: A sensor equipped pillbox tracks medication taking [33].

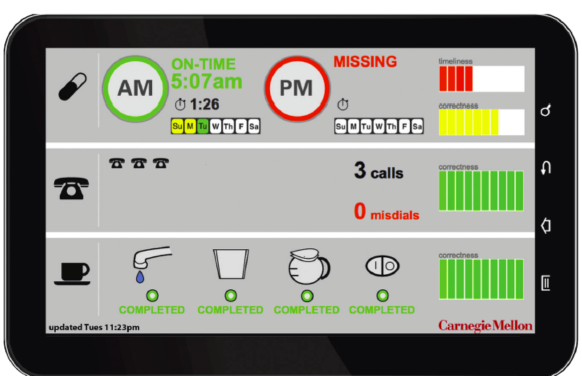

Fig. 7. Giving real-time feedback to support establishing routines: Users can see on an ambient device if they have already taken their medication [33].

Huang et. al. introduced another approach how tracking can support users to establish healthy routines. Other than in Lee et. al. technology is moderating the user's routines without having him to consciously change his actions. In their system EZWakeup items of everyday life are equipped with technology to smoothly wake the user up. Those items adapt to the user's tracked sleeping behaviour. A bed sheet equipped with more than 8000 piezo sensors senses the sleepers body parts, the body movement, respiration signals and sleeping postures. This information is analysed to evaluate if the sleeper is in REM, shallow or deep sleep. When the set wakeup time comes close, external stimuli adapt their frequency and strength to the current sleeping state to guide the sleepers through different sleeping stages and smoothly wake him up. External stimuli included audio and vibration emitted from a smartphone and light emitted from a torchiere. When the sleeper is in deep sleep stage the system emitters repeated gentle but high frequency stimuli, when the sleeper was in REM the system emitted gentle stimuli with constant low frequency signals and finally, when the sleeper was guided smoothly into light sleep he was woken up by repeated high frequency and large strength signals. Six volunteers participated in a pilot study where all of them used the system for three non-consecutive nights. Five participants reported that the system affected their sleep stages and improved the sleep quality. One participant didn't recognise an effect of smoothly waking up, however the logged data showed that she didn't fall into deep sleep or REM during these nights at all, which explains the missing effect [14].

2.2.2 Gamification

Another approach is enhancing the user experience by making tasks and routines more enjoyable. Gamification follows the strategy of integrating elements of video games in non-game environments, like health routines or doing sports [34]. Examples of game mechanics are ownership, achievements, quests, status and community collaboration [35].

Shao et. al. showed how logged data can be used to motivate children to brush their teeth properly. They addressed the problem that most children in China receive minimal information about dental hygiene and see tooth brushing as an annoying procedure. They included tooth brushing in a game by using data logged by the toothbrush and a smartphone. The toothbrush recognises the brushing duration and frequency as well as if all tooth-brushing regions have been treated yet. To identify the regions and patterns the toothbrush is equipped with with three-axis accelerometers and magnetic sensors. A red light sensor supports detection of early onsets of caries due to the effect that bacteria causing caries has an fluorescence effect in red light. When activities of the toothbrush are detected, the game starts and the game's interface appears on a mirror display. In the game the child can destroy monsters by brushing certain regions of his teeth. The monster have different colors that reflect the different regions of the denture (inner, outer and chewing surface). Predefined movement of the toothbrush "destroys the monsters". The researchers tested the concept on low-fidelity prototypes with 16 children, where 15 of them indicated enjoying tooth brushing more when playing the game [36].

2.2.3 Telemedicine

Monitoring the user's behaviour or body functions in his daily life opens up new possibilities in health care when providing this data to health professionals [37][38]. Traditionally medical check-up or therapy sessions are mainly conducted in a practice, laboratory or hospital. However with an ageing population [1], a shortage of medical service in remote and rural areas [3] and more and more people having to help themselves as they don't live together with family members [4] solutions are needed to meet these challenges. Monitoring can support health professionals to remotely treat patients. An example is the pilot project Herz-Mobil in Tirol, Austria. Von der Heidt et. al. introduced this disease management program where patients are supported in self-managing their health after their stay in the hospital recovering from heart failure. The patients measure blood pressure, heart rate, weight, well-being, and medication-taking at home daily and send this information via a mobile phone to a central health data center. This information is reviewed at least once a week by a physician. If there are abnormalities in the data set, the system automatically detects them and immediately notifies the health professionals. They can react accordingly by informing the patient how to change the current therapy [37].

Furthermore with an increasing number of people suffering from chronic diseases [2], self-tracking and ubiquitous sensing systems can expand the catalogue of existing monitoring practices, such as conducting a long-term ECG. Patients monitoring their behaviour in daily life can give healthcare professionals a broader view on the patient. By sensing everyday tasks medical check-ups can be incorporated in familiar routines or a familiar environment. Health professionals can use the real-life data to evaluate the patient's health status. An example is the system introduced by Chen et. al. which uses a spoon to detect nervous system diseases. In this approach a spoon and a wristband are equipped with a three-axis accelerometer and a three-axis gyroscope. The spoon also is equipped with a capacity sensor. Chen et. al. conducted a study with 300 participants, where 15 of them had a history of nervous system diseases leading to tremors. In the study each of the participants was instructed to pick up the spoon with the dominant hand, pick up a ball with the spoon, move the spoon to a bowl and drop the ball in the bowl. The evaluation of the sensor's data showed that the patterns of the signals of the accelerometer and the gyroscope where relatively similar between participants with and without nervous system diseases. But the patterns of the capacity sensors differed between those groups: the shaking of the patients' hands can be seen in the recordings [38].

Data gained by ubiquitous sensing can also be used to control if users perform therapy properly. The work presented by David Muoz et. al. shows an approach how physical therapy can be enhanced by providing data of everyday life to the therapist. Between therapy sessions patients usually should perform exercises at home. However physical therapists have no reliable way of knowing if the patients do their exercises and if they are doing them right. The researchers introduced a wearable device which logs knee movement during rehabilitation. The wearable knee brace with embedded sensors registers knee movement. This information can be provided to the physical therapists for evaluation of the rehabilitation process and for giving feedback to the patient [39].

3 Discussion

In the previous sections trends were illustrated how personal data representing aspects of the user's daily life can be used to promote health. We found that self-monitoring can raise the user's self-awareness and self-regulation by showing patterns in behaviour or emotions which can support the user to adapt his behaviour. The user can be also supported in integrating health routines with monitored existing routines or by augmenting health routines to make them more enjoyable. Furthermore health professionals can gain new methods and a broader view on the patient by getting "real life data" of the patient's daily life.

Besides illustrating how self-monitoring can have a positive effect on the user's health, we want to answer the question, if self-monitoring is changing the patient's role in healthcare. Is self-monitoring and ubiquitous sensing empowering the patient to have a more self-determinant in managing the own health? To answer this questions let us have a closer look at the Quantified Self movement. An evaluation of video posts of quantified selfers showed that self-monitoring helped them in caring for their health. Choe et. al. analysed posts of 52 extreme users of self-tracking in order to understand their practices in collecting and exploring personal data. 67 percent of them tracked one or more health related qualities in order to improve aspects of health. In doing so they set specific health-related goals, for example "finding triggers for an allergy, finding out how exercise affects body mass and weight, finding the right drug dosage, or executing a treatment plan for treating panic attacks". The quantified selfers had to overcome pitfalls such as tracking too many things, not tracking triggers together with context or lacking scientific rigor. By visualizing and interpreting their data they could create meaning of their behaviour and establish healthy habits or identify triggers of symptoms. The participants also reported they were more aware of themselves and the surrounding environment [40].

In contrast to a typical clinical setting the participants had full control of what to monitor but also no professional support in how and which conclusions to derive. The participants identified triggers or unhealthy habits independently. They monitored their body and their behaviour themselves and recognised patterns on their own. While it is reasonable to criticize that these finding are based on the experiences of a small group of self-tracking-experts and that scientific or medical expertise was missing one can clearly see that those participants pursued their health related goals self-determined and self-monitoring provided the base to do so.

Self-monitoring can also empower patients by giving them a sense of control of their body and by supporting a positive patient health professional relationship. Patel et. al. found that real-time tracking can support cancer patients during therapy by giving them the base to better communicate with health professionals. Cancer patients suffer from a variety of symptoms while undergoing therapy. However they often have problems to clearly communicate those symptoms to health professionals as they manage them at home in-between exhausting therapy units such as radiation or surgery. Chemotherapy makes it even more difficult for cancer patients to recall past symptoms. Tracking those symptoms in real-time, at the moment when the symptom is experienced, helps patients to better communicate with the health professionals. Seeing progress in the own therapy, with its ups and downs can give psychosocial comfort. A properly designed tool, which is giving patients ownership over the tracked data "could help patients to better manage their treatment, communicate with their providers, and maintain control over their care and their lives" [41].

Sharing tracked data with others can be further empowering for patients. Comparing the own health related data with the information of other patients in similar health conditions gives patients a reference when the want to adapt their treatment. It also allows them to actively engage in citizens' science projects which aim to find a cure for the own disease. On the platform patientslikeme.com patients share their conditions and tracked medical history. On one hand this data can help them to find patients with similar conditions which allows them to compare experiences and symptoms. On the other hand this data also helps to understand side effects and correlations of treatments. This gives patients the scope to change their treatment or physicians [42]. Furthermore patients can actively participate in finding the right medical treatment of their condition as their shared data of treatment histories and evaluations on medical products "may aid in evaluating the effectiveness and safety of some treatments more efficiently and over a longer period of time course than is feasible through traditional trials" [43].

An pilot project conducted in the city of Louisville is an example of how tracking citizen's everyday behaviour can empower a community to improve the health of their inhabitants. In the project asthma patients were given special inhalers which are connected to their user's smartphone via bluetooth. When the inhaler is used information about the usage, including frequency, time and location, is sent to a central platform. Information of 5,400 usages were collected during the project phase of 13 months. This information gives patients the possibility to find triggers where asthma attacks most likely occur, for example if they see that they always have their attacks when they visit their smoking grandmother. Due to this empowerment it is easier for the patients to manage their asthma. The information also helps physicians to adjust medication. However the interesting benefit becomes apparent when visualising the data on a map of the city and adding further context, such as factories or highly frequented roads *(see figure 8)*. The map visualises the locations where citizens have problems with breathing [44]. This information is a basis for action for the community. Citizens tracking their everyday life's routines can give the community the information needed to deploy interventions and actively change the environment to improve the people's health.

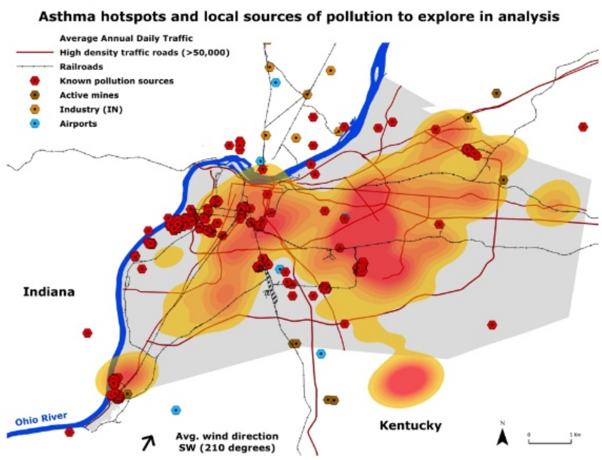

Fig. 8. Visualisation of the patient's usage of inhalers together with further context. (Source: Screenshot by the author of http://de.slideshare.net/HealthDataConsortium/louisville-asthmapolis)

However besides all those potential benefits one must keep in mind that medical information and tracked everyday behaviour is some of the patient's most personal information. By publishing and sharing it with others the patient looses control as distribution to third parties and a misuse can not be ruled out. Data protection is a critical aspect in self-monitoring health conditions as one can be put under pressure or denied access to aspects of life. Examples listed in an article of The Guardian show how medical information was negatively affecting a patient's life because it was shared outside the relationship of confidentiality between them and medical experts. Those examples include a woman who lost her job because of her boss was informed about her mental problems, a man who didn't get a place in a care home, because they found that he was homosexual and about a woman whose uncle found that she had an abortion [45]. Also a study conducted by McNaney et. al. showed that patients are afraid of sharing personal medical information if anonymity is not guaranteed. In their study they interviewed Parkinson's patients in order to collected requirements for an exergame, which is supposed to support patients in training their handicaps. Some participants expressed concrete fears of repression, if their data, collected by the rehabilitation application, was available to governmental agencies. As the impacts of their disease come in on and off phases, they were concerned that they would get denied physical therapy if their condition was seen to progress with the exergame or that they would have to return to work, although they are not healthy [46].

A further example of how patients might feel under pressure or discriminated is a programme of the South African insurance company Discovery. Their programme Vitality aims to motivate their policy holders to engage in healthy lifestyle by getting rewards for healthy habits such as physical activity or stopping smoking. Rewards are for example discounts on certain health related products or a discount on their premium. Part of the programme is to share medical information and tracked data about the exercising habits with the insurer. For example is the insurance company notified when a policy holder enters a fitness studio [47]. On the positive side this example shows how tracking information gives insurer the possibility to motivate their insurees. On the negative side insurees might feel to get restricted in their self-determination and put under pressure to share their personal data. This example it all about finding the right balance between promoting and punishing. If people do have a choice those incentives can be considered as tools and support for the insurees to actively engage in a healthy lifestyle. However if people do not have a choice, for example because of a chronic condition which doesn't allow them to do sports or financial shortage they might feel discriminated by having to pay more for their premium as they don't get a discount. In this case the approach can be seen as a opposition of solidarity, one of the basic principles of insurances. This approach is based on the idea that health can be actively shaped by the patient adapting his behaviour, which brings us to a further critical point.

The train of thought that, if all numbers are available and considered a logical behavioural change can be derived to optimizes a condition, has a negative connotation. In reverse this technical way of thinking could mean that if someone is in a bad condition he might have done something wrong. In the domain of health self-optimization would imply that all diseases could be managed or solved when knowing all the facts. One might be in favour of blaming the individual for making the wrong choices. However in 2011 the UN clearly pointed out that a healthy life is dependent of social, economical and environmental factors. The UN resolution confirms that people living in developing and lower-income countries are affected the hardest by non-communicable diseases. Poverty, lack of education and social determinants such as missing access to healthcare, a unhealthy workplace or missing awareness are closely linked to the risk factors [48]. This shows that the individual context must always be taken into consideration when trying to draw conclusions on health based on behaviour.

In western medicine diseases are seen as treatable disorders of the body. To cure bodies they are objectified. The body and his functions and tissues are measured and examined in order to find the reason why the body is deviant. To manage diseases medical experts shift part of the knowledge, derived from measurement and tests in clinical settings, to patients in order to empower them to manage their disease [49][50]. This approach of quantifying the body implies several problems when managing a disease in real life:

Tracking health related qualities can lead to negative feelings and and fixation on health. Lupon examined why people use tracking software and found that the users preferred to rely on measured data over haptic sensations of the own body. The virtual image of the body the data creates is regarded as scientifically neutral and therefore more meaningful than the own experience of the body. Users don't see that numbers are not neutral and always depend on the context they are put in. This trust in tracked health data instead of on the own sensations can led to negative effects as some quantified selfers reported feelings of anxiety, failure or self-hatred and a too strong focus on health [51]. This obsession with health also comes apparent when looking on the numbers of Choe et. al. In their study 67 percent of the quantified selfers tracked one or more health related qualities, although only 35 percent of the participants had a health condition.

Furthermore tracked biomedical information can be demotivational especially for patients with chronic conditions. Not every disease can be cured and not every health condition can be improved. Some conditions are just getting worse over time. In the previously mentioned study of McNaney et. al. Parkinson's patients mentioned one of the worst restrictions they experience is the feeling of social embarrassment and loss of self-confidence. They don't want to be confronted with the degenerative nature of their disease, which means they don't want to see the tracked decline of their performance. To see this information makes them feel demoralized. To build self-confidence and stay positive the patients wish to get feedback on their achievements, but the software should leave the information out which reveals the degenerative nature of their disease [46].

These examples show that the raw data of bodily functions isn't sufficient to describe and manage diseases. A further perspective is missing, as diseases are not only measured but also experienced. Pain, dizziness, weakness, disorientation, nausea, fear, motivation, those feelings the patient senses himself. The patient is experiencing a disease as part of his everyday life as he is affected in what to eat, how much money he has to spend, when to measure the blood sugar and so on. To truly empower patients to handle their conditions in real life both the objective and the subjective view on the body must be taken into account.

To be aware of the own body is an important factor to successfully manage health in everyday life. This sensitivity towards the own body can be trained with measured data. Mol et. al. examined how type 1 diabetes patients avoid hypoglycaemia, a potentially lethal condition when blood sugar is too low. They found that self-awareness is at least as important as measuring the level of blood sugar for dealing with the condition. Having the sensitivity for the own body and feeling that a hypoglycaemia is coming gives patients the possibility to act, for example to eat an apple to raise blood sugar. This self-awareness is especially important as it gives patients the ability to react when an unexpected hypoglycaemia is coming. With an inner sensitivity they can lead more flexible lives and depart from their routines more often. However not all people are self-aware and not all of them are equally good in sensing the own body. Also the own feeling and the measured value might be in contrast. Mol et. al. propose to integrate the objective and subjective view on the body for example by using measured data to train the inner sensitivity. In this special case a training of self-awareness would be to guess blood sugar before comparing it with the measured index [50].

Also medical experts knowledge alone, represented by a quantified view on the patient's body, falls short to meet the complex demands of living with a chronic diseases. The knowledge patients build by their own by experiencing and managing their health in everyday life must be regarded as equally valid and important in managing diseases. Currently the medical knowledge, based on objectification of the body and testing in clinical settings, is considered as superior. Power and knowledge over the objectified body is transferred to the patients only as far as it is needed to ensure the patient's compliance to the treatment recommended by medical experts. However this approach shows his shortcomings when applied in the patients everyday life. Outside from clinical settings in patient's real life the complexity of parameters is uncontrollable and unpredictable. As Storni puts it, for type 1 diabetes patients "disease is so ubiquitous and ever-present in their lives that it is not simply a disease but rather a complex and difficult-to-manage lifestyle condition" and "what worked today might not work tomorrow, what worked in the hospital might not work at home and what work for the doctor might not work for the patient" [49]. Storni claims that it is important to put the focus on the knowledge which is looking on the effects of actions rather than on the causes of conditions, which means that it "should be about encouraging patients to become inquisitive and enabled to produce the knowledge and actions that are relevant to their perspective in partnership with their medical experts, if possible" [49].

Translated to the domain of self-monitoring this could mean that to truly empower the patient, he should not only focus on the tracked data and he should not consider this information as neutral. Just applying the medical view, because monitoring bodily functions is now available to consumers isn't sufficient to manage health. The user should rely on his inner sensitivity and consider his everyday life to build meaning out of the data. As diseases are more than an error or deviation in the image of a perfectly healthy body, as they are part of everyday life, are effecting everyday life and are brought into being because of everyday life, the approach of just eliminating the one thing in the body which makes it sick or to improve one quality to make him stronger is to short-sighted. As the body isn't just a cluster of cells shielded in a clinical environment the true potential of self-monitoring in the domain of health is to raise awareness for bodily signals and to built knowledge out of the interactions with the surrounding, the social network and the activities. This knowledge supports patients to organise their life around the disease.

4 Conclusion

The World Health Organisation (WHO) defines health as "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity" [52]. This definition can be interpreted in the following way: Health as well-being is part of everyday life and everyday life is part of health. If this interconnection of health and everyday life is recognised, new prospects in health promotion arise. Those approaches can be supported by HCI technology. Recognising the own daily life with its pattern and routines puts someone in the position to adapt his behaviour. On a higher level this means the representation of a group of people's behaviour gives a community the reference to make their environment healthier. Monitoring the own daily life enables patients to self-determined care for their own health and to communicate with health professionals on an equal level. However with all those prospects in mind it must be considered that tracked everyday data is a person's most personal information. One of the future tasks must be to find a solution how these data can be used to promote a healthy life and environment without putting an exposed patient into the public unprotected from potential misuse.

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Reactive Objects

Sebastian Siepe

Abstract— The *Internet of things* era brings up new devices that are created to perform specific and individual tasks. With the creation of those connected devices that feature all kinds of shapes and functionalities, also new ways of interaction, new possibilities to input information and new ways to display this information become possible. Therefore, this paper takes a look at new connected devices, that provide haptic, tangible and physical elements in order to interact and exchange information. Recent research showed, that physical objects enable us to use our well developed sensing and touching capabilities in order to exchange information intuitively. Therefore, physical objects can give us a new dimension of interaction that goes beyond the Graphical User Interfaces (GUIs), which is mainly used in nowadays Human Computer Interaction (HCI). This paper presents different physical devices that can be used to exchange information, by shaping or changing them in physical ways. Furthermore, physical objects will be presented that have the capability to change their shape, form or color autonomously in order to make information visible and understandable. In addition, a glance look will be provided on how these new devices shall be designed in order to be accepted and understood by humans and what kind of impact they can have in our day to day HCI.

Index Terms— Reactive Objects, Tangible User Interfaces, TUIs, haptic feedback, shape changing objects

1 Introduction

In the *Internet of Things* era, we come into contact with new devices that measure and observe their environment constantly. Those devices operated in the past completely on their own, like thermostats, fridges or wearables, but become now part of the internet in order to communicate and exchange information [9]. This connection does not only bring up new devices, but also new ways of communication and interaction. Therefore and due to the *Internet of Things*, devices appear that feature other input and interaction mechanisms then the Graphical User Interfaces (GUIs) that we are already accustomed to. This paper wants to introduce the term *Reactive Object*. This term describes a device that features new ways of interaction that can go beyond GUIs. Therefore, *Reactive Objects* have the capability to 'express', 'display' or receive information in multiple ways. For example by changing their shape, form, color, position, weight or temperature. Some *Reactive Objects* even provide the capability to receive input information when they are touched, transformed or modified. In addition, *Reactive Objects* are often designed to perform one specific task or interaction and are therefore single-purposed.

The key idea behind those *Reactive Objects* is, to give physical form to digital information [5]. With this approach of interaction, we can use our sophisticated skills to sense and manipulate our environment for Human Computer Interaction.

2 Overview

This paper will present a selection of objects that provide the possibility to be altered or to interact with in tangible ways. Therefore, the following sections will enlighten *Reactive Objects* in different example fields of work, were such single-purposed devices appear. The following section presents devices that provide new ways of communication. Therefore, *Reactive Objects* are described that can be manipulated in order to input information into a system, but can also react autonomously at the same time to display data. Both interactive elements are needed in order to establish an interchange of information between remote partners. Further on, the working field of music will be enlightened, where *Reactive Objects* are already established in order to shape and manipulate sound intuitively. The fifth section covers devices that are designed with the purpose to change human behavior or to transmit information to the user intuitively. Hence, these objects are not created in order to shape or manipulate data directly, but to make this data visible and understandable for the user in intuitive ways. Besides the fact that this paper tries to categorize objects into the presented example fields of work, *Reactive Objects* are not limited to these environments. Devices that feature interactive and tangible elements can also be envisioned in completely different surroundings and for other purposes. Nevertheless, the categorization in this paper was made, because the depicted example *Reactive Objects* provide a wide variety of different capabilities and ways of interaction.

In computer science, there has already been research on different types of *Reactive Objects*. One type is often described as *Tangible User Interface* (TUI). TUIs are basically understood as systems, that can be manipulated by humans, whereby the connection between the physical object and the digital information is seen as the key aspect [20]. But TUIs are often multi-purposed and therefore provide the possibility to manipulate or display a wide variety of information. Whereas *Reactive Objects* can be understood as objects that have the capability to change either shape, form, color or it's place autonomously and are clearly single-purposed. Those objects are very effective in getting user's attention in a very intuitive way [17]. Furthermore they are very effective in expressing and transmitting information. As already shown by Gomes et al. [2], objects that can change in shape have the capability to transmit little messages or notifications in a quiet, effective and subtle way. Hence, the change in shape can be very well interpreted by the user and provide the possibility to encode different information like notifications that differ in importance or topicality.

In order for users to interact and engage with *Reactive Objects*, research showed that is is helpful, to consider certain design principles [23]. Therefore, it was shown that for a better interaction and engagement with the user, it is helpful when *Reactive Objects* are always visible and integrate well into their environments, but are also bound to a certain place or area.

3 Communication through Reactive Objects

Reactive Objects that can be changed in shape, size, color, temperature or position, do not only provide a new dimension of interaction, but can also facilitate interactions that are very precise, intuitive or handy. For example materials like sand or clay can be manipulated very precisely by humans with their hands and fingers, in order to create landscape designs as shown by Piper et al. with *Illuminating Clay* [18].

The following section presents different example *Reactive Objects*, that feature, like *Illuminating Clay*, a set of new ways of interaction that are created for the specific purpose of communication. These de-

- *Sebastian Siepe is studying Media Informatics at the University of Munich, Germany, E-mail: Sebastian.Siepe@campus.lmu.de*
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vices can give a hint how telecommunication could be realized in the near future. Besides communication itself, also an outlook will be provided on shape changing objects that use direct communication in order to ease the process of teaching and learning.

Wrigglo A new approach of manipulating and displaying data is presented with the *Reactive Object Wrigglo* [17]. This object represents a smart phone case that has two antenna-like attachments called *Wrigglos*, as shown in *figure 1*. Each *Wrigglo* has the capability to change it's shape autonomously. This functionality can be used for a shape based, non-verbal or non-textual communication.

The principle behind *Wrigglo* is pairwise communication. Therefore, each smart phone case has two *Wrigglos* attached to it. The left antenna represents the person to communicate with and the right antenna stands for the user itself. Each user can now alter it's *Wrigglo*, by manipulating a joystick that is integrated into the smart phone case. The antenna will follow the joystick's movement automatically on both coupled devices in real time. Therefore, the information about the actual shape of each *Wrigglo* is transmitted over the internet to it's counterpart.

In order to express and shape different 'messages', each *Wrigglo* provides the possibility to be bend in any direction the joystick forces it to. But the shape changing is not only limited to the four directions front, back, left and right. Each *Wrigglo* can also be shrunk. This effect can be reached by touching the head of it.

Fig. 1. Communication with the shape changing Object *Wrigglo* [17]

The realization of *Wrigglo* shows that *Reactive Objects* can often provide two ways of interaction: On the one side the possibility to input information into a system and on the other side to receive and interpret this information through the same reactive mechanism. As shown with *Wrigglo*, these two ways of interaction often arises with *Reactive Objects* that are used for communication. Communication between remote partners is only possible if all partners can input and receive information . Hence, also the following project *Physical TelePresence* [11] that describes another *Reactive Object* for communication, provides those two sides of interaction.

Physical Telepresence When we observe common digital audio-visual communication with remote partners, we can see that the communication is mainly bound to displays, cameras and microphones, in order to show the interaction of the counterpart. But as reported by Leithinger et al. [11], a lot of interpersonal communication is based on physical interaction with the counterpart like handshakes or physical gestures. Also by regarding communicating on work-related topics, in specific fields of work often physical objects like surfaces, shapes, colors or spaces are discussed. Due to the reason that audio-visual communication completely lacks those physical representations, *Physical Telepresence* tries to integrate and bring back physical aspects into the communication of remote partners.

The *Physical Telepresence* system contains of an shape-changing display, two cameras and two projectors that are linked together in order to establish the communication between two remote places. The shape-changing display is a representation of the *inForm* platform [1]. It consist of 900 different plastic pins, 30 pins in width and 30 pins in height, in order to form altogether a square. These pins can be extended in height on the table, in which they are embedded. Therefore, by manipulating the height of the pins, different shapes and forms can be created. But *inFORM* is not limited to the display of shapes. The pins can also be manipulated directly, by pressing or pushing them. This information will be recognized by *inFORM* and provided for further processing.

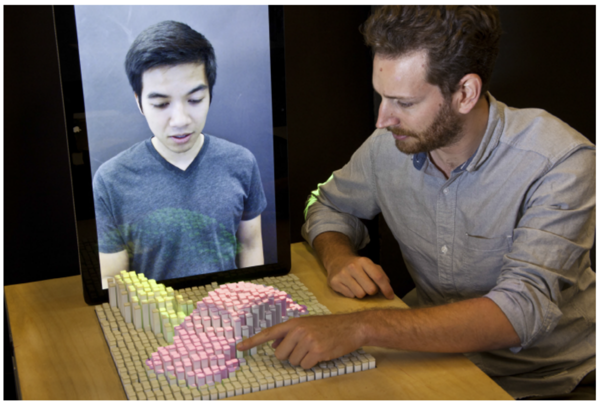

Fig. 2. Communication by the manipulation of physical representations of different objects with the *Physical Telepresence* system [11]

The realization of *Physical Telepresence* provides three ways of communication. One way can be a multi-directional interaction, provided by the manipulation of various shape displays that are linked together. Therefore, each participant of the communication has its own shape display that can be manipulated. The information about the alteration will be transferred directly to the other linked display and resolute in an appropriate shape changing effect.

Also a multi-directional interaction can be achieved, by providing the view for every participant on one single shape changing display, as shown in *figure 2*. By this way of communication, one participant can manipulate the shape display directly, while the information about the alteration is passed on to the other participants using common audio-visual communication techniques. But the alteration of the shape display itself is not only limited to the participant that can manipulate the shape display directly. By the use of a camera that tracks the movements of the remote partners, this information can be interpreted and passed on to the shape display, in order to manipulate it. Therefore all participants can access and manipulate the one shape changing display and the objects that it represents.

In addition, the third way of interaction with *Physical Telepresence* is described as asymmetric teleoperation. Therefore, multiple participants are linked to one remote shape changing display. The movements of each participant will be transmitted and can resolute in alteration on the one shape changing display that is used in common.

Besides the creation and manipulation of physical objects with the *Physical Telepresence* system, it can can also be used to move objects that lye on the shape changing display from a remote location. By tracking the remote users movements and transferring this data to *inFORM*, objects like smartphones, balls or torches that are small enough to fit onto the surfaces, can be moved. Therefore the *Physical Telepresence* can also be used as an physical, interactive interface that facilitates physical movements and gestures from a remote location. With this approach, also inter-human interactions like handshakes or some kind of touching could be achieved.

Linked-Stick Besides communication, *Reactive Objects* can also be used in other areas where information needs to be exchanged. A learning environment is such an example, where *Reactive Objects* can help to ease the transmission of knowledge between trainer and trainee. This approach of exchanging information in a learning environment is pursuit by the project *Linked-Stick* [15].

The *Linked-Stick* system consists of two hand held shape changing sticks as shown in *figure 3*. One stick is seen as the performer and tracks the motions and movements a person performs with it. The second stick will follow the movements by bending in the same direction, as the performer stick. The data of the performer stick can be recorded, but also transmitted simultaneously from one device to the other.

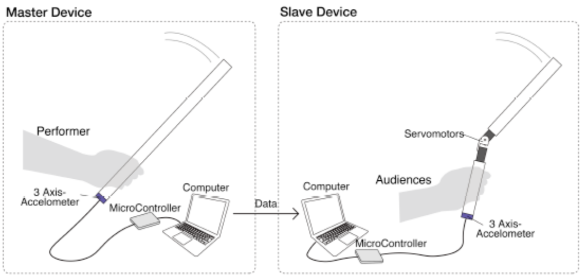

Fig. 3. Illustration of *Linked-Stick* [15]

The intention of this shape-changing device is to provide direct haptic feedback in learning environments, but also in other areas where stick-like tools come into action. The paper by Ken Nakagaki et al. [15] envisions multiple different scenarios, where such a tool could provide haptic feedback in completely new areas. When we look at sports that make use of stick-like equipment, like Tennis, Baseball or Golf, the user's experience of a prerecorded or live sports-game could be enhanced massively, by feeling the movement, power and speed of the player's movement just by holding a *Linked-Stick* that imitates the players action. But also in a learning environment, this device could ease and accelerate the learning process between trainer and trainee. For example by using the *Linked-Stick* as a conductor's baton. The trainee could listen to the classical music, while feeling the movements and instructions the conductor gives to the orchestra.

4 Shaping music with Reactive Objects

Regarding the field of music in general, haptic feedback always played and still plays an important role. For example by playing music on an instrument, the haptic feedback of the instrument is very important for the player, in order to feel, shape and reproduce music and sound. Also in the field of professional music production, mixers and music shaping devices are used that provide haptic and direct feedback through faders, knobs or buttons to shape music intuitively.

Therefore, in the area of music, TUIs, *Reactive Objects* and haptic elements are spread fare more widely then in other areas of Human Computer Interaction (HCI). Back in the days, when the creation of music was completely analog, sound engineers and artist used mixers and sound shaping devices with nobs, buttons and sliders to shape and mix music and sound. Those haptic elements gave sound engineers the capability to control the electrical transformation of the analog music signal intuitively. When the production of music turned digital, sound engineers didn't want to change the way they were producing music, but also wanted to benefit from the advantages, digital music production provided. Therefore, mixing and sound shaping devices appeared that process and shape sound completely digital, but provide the same haptic elements like faders, sliders, knobs or buttons. Most of those devices simply copy the user interfaces of analog mixers to provide sound engineers the same haptic feeling like analog devices.

But not only in the field of professional music creation is haptic and reactive feedback quite important. Also on the consumer side, devices appear that feature haptic elements. In addition to that and due to the *Internet of Things* era, many haptic music devices can now be connected to the internet in order to exchange information. All those features can be found for example in the *reacTable* system [7].

reacTable This device represents a round tabletop that features a luminous, reactive surface. In order to create music with *reacTable*, small physical objects can be moved or rotated on the tabletops' surface, as shown in *figure 4*. This alteration of the physical objects will be tracked and resolutes in an automatically adaption of the music to these movements. Each physical *reacTable* object can be seen as a synthesizer that performs a specific task or functionality, due to it's shape. Therefore, each object is bound to a specific set of functionalities that will be enabled, when the object touches the luminous surface. *reacTable* provides the possibility to place multiple objects on its surface. This feature enables the interaction between various objects that differ in their set of functionalities and sound shaping characteristics. The interactions between different objects is highlited by visible lines on the tabletop that connect the different objects. Those lines show the actual waveform of the music that is generated by the linked objects and therefore displays the musical content and interaction of two objects in a visual way. In addition, also the behavior of the *reacTable* objects itself is displayed by an aura that surrounds each object visually. This aura describes the specific set of parameters and characteristics of each *reacTable* object and therefore the alteration of sound that each digital synthesizer performs.

Fig. 4. Creation of live music by using haptic elements on the *reacTable* system. ©Lighuen Desanto [21]

In order for *reacTable* to function, one camera, one projector, a signal processing unit as well as loudspeaker are integrated into the tabletop. The camera has the capability to be sensitive to infrared light. This capability has the advantage, that no occlusion can occur with the projector. The camera tracks the positions of the various *reacTable* objects and the movements and gestures made by the user. This information will then be passed on to the signal processing unit, where it directly influences the shape of sound. Additionally, the information of the user's interaction and it's effects will be also interpreted by the projector in order to visualize these interactions for the user in real time on the tabletop.

Besides the functionality to shape sound with physical elements, *reacTable* provides also the capability to upload recorded music-sessions and make them available for the *reacTable*-community [22]. Within the community, songs can be downloaded, shared and users can listen to them. In addition, these recorded music-sessions can be played back or modified on a smartphone- and tablet app, that provides similar functionalities as the *reacTable* system, just lacking the haptic objects. Hence, the music can be spread onto different devices and places over the internet.

Pick Up and Play The direct link over the internet to receive information is also used by the *Pick Up and Play* concept [12]. This concept is based on little cubes that can be used to manage the playback of music content from the audio streaming platform *Spotify*, as shown in *figure 5*. The *Pick Up and Play* concept is realized with six *Stifteo Cubes* [14]. Those cubes are 1.5 inches in size, have the capability to detect movements, are touch sensitive, feature a full-color touchscreen and can interact with each other when they are moved, tilted, rotated or located near to each other. All cubes are connected to the internet and have therefore the possibility to stream audio content from *Spotify*. Martens, who envisioned the concept in his master thesis, describes eight different scenarios in which the cubes can provide a new way of interaction with the playback of music. These scenarios can be entered by shaking, turning or re-locating the cubes. For example the shuffle mode can be enabled when one of the cubes is shaked. This will lead to the random replay of music. Furthermore, the cubes can adopt different roles and specific functionalities. In order to enter the *Mood* mode, one cube serves as main controller. This main cube can switch between different moods. By coupling it with another cube, a playlist of songs that are categorized in this specific mood of the main cube will be played. Hence, the cubes are also aware, if they are coupled directly. This interaction of coupling two or even multiple cubes can lead to various results, from sharing music with friends, over copying music from one cube to another and even play music from related artists, whereby each cube represents one of those artists.

Fig. 5. Usage of the *Pick Up and Play* cubes. ©Roy Martens [13]

past.fm An other *Reactive Object* that deals also with the playback of music from audio streaming plattforms is *past.fm* [19]. This tangible device is conected to the *last.fm* streaming platform and features an haptic slider, which enables the user to scroll through different music histories. By putting a physical token into the *past.fm* device, different music genres can be loaded. Each token stands therefore for a specific genre that will be loaded, as soon as the token is attached. But these tokens can also represent different users and their timelines. Hence, by attaching personalized tokens, the user can scroll through it's own listening timeline of his or her *last.fm* account. This concept leads also to new ways of sharing music. Different users are now enabled to share their music by simply exchanging their own personalized physical tokens.

5 Changing human behavior

Reactive Objects can not only provide the possibility to receive information by alter or manipulate them in physical ways, but are also very applicable to express information through the autonomous change of shape, color, temperature or weight. Research showed that humans have the capability to manipulate and recognize changes in their environment in an intuitive and relatively effortless way [20]. Furthermore, information can be recognized best, when this information is clearly mapped to an object and it's spacial functionality. If this preconditions are met, information can be grasped intuitively and adapted clearly from the physical object. Considering these principles, *Reactive Objects* can also be used to remind and encourage people to perform specific tasks. By doing so, a change in human behavior is hoped for.

The capability to receive information of *Reactive Objects* in an effortless and intuitive way, can give us a new dimension besides common HCI techniques as the Graphical User Interface in order to use our well developed skills to receive and grasp information. Therefore, the following section depicts a set of examples *Reactive Objects* that use new, physical and form changing techniques in order to ease HCI. Furthermore different use cases will be present, where those techniques can be executed in order to facilitate new ways of the exchange of information.

Shape changing mobile phone The shape changing mobile phone device [4] makes use of our human capability to recognize the change of shape. Therefore, the shape changing mobile phone describes a mobile-phone like shaped box that can change its geometry, by tilting its back plate. Four servo motors are located in the corners of the box that provide the movement around two axis. The back plate can therefore either be tilted by 15 degrees in each direction, or the thickness of the entire box can be changed by up to 15mm in depth as shown in *figure 6*.

By pushing the idea to change the shape and characteristics of a mobile phone further, a follow-up project by Hemmert et al., arose. In this follow-up project, a phone-like case prototype was realized that had the cpability to change the gravitational properties of the phone. This weight shifting mobile phone [3] moves an internal weight along two axis in order to change its gravitational characteristics. This capability of changing the gravitation coupled with the possibility to change the shape of the mobile phone, lead Hemmert et al. [3] to envision different use cases for those reactive devices. Those use cases were envisioned, to use the shape-changing functionalities of the prototypes in order to test how well humans respond to this new techniques to express and transmit information.

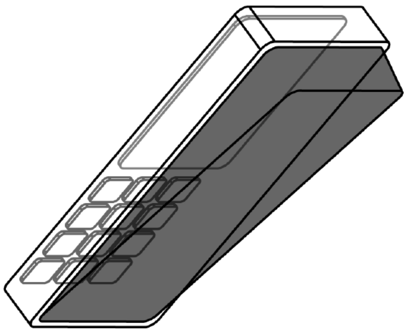

Fig. 6. Illustration of the shape changing mobile phone [4]

One is described as *Haptic Pointing*, whereby the shifting of gravitation can be used to point to objects that are located outside of the device. This *Haptic Pointing* could be combined with the possibility to shape the devices' form, in order to navigate the user to a specific goal. Nowadays, navigation systems and applications rely mainly on graphical and audible elements as arrows or audible commands, in order to guide the user. But with the weight and shape shifting approach, users could be led intuitively, by shape changing and weight changing effects to their destination. For example by shifting the weight onto the right side while bending the phone in the same direction indicates the user to take a right while approaching its destination.

While the shape and weight shifting mobile phone provides real haptic feedback of the information that the user can physicaly feel in its hand, the following *Reactive Object* presents information only in an visual way, but still by shaping and adapting its form in order to display the information.

Breakaway This *Reactive Object* [6] is capable to measures the sitting position of users and gives direct feedback on the way and how long the person is sitting. It is designed to encourage people to take breaks during work and has the clear intention to change the sitting behavior of the user. Therefore, different sensors are placed in the user's chair that measure in which position and how long the person is already sitting. This data will be transferred to *Breakaway*, a small device that consists basically of a stretched rectangle of paper. Furthermore and in order to bend *Breakaway*, a string of beads was attached to the paper. This strings can be manipulated with micro controllers in order to manipulate and change the shape of the device. The dimensions of *Breakaway* are chosen in a way that the device can be located near a screen and in the field of sight of the user and therefore be visible consequently. But its shape is not to big to distract the user from its tasks in an ongoing way. In order for *Breakaway* to express the sitting information of the user, the device uses sensors that are located in the users chair. These sensors check continuously how long the user has been sitting and passes this information on to the device. Before the user starts sitting in its chair, *Breakaway* will be in an upright and therefore healthy position. After the user has been sitting in the chair for one hour, the sculpture will move to its first slouching pose. After wards, two more slouching positions well be presented after 120 and 180 minutes of sitting. If now the user recognized that he or she has been sitting for too long, *Breakaway* can be brought into an upright position again, by leaving the chair for at least ten minutes, as shown in *figure 7*. With this behavior of the device, the user can always judge in which position he or she has been for the last time. The *Breakaway* project tries to manipulate human behavior and encourage people to take breaks during work with the presented *Reactive Object*.

In order to display the desired information, *Breakaway* uses different design principles to be accepted and understood by the user in an intuitive way. Therefore, the designers tried to express information in an abstract way. The collected data from the sensors should not be presented raw, but transformed into an intuitive and graspable form. Furthermore, data should be presented in an non-obtrusive manner. Hence, the information should be visible at all times, but not discard from work, even when the information and therefore the shape of *Breakaway* changes. Also the design had to be done in a way, that users would willingly display this personal information in an public space like an office. Therefore, the device had to be aesthetic, in order to be interesting for the user for a longer period of time.

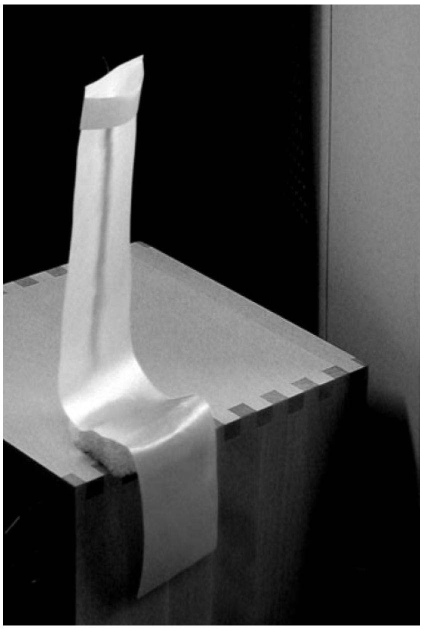

Fig. 7. *Breakaway* imitates users sitting position [6]

BRiK Also *BRiK* [16] tries to change human behavior in an intuitive way. Its goal is, similar to *Breakaway*, to encourage people to take more breaks during work. In order to do so, *BRiK* is designed as an small sculpture that can be attached to the ceiling above the users desk, as shown in *figure 8*. While the user is working, the sculpture will constantly lower its position until it reached the table. *BRiK* will need one hour to reach the table and then starts blinking in an subtle way. This behavior indicates the user that it is time, to take a break from work. If the user whishes to delay the break, *BRiK* can be lifted from the table in order to expand the time between the breaks. When the user then decides to finally take a break, the sculpture can be pulled gently in order to bring it back in its original position. The again, it will take the device one hour to reach the table and remind the user to take a further break.

Fig. 8. *BRiK* reminds the user to take breaks during work [16]

6 Discussion

In order for *Reactive Objects* to be accepted and understood by humans, research showed that interaction can be eased by considering certain design principles. When those design principles are met by a physical object, users reaction can be positive and even lead to an change in behavior.

Research made by Zuckermann et al. [23], who tried to understand how physical objects can help people diagnosed with ADHD to perform daily tasks, showed that physical objects can have an positive impact when different design principles are applied to them. Those principles are described as:

- *Visibility and persistency*. According to Zuckermann, physical objects should be visible constantly. Thereby, they are constant reminders of tasks or specific information just by being present at any time, even when they are switched off. Furthermore, when physical objects are bound to a specific place, information can be received more effectively, because memory is location-dependent.
- *Tangible representation*. By providing a *Tangible representation* of a physical object, information can be communicated in an multi-sensory way, by being visible and touchable. This may help to present abstract information in a concrete way.
- *Affordance*. When a change in behavior is hoped-for, the user needs to reflect its interactions and realize its mistakes. Intuitive device affordances can encouraged the user to interact with the object and therefore reflect its behaviour.

Besides those base principles that describe the locations and tangible elements of *Reactive Object*, also the way how those objects can be altered or changed in shape is important in order for users to interact with them. During the *Breakaway* project, Jafarinaimi et al. [6] showed that humans are very sensitive to the poses of other humans. Therefore, different moods and expressions can very precisely be displayed by using human gestures. Furthermore it was shown, that different poses of humans can be expressed in a very simple and effective manner. Hence, the design and alteration of *Breakaway* was based on the so called *Line of Action* [10]. This method was created by Disney in order to express different moods just by changing the pose of a cartoon-figure. The *Line of Action* describes a line that goes through the whole body of a figure. The line indicates in which directions the different body parts have to be bend in order to express the desired mood. This principle shows that the adaption of information into human gestures or ways of human interaction can be very precise and effective, because we are already used to it.

Taking these principles into account, this paper advises to only display a specific and limited set of data by the reactive device. By sticking to this guideline, the user will always know which specific information the device is referring to and can gather this information more easily. In addition, if those devices can adapt to our well developed sensing and touching skills, information will be transmitted in an intuitive and effortless way and therefore very effectively. But it also has to be clear, that *Reactive Objects* can and will not replace all HCI methods that are common nowadays. If for example a wide variety of data needs to be presented, a classical GUI can be fare more intuitive and better suited in order to transmit these information. Nevertheless, *Reactive Objects* can be seen as an additional way to transmit and present information. Especially when the set of data is unique and small, these devices can facilitate a better and more intuitive interaction for the user.

A further conclusion that could be drawn by presenting the different example *Reactive Objects* has been, that nearly all objects for physical interaction are designed to function in private environments like homes, offices or other personal spaces. Only one physical object could be found that was designed to be placed in a public space. This object describes a reactive bench that provides the capability to transmit information of the people sitting on it to a linked and remote located bench [8].

Multiple reasons could explain this inhomogeneous allocation of private and public *Reactive Objects*. One reason could lie in the adaption phase that often is occurring, when the user is not familiar with the object. Even when those objects provide the possibility to transmit information intuitively, users need some time in order to get to know how and in which ways the object reacts to the given information. This adaption and process of getting familiar with the device can be much easier achieved in a private environment with a limited number of users. An other key aspect could be that the measured and used data by these example objects has often been private, like the sitting position and time of users or their *Spotify* play lists. Therefore, also the physical reaction should stay and be displayed in a private area. In addition, the presented example objects were mostly created in computer science research projects, where it is often easier to collect and display specific private data then information of public users. Also privacy issues can make it difficult to gather public information.

Nevertheless, *Reactive Objects* could very well be placed in public spaces in order to display and express information intuitively. For example in a parking deck where nearly no parking spaces are available anymore, a *Reactive Object* could be envisioned that consists of a physical representation of a car that can alter it's position in height. Depending, on which level parking spots are still available, the representation of the car could move up or down to indicate the driver where to find one of the last spots intuitively. This simple *Reactive Object* shows that also in public spaces intuitive ways of HCI can be established in order to ease the transmission of information. Therefore, computer science will hopefully in the future also deal with physical objects in public spaces and therefore try to discover all features and possibilities that *Reactive Objects* can provide.

7 Conclusion

This paper showed, that *Reactive Objects* can be used in a very effective way to either input information into a system or display them. Therefore, *Reactive Objects* make use of our well developed sensing, touching and shaping skills and adapt to our senses in order to ease HCI. With those objects, information can be transmitted in ways that go beyond graphical interaction techniques. Those reactive ways and tangible interaction techniques are proved as very intuitive and nearly effortless, because they are common to us naturally.

To use those new interaction techniques, this paper presented a variety of different physical objects that have been created in the field of computer science in order to exchange specific information. And due to the *Internet of things* era this process will continue and more and more *Reactive Objects* with new interaction techniques will show up in the near future.

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Evoking Behavioral Change with Ambient Devices

Lena Streppel

Abstract— The recent research brought up many examples for ambient displays. This work considers such devices in the context of persuasion. These are ambient devices that aim in changing the users attitudes or behaviour. This works by visualizing informations constantly without being intrusive. The wide range of design possibilities from small furnitures to large architectural installations is shown in this work. Based on different examples the characteristics of such devices are explored and aims like creating awareness as well as observed effects are covered. Concerning related work there are some design strategies presented which can help developing a new persuasive ambient device that should change the users behaviour. The second half of the work addresses also the limits and risks of this kind of devices. New technical devices often have internet access and can communicate with others. Among this technical evolution towards the Internet of Things (IoT) the ethical aspects of data collection and manipulation are often ignored. On the one hand there are many new possibilities to show ambient information and on the other hand risks like misuse or manipulation come up. Both, risks and possibilities of the IoT are illustrated in this work.

Index Terms—Ambient displays, Persuasive technology, Information visualization, Behaviour change, Internet of Things, ethical risks

1 INTRODUCTION

Ambient devices have an aestetic appearance which shows non-critical information in the direct environment of the user [15]. There are big scopes for design, ”from relatively large-scale spatial installations towards more personalized applications in the realm of ubiquitous and wearable computing” [17]. The current development of technical devices increases the possibilities of showing data. Also the collection of data becomes easier because of modern technologies and so the range of use of ambient information systems increases. Furthermore the evolution towards the internet of things enables undreamed-of possibilities for the design and the use of ambient displays.

”Because such a display is able to convey information in a subjectively pleasant way over a relatively long period of time [...] particular ambient display techniques have the potential to be used for persuasive applications” [17]. The intention of such persuasive devices is to change the user’s behaviour and his attitudes [6]. So the ambient device not only informs the user of something, it also evokes a change in his behaviour. Fogg names ”seven types of persuasive technology tools” such as tailoring, reducing and conditioning [7]. These are aspects which can be achieved with ambient devices. The shown data can be tailored to the individual, a complex goal like environment protection can be reduced to a simple task and an aesthetic device can give positive reinforcement.

The research of the last years created a lot of examples for persuasive ambient devices. They all want to create awareness towards modern lifestyle aspects like healthy living, social behaviour or environment protection. So the main aspect is to support the human being in his life by showing him some data in the periphery of his daily context. This shall evoke positive behavioral change. In addition to positive use cases this paper also takes the possibility into account that the behaviour changes in a different direction or that the shown data is manipulated and used in a bad way.

This paper first illustrates examples and research findings in chapter two. The following sections refer to these examples over and over again. Chapter three gives an overview of the characteristics of ambient displays in the context of persuasion. Aspects like placement, aims and effects are explained. Subsequent there is a summary of design requests, based on the examples in chapter two and additional research findings. It follows an estimation of technical and ethical limits and of potential risks by using persuasive devices. At the end there is a general view of chances, possibilities and useful application areas, followed by the conclusion.

- *Lena Streppel is studying Media Informatics at the University of Munich, Germany, E-mail: lena.streppel@campus.lmu.de*

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2 USE CASES AND EXAMPLES

There are many scientific examples where persuasive ambient devices are used in different contexts. The particular ideas differ in design approaches and concrete aims. The following subsections present ambient devices which are designed for creating awareness in the fields environment, social behaviour and health. Also user study results are presented. Because of the numerous works some are just named at the end of each sections. In addition to scientific work there are commercial products illustrated.

2.1 Environmental Awareness

The Power-Aware Cord [10] displays how much energy is used through this one cord *(see figure 1)*. For the human it becomes possible to understand the local energy consumption, something which is not visible otherwise. By glowing uninterrupted the cord creates awareness at any time. The person gets direct feedback when he plugs a device into the sockets - by this he is able to interact with this ambient display. Also the device is a tangible daily-use object and has no numbers or graphs. In a user study 13 of 15 people realized that the light is a metaphor for the electrical current. As positive feedback the paper mentions some suggestions from the participants for serious use. These are teaching ”children about electricity”, ”test stand-by products” and other pedagogical qualities. ”All except one of the fifteen test people were positive about having a Power-Aware Cord at home” [10].

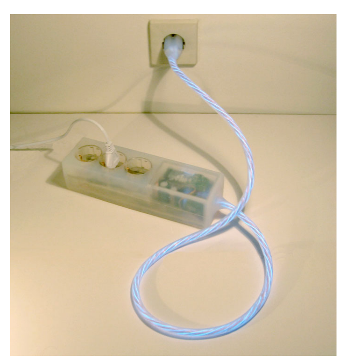

Fig. 1. Prototype of the Power-Aware Cord: depending on the light it shows the energy consumption [10]

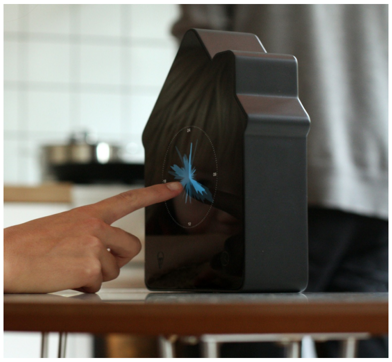

Fig. 2. ”Energy AWARE Clock in the 24 hour view, showing the electricity consumption for the whole day and two days back in time.” [2]

Fig. 3. Awareness of social behaviour; Left: Light installation in meeting rooms to support time management [19] Right: USB-device representing the written mood [17]

Another device showing the electricity consumption is the Energy AWARE Clock [2] shown in figure 2 . The difference in the shown data is that this clock considers the whole household while the Power-Aware Cord is conscious restricted to the local cord. One central thought behind this device is that before you can save energy you need to understand at what time and on which places the electricity is consumed. But these informations cannot be found on any bill or meters. Therefore the device is like a wall clock with a round display showing a circular graph representing the electricity consumption. ”A complete turn represents 1 minute, 1 hour, 24 hours or one week, depending on which view is selected” [2]. The results of a three month user study show that first the participants were curious and tried the effect of turning on and off some devices and looking for the direct feedback on the clock. At the end the participants recognized how much each device uses. The clock is described as playful and ”a tool for learning” [2].

Environmental awareness is not only energy consumption, amongst others it is also water consumption. The WaterBot [1] for example colours the stream of water, so the user becomes aware of wasting hot water. Other ambient devices in the context of environment can be found in ”The Design of Eco-Feedback Technology” [8].

2.2 Realizing Social Behaviour

A different context for persuasive ambient devices is the communication and behaviour towards others. The aim is to create awareness of the own behaviour and in fact adapt the behaviour considering the realized situation.

One example is an in-door light installation which supports the time schedule in meetings [19]. Halogen spots lighting down and up on a wall represent the meeting progress *(see figure 3)*. The light colour shows the progress of the meeting schedule while the intensity codes the presentation mode. By dimming and blinking the light indicates when a given time is almost elapsed or when presentation time is almost over. So the current speaker is aware of the time progress and based on this knowledge she can reduce her content so it fits into the remaining time. Research findings are that orientation and colours are effective for pre-attentive processing and no speaker in the user study got distracted by this ambient device. Such a system can either mirror the meeting situation or it can be designed proactive and by this supporting the schedule.

Another device concerning social behaviour is the color-changing USB-device in figure 3. The egg ”wiggles and rocks in different motion typologies in reaction to the human emotions depicted during an online chat conversation” [17]. The user gets feedback about his written words. He can realize what mood he is sending and maybe becomes aware of his actual behaviour.

2.3 Healthy Living

One more context in which persuasive ambient devices can be useful is a healthy lifestyle. The following examples want to create awareness concerning the movement in our everyday life. By this the people get information which let them reflect their behaviour and as consequence develop a will to move more.

Rogers et al. [22] investigated different approaches to motivate people to take the stairs instead of the elevator at their working place. Figure 4 illustrates two of them. The upper side is a public display showing five pie charts. They contain the historical data how many percentage of the people used the stairs or the elevator on a certain working day. The lower image shows twinkly lights which activate by stepping on them. They lead to the stairs and deviate from the view to the elevator. An eight week in-the-wild study was performed with all approaches placed good visible in one building. The public display showing the history is described as easy to read and to interpret. Participants were interested in and discussing more about the topic stairs or elevator and by this the installations created awareness of this health topic. The collected data shows that significant more people used the stairs after installation. In contrast not many people said that they changed their behaviour. In fact the people unconsciously took the stairs more often because of the ambient devices.

A more personal way for improving awareness is using mobile phones as ambient displays, what makes it accessible everywhere. For example the UbiFit [3] system is for self-monitoring ones physical activity in every day life. It uses a garden metaphor for representing healthy behaviour. To support the persuasion Consolvo et al. use a goal-setting approach, where the user can not only see his progress, he also has goals to achieve. In a three-month field study ”most participants would prefer to set their goal themselves [...] or work with a fitness expert to set a goal” [3]. The preferred timeframe is one week, because of a clear deadline and new start each week. The research findings show that goal-setting can be ”an effective way to encourage behavior change” [3]. This device was developed to successfully proof eight design strategies for persuasive technologies [4]. A description can be found in chapter four.

Also commercial products use such small displays for health information. Wearables like the Samsung Gear fit or Microsoft BAND give users the possibility to become aware of their own health. The persuasive aspect is not in the focus of the commercial devices, but people who buy them are interested in the health functions and have the motivation to behave respecting to their measures.

There also exist local and personal artefacts like Breakaway [12] to support healthy behaviour in every day life. The small sculpture in figure 5 is placed on a working desk. Its shape adapts the form of the human body, so when the person is working some hours she and the sculpture move from an upright position to a slouching one. Through Breakaway the person can reflect her unhealthy position and is able to realize that she should take a break. The only participant of the user study orientated herself on the sculptures when to take a break, so in this one case the persuasion is successful. Furthermore she names an advantage of the sculpture in contrast to a digital reminder: the latter keeps interrupting in busy times, but the sculpture can be ignored.

One more example is for motivating to do regular walking exercises. It is a display passively placed on a small mirror which ”can

Fig. 4. Two approaches of one installation for creating awareness of stair usage. Above: a public display called The History; Bottom: twinkly lights guiding to the stairs, called Follow-the-Lights. [22]

provide a person with an opportunity to notice his/her level of walking exercise" [9]. People looking into a mirror stay there a while, so the mirror gets more attention than just a quick look. Small triangles augmenting the mirrored image show for example the day-by-day walking history. Depending on the shape a person can compare if she walked more or less than the last day. A small user study with six participants pointed out a positive feedback after three to five weeks. People liked being aware of their walking history and even seeing a small number increasing satisfied a participant.

Another commercial product is the Ambient Orb[1]. It is an aesthetic glass ball which can glow in different colours. There is no special context for this device because the user can choose between different data channels. It can display weather, stock market or traffic congestion for example. Designed like a furniture it is placed in any room where the user can realize special changes while actually doing a primary task. The Ambient Orb is also used in other projects like the peripheral Displays Toolkit [16].

3 CHARACTERISTICS OF PERSUASIVE AMBIENT DISPLAYS

The main characteristic of an ambient device is that there are not many boundaries because so many things are possible in design and placement. Nevertheless some aspects are worth to be summarized. So based on the illustrated examples this chapter gives an overview about characteristics of ambient devices aiming at behaviour change. It names properties and features of the appearance and explains the importance of the message of such a device. Also the aims and the possible effects are specified including some drawbacks.

[1] www.ambientdevices.com

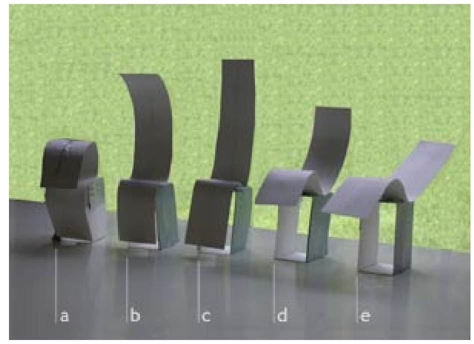

Fig. 5. An example for supporting healthy living: the sculpture Breakaway which mirrors a sitting position [12]

3.1 Placement and Appearance

Persuasive ambient devices can have different appearances. Mostly they are part of architecture or furniture. By this they can be part of a wall [19] or the floor [22] and they can be artefacts on a desk [12] or elsewhere. No matter how big they are, they optional have a display. So small screens and public displays [22] are a common appearance. Concerning the technical progress they can also be portable devices like phones [3], accessories, clothes or other wearables.

Because of the wide range of appearance the location of an ambient device is variable too. A wearable is most often next to or even part of the person it belongs to. If it is not that personal the location of an ambient display can either be private or public, in a household [2] or in a company [22]. Other public contexts like schools or stores are possible too, but for a persuasive influence in behaviour it is probably necessary to see the device frequently and more than one time. This is because the behaviour change comes over time [10]. In addition the specific location in the room or building is important for the motivation and the possible persuasion [2]. In fact the device should be visible or accessible from any place in a room or building [10].

A persuasive ambient device is finally designed for every day use and it constantly provides information [10] as all of the examples do. By this it is possible for the user to get realtime feedback [2, 10] even if direct interaction is not always possible. But the appearance of an ambient device can sometimes be influenced by changing the own behaviour, because than the shown data is changing too.

Examples in chapter two show that ambient devices communicate information in an alternative way and don't always need a screen. "They demonstrate more explorative design approaches that are more inspired by digital, interactive art works than traditional data mapping algorithms" [17]. So often it is a "tangible real worl object" [10] which can be perceived by different senses. Concrete design requests for persuasive ambient devices are illustrated in chapter four.

3.2 Aims and transported message

As the examples show, the basic aim of the considered devices is creating awareness and as a result a change in behaviour. Also motivation, compliance and a change in attitude and in worldview are part of persuasion [6]. The behaviour should always change in a positive way. Concerning chapter two this means the user should think of the environment and use less energy and water, he should think of his health and behave in a good way for his own body. The ambient device wants to "provoke thoughts" [10] in these directions. The non-obtrusive way of communication makes an ambient device good for persuasion [17]. They want to say something like this:

> For example the Power-Aware Cord:
> Obtrusive message would be:
> *Pay attention! Put this plug out of the socket!*
> What the ambient device is saying:
> *Hey, the thing in your socket uses energy right now. Think about it!*

For example Breakaway:
Obtrusive message would be:
Take a break now!
What the ambient device is saying:
Hey, this is how you are sitting there. You know?

So the user first thinks about the message and then he decides himself what to do. He can as well ignore the device if he wants to [12]. The device just encourage the user to reflect [22].

This means that ”ambient artifacts utilize the data to communicate a more elaborate, subjective message” [17]. The user should become aware of this message. Other ambient devices which do not necessarily aim in persuasion ”focus on conveying simple but meaningful patterns within datasets” [17]. The placement of such devices do ”not force the user to walk up to the device but rather to receive the information at a glance from a distance” [10]. This supports the non-obtrusive being.

Furthermore many ambient devices aim in influencing at ”choice moments” [22]. For evoking a change in behaviour there need to be a different possible behaviour pattern. This is in particular given in such choice moments like taking the stairs or the elevator or the situation of taking a break now or later. An ambient device that wants to be persuasive can be build on an every day situation where a different choice supports a good lifestyle. But as the Power-Aware Cord [10] shows, it is also possible to create such a moment where the original behaviour is doing nothing.

3.3 Observed effects

The examples in chapter two show that ambient devices can have persuasive effects. Concerning the stair usage the results of a three-month study lead to the assumption that ”ambient displays can influence at an unconscious or conscious level” [22] because as written above the stair-usage increased but the people said they did not change their behaviour. Also the three-month study of the Energy AWARE Clock [2] shows this difference between observed behaviour and sense of self. The goal-setting approach of UbiFit [3] creates an active contact with the device which leads to conscious changing. Also Breakaway [12] leads to more conscious decisions at what time the person takes a break, but there was no large userstudy.

The Power-Aware Cord and the installation for more stair-usage both describe interested participants who were curious. Also the findings of the Energy AWARE Clock show an exploring phase in the beginning with ”playful curiosity” [2]. Placed in a public space the installations of Rogers et al. [22] generate discussions and by this the whole topic of using stairs or the elevator becomes more present. People talking about a topic raises its value. This could be a reason for unconsciously more stair usage and can also appear in a more-person household.

The effect of the considered devices differs also depending on whether a person is alone or part of a group. The in-the-wild study of Rogers et al. found that persons walking alone did not talk aloud, even if they stopped for watching. Groups often started to discuss and also made conversation with people around them [22]. So using a public context respectively involve more than one person supports the opportunity of conversations and discussions. This can support the mentioned effect of raising a topic to be present in the peoples mind.

A second phase in the contact with the Energy AWARE Clock [2] is a confirmation phase. During this phase the device is like ”an artefact you throw a glance at now and then to relate to the current situation”, like a traditional clock [2]. The usage is described as a habit and the participants felt like having ”control over their electricity use”, the clock is like an reminder [2]. This example shows that an ambient device can be accepted and integrated in every day life and that a long-term usage makes sense. It is possible to motivate a household to be aware of and to be interested in their energy consumption. One participant described it as routine.

3.4 Drawbacks

Each single device has its own drawbacks. For example the Power-Aware Cord [10] uses energy by itself although its aim is to reduce energy usage. A part of the study mentioned that the light ”would be irritating when you sleep” [10]. A similar statement came up in the user study of Energy AWARE Clock: ”One family decided to move [it] to the laundry room at an early stage because they felt it was too present and disturbing in a way, rejecting its centrality” [2].

Instead of single drawbacks this paper focuses on overall limits of persuasive devices. Chapter five gives an overview on limits and risks like data manipulation, whereas chapter seven mentions the possibilities.

4 Design challenges

In this chapter the complexity of showing information and being aesthetic at once is described. Then there is an introduction in design requests based on the named examples, followed by design strategies for persuasive ambient devices. The chapter clarifies what is important developing such a device and what needs to be fulfilled that it has a chance to work properly.

4.1 Balance of Information and Aesthetic

First of all the illustrated informations have to be non-critical to anyone. Second the information capacity of an ambient device is limited and differs from device to device [20]. Devices such as Breakaway [12] do not have problems with the amount of showed information. The illustrated example for time management in meetings was intentional designed with low information capacity, because in meeting situations the people have primary tasks and no extra time for thinking about a display [19]. In contrast the Power-Aware Cord wants ”to display a wide range of information values”, because even small differences in energy use should be visible, for example ”the one between a 40 W and a 60 W light bulb” [10]. By having a display the Energy AWARE Clock [2] is able to show a lot of information. Thereby it is possible to compare the data of different days on just one screen supplemented through different modes of the view [2].

However the comfort in the perception is important. The Power-Aware Cord for example irritates some user when the light is pulsing or flowing at a high level, whereas a static intensity of the light is not very informative [10]. There need to be a ”balance between visual comfort and the ability to convey enough information” [10] respectively a ”balance between aesthetical and information quality” [19].

4.2 Appearance Requests

The related work in chapter two contains some aspects concerning the particular designs. These are summarized in the first subsection and mapped to the four design dimensions of Fang [5]. The second one shows design strategies which are written down by Consolvo et al. [4] based on the findings concerning Breakaway [12].

4.2.1 Design aspects

Fang [5] describes design dimensions with regard to persuasive feedback systems. These systems are reduced to devices with digital displays, anyway the named dimensions can be found in the illustrated examples concerning ambient devices. Being ambient is even one of the dimensions, all together are these:

ambient Advantages of being ambient is being passive and not to disturb during daily life [5]. ”Pre-attentive processing” is sometimes supported [19] and it is usually intuitive to understand [10]. To keep an installation like this it is also important to collect the data in a passive way and not to be dependent on user intake [18]. And again the aesthetic aspect concerning the ”artwork-like appearance” is profitable, because it is pleasing for the user and blends into the environment [5].

aesthetic The aesthetic dimension was described in the last chapter. It is about visual comfort, good feeling and drawing attention in public areas [5].

emotionally-engaged Concerning the emotionally-engaged dimension Fang says that "if the users are emotionally engaged in the persuasive system, they are motivated to change behavior" [5]. He also names the virtual pet approach which can increase the relationship from user to device.

metaphorical The metaphorical dimension is a basic way of communication and a common way of designing User Interfaces [5]. It means picking up an idea from a different context to support the understanding and explanation in another one. There is also a connection to the emotionally-engaged dimension. "Iconic and metaphorical images trigger [...] more awareness and motivation for future behavior changes through emotional attachment" [13].

4.2.2 Useful design strategies

The design of the presented example Breakaway [12] is based on four design goals. Consolvo et al. [4] used these as a basis for a summery of eight design strategies for persuasive technologies. They successful validated them by building and evaluating an own system. This chapter sums up these strategies which are generalized "to apply to everyday behavior changes" [4]. Some of them have already been discussed and some are overlapping with others. The following list shows all of them:

Abstract and Reflective Using raw or explicit data is not productive. An abstract form of the data works better to show users their behaviour. [4] This strategy is similar to the already considered aspect of balancing information and aesthetic.

Unobtrusive This aspect is similar to the ambient one named in Fangs [5] design dimensions. It concerns the way of presenting the data: discrete, unobtrusive and not interrupting but present when needed. Especially the possibility to ignore the device is pointed out as important [4].

Public The user needs to feel comfortable when he is in public with the device [4]. This is similar to the described importance of an aesthetic device. Through the modern technologies such devices can always be with the user and as a wearable it has to be an attractive appearance to be accepted by other persons.

Aesthetic This point is related to the last one. A personal object in long-term use needs to be comfortable, interesting and inducing positive feelings [4].

Positive Evoking a change in behaviour works best if the user gets positive reinforcement. Punishments are not necessary but through positive communication the interest can be kept. This is important because the user decides when to use the device. A negative occurrence of it will not lead to a long-term usage. Kinds of rewards can also lead to a positive relationship, also in combination with goal-setting which was described in chapter two [4].

Controllable This strategy gives the user control about the data, so that he can manipulate and change it, so he can correct the data depending on his perception. One reason for giving him this right is that technology collecting data is not error free and the user feels upset in this cases [4]. This aspect of data manipulation differs from the already named point of passive data collection [18] in the last part of this chapter.

Trending / Historical The user can see differences in the data when he also has access to historical data. It is particularly important in combination with goal-setting. By having historical data a user can make better decisions because the situation is not isolated [4].

Comprehensive It is important to think of all possible behaviours an not only the ones which the technology can deal with [4].

An additional aspect of designing an persuasive ambient device is the integration of users into the design process. Concerning ambient energy saving displays Kluckner et al. [14] suggest that potential user of the device should be involved, because then it would rather support a long-term behaviour change. By this the consumers can tell in what extent they are "willing to integrate such an interface into their daily life" [14].

Theses strategies pick up some characteristics already named in this work. Especially the device being aesthetic and unobtrusive seem important. They can support conditioning, one of the persuasive technology tools of Fogg [7]. Other strategies are not mandatory but using some of them may lead to design which is able to create enough awareness to change behaviour.

5 LIMITS AND POTENTIAL RISKS

Ambient devices and persuasion have both limits: technical, natural and especially ethical ones. This chapter presents the thoughts of Purpura et al. [21] concerning ethical aspects of persuasive computing. Some own thoughts on possible manipulation of such ambient devices are added.

5.1 Natural and technical limits of persuasive devices

Nowadays technical boundaries are shifting so that the limitations through this factor are fading away more and more. As seen in chapter two there are already commercial products in the area of persuasive ambient devices. But there are still natural, human limits and ethical limits which may differ between countries.

Natural limits like constraints in the users capability cannot easily be moved. Users have different characteristics, different physical and mental skills. Someone sitting in a wheel-chair cannot decide to use the stairs. Persons who do not care for art are probably not interested in a sculpture on their desk. And maybe there are aggressive, churning people who do not care about some lights in a meeting room. Also the current situation and mood of a person may probably have an influence in the effect of ambient devices. These are limits where probably no device has a chance to change behaviour. But designing special devices for special contexts could unlock some contexts where persuasion is maybe easier because of special abilities. These kind of aspects are covered in chapter six.

5.2 Ethical limits and the crossing to risks

Ethical aspects always differ between countries, but the following apply to all of them. Purpura et al. [21] developed Fit4Life, an extensive persuasive design for supporting healthy living - it is meant as a satire. The work aims in presenting three critical points concerning such devices which are general meant for persuasive computing and not reduced to ambient devices. This is why the recent chapters can weaken a few aspects, but the whole topic of risks stays.

5.2.1 Entry to coercion

One critical aspect is "the extent to which persuasion can shade into coercion" [21]. Basically a person uses a device aiming in changing his own behaviour. The question is: is a goal his own goal or is it a social goal, defined by the designer? The goal of persuasion maybe should be "acceptable to a wider group", it should support the public point of view [21]. The user nearly should behave like the majority would do. This is like forcing him to behave different from his individual way, while he thinks it is good for him. Is it coercion?

Fogg wrote in 1999: "the dark side of changing attitudes and behaviors leads toward manipulation and coercion" [6]. This leads to the risk of persuasive devices being "used for destructive purposes" [6]. If it is possible to change behaviour in a positive way, it could be possible to change it in a bad way. Is it possible that in a dictatorship the social behaviour is massively changed in a "wrong" direction with persuasive devices? In a way the people do not realize it? This is an extreme example but changing attitudes in a bad way may be possible.

If the use of such devices is voluntarily, it still is persuasion, but ”if force (coercion) or misinformation (deception) are used, these would fall outside of the realm of persuasive technology” [11].

5.2.2 Society goes persuasive

Purpura et al. [21] worry that ”persuasive computing and broader cultural trends towards scientific rationalization” reinforce each other. Based on ”irrationality of rationality” it means that a sum of widespread emphasis on ”individual rational attributes leads to solutions that are globally irrational” [21]. Thoughts on this aspect are based in the fact that their satirical design would be accepted by the people without realizing the serious background. The modern lifestyle includes more and more devices and the question is if our abilities of managing our lifes will be determined by technology.

In this context the risk of excessive usage of a device comes up. An extreme example is that a user is dependant of a persuasive device. He does not get along without it and if it is not available he maybe makes decisions worse than before he had the device. Or maybe he just does not care for his health without having access to it, he moves less because he gets no feedback.

There are some more risks concerning the usage. What about evoking bad or unwanted behaviour through wrong usage? The ambient device just wants to create awareness and it cannot control the direction of the upcoming thoughts in the users head. Depending on the natural limits there could be persons with less mental capability who conclude different things and behave unexpected. Also social issues are possible. As a daily use object the ambient device is present in a particular context. What if the user does not adapt his behaviour? If the display shows a negative state all day long, this could influence the mood in a negative way and in fact demotivate him. The direct feedback of such a device is important but what if there is no reason for it to change to a positive state?

5.2.3 Technology versus human being

The third point Purpura et al. [21] mention concerns the technology itself. This can collect quantitative data of the user but it is not able to realize or track emotions. By this the persuasive influence is only based on data without noticing the mood or experiences of the user. The behaviour of the technology tends to surveillance without respecting privacy.

An obvious risk in the context of data collection is the misuse of information and privacy. Then there is some kind of data which should not become public or which leads to emotional pressure if the wrong people are aware of it. But as written in this paper ambient devices should use non-critical data and that weakens this effect.

Another risk is a change of the displayed data on purpose. This means to betray the user by manipulating the visible information without involving him. Depending on the data it is possible that this sometimes leads to more positive behaviour because the user thinks he has bad values or else. But overall such a misuse of an persuasive device is no good practice and in extreme cases it can be seen as the illustrated coercion. An ambient display should always be trustworthy, especially if it relies on personal data [17].

6 Possibilities and Use Cases

As shown in chapter two there exist commercial persuasive devices nowadays, so there are reasonable contexts for them. Especially the evolution of modern technique towards the internet of things (IoT) brings probably up unforeseen possibilities for design and for usage. A breath connection between devices, displays and wearables leads to more and more data sources. Also combined approaches for presenting the data seem attractive. Instead of awareness in just one room multiple devices in a whole house or other buildings could work together and be dependent on others. The created awareness would not be reduced to one location. Maybe more distributed ambient influence on one day increases the effect of behaviour change in the long run. The IoT makes things possible we are probably not even thinking about.

The faraway dreams of persuasive ambient devices lead to healthy living, good social behaviour and pro-environmental attitudes. Individuals have a positive and healthy way of life. They are more productive in meetings and maybe work more productive because of a motivated lifestyle. Furthermore people communicate in a more friendly way, there is less social stress and each individual has a high-quality life. Not to forget the quiet conscience because of protecting our environment. So this is the theoretical way of life the devices show us.

As seen in the illustrated examples in chapter two people nowadays are already happy by understanding a little more of their surroundings. The persuasive devices are kind of extended perception. They make things visible which remained unseen before. They translate data into useful information. They just create awareness where it is missed.

A real use case named in the work of the Power-Aware Cord [10] is the pedagogical context. Maybe in the public environment of a school or kindergarten ambient devices can support the education - not by active instruction but by teaching a better ”normal” way of behaviour in every day. Children learn different than adults and they maybe do not have plugged-in behaviours. The persuasive effects could be more efficient because children have the ability to learn easier.

Depending on chapter five it could be possible to increase the usage of ambient devices by specially designing it for particular groups. This is also one of the persuasive technology tools which are named in the introduction: tailoring [7]. By defining a target audience it could be possible to specialize the device and by this getting more agreement and attention from the users. Also the reduction of a different mental type of human being could effect the impact of persuasion.

As named in the introduction the persuasive technology tools [7] reduction and conditioning can be established in ambient devices. They bring up the possibility to divide a complex goal into simple tasks and to reward correct behaviour by giving positive feedback. The persuasive technology tools not named yet are tunneling, self-monitoring, surveillance and suggestion. Tunneling means guiding a person along a way, what is not directly expected by an ambient device. Also explicit suggestions disagree with their unobtrusive character. But through an ambient device it is possible to do self-monitoring without big effort, what supports its daily usage. Showing data collected through surveillance makes it possible to compare the own behaviour with the average one. But used in a negative way the ethical aspects named in chapter five become relevant.

7 Conclusion

The big amount of examples including commercial ones show the potential of ambient devices in context of persuasion. Different shapes are possible from small sculptures to wall-sized installations or just displays in any size. Normally an ambient device is part of the architecture and it can be placed in households or in public domains. The presented aim of creating environmental awareness results in less energy or water consumption. An influence of the social behaviour is for example possible through time management support in meetings. A healthy lifestyle can be supported through mirroring the humans sitting behaviour or through creating awareness of the possibility to choose between stairs and elevator.

Ambient devices are passive and by showing non-critical data they are placed on a good visible place. This non-obtrusive being makes it a friendly device which aims in telling new things and not in giving orders. The user gets aware of something and can based on this knowledge decide himself how to behave. One approach is influencing the user in choice moments, a different one uses goal-setting. The related work presents some positive results of studies. Group situations can have an impact on the effect. Also public context leads to more communication respectively awareness of a topic. A changed behaviour can be unconscious, so the user does not realize a difference, although collected data shows the opposite.

Basic design aspects seen in all examples are ambience and aesthetic. Using emotion and metaphors is also good practice. This work presented in addition eight design strategies which includes to design not only unobtrusive, aesthetic and public but also abstract,positive, controllable, comprehensive and trending.

Technical limits are moving what leads to unseen possibilities in the context of the IoT. But ethical limits should not be disregarded. Persuasion is not far away from coercion and also an overuse or a wrong use of a device may lead to unwanted behaviour. An important aspect is the power of technology. Build on quantitative data the devices are not able to realize emotion or other human reactions. Furthermore the data can be misused or manipulated in a unethical way.

Next to this critical reflections this work illustrated some possibilities for persuasive ambient devices coming up with IoT. A network of devices and displays can collect more data and by working together new ways of display become possible. Future work can explore new designs in new maybe specialized contexts. Is it possible to change a behaviour for a longer time? What messages can effect the most awareness? Is being too ambient possible?

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Smart Devices in Meetings

Florian Weiß

Abstract— Meetings are a valued practice to exchange knowledge, create solutions and work towards common goals. However, problems such as imbalanced participation or undesired behavior lead to unsatisfying results. Current techniques and electronic tools strive to support collaborative work, but introduce new challenges. This work concentrates on novel approaches for meeting support, and divides the topic into two areas: smart devices providing feedback and interactive applications for brainstorming support. First the problem and existing solutions are examined before novel applications are presented. For each category designs, implementations and results of user studies are investigated. Providing ambient feedback about behavior during meetings helped to balance the participation level without causing distraction. Digital multitouch tables facilitate the creation and categorization of ideas as well as face-to-face collaboration. To give insight into the similarities and differences between the systems, a comparison is presented. While all implementations provide valuable benefits, combined approaches fusing the different aspects could be promising, resulting in even more powerful tools.

Index Terms—Meeting Support, Smart Devices, Tabletop Interface, Social Visualization, Collaboration

1 Introduction

Meetings are an important part of our every day life. They are frequent activities at work, school, university or in the scientific field. Sharing information, discussing options and making decisions are vital for problem solving. Although meetings build a platform to represent individual opinions, create new ideas or achieve common goals, they are often seen as ineffective and inefficient by the attendees. Lack of collaboration or missing coordination could result in decreased motivation and rejection. Shyness due to the fear of judgment and aggressive dominant behavior are undesired and interfere with the process [5]. Nevertheless, teamwork and exchanging knowledge are crucial factors to obtain solutions to complex challenges. Hence the question is: How can this situation be improved?

This topic has been addressed over the past years. Brainstorming techniques [16] have been developed over time to aid idea generation. Behavioral studies evaluated the influence of a facilitator or mediator attending discussions or decision making scenarios. Even electronic systems were designed and developed to test their influence on meetings, since these days nearly everyone is familiar with smart phones and personal computers and since the capabilities of these devices are constantly improving. The additional possibilities offer new opportunities to build on previous results and enhance existing methods with technology.

In the context of Computer Supported Cooperative Work (CSCW) conferences are held[1] to investigate how computer systems can support collaboration and affect groups. The purpose is to offer new designs or ways of interaction or visualization. Particularly smart devices have the potential to affect the user's behavior in positive ways. They are electronic devices with embedded sensors and transmitters which monitor the environment and communicate with each other in order to share information [22]. This technology can adjust according to a new situation and react in a desired way or give feedback about the current state. Due to the ability of devices to communicate between each other and due to the diversity of input methods (like multitouch and other tangible interfaces), various implementations are possible. Due to the potential combinations, different aspects of problems can be addressed and optimized.

- *Florian Weiß is studying Media Informatics at the University of Munich, Germany, E-mail: weissf@cip.ifi.lmu.de*

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[1] http://cscw.acm.org/2015/

In this paper I present a survey and review of smart devices, their influence on meetings and how they support and affect them. I start with an overview of related work and existing problems in the general field of collaboration. Secondly, existing novel approaches with smart devices are presented in two parts. On the one hand smart devices with interactive interfaces and on the other hand smart devices providing feedback about the behavior of the participants are presented. For each I give a general overview and examples of implementations and studies. I conclude with a comparison, discussion and outlook for future work.

2 Group Decision Making

Brainstorming has proven to be an effective technique for meetings and is frequently used for collaborative problem solving [16]. It relies on communication and information sharing to optimize the result. Brainstorming consists of two phases: a *storming* and a *norming phase*. The first phase is solely used to generate ideas as a base for the second phase. The focus is on quantity and even unusual ideas are appreciated to create a bigger picture. During the *norming phase* categories and structures are formed in order to combine similar concepts or ideas, thus motivating discussion and reflection. However, new challenges arise reducing the effectiveness of collaborative work.

To be able to design systems which support idea generation and decision making meetings, the potential problems have to be investigated. Three key problems were identified by Diehl and Stroebe [5].

- free riding (social loafing)
- production blocking
- evaluation apprehensions

Social loafing, where people tend to put less effort into their work when they are part of a group, can occur from *free riding*, due to the believe that other team member can additionally cover their part. This can result in the *sucker effect*, where individuals reduce their level of participation in order to balance the contributions. "When everyone gets the same grade for the group project, why should I do all the work on my own?" As a consequence, the group is less productive and outcome is more likely to be disappointing. *Production blocking* occurs when participants cannot release their ideas or comments. It is possible that statements are forgotten or suppressed during the process, since they are no longer relevant for the current state of the discussion. The fear of judgment or negative feedback is *evaluation apprehension*. Members withhold their ideas, restrain themselves and lower their participation.

Based on these facts a number of customized brainstorming techniques have been developed. Nominal brainstorming, where each participant is isolated during the storming phase to reduce evaluation apprehension, or a group passing technique, allowing members to build on the others' ideas to decrease production blocking, are examples for such techniques. To aid and support the categorization process during the *norming phase*, Post-its and whiteboards can be used.

With the help of technology existing approaches can further be improved. Electronic Brainstorming Systems (EBS) are designed to enhance the meeting process and outcome. Using computer networks enables distributed conferences [8] or tracking and storing the process for later review. Participants can work in parallel to prevent production blocking. Individual contributions can be visualized on a shared interface to reduce free riding and support collaboration. A certain kind of anonymity prevents evaluation apprehension.

Although EBS address the previously stated problems, working on a personal computer reduces face-to-face interaction, which has shown to be an essential factor [7]. Facial expressions and body language are important parts of social interaction and have a big influence on our behavior. The way the participants act during meetings can improve collaboration or shut it down. Therefore facilitators are present during discussions to mediate the sessions. Providing feedback on behavior and group dynamics have been proven to lead to higher satisfaction and consequently a better overall performance [19]. As a result the participants reflect about their current actions and can adjust according to the situation. Since personal computer or smart phones are considered disruptive, new ways to support face-to-face collaboration are investigated.

Smart devices offer great potential to combine the advantages of EBS and to enable face-to-face interaction for meetings. Embedded sensors, networking and communication between devices allow reaction according to measured information, whereas multitouch displays provide access to a wide range of interaction possibilities. Since there are multiple factors that influence the outcome, different approaches are followed to overcome the problems and improve the general result. In the next part I introduce some of the novel approaches which support brainstorming and decision making meetings with smart devices.

3 Interactive Interfaces to Support Brainstorming

To enhance existing brainstorming techniques interactive smart devices can be utilized. The goal of the later described systems was to combine the beneficial aspects of conventional brainstorming with the support that smart devices could provide, to overcome the general problems. Taking the already proven methods into consideration, similar approaches have been derived, adapted and implemented.

The research of Buisine et. al [2] showed that the collaborative behavior can be influenced with multitouch displays, but that other new difficulties arise. If the user interface is too complicated and overloaded with information the participants lose focus of the creative process. To avoid negative impact on the creative process of brainstorming, the research of special requirements is an important topic, as described in several publications [9, 18].

Depending on the chosen devices and implementation, different focus areas are addressed and investigated. Some studies concentrated on the enhancement of idea generation with smart devices and its features [2, 3, 11, 17], others examined user satisfaction or the impact of external influences like time pressure on meeting behavior [17].

In this chapter three different approaches, all supporting brainstorming meetings in a multitouch table environment, are presented. The systems use different input devices to generate and store the ideas. Each system implements a set of gestures to manipulate the individual representation of the participant's thoughts and organize them on the table. The systems are actively used by the participants to improve the brainstorming sessions.

3.1 Brainstorming on Collaborative Multitouch Table

With **Firestorm** [3] an interactive multitouch tabletop system to support brainstorming was designed and implemented. A set of design rules optimizing the user interface were established and followed after a preliminary study. During the main study the authors compared a conventional brainstorming technique with the refined version of Firestorm.

For the best support of brainstorming the *storming phase* and the *norming phase* were optimized separately. To improve the number of ideas generated during the *storming phase*, a wireless keyboard was used by each participant. Every user could write down their ideas, which were visualized on a one line note, similar to Post-its or cards. The notes were displayed after pressing the enter button and arranged spiral-shaped in the middle of the tabletop, readable for every participant. Colors of the cards referred to the author of the idea. After the idea creation during the *storming phase*, the *norming phase* to categorize and structure ideas started. Firestorm offered several options to support this brainstorming phase. Notes could be rearranged or discarded using gestures on the multitouch table. Through flipping an idea card it was transformed into a container with the ability to store other ideas (see figure 1). This way hierarchical structures could be created. Dragging single notes or drawing a lasso around multiple cards could aggregate them into a container. Due to the implemented archive function, the complete idea generation and categorization process could be stored and later analyzed in detail.

For the main study Firestorm was compared to a whiteboard brainstorming session. Groups of four participants processed similar problems under each condition. During the whiteboard setup the outcome of the *storming phase* was printed and handed out to every user. Thereafter the board was cleaned and used for the *norming phase*, to reach a fair comparison between the two conditions. For the evaluation the number of ideas generated during the first phase and the categorization during the second phase was observed.

The user study was analyzed regarding the previously considered design goal to support the collaboration of the participants. The first phase was mainly supported by wireless keyboard input. With the aid of a wireless keyboard users could create ideas individually and parallel to other participants. Since every participant was familiar with keyboards and its usage they could easily write down their ideas without having to learn the usage of a new interface or being distracted by the multitouch table. Indicating the author of each note, the color coding helped the users to get an overview of their contribution which served as a motivation. Table interaction was applied during the second phase. The possibility to flip cards to create containers and categorize ideas was very well received. Collecting

Fig. 1. Firestorm interface during the norming phase. Containers with title are used for categorization. Users' contributions are indicated with individual colors [3].

related notes with the lasso function to build subcategories or topics, supported the *norming phase* and was frequently used. Through the hierarchical structure it was simple to organize and group the ideas generated during the first phase. The archive function offered additional opportunities to analyze the process of the brainstorming session. Furthermore the authors suggested to implement a new third phase, where the participants could review and recall the states during the meeting - potentially to create additional ideas based on them.

Summarizing the outcome of the main study, Firestorm is designed and optimized to support both phases of the brainstorming process individually for a better group collaboration.

3.2 Shared Table and Wall Interface for Collaboration

In the paper "Designing for Collaborated Creative Problem Solving" [9] the authors created a system to support brainstorming and decision making. Based on an analysis of influencing factors they decided to combine a table and a wall interface to improve collaboration. To reference this system, the term **Digital Post-its** is used in this paper.

The general idea was to give the participants a tool to create and arrange Post-its. As input device a pen was used. To create a new idea the participant drew a box on the table and an empty Post-it appeared. For easy editing the note stayed large and faced to the creator. Completed Post-its were reduced in size, while still readable, and could be rearranged on the table. Additionally the Post-it became visible on the wall display. Gestures were implemented to edit existing notes, to change their position or to delete them. One feature of the implementation in contrast to the "real world" Post-its was that the participants were able to skid their ideas across the table to share them and get direct feedback. Another important factor was that parallel working of all users was enabled, since everybody had their own working space on the table. For a better overview idea grouping and clustering was supported by the wall display. Participants could organize and reorder the Post-its, draw circles around them to build groups and connect them with one another.

The evaluation of the design was tested during two brainstorming sessions. Groups consisted of two people and had to create ideas during the sessions with and without the Digital Post-its system. For the task without digital support, the original paper-based brainstorming technique was applied. To investigate the usability and effectiveness, the number of generated and exchanged ideas were compared between the different setups. The table solution offered the participants the opportunity to sit facing towards each other. The wall display was located next to the table (see figure 2), where they could group ideas.

In general the participants were not distracted by the Post-its system and preferred it over the paper-based technique. Since the user could rely on knowledge they already had about Post-its, the interface and usage was easy to learn. The additional possibility to skid the idea to the other participant was very popular. While supporting parallel input, due to the individual working areas, a fluid interaction without blocking was enabled. Although the amount of ideas generated did not increase significantly, other benefits of the system were valued. The table arrangement offered the opportunity for face-to-face communication with all its advantages like body language and facial expressions. The structured presentation of the created ideas on the wall display allowed the participants to rearrange the Post-its easily but also to review the already reached results. In some cases where the brainstorming process stagnated, the overview on the wall display initiated a new creative phase based on previous notations.

Altogether this paper showed that the combination of a wall display and an interactive table can support group collaboration and profit from the individual benefits.

Fig. 2. Idea generation and organization with the table and wall setup. Post-its are created and organized with a pen. The wall display is used for categorization and overview [9].

3.3 Voice Recognition and Semantic Knowledge Database

In their work "WordPlay: A Table-Top Interface for Collaborative Brainstorming and Decision Making" [10] the authors implemented a multitouch table system (referenced as **WordPlay**). As primary input device they used a microphone activated by a press button, which was attached to the table.

The system offered two ways for creating ideas. With the microphone spoken ideas were recorded and translated into text with a word recognition tool and displayed on the table (see figure 3). To correct false speech detection related to a small error rate of the tool but also to non-English accents, a multitouch keyboard was available on demand. Alternatively, participants could touch existing ideas on the table to get a list of associated statements from a linked semantic knowledge database. A collection of additional ideas grew out of the original and could be kept or discarded by the user. After a certain period of time unused associations faded away in order to reduce complexity. Ideas were displayed on the table as short phrases or sentences and could be manipulated on the multitouch interface. Resizing, rotation and repositioning by the users were fully supported. For individual decision making or brainstorming settings, special backgrounds were provided, for instance to sort and group pro and con arguments or to rate ideas.

The system was tested and evaluated in different application areas. Due to the input of ideas with a microphone, it was important to reduce background noise. The experiments distinguished between two types of meetings. One scenario was to decide between a set of possible choices, the other was a brainstorming session to generate ideas. Application areas were: lab demos, museum events and the groups internal usage.

Fig. 3. WordPlay table with microphone and voice recognition as input device for idea generation. Manipulation and organization of displayed phrases via touch gestures [10].

The focus of the evaluation was to investigative the usability of the system and not the comparison with other brainstorming techniques. In conclusion the authors stated that WordPlay was easy to use for the participants. Voice recognition enabled comfortable recording and visualization of ideas or phrases on the table. Associations retrieved from the linked semantic knowledge database improved the idea generation and led to new directions to think of. Hiding untouched ideas after a short time period helped the participants to fade out undesired and unused phrases. To rate and categorize ideas different backgrounds were utilized for keeping the overview of the complete picture. While multiple users could control the interface simultaneously the study revieled that resizing the global view was difficult. This could result in confusion for participants who did not directly manipulate the table. Therefore, instead of making it a global action, scaling should be implemented as an individual control for each participant.

WordPlay presented a system to include the computer as an additional participant via a linked semantic knowledge database for associations and additional idea generation. Offering the microphone and voice recognition, WordPlay simplified the idea generation and logging process.

4 Influence of Visual Feedback on Social Behavior

A different approach to influence the meeting scenario is to provide feedback during the sessions. Whereas the previous chapter focused on devices to be actively used by the participants, in this section I compare various forms of displaying feedback about social behavior to the user. Several studies already proved that providing information about their performance during discussions had an impact on the user's behavior and could be used to influence social dynamics ([1, 6, 14, 20, 21]).

In this chapter I provide an overview about the ideas, implementations, studies and results of four selected papers. Each has a special focus and investigates different aspects and influence on the meeting process and outcome. To implement the individual systems, different factors were taken into account which are presented in this chapter. The way the information is presented, the location and type of the display or what aspects of the meetings are visualized were considered. The common intention of all the methods followed in these publications is to improve the information exchange and to balance the participation level.

4.1 Influencing Group Participation with a Shared Display

DiMiccio et al. evaluated the influence of a shared display on group decision making, regarding critical information involved [6]. The idea was to display the individual speaking time and turns, in order to balance participation and improve information sharing without loosing the critical information. The system is referenced as **Shared Display** in this paper.

For their study they used two wall displays to give feedback to every participant about their individual speaking time. Each individual's speech was recorded with a microphone and processed to be displayed in real time. To make a fair judgment on the participation of each member only the essential information was captured and used for calculation. In the meeting room two displays were placed sideways to the participants, so that they were not disturbed in their discussions. The displays showed histograms with the individual participation level compared to each other (see figure 4). The categories were: over-, under- and normal participation. Additionally a row of circles above the histogram shows the chronology and duration of the speakers.

The general setup of the user study was a face-to-face meeting between four people. Overall there were two groups each discussing problems in two rounds. One group had to complete the tasks without the aid of the shared display. The other group also used no display in

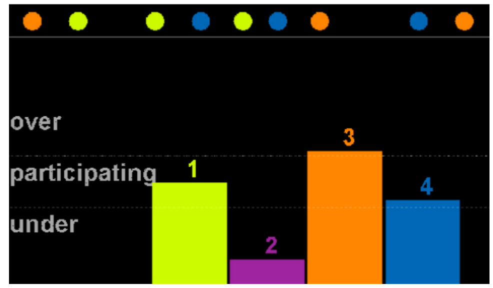

Fig. 4. Simple visualization of the group participation on the wall display with bar graphs. Speaking turns indicated through colored circles on the top row [6].

the first discussion round and were supported by the display during their second decision making session. Every group was provided with general information about the topic. Furthermore each participant got extra information, which was not disclosed to the other members. The goal was to motivate knowledge exchange and communication. Critical information, which was crucial for determining the right decision, was only provided to one participant per group. This fact was not explained to the groups, but the individuals recognized the importance of this fact during the discussions.

Evaluating the results of the user study, the authors compared their findings between the different groups and the two sessions. The study showed that the displays did not disturb the decision making process. Since they were not located in the direct view of the participants, the information was not the center of the attention, but could be recognized on demand. With the feedback of the shared displays the second group did change their discussion behavior during the second task. This was not observed compared to the first group without display. The study indicated that participants, who over-participated during the first task, regulated their speaking time due to the feedback. This only applied for subjects without critical information. On the other hand, members with critical information knew their importance for the decision making and did not reduce their participation share. This means that the quality of the decision did not suffer from the usage of this setup. Participants with a low participation level were not encouraged, since they found the feedback not accurate compared to their own impression, resulting them to ignore displayed information.

Overall this paper concluded that while over-participation was regulated to a better level, the crucial information holders did not restrict their participation in order to ensure that these facts are shared with the other members.

4.2 Metaphorical Group Mirror on Table or Wall

Groupgarden [21] is an implementation of ambient feedback via metaphors. Instead of displaying bar graphs the idea was to give the user feedback via images and to motivate the group to collaborate in a playful way [4]. Additionally the paper examined the influence of the location of the display.

The original Groupgarden used a wall display, but for the location study the concept was additionally adapted to a table display. For comparison of the tasks, the number of ideas generated during brainstorming meetings were counted and presented. To generate the feedback and to control the application, an operator was necessary (Wizard of Oz [13]). As an individual visualization of each user, flowers with petals were displayed. The number of ideas were represented by the number of petals and the size of the flower. As group feedback a tree was implemented, which grew according to the balance of the participants and the overall number of ideas. An unbalanced distribution of ideas resulted in a small leafless tree, whereas even participation created a prosperous tree. In addition bad

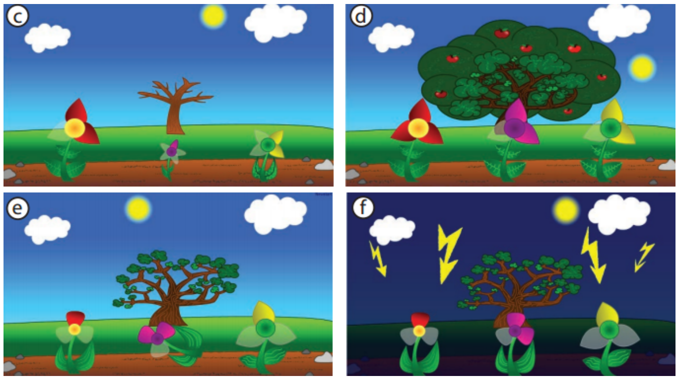

Fig. 5. Visualization of different states during a brainstorming session with three participants represented as flowers. Group performance is represented through the tree. Different states: c) unbalanced, d) balanced, e) individual warning ,f) group warning [21].

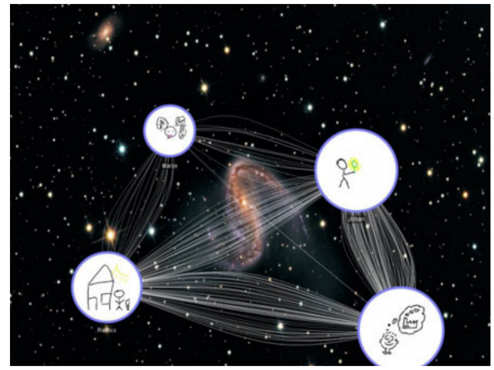

Fig. 6. ”The Social Mirror of four participants as displayed on the shared vertical screen and on the tablet PC. Distance between avatars signals level of agreement, size of avatars signals participation level, and lines between avatars signals interactivity level between pairs of participants” [12].

weather warned the users about bad behavior and going off topic (see figure 5).

The user study of the brainstorming sessions was divided into two parts. At first groups were selected to complete two brainstorming tasks, each without and with Groupgarden displayed on the wall. Groups consisted of three participants and could choose how to arrange their chairs during the meeting. They had to chose if they preferred to be turned to the display or to sit face-to-face to each other. Based on the fact that in brainstorming meetings face-to-face is an important factor, they conducted a second study to investigate the influence of the display location. So the focus of the second study was a comparison between the original wall display and a table display adaptation. The table setup was a face-to-face meeting around a table with the display, where every participant had their flower in front of him/her and the tree in the middle.

With the use of Groupgarden the number of ideas generated by each participants were balanced, in contrast to the groups with no feedback. Over-, as well as under-participation were adjusted. The playful character of the implementation motivated the users to improve their individual as well as the group result. Even participants with fewer ideas in the task without Groupgarden tried to enhance their contribution in order to achieve a better outcome, rather than giving up. Since the tree reflected the balance of the group, it drew attention of users with a higher amount of ideas to look for smaller flowers, encourage them to participate and self-regulate their dominance. The second study unveiled, that the location of the display had no direct influence on the amount of ideas generated or their distribution. In both cases (wall and table) the participation was well balanced and supported by Groupgarden. Some participants stated that the table solution was better for maintaining eye contact and that it supported collaboration. Other users chose the wall display over the table since it was less distracting and served as ambient feedback. Depending on personal preferences either the wall or the table solution were favored.

Groupgarden regulated the group participation in a positive way, because over- and under-participation was well adjusted via feedback through metaphors. Investigating the location of the display, the findings were dependent on personal preferences only, but had no influence on the overall improvement.

4.3 Visualizing Level of Agreement during Discussions

Based on the research and suggestion of Karahalios [12] the influence of the level of agreement should be investigated. The original work consisted of two types of Social Mirrors: The Conventional Clock to display speaking turns and length and the Conventional Vote to visualize the level of agreement. The paper ”The Effects Visual Feedback on Social Behavior during Decision Making Meeting” [1] describes an implementation of a new Social Mirror, combining these aspects.

The implementation consisted of a personal computer for each participant, a shared table display and a wall display. Each user had to start by creating their own avatar they could refer to. The mapping of the avatars to their owners was displayed on the table display. The wall display and the personal computers were used for visualization of behavior and level of agreement. The size of each avatar circle represented the individual speaking time and participation level calculated through automatic speaker detection. The interactivity level between two participants was indicated with lines between the avatars. Proximity of avatars signaled a good level of agreement, while distance stood for disagreement (see figure 6). With the user interface on the PC the participants controlled the position of their avatars to show their opinions. In this paper, I use **Social Mirror** to refer to the latter described system.

To investigate the Social Mirror system, a study with two groups in total was done with the focus on providing active feedback about individual opinions and agreement. Each group had four members, one external facilitator and an additional operator providing a mind map of the discussion. Roles were predefined for every participant to state four positions. Through discussion of a given problem, a collaborative decision had to be made. The system was briefly introduced, but only regarding the possibility to show which concept they prefer and which opinion they share. It was not explained how the size of the avatar or the lines between them should be interpreted and influenced. Similar to the other studies one task was held without feedback and a second task with the aid of the Social Mirror. Based on different background designs the users could vote for their preferred decision or display their satisfaction with the outcome of the discussion.

Although the users were not informed about the visualization of their speaking length and talking turns, they had the impression, that the use of the Social Mirror led to a change in their social behavior. Because of the awareness of the level of agreement from other participants, they could individually adjust their actions. The non verbal feedback that the participants could give to the group by moving the avatar closer or further away from other user was helpful to recognize the opinions about the statements. This also gave insights about the preferences of the participants for the facilitator and pointed out extreme positions. Additionally each member was constantly engaged in forming an opinion, share their thoughts and work towards decisions.

Table 1. Summary of design decisions and individual implementations of interactive solutions for brainstorming support.

System	Input device	Output device	Idea generation	Idea visualization	Categorization support	User limit
Firestorm	wireless keyboard gestures	multi-touch table	writing on keyboard	one line note cards spiral-shaped orientation	container & hierarchies lasso gesture	4
Digital Post-its	pen gestures	multi-touch table wall display	handwriting drawing	Post-its individual workspace	wall display grouping	2
Wordplay	microphone virtual keyboard gestures	multi-touch table	voice recognition write on keyboard semantic knowledge database	animated phrases common workspace	different backgrounds	>3

In contrast to previously shown studies the task without Social Mirror had a better balance in the participation level. The questioning after the tasks showed, that the participants could realize the correlation between avatar size and speaking time although previously not explained. Since the focus of attention was on displaying and controlling the level of agreement via their avatar, and since the visualization of the other factors were not explicitly mentioned before, the participants only concentrated on the given suggestions of usage. Therefore the outcome of the study differs from the other experiments.

The evaluation of Social Mirror showed that giving feedback about the level of agreement can be a useful feature to influence the social behavior in decision making meetings and support no verbal expression of agreement and disagreement.

4.4 Enhancing Collaboration using Sociometric Feedback

An approach for portable meeting support is **Meeting Mediator** (abbreviated with MM) [14]. MM uses sociometric signals to provide real time feedback on mobile phones for co-located and distributed meeting scenarios.

For the studies of Kim et al. a combination of two smart devices were used. The visual feedback to each participant was displayed on a personal smart phone. Every user was represented by a square in one corner of the display. A circle in the center was connected to the user square with a line and changed its color from white to green according to the degree of good collaboration. The thickness of the lines represented the speaking time of the individual participants and pulled the circle towards their corner indicating over-participation (see figure 7). To control the visual feedback sociometric badges (worn around the neck) were used which transferred the information via Blue tooth to the smart phone. The sociometric badges collected not only speaking time, but also other speech characteristics like speaking speed or tone of voice. Additionally, body movement, proximity to other badges or face-to-face interaction could be detected and used for evaluation. Sociometric badges are described in detail in [15].

For the user study, major points of interest other than improving

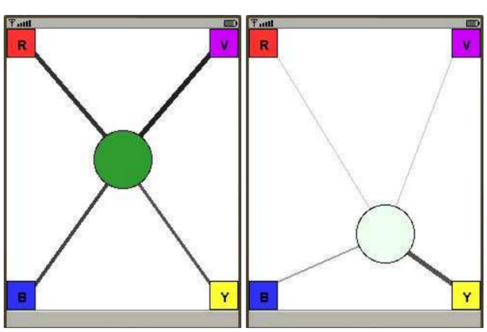

Fig. 7. Meeting Mediator interface during a balanced participation (left) and a one sided discussion (right) on the phone display. The color of the circle indicated group interactivity, position represents participation balance and the line thickness indicates individual speaking time [14].

the interactivity, were the influence of dominant participants on the group dynamics and the reduction of differences between co-located and distributed meetings. To test the effects of MM, groups of four people were built. Groups which had the feedback of MM and groups without feedback had to solve two tasks. Each in a co-located setup and in a distributed meeting scenario where the group members were separated. The tasks were derived from the ”Twenty Question” game, where one player is the answerer who chooses a secret to guess and the other players have 20 questions with ”yes”- or ”no”- answers to find the solution. During the first phase ten questions including answers were presented to the group. Through brainstorming and collaboration the members had to generate appropriate ideas for the given set of questions and corresponding answers. During the second phase (problem solving) the additional ten questions could be asked to an external ”answerer” who had the solution to the quiz. Indicators for a good collaboration was the number of questions needed to obtain the correct conclusion.

The results of the evaluation state that MM had a positive effect on the group participation. The difference between dominant and non dominant participants could be reduced. The color changing circle helped to balance the change of speaking turns. Furthermore MM was able to identify dominant people and with this detection it could be shown that dominant participants had an influence on the group dynamic. For groups with one or even multiple dominant speakers, MM could make distributed meetings more like co-located collaboration. However MM could not reduce the difference between the two task settings for groups with only non dominant participants. This emphasized the important factor which dominant people play in group collaboration.

In summary the study of MM showed, that it could detect social interaction between co-located and distributed meetings and give feedback to influence and improve group collaboration especially in scenarios where dominant speaker are participating.

5 Overview

In the previous chapter I presented the chosen applications in detail including the overall system and their individual user studies. Although the common goal was to design applications to improve idea generation and collaboration during meetings, several different approaches were chosen to address problems in these scenarios. For a better overview the general setup of the systems are summarized and compared within their category.

5.1 Interactive Multitouch Systems

Basically the main differences between the three interactive multitouch table systems were the input devices, the way of interaction and the support of the brainstorming process (see table 1). Building on common knowledge, devices like pen or keyboard were chosen or familiar gestures from smart phone usage were implemented. Only a few new actions had to be learned which simplified the operation of the system and avoided distraction from the task. The plain surface of the table interface supported face-to-face interaction to improve collaboration and awareness.

Table 2. Summary of design decisions and individual implementations of systems providing ambient feedback to influence group dynamics.

System	Input device	Output device	Measurements	Visualization: Indicators	User limit
Shared Display	microphone speaking time detection	two ambient wall displays	speaking time speaking turns & duration	bar graphs: participation level colored circles: speech duration	4
Groupgarden	wizard of OZ	wall or table display	number of ideas balance of participation	flowers (user): ideas via petals & growth tree (group): balance via growth bad behavior: thunderstorms	3
Social Mirror	PC: user controlled speaking time detection	shared table & wall display	level of agreement speaking time interactivity	avatar distance: agreement avatar size: participation connection lines: speaking turns	4-8
Meeting Mediator	sociometric badges (social behavior)	smart phone display	speaking time speech characteristics body movement	colored corner box: user circle color: participation level distance to corner & thickness of lines: individual participation	4

To reduce social loafing Firestorm decided to use colored note cards to indicate the author of the ideas. Through this participants were always aware of their contribution. This fact was not directly addressed nor needed in the Digital Post-its setup because of the limitation to only two users.

For the categorization, Firestorm decided to use container and hierarchy structures on the table, whereas the table of Digital Post-its was only used as shared working space. The grouping could be performed on the wall display to get a better overview of the intermediate results. Wordplay used different backgrounds with patterns aiding the users.

Parallel input was supported by individual input devices or working spaces to prevent production blocking. Every action could be performed independently from the other participants, but the result was displayed in real-time for the entire group. Solely WordPlay had problems with their implemented ”zoom” function, since it affected the whole viewport and disturbed the others.

Although WordPlay did not compare their performance with traditional brainstorming techniques it was selected for this paper because of the fact that it combines speech recognition and a semantic knowledge database to enhance idea generation.

5.2 Ambient Feedback Systems

In contrast to the previously mentioned applications, the following systems focus on the presentation of feedback to the participants of the meetings in order to influence group dynamics. The selection of publications was chosen so that a broad range of different influencing factors, their respective visualization and their impact on the sessions could be presented. Although the common goal was the same, each system had it's individual focus and design. An overview of the different visualization indicators and system setups is summarized in table 2.

To verify the effects on brainstorming and decision making, individual user studies were developed. The Groupgarden study compared a conventional brainstorming session with their system. Shared Display gave each participant identical information as well as additional facts. One of the members got special knowledge about the given problem, to swing the decision in the right direction. For the Social Mirror study, each user had their own position and had to decide between four stated concepts. Meeting Mediator divided the ”Twenty Question” game into an idea generation and decision making phase. This shows that every application had a special focus area of investigation.

To provide feedback, information of various types was presented. For visualization Shared Display selected bar graphs to display the participation level of each user and animated circles for speaking turns. This simple design allowed easy comparison. Participants suffering from under-participation ignored the feedback and could not be motivated. Important to note is that the holders of critical information did not reduce their participation level because of the relevance of their input.

Representing the number of ideas as growing flowers (metaphors), Groupgarden showed its positive impact on the group dynamics. Under- and over-participation could be regulated. Feedback on group performance and the chance to achieve a greater tree motivated team members to collaborate in order to reach a better result. The investigation of the location of the display showed that the placement, either on the wall or on the table, did not directly influence the outcome.

The focus of the Social Mirror implementation was to display the level of agreement. Participants constantly formed their opinion and could not only indicate their position but also react to the feedback of others. With the aid of Sociometric Badges Meeting Mediator was able to take additional information into account. In addition to the talking turns and duration, speech energy and movement could be detected. This enabled the device to identify dominant participants and their influence on the group dynamics.

Only MM offered the possibility to be utilized in co-located as well as distributed meetings and compared both scenarios. The MM study concluded that it reduces the differences between these two types, due to the consideration and visualization of social signals. Despite the differences, all systems showed a positive impact on the behavior of the individuals, the participation level and the general collaboration.

6 Discussion

All the previously presented papers showed that smart devices have an influence on meetings. Diverse implementations and design choices addressed various problem areas of collaboration and were able to increase the users' satisfaction compared to conventional methods. Although not every solution amplified the outcome in terms of the number of ideas generated or chosen solution, the electronic support added individual benefits.

Based on the observation of the described systems general design principals can be derived which should be considered for future works. Firstly face-to-face interaction should be enabled during brainstorming and meetings since facial expressions and body language have a big influence on our behavior [7]. Therefore table displays provide the solution to provide ambient feedback (see chapter 4.2), as well as allowing multiple users to switch between collaboration and individual idea generation. Secondly the system must not distract from the main task. Information and interaction should be available but not demand dedicated concentration or time from the user to understand the message or operate the device. Thirdly, systems should be easy to learn and understand. This applies to the operation of the input devices as well as the information visualization. In the presented papers, well-known brainstorming techniques were adapted to simplify the handling of the systems. Feedback should not be overloaded with information and a simple and intuitive design supports quick interpretation by the participants. These principals were taken into account by all the presented systems but realized in different ways and to a certain extend.

A direct comparison of the presented applications is difficult, because each study focused on their particular design goals. Hence they compared their systems against the traditional brainstorming scenario to identify their advantages and improvements. To understand the influence of the individual design choices a study should be carried out were the implementations are compared against each other. A general setup with equal starting conditions and tasks should be selected to achieve comparable results. An adaptation of the ”Twenty Questions” game from [14] could be suitable for interactive brainstorming support and ambient feedback applications, since it combines an idea generation and decision making phase. This might help to identify the impact of chosen input devices or visualization types on the meeting process and outcome.

Based on the results of such a study a combination of interactive and feedback systems could be derived, which might offer even more benefits for meetings and collaboration. Devices providing feedback as well as interactive solutions for brainstorming support need displays for visualization and interaction. During the *storming phase* of a brainstorming task multitouch table offer face-to-face interaction and enable parallel input to reduce production blocking. In the *norming phase* categorization and discussion could be supported with ambient feedback. The information can be used to reflect on behavior, balance participation or to display level of agreement. Digital Post-its already combine personal working spaces on a multitouch table and a wall display to provide an overview of the generated ideas. It could be a possibility to include feedback on the display about the progress and participation level of the group with flowers and trees or to make use of Sociometric Badges to enable distributed meeting scenarios. Even novel technologies like Google Glass or Apple Watch might offer new opportunities for visualization or input methods.

7 Conclusion

In conclusion this paper provides an overview of existing approaches supporting brainstorming or decision making during meetings. Interactive systems improve the idea generation process, whereas smart devices with ambient feedback can influence the behavior of groups. A big advantage of smart devices is their capability to gather information about the environment with sensors and transfer them to displays for visualization. Existing methods and techniques are enhanced with this technology eliminating the problems described in chapter 2.

Building on already established concepts for meeting support smart devices can add additional benefits, increasing the contribution and satisfaction of the participants. Multitouch table systems allow face-to-face interaction which improves collaboration and support creation and categorization of ideas during brainstorming tasks. Generally ambient feedback provided by smart devices result in a more balanced participation level and has a positive effect on the social behavior, without distracting the participants.

Despite the different intentions of the presented studies common approaches have been identified and summarized in chapter 5. Some of the previously stated design choices could be transferred into other systems to compare the resulting application with their original solution.

Given the proven impacts of the presented concepts, future studies and implementations should be based on the design ideas and findings to combine their benefits and further improve the process and outcome of meetings.

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Implicit Authentication 2.0: Behavioural Biometrics in Smart Environments

Christoph Ziegler

Abstract—This article discusses the applicability of behavioural biometrics for smart environments. We overview common applications and the technological groundwork of smart environments and present risks with regard to information security their inhabitants are exposed to. We review a selection of existing work on behavioural biometrics including common working principles of biometric authentication systems and behavioural properties assessed to authenticate identities. On this basis we show that behavioural biometrics can help improving reliability and usability of the authentication system compared to explicit authentication techniques. Along with that we constitute privacy issues that need to be solved before behavioural biometrics can actually be used in the fields.

Index Terms—implicit authentication, behavioural biometrics, smart environments, ubiquitous computing, internet of things

1 Introduction

Youngblood et al. define a smart environment as "[...] *one that is able to acquire and apply knowledge about the environment and its inhabitants in order to improve their experience in that environment.*" [46]. It is related to Marc Weisers vision of "*Ubiquitous Computing*" (Ubicomp) according to which the "[...] *physical world* [...] *is richly and invisibly interwoven with sensors, actuators, displays, and computational elements, embedded seamlessly in the everyday objects of our lives, and connected through a continuous network.*" [41]. Smart environments build an own class of applications in the "*Internet of Things*" [3]. Kevin Ashton introduced that term for his idea that information in the future internet will not only be generated and maintained by humans but also by devices [2].

There are smart-environment applications in different domains like comfortable homes and offices or healthcare. Kidd et al. [23] introduced the "*Aware Home*". The Aware Home provides means to find "*Frequently Lost Objects*" like keys, wallets, glasses or remote controls. It can monitor the medical state of its inhabitance and call the ambulance in the case of an emergency – a feature which could support independent living for elderly people, who would not be forced to move out of their own homes for medical care. Moreover, smart houses could optimise power consumption costs by observing energy prices [3]. Smart refrigerators with LCD screens could tell the user what is inside and list things that are about to expire – while being on the move, a smartphone application could inform the user about missing ingredients [38].

To realise applications like those mentioned above, smart environments constantly need to collect data about the environment and its inhabitants, process that data and draw conclusions to react on environmental changes to the benefit of the inhabitants. However, data captured in that process may contain critical information. It may affect people's privacy. Some information may also have a bearing on people's health [3, 4, 13, 31, 38]. Thus, it needs to be ensured that information can only be accessed and altered by privileged users. To assess whether an individual is the one it claims to be, proper authentication mechanisms are needed.

But, how could people be authenticated in a smart environment? Devices like small sensors or small computing elements may not have appropriate input methods to enter PIN codes or passwords. Plus, requesting the user to execute certain actions in order to use the system would somehow contradict to Weiser's vision that computers support people handling tasks without them noticing [40]. Another question is, when do people have to be authenticated? People may stay in a smart environment for days. Is it sufficient to authenticate them when they enter the environment? Do they have to explicitly log out when they leave the environment? What if they forget to log out? Do they have to be authenticated periodically? Is not this cumbersome?

Similar questions have been asked for mobile devices like tablets and smartphones. Jakobsson et al. query that authentication mechanisms that rely on the three classical authentication criteria *knowledge*, *ownership* and *physical properties* provide a satisfying answer. They see a solution in implicit authentication based on behavioural biometrics. Implicit authentication they define as "[...] *the ability to authenticate* [...] *users based on their actions they would carry out anyway.*" [18]. According to Yampolskiy et al., with behavioural biometrics one can "[...] *quantify behavioural traits exhibited by users and use resulting features profiles to successfully verify identity.*". Moreover they note that behavioural biometrics could be collected without any knowledge of the user [45], which supports the Ubicomp idea. The idea to use behavioural biometrics for unobtrusive authentication of users is not new. Orr et al. [32] equipped the Aware Home with pressure sensors in the floor for identifying its inhabitants by their gait. However, to the best of our knowledge, there is no broad assessment of behavioural biometrics in the context of smart environments.

In the following we address this gap and discus how behavioural biometrics could be used to authenticate users in smart environments. In section *2 Smart Environments* we provide examples for common applications of smart environments and overview the technological groundwork. This includes the common architecture pattern for smart environments as well as a taxonomy for devices present in smart environments. Section *3 Behavioral Biometrics* describes the general working principles of biometric systems and overviews existing approaches for authentication based on behavioural biometrics. Finally, in section *4 Discussion* we outline how behavioural biometrics could be employed in smart environments and how usability and information security could profit. We also state open technological and conceptual questions that need to be addressed by future research to close gaps that hinder an effective use of behavioural biometrics in smart environments. Section *5 Conclusion* provides a wrap up of our key results.

2 Smart Environments

This section provides an overview on smart environments. We present how inhabitants of a smart environment benefit from a number of intelligent applications, before we present a high level overview of the enabling technologies. On this basis we portray risks with regard to the security of users and their information to raise awareness for the need of reliable security measures. After that we present examples for existing work on security systems and authentication mechanism for smart environments, before we dive into behavioural biometrics in the next section.

- *Christoph Ziegler is studying Media Informatics at the University of Munich, Germany, E-mail: c.ziegler@campus.lmu.de*
- *This research paper was written for the Media Informatics Advanced Seminar 'Human Computer Interaction in the Internet of Things Era', 2015*

2.1 Applications

Applications for smart environments are manifold. To illustrate this we exemplify applications from four domains; these are: *smart homes*, *smart media devices*, *smart traffic systems* and *smart health*.

Smart homes can take off the task of regulating rooms heating and lighting by automatically adapting to environmental changes and peoples preferences. By concurrent monitoring energy prices they can help users saving energy resources and money alike [3, 4, 38]. Inhabitants of smart homes may get rid of shopping lists. The house is aware of available groceries and can notify users if foodstuffs are about to run out or about to expire. The house can recommend recipes for dinner that match the available ingredients. It can prevent its inhabitants from adverse fate for example by warning of problematic items in the washing machine [34]. Intelligent fire alarm systems that monitor smoke and concentration of carbon monoxide can give early warnings and inform the fire brigade and thus prevent people from serious harm [38]. Along with acting autonomously, smart homes allow their inhabitants remotely monitoring and controlling household appliances like cookers or washing machines via their smartphones. Smart monitoring applications send notifications to the smartphone in case of incidents like flooded basements [13, 38].

Smart media devices may change the way users experience audiovisual media. Intelligent consumer-electronic systems may start the playback of music of the users' favour when entering a room. The music may follow them when moving to other rooms. The system may recognise users singing a song and automatically start the playback of that song [34]. Atzori et al. [3] outline a scenario for a smart game room. The game is designed as a real-life jump-and-run game. Objects are automatically placed in the room. Users have to jump or crawl from one object to another without touching the floor. The room and the players are equipped with a number of sensors that capture data on location, movement, acceleration, humidity, temperature, noise, voice, visual information, heart rate and blood pressure to conclude on excitement and energy levels of the players. This information is used to control the level of difficulty of the game to maximise players' joy in the game.

Smart traffic systems could make traffic more secure and optimise traffic flow. From monitoring traffic they could capture traffic patterns, which than could be used for traffic planning and thus for avoidance of traffic jams. They could monitor the transportation of hazardous materials and implement mechanisms for collision avoidance [3]. Drivers could be notified of dangerous road conditions. Cars could drive entirely autonomous and make error-prone humans behind the wheel dispensable. Moreover autonomous cars would pave the way for visual impaired people to use individual traffic [13].

Smart health applications can help people living a healthy live and can assist people with serious diseases to a more independent live. Smart training machines in gyms could be fed with training schedules of a personal trainer. Users starting their workout are automatically recognised by the training machine. Health parameters are monitored during the training session and used to check whether the user is too strained or relaxed. The exercise profile can be adapted accordingly [3]. Smart tooth brushes can help maintaining dental health by capturing data on how users' brush their teeth. Data is forwarded to and analysed by the dentist who gives instructions for optimising oral hygiene [38]. Monitoring of health parameters can enable ad-hoc diagnosis and thus allow prompt provisioning of medical attention. Implantable devices can be used to store health records that can save lives in emergency situations for example for patients with diabetes, cancer, coronary, heart diseases or stroke [4].

2.2 Underlying technology

All of the above mentioned applications collect data about environments and their inhabitants. They process this data and react to it. Sensing, processing and reacting is done by devices in the environment. Nixon et al. [31] differentiate between four classes of devices: *fixed* or *mobile sensors* and *fixed* or *mobile computing* elements. Examples for fixed sensors are door and window sensors, thermostatic controls, RFID readers or CCTV cameras. Examples for mobile sensors are accelerometers and gyroscopes in smartphones or RFID tags. Fixed computing elements are desktop computers, smart TVs, servers, printers, coffee machines or air conditioners. Examples for mobile computing elements are notebooks, tablets, smart watches, smart wheelchairs, robots, vehicles.

These devices build a heterogeneous grid that is to sense environmental changes, to compute conclusions and to control a consistent behaviour of all subsequent actions. This can only be handled on the basis of a well organised infrastructure within a smart environment. Atzori et al. [3] propose a generic architecture for smart environments which they derived from a review of different works in the Internet of Things domain. An illustration of their layered approach is shown in Fig. 1. Basically, the architecture can be decomposed into three main layers, these are: *objects*, *middleware* and *applications*. At the bottom layer there are objects. Following Nixons classification these are sensors and computing devices. On the top layer there are applications that make use of the gathered data and expose certain functionalities to the users. The middleware abstracts details of different underlying technologies and thus eases the development of applications on a given infrastructure. The middleware follows a service-oriented architecture (SOA). A SOA allows decomposing complex monolithic systems into applications consisting of an echosystem of simpler and well-defined components (services).

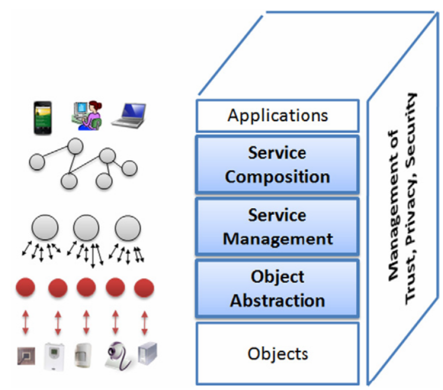


Fig. 1: Architecture of a Smart Environment [3]

Atzori et al. decompose the middleware into three organisational layers: *object abstraction*, *service management* and *service composition*. The service composition layer allows combining services offered by different networked objects. This layer is not aware of the actual objects but only of services. It provides a catalogue of currently connected services which are available for service composition. The service management layer provides lower-level services for object management like object discovery, status monitoring and configuration services. It also provides a service repository listing the services associated to objects. Object abstraction allows uniform access to devices. As depicted in in *Fig. 1* the middleware is also responsible for security management. The next subsection exemplifies security and privacy risks and thus stresses the need for reliable counter measures. It presents existing authentication mechanisms for preventing critical information from being accessed or altered by unauthorised users.

2.3 Security risks and counter measures

A report published by the Federal Trade Commission (FTC) [13] constitutes security risks in smart environments. In general they state exploits could harm users by:

1. Enabling unauthorized access and misuse of personal information.
2. Facilitating attacks on other systems.
3. Creating safety risks that affect physical safety of people.

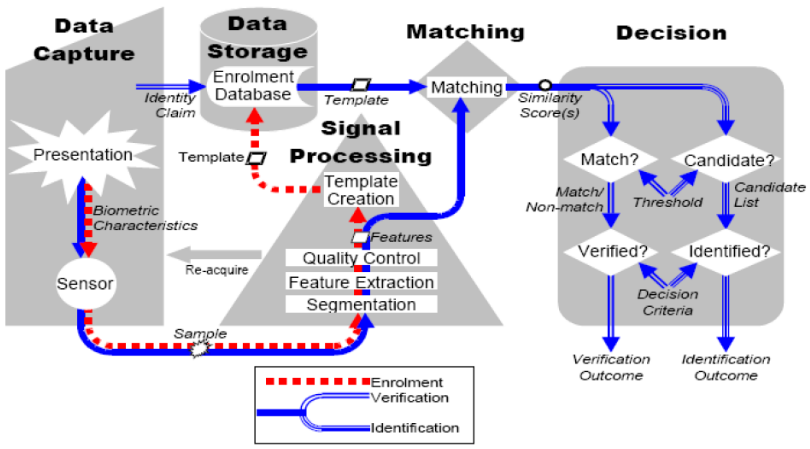


Fig. 2: Building blocks of the biometric system and their role in enrolment and identification or verification [1]

A possible threat scenario for 1 is a thief that has access to a households smart meters. Monitoring the energy consumption the thief can determine whether someone is at home or not. Some devices for example smart TVs may store sensitive financial account information or passwords. Exploits could facilitate theft or fraud of these information. 2 refers for example to distributed denial of service attacks which rely on a network of corrupted devices – the more devices under control the more effective the attack. Security vulnerabilities in the infrastructure of smart environments could enable attackers to assemble large numbers of devices to use in such attacks. A threat scenario for 3 could be an attacker that hacks into medical devices. The FTC report mentions a case where an attacker was able to take over the control of insulin pumps and change their settings such that they stopped delivering medicine.

To save users from the above mentioned risks, reliable security measures for smart environments are a crucial requirement. Different approaches are discussed in literature. Along with general consideration on information security, see for example Nixon et al. [31], there are approaches on authentication in smart environments. A general infrastructure for authentication and authorisation that abstracts from the actual authentication method has been proposed by Lee et al. [25]. Sidiqui et al. [36] combine authentication techniques based on ownership, knowledge and physical properties for authentication in smart environments. Their approach uses passwords (knowledge) typed into smartphones (ownership) equipped with fingerprint sensors (physical properties). A technique based on physical properties is described by Hansen et al. [16]. They introduce a computer-vision-based system that enables persistence of the authentication decision by constantly tracking the user. In the following we complement these findings with a survey on approaches that introduced behavioural biometrics for other user contexts. Later we will discuss how these techniques can be applied to smart environments.

3 Behavioral Biometrics

Classical authentication criteria analyse knowledge – *something you know*, ownership – *something you have* or physical properties – *something you are*. In many cases they require explicit actions by a user for authentication for example typing in a PIN code, holding a smart card to a card reader or pressing a finger on a dedicated sensor respectively. Behavioural biometrics look at *something you do* and *the way you do it*. The authentication process is entirely implicit, meaning the user does not need to execute dedicated actions. Behavioural biometrics can be used as a primary authentication method to replace authentication mechanisms based on knowledge, ownership or physical properties. In addition they can back-up these authentication methods [18]. As described by Jorgensen et al. [20] behavioural biometrics can be applied in two authentication scenarios which they refer to as *static* and *continuous*. In static scenarios users are verified at specific times – typically when a users logs in. In contrast in continuous scenarios users are verified throughout the whole session.

Fig. 2 describes the working principle of a biometric system as defined in ISO/IEC JTC1 SC37 [1]. This principle applies to the approaches on behavioural biometrics presented later in this section. Before a biometric system can assess users identities it needs to pass through the *enrolment phase*. This is when the system collects knowledge on individuals. This knowledge can be used for future *verification* and *identification* tasks. Verification is when the system assesses if an individual is the one it claims to be. Identification recognises known users. Tasks in the enrolment, verification or identification phases are assigned to different building blocks. The building blocks of a biometric system are:

- *Data Capture*: comprises sensors that capture data on biometric characteristics.
- *Signal Processing*: extracts significant features and maps them to a feature vector. In the enrolment phase it passes feature vectors to the data storage block. In the verification or identification phases it passes feature vectors to the Matching block.
- *Data Storage*: stores feature vectors for known individuals.
- *Matching*: compares incoming feature vectors to known feature vector and computes a similarity score. It passes the score to the decision block.
- *Decision*: matches the similarity score against pre-defined criteria and draws a conclusion (verification/identification) on the identity of the observed subject.

In *2 Smart Environments* we already outlined different classes of sensors present in smart environments. In a biometric system these devices are part of the data capturing block. The next section focuses on the signal processing block. We present examples for behavioural properties that can be used for identity verification and go into existing approaches for extraction of significant features from measured data. In *3.2 Multi-factor authentication* we present two approaches for decision making based on similarity scores from multiple authentication processes.

3.1 Signal Processing

In the following we present examples for behavioural biometrics. We divide these behavioural properties into two groups. The first group consists of properties that are captured while people are interacting with input devices like keyboards, computer mice or touch screens. The second group is build of properties that can be measured whilst people are doing things in an environment. We present behavioural biometrics that analyse peoples gait, the way they execute certain gestures and their motor-skills.

3.1.1 Interaction with input devices

There are a number of works that propose analysis of people's interaction with input devices to verify their identity. Below some basic ideas are presented.

Keystroke dynamics are used to verify users identities based on their typing behaviour on keyboards. Algorithms are build such that they do not require additional hardware, but rely on those features that can be measured from typing on a conventional keyboard. Typical features are illustrated in *Fig. 3*. Proposals for identity verification based on keystroke dynamics can be found in [10, 11, 19].

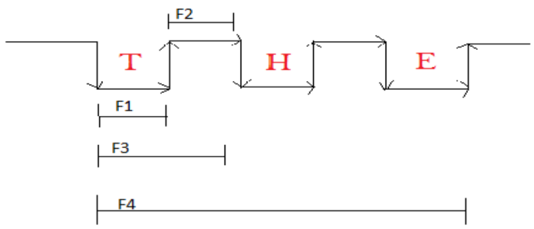


Fig. 3: Illustration of keystroke features extracted for the word "THE", where: F1 is the *duration*: the time between consecutive key presses, F2 is the *flight time*: the time between the release of one key and the press of the next key, F3 is the *diagraph time*: the the time between consecutive key presses and F4 is the *whole word duration*: the time it takes to type a certain word [11].

Mouse movement is analysed to authenticate users based on how they use a computer mouse. Jorgensen et al. [20] provide a survey on different mouse movement approaches. All reviewed approaches capture raw mouse events like move, button up/down. Each event may be associated with different attributes like timestamp, cursor coordinates and event type. Events are converted into higher level abstractions like point-and-click or drag-and-drop and the additional attributes associated with the low-level events are used to compute the direction, speed and curvature of movements. This preprocessed data provides the basis for the recognition of behavioural patterns.

Touch input behaviour as identity verification criterion has been proposed by a couple of recent works. Kolly at al. [24] analyse the pressure value of touch events that are returned by the Android operation system when a user touches elements in the user interface, for example buttons. They consider mean and maximal pressure of an event, point in time when the maximal pressure occurs, the minimal and the maximal pressure gradient, the hold time and the position of the event. This data is applied for continuous user identification and continuous detection of anomalies (an unauthorised user, for example a thief, makes use of the phone). De Luca et al. [12] use time series of X- and Y-coordinates, pressure and the size of the touch area for static identity verification. Event data is recorded during the execution of unlock gestures and compare it to pre-recorded time sequences. Burgbacher et al. [6] use the same features for continuous authentication of users based on word gestures on a virtual keyboard. Buschek et al. [7] combined working principles for analysis keystroke dynamic (duration, flight time etc.) and touch input behaviour (X- and Y-coordinates, pressure etc.) to verify users based on their typing behaviour on virtual keyboards. Bo et al. [5] assume a dependence between the touch behaviour and the application a subject is currently using. Moreover their feature vector considers the event type (tap, scroll, fling) and micro-movements of the device cause by the users physical interaction, see *Fig. 4*.

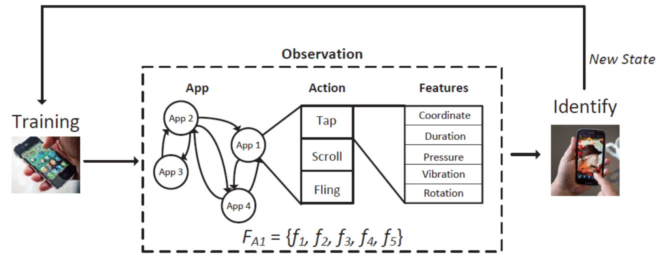


Fig. 4: Combining touch input behaviour with micro-movements and application usage [5]

3.1.2 Interaction with environment

Along with above mentioned techniques, there are approaches that implicitly authenticate identities without needing them to explicitly interact with an input device. These approaches especially analyse patterns of how people behave in an environment.

Gait, the way one walks, is assumed to be unique to individuals by a number of works using gait as a feature for identity verification. Lee et al. [26] propose a *computer vision* based method for gait recognition. Fig. 5 illustrates the first steps of their algorithm. The first step segments the walking person from the background and extracts its silhouette. The second step divides the silhouette into seven regions. In a third step an ellipse is fit to each of the foreground regions of the seven segments. The temporal change of the characteristics of the ellipses (centroid, aspect ratio of major and minor axis and orientation of the major axis) are subsequently used as features for the assessment. Their approach is restricted to canonical view of a walking person which is perpendicular to the direction of walk. A similar but more elaborate approach has been described in [39].

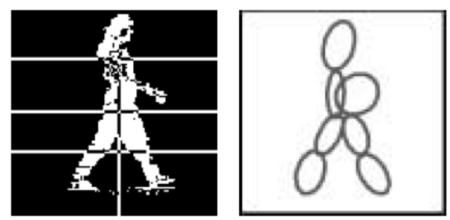


Fig. 5: Gait recognition based on computer vision: Silhouette of the person divided into seven regions (left); ellipses fitted to each region (right) [26]. Temporal changes of the characteristics of the ellipses (centroid, aspect ratio of major and minor axis and orientation of the major axis) are used for identity verification.

Nickel et al. [30] use *accelerator data of mobile devices* for gait recognition. First the captured three dimensional sensor data is preprocessed. Linear interpolation is used to fit the data to a fixed sampling rate which is necessary for subsequent comparison of data sets. Resulting time sequences get normalised by subtracting the mean value of the respective dimension from each sample value. After this the data sets are segmented by rectangular windows. Each segment is represented by a feature vector of different statistical features like mean, minimal and maximal value, binned distribution, root mean squared acceleration. The feature vector is complemented by spectral representations of the acceleration signal segments and subsequently used for identity verification.

As already mentioned in the Introduction, Orr et al. [32] propose the "*Smart Floor*" which uses gait recognition identify inhabitants of the Aware Home. *Sensors in the floor* measure the ground reaction force caused by footsteps. *Fig. 6* shows a time sequence of force values measured for one footstep. Statistical analysis of the measured time sequences result in a ten-dimensional feature vector for classification. Features include: mean value, standard deviation, length, area under the curve, coordinates of curves maxima, coordinate of the minimum between the maxima.

Gesture. The ability to detect *what* gestures people execute holds a huge potential for human-computer interaction. Research in gesture recognition is not a new discipline and has produced mature results [14, 28, 33]. Different works in the field of behavioural biometrics approach analysing *how* people execute gestures for implicit authentication. Hayashi et al. [17] propose a method for authenticating users based on the way they wave, see *Fig. 7(a)*. In fact they combine

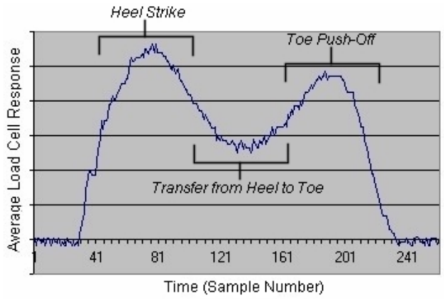
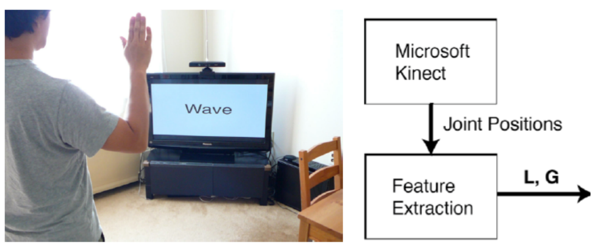


Fig. 6: Gait recognition based on pressure sensors in the floor: time sequence of force values measured for one footstep [32]

physiological and behavioural properties. They use three dimensional spatial information captured with a Microsoft Kinect to collect data on the length of the users' body segments and trajectories of three-dimensional positions of the users' joints. Build two feature vectors – the body length vector and the gesture vector, see *Fig. 7(b)*. Both vectors are concatenated and used for subsequent classification.



(a) User in front of display and Kinect executing a wave gesture

(b) Extraction of feature vectors from Kinect images

Fig. 7: Authentication based on waving behaviour with Kinect [17]

A similar solution has been proposed by Gomez-Caballero et al. [15]. They use three dimensional spatial information captured with a TOF camera to extract the position of characteristic landmarks on the users body. The feature vector for classification is build on the landmark positions.

Motor skill. In [42] Yampolskiy et al. overview a class of behavioural properties which they refer to as motor-skill behavioural biometrics. They define motor-skill behavioural biometrics as being "[...] *those biometrics which are based on innate, unique and stable muscle actions of the user while performing a particular task* [...]". Along with those properties described in this section they identify: *Blinking*, *Dynamic facial features*, *Handgrip*, *Haptic* and *Lip movement*.

3.2 Multi-factor authentication

Mobile devices comprise a number of sensors which provide information on different behavioural properties. This encouraged research on implicit authentication of users of mobile devices to find solutions for combining results from different authentication processes. Below we present two of them.

Tanviruzzaman et al. [37] propose assessment of scores obtained from the feature matching process by a central decision module. The decision module maintains threshold values for scores for each matching process. Thresholds are compared to values from the respective the matching processes. If one of the values is less than the threshold security checking gets more stringent or the checking may go one level up, for example by asking the user to explicitly authenticate with a password. The approach is illustrated in *Fig. 8*.

Shi et al. [35] present an approach for combining authentication scores from the assessment of different statistically independent behavioural features. They assume that certain actions of a user have a temporal relation – peoples daily or weekly routines follow certain pat-

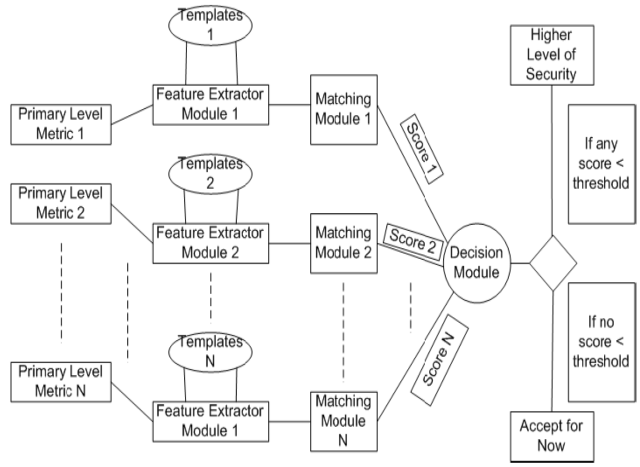


Fig. 8: Combining different similarity scores: if one of the similarity scores falls below a certain threshold the decision module security checking gets more stringent or the checking may go one level up [37].

terns. For example users with an office job would write more emails in the time between 9am and 5pm on a working day than they would do on a Saturday night. Behavioural features are modelled as random variables V. Their user model U is a combination of the k probability density function conditioned on the variable $T =$ (time of the day, day of the week):

$$U := [p(V_1|T), p(V_2|T), ..., p(V_k|T)] \tag{1}$$

Probability density functions are estimated in the enrolment phase of the authentication system. During the detection phase the system records measurements v of the features V at time t. The similarity score S corresponds the probability that equals the product of the probabilities of the individual measurements:

$$S := p(v_1|t) \cdot (v_2|t) \cdot \ldots \cdot (v_k|t) \tag{2}$$

4 Discussion

The above sections overviewed the general constitution of smart environments and different approaches to quantify and evaluate people's behavioural traits for identity verification. In the following we discuss how behavioural biometrics can be used for authenticating users in smart environments and go over their benefits compared to explicit authentication mechanisms. Section *4.2* outlines conceptual and technological gaps to be addressed by future research.

4.1 Behavioural Biometrics in Smart Environments

In the following we discuss the applicability of behavioural biometrics for smart environments. Therefore we will focus on answering two questions. These are:

1. How do behavioural biometrics fit the technological set-up of smart environments?
2. What are the benefits of behavioural biometrics in smart environments over other authentication methods?

Question 1 has two main facets. The first is: can behavioural biometrics be implemented on the available infrastructure? Part of this question is: does the technical basis of a smart environment fit the needs of the biometric system? Comparing the general architecture of smart environments depicted in *Fig. 1* and the working principles of the biometric system illustrated in *Fig. 2*, one can make out certain commonalities. Both use sensors as providers of data that is further processed for decision making. Along with sensor data, the upper layers in the architecture of smart environments abstract from individual devices and aggregate computing and memory resources. These resources are needed for storage of feature templates and signal processing, matching and decision making processes in the biometric system. The smart environment provides everything the biometric system needs to work.

Another objective of the first facet is: which techniques can be employed on the basis of available sensing devices? Tabs, pads and boards play a central role in Marc Weisers Ubicomp vision [40]. With the exception that these devices are not foreseen to be personal devices, but rather common goods that constantly change their possessors, they are similar to nowadays smartphones, tablet PCs and touch tables respectively. The approaches presented in *3.1* provide a set of facilities to authenticate individuals on these kind of devices. Analysis of touch input is applicable to all of these devices. Gait recognition based on motion-sensor data as presented by Nickel et al. [30] is an interesting approach to use smartphones (or tabs) to verify users when not explicitly interacting with the device. Moreover, it is likely that fixed desktop computers equipped with keyboard and mouse will still play a role in clerical work in future. Hence, analysis of keystroke dynamics and mouse movement holds a potential for implicit authentication in smart environments. Fixed sensors for motion capturing in game consoles or video cameras of CCTV systems as well as mobile sensors that people carry with them, for example in intelligent clothes [27], could be use for gait, gesture or motor-skill analysis. Moreover there maybe additional hardware dedicated to unobtrusive authentication like pressure sensors in the floor for gait recognition as proposed by Orr et al. [32].

The second facet of the question 1 is: can the techniques for behavioural-biometrics-based authentication even profit from the technological set-up within the smart environment? The approaches for multi-factor authentication presented in *3.2* are abstract of the computing environment or the source of measured data. Their applicability is not restricted to authentication on mobile devices and can be used in smart environments. The abundance of information from a variety of sensors smart environments can make authentication decisions even more reliable.

In the *Introduction* we posed a couple questions. Answers to these questions also provide answers to question 2. The first question from the introduction was: how can people be authenticated in a smart environment (on devices with restricted input methods)? Behavioural biometrics can supersede knowledge-based authentication mechanisms that require input methods for PIN codes or passwords. Behavioural biometrics with short detection time like the wave system proposed by Hayashi et al. [17] could, after a certain training time, also be used for ad-hoc authentication. Karelsky et al. [21] conducted an elicitation study on gestures people would use for a door to open. As a byproduct, they found that people feel more convenient with using a gesture than with using a key card to open the door. This shows that even if the authentication mechanism requires a certain (explicit) action, behavioural biometrics can help improving the user experience.

The second question from the introduction was: when do people have to be authenticated? Static behavioural biometrics can be used to authenticate users at the beginning of a user session, for example when they enter the environment. These mechanisms have a short detection period and are able to back-up explicit authentication mechanisms or replace them. Behavioural biometrics for continuous authentication can be used to unobtrusively verify the users identity throughout a session and thus achieve a single-sign-on behaviour [29].

Along with making authentication mechanisms more reliable and usable, behavioural biometrics could also help improving the whole information security system. Yampolskiy [43, 44] where able to detect malicious artificially intelligent software agents by modelling behaviour trusted users and anomaly detection mechanisms.

4.2 Open research questions

As outlined above behavioural biometrics hold a huge potential for improving reliability and usability of authentication mechanisms in smart environments. However, questions remain open. These are:

1. Which behavioural biometric is the most reliable one?
2. How can existing approaches adapted to other device classes?
3. How can the privacy of the inhabitants of a smart environment be preserved?

Question 1 addresses the issue that it is hard to compare different behavioural biometrics. Reported evaluations differ with regard to different aspects. Training and test data sets differ with regard to the amount of data, source of the data or the way the data was recorded. Approaches use different training and detection times. Moreover studies use different indicators to asses the performance of the approaches under review. Khan et al. [22] proposed performance criteria for evaluating behavioural biometrics on smartphones. They also used a common dataset recorded by 300 participants to evaluate conceptually different authentication approaches (gait, touch, keystroke). They open sourced that data to provide a common benchmark to other research in that domain. A challenge for future research is seen in the provision a similar performance evaluation framework. The framework should cover common performance criteria and a standardised data set that allows comparative assessment of behavioural biometrics that differ in the features they analyse and sensors they use.

The behavioural biometrics presented in *3.1* are designed for specific devices and sensors. Smart environments of the future will be equipped with new kinds of devices like smart clothes. Question 2 addresses research and development work needed to transfer and adapt existing knowledge to these devices to utilise upcoming sensing capabilities to their full potential.

Question 3 addresses not a technical problem, but rather a conceptual one. Where will peoples' profiles be stored? Who owns that data? In their above mentioned report, the FTC states that sensors in nowadays smartphones provide sufficient information to make out peoples mood, stress levels, personality type, bipolar disorder, demographics (e.g. gender, marital status, job status, age), smoking habits, overall well-being, progression of Parkinsons disease, sleep patterns, happiness, levels of exercise, types of physical activity or movement. They mention that this information could be misused by companies to make decisions on credits, insurances or employments [13]. As these examples show, an answer to the question where is our data stored and who keeps it for us is of outmost importance. In their considerations on implicit authentication on mobile devices Jacobsson et al. [18] identify two potential locations where the authentication decision could be made: on the device or in the cloud. Assessment on the device comes with the full control of the users over their data. A drawback of this approach is that mobile devices have restricted resources with regard computing power, energy and might deliver weaker results. Moreover the approach seems hardly applicable to smart environments where different devices share the responsibility of verifying users' identities. How can a consistent state be guaranteed without a central control unit. Outsourcing identity assessment to the cloud comes with more computing power, lower restrictions with regards to memory and energy and thus more data that can be considered. On the other hand users loose control over their data. Future research needs to target at solving this dilemma.

5 Conclusion

We studied behavioural biometrics as a mean to authenticate users' in smart environments. Therefore we investigated the nature of smart environments: the spectrum of applications, the technological groundwork and risks for information security. We surveyed two groups of behavioural biometrics: one analysing people's interaction with input devices (keystroke dynamics, mouse movements and touch input behaviour) and one analysing people's actions in environments (gait, gesture and motor-skills). Moreover we overviewed two approaches for combining different authentication scores to a single authentication decision.

On that basis we discussed the applicability of behavioural biometrics for smart environments. We found that, in principle, smart environments provide all technological means behavioural biometrics need to work. Different sensors all over a smart environment collect data on different behavioural characteristics that can be aggregated to compute reliable authentication decisions. Moreover we conclude from different reports in literature that behavioural biometrics can help making authentication mechanisms more usable.

We see potential for future work in research in a standardised evaluation framework that provides common benchmarks for behavioural biometrics. This would allow a fair comparison of different approaches. It would help people in charge of information security management in smart environments designing authentication systems and picking the right authentication techniques for their purposes. A major challenge is seen in solving privacy issues. Behavioural biometrics rely on data that is unique to the respective user and contains precise profiles of their actions. Satisfying answers on where this data is stored, who owns it and how can users keep control over it need to be addressed before behavioural biometrics can be used in the fields.

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