JoyTilt: Between Autonomy and Control of a Robot Vacuum Cleaner

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ABSTRACT

Domestic IoT appliances like smart speakers, smart locks and robot vacuum cleaners are usually connected, monitored and controlled via smartphone apps. Despite the rich number of sensors and actuators available in smartphones, these apps primarily provide graphical user interfaces with these appliances. To explore a more somatically engaging experience the prototype JoyTilt was designed. It is a tilt-based remote control for robotic vacuum cleaners that was developed and tested with users. JoyTilt enabled participants to have their gaze focused on the robotic vacuum cleaner while controlling it. Interviews with the participants provide suggestions for balancing control of robot vacuum cleaners while keeping the robot's autonomy. In this study the somaesthetics, the interactive materials and choice of interaction model come together in the design to shape the human-robot relationship. Lastly, the study highlights the values of further considering the bodily experience when designing apps.

CCS CONCEPTS

• Human-centered computing~Human computer interaction (HCI)~Interaction techniques~Gestural input

KEYWORDS

Domestic robots; Embodied Design; Gestures; Human-IoT experiences.

1 INTRODUCTION

An increasingly common way of interacting with the world around us is through applications on smartphones [1]. Being mostly associated with their tiny graphical interfaces [3], it is also well known that smartphones include a rich set of motion sensors, light sensors and sound detection, along with auditory and haptic feedback, which could provide very different experiences. Although smartphones contain these sensors and more, they are rarely used to communicate with smart appliances in your home. Development of apps is also still bound to the desktop paradigm in its focus on the visual and clickable interaction and user flow as they are typically shaped in desktop settings.

The bodily experience of mobile apps are largely disregarded in app development today, in particular when it comes to apps used to control and interact with autonomous or semi-autonomous devices in IoT settings. To explore this topic an exploratory design of playful interactions with the robot vacuum cleaner Pure i9 from Electrolux was conducted. The explorations resulted in the prototype JoyTilt that enables users to control the robot vacuum cleaner by tilting a phone. The study was conducted at Electrolux in the Consumer Experience Software Team for air purifiers and robot vacuum cleaners.

This study aimed at creating a connected physical experience rather than the normal smartphone application standard of visual experience. We propose an aesthetic quality in designing that type of experience, focusing on a connected experience with a physical appliance being just that - physical. This study highlights how JoyTilt enabled users to keep their gaze on the robot while controlling it. The study also found that JoyTilt provides a way of temporarily taking control over the autonomous robot when it misses some dirt or needs help getting past an obstacle. The design was engaging, created a somatically connected experience and opened a space for further ideation.

2 BACKGROUND

Robot vacuum cleaners are tools for vacuuming our floors, but also a social part of the households they are in. By naming the vacuums, talking to them and videotaping our pets riding on them we are welcoming them to take part in the more playful and social activities in the home. The robot is perhaps acquired for cleaning your home, but also blends into the varying social contexts they are put in. Another social practice is personalizing technology by putting stickers or clothing on it that was studied in [9]. The robot vacuum cleaner is thus adopted both as a cleaning tool and as an object for playing.

Interaction with technology shapes the way people move and how they feel. Different user interfaces and interactions change not only the users "mental models", but also their behaviors and experiences. For instance, it is well known that interaction with a graphical interface differs from interactions with text-based interfaces or command-line interfaces [17], and that graphical interfaces do not offer the same bodily engagement as physical interfaces. However, smartphones allow interaction far beyond the graphical interface. Because of the physical nature of domestic appliances, it makes sense to explore more physically rich interfaces for IoT at home.

2.1 Socializing with autonomous robots

How to control autonomous robots as well as the ethical considerations when designing that type of physical experience is studied in [7]. That study examined an artists' process of learning how drones work, adapting their behavior to work with the artist and designing drone behavior for an opera performance. The method used was close analysis of recorded video of the choreographer and the dancer as well as other observations around the design process. Eriksson et.al describe how the drones are following the dancer's movements, but that it is important for their purpose of being expressive that they retain some autonomy. They conclude that as a designer you have to take into consideration how your design has an impact on the user's movement in the space and their behavior towards others. With a domestic robot like a robotic vacuum cleaner this interaction shapes everyday life, other people and pets in a very direct way.

Many studies have investigated the user's relationship and interaction with robotic vacuum cleaners at home and its long-term development [19, 20]. The studies show in which ways the robot changes the users' cleaning behavior and how the family dynamics around cleaning shift. In an ethnographic study on the long-term use of robot vacuum cleaners [11] the robot changes cleaning from an activity performed mainly by a single person in the household to concern everyone.

While it is important to consider how robot design influences the social context in a household it is also important to consider the human-robot relationship. There is an ethical consideration in how the owner feels about the appliance and how they treat it. Human-robot collaboration and human control of robots facilitates empathy for the robot [23].

2.2 Autonomy and Control

Having user input in the phone using tilting and the feedback in the robot moving provides a separation of input and output. This enables the user to keep their focus on the robot and its context when navigating because they do not need to use their gaze for input. The design is providing a multimodal way of controlling the robot [21]. Multimodal feedback in communication with robots, in this case drones, is also explored in a recent study [16]. That study found that the mechanical sound from the propellers on the drone provided feedback on how smooth the user's movements were. Additionally, it found that the participants in the study took some time to learn the movements. Therefore, the movements were introduced one dimension at a time and the design suggestion for these types of systems is to keep the mapping simple but leave room for learning and skill development.

Controlling robot vacuum cleaners using gestures detected by a smartwatch has been examined in [6]. The gestures in that experiment were chosen based on how well they map to the gestures used to control a car. Because the robot vacuum has wheels the designers assumed the gestures of driving a car would map well to the gestures for controlling a robot on wheels. This might be a good starting point for designing an interface. However, the notion that there are natural interfaces has been refuted [18]. To test the gestures an experiment was conducted where the participants were asked to follow a path drawn on the floor. The study found that the participants perceived that they had an easy time navigating using gestures, even though they were visibly struggling performing the task. The discrepancy between the actual experience and self-reporting motivates a video analysis of the interaction design proposed in this study.

Tilting has been used as an alternative to inaccessible interactions in [4,13, 24]. In [13] a tilting motion was used to set the color of led lights. The Press & Tilt method has been studied in [2, 24] as an alternative for people with disabilities. Motion has also been used in game controllers with examples like Nintendo Wii [22] getting motion control into the mainstream in 2006. The latest Nintendo Switch [22] from 2020 has a built-in gyroscope and accelerometer for using tilting as user input. It is also a common interaction in games using smartphones.

3 METHODS

The project was conducted based on a constructive design research approach [15]. Below is an overview of the methods involved in this process.

3.1 User Survey

A user survey of 2534 participants from around the world was analysed and used as inspiration for the design. The survey provided an introduction to the users' perspective on the product, their use cases and pain points, and highlighted aspects that users found confusing about the robots movement, and also some creative ideas for solutions. Some of the comments confirmed the hypothesis that users want to help the robot to find its way around the house and a few users explicitly requested control of the robot as if it was an RC car, as exemplified by this quote:

"I want to be able to control the robot like a toy car".

3.2 Technical Setup

The developed system was built on top of an existing interface that enabled remote control using on-screen buttons on a PC, enabling the robot to go forwards or backward and turn slightly left or right at the same time and spin on its own axis left or right. With this interface an exploratory process began with the goal to use smartphone sensors for controlling the robot. Because of technical and legal regulations, we were not allowed to connect the app directly to the robot, instead the phone had to be connected to the PC using a USB cord during all the prototype- and testing phases.

3.3 Mapping of Gestures

The mapping of gestures with robot movements was informed by conducting hands-only inspired experiments [5], along with the designer/developer's first-person perspective [14] of the prototypes. The playfulness in treating the vacuum as a toy car along with an interest in exploring somatically engaging interactions informed the choice to use tilting for controlling the robot.

A participatory design approach was used for ideation on how to make the mapping between gestures and robotic movement. Three participants from a family that have a robot vacuum cleaner were recruited to conduct a short and informal variant of a hands-only experiment. The participants were asked to use their phones (in standby mode) to show how they would make a robot go in different directions if the robot would be able to sense the phone. These experiments resulted in the insight that the users would expect the robot to sense and follow the direction that the phone is pointed to. Two of the users used swiping motions using their whole arm to send the robot in different directions.

The swiping gesture was tested and implemented in an iterative design process. In developing the gesture an objective was to keep the acceleration required to move the robot to a minimum. This metric was leveraged against the acceleration that was generated by moving the phone back to the starting position. When the gesture was fully implemented using accelerometer data from the phone, the movement felt a bit strained. Using first-person perspective, it was decided to change the mapping to involve an easier movement. Instead, the mapping was changed to involve the gyroscope using a tilting motion. This interaction felt casual compared to the more physically taxing almost throwing motion using accelerometers.

3.4 User testing

An experiment was designed to evaluate the bodily experience and open up a physical design space for further ideation around app designs for IoT devices at Electrolux. The test was set up as a comparison between JoyTilt and the existing Spot Cleaning functionality. When using spot cleaning, users physically pick up their robot, press a button and it starts cleaning in an area of 1 square meter around it. Joytilt could thus be seen as an alternative and app-connected functionality.

For the test 10 participants (6 male, 4 female, age range 25-50) were recruited among peer students and colleagues at KTH and at the office where the experiments took place.

Participant selection was limited due to COVID-19. The test consisted of 3 parts. Firstly, the participants vacuumed rice off the floor using spot cleaning. Secondly, they used JoyTilt to achieve the same result. Thirdly, the participants evaluated both experiences on a five-point scale based on four parameters; playfulness, easiness, efficiency, enjoyment. These parameters were chosen to reflect and discuss aspects of user experience. Overall, JoyTilt received better scoring in all aspects, except easiness. JoyTilt was perceived as more efficient (3.9), playful (4.6) and enjoyable (2,6) for the users.

The scoring was used as a conversation point to gather the participants' opinions about each system. Therefore the participants were asked to motivate their rating while filling out the form. This method of gathering context for the ranking of a novel experience was used in a similar way in [12]. The participants were then asked if they could think of use cases for the two functionalities, if they had not discussed this during the experiment. Additionally, they were asked to reimagine JoyTilt and show how they would design the control of the robot, mimicking the hands-only experiment done in the design stage.

Figure 1: Image of the floor as staged for the user testing. Framed as a playful navigation task, the tape represents walls for the user to navigate the robot around, with the goal of vacuuming all the rice thrown on the floor.

Since the test situation was highly experimental and artificial, the participants were asked to imagine a "real" scenario where they would use it. Additionally, some obstacles were placed in the space, to add meaning and challenge to the task, in a sense imitating some features in a real context. Note that the focus here was on the interface. The experiment was set up as a framework for testing the design, and not the entire socio-physical context that the system was designed for.

For analyzing the experiment video analysis was used. By closely studying the participants interacting with JoyTilt in video recordings and listening to what they said information on their bodily experience was revealed. This approach allows us to see and hear what the users expressed during the experiments and compare that to the self-reported experiences.

4 RESULTS AND DISCUSSION

4.1 Attention, Gaze and Posture

Gaze is an important indicator of attention and allows for observing a person's intention and emotion [8]. Therefore, understanding gaze is an important social skill that humans use to understand each other. During the experiments the participants were focused on the interaction with JoyTilt and were looking at the robot while answering the experimenter's questions. Sometimes they would pause in the middle of a sentence to change the robot´s direction before continuing talking about their experience. All participants had their gaze focused on the robot when testing JoyTilt, except for some glances on the phone. Due to the preservation of anonymity, it is not possible to show images of the participants' gaze. However, you can tell by the way the phone is positioned in relation to the participants' bodies in Figures 2-12 that they are not looking at the phone. In Figure 13 the participant is looking at the phone.

4.2 Bodily sensation

Five participants had a relaxed stance (Figures 2, 3, 4, 5) and used small movements in their wrists to control the robot. Notice how only the hands are moving and the body stays in the same position. These participants stood completely still during the experiment, with gaze focusing on the robot. Three of them reported that they perceived controlling the robot to be easy, while the other two said it was hard.

Figures 2, 3, 4, 5: Participant during the experiment using JoyTilt with a relaxed posture, their gaze on the robot vacuum cleaner and moving only their hand to control the robot vacuum cleaner.

Three of the participants had a more tense stance and looked less comfortable while controlling the robot (Figures 6, 7, 8, 9). This group also stood still and made small movements with their hands to control the robot while the rest of the body was still, gaze focused on the robot. The tense stance made it look like the participants put a lot of effort into controlling the robot. It looked almost like they were ready to perform a high-intensity bodily movement. Below is a quote from one of these participants talking about the experience:

"I'm forced to be in a certain position with my hand. I'm adjusting my posture to where the phone is. If I could do this in a more relaxed mode where I choose the angle, then that would be better. Right now I feel a little cramped. [...] It is the technology telling me what to do rather than me using the technology..."

In this group all participants said that they thought controlling the robot was easy, however they had suggestions for improving the interaction.

Two of the participants used their whole bodies to control the robot. They both reported that they would be walking around while controlling it if it were not for the cord that was plugged into the phone. One of these participants looked tense at the beginning, but relaxed and started making larger movements as they became more comfortable with using JoyTilt (Figures 10, 11, 12, 13). These participants gave a high score in easiness and said that they found JoyTilt easy to use.

Figures 6, 7, 8, 9: Participant during the experiment using JoyTilt with a tense posture, their gaze on the robot vacuum cleaner and moving only their hand to control the robot vacuum cleaner.

In Figures 2-13, you can tell by the position of the shoulders and feet that the participant was changing their stance and body position as they were controlling the robot. One of these participants had expressed skepticism towards mobile interaction with a physical product like the robot vacuum cleaner. When they were asked to talk about how playful they thought JoyTilt was they said that the interaction was so physical that they forgot that they were using a phone.

"You forget that you use the mobile phone"

This result indicates that there are experiences, not associated with using a phone, that were still facilitated by a phone.

4.3 Mapping of movements

When asked how to map gestures to robot movement almost all participants had a unique design suggestion. However, some common themes were discerned. The participants that used their whole body when controlling the robot suggested ways of controlling the robot that did not involve a phone. One suggested placing the phone on your body and mapping movements to tilting their whole body. Four of the participants were either happy with the design and would not change it or suggested some variation of tilting the phone. Three participants suggested using a joystick instead of a phone in different ways.

One participant commented on the backwards motion when using JoyTilt.

"It is ok for the backwards motion to be awkward because I don't think I would use it a lot"

Five of the participants had issues with overcompensation when they perceived the robot did not obey their gestures, e.g. tilting the phone beyond the threshold where the phone recognizes it. Some participants would proceed to speak to the robot when it did not do what they expected. When the participant started overcompensating, they were informed that the robot does not listen to exaggerated movements.

Figures 10, 11, 12, 13: Participant during the experiment using JoyTilt using their whole body to control the robot vacuum cleaner.

4.4 Effort

All participants were able to use JoyTilt and collect all the rice. However, two participants had some issues and took longer to get all grains of rice. Both of these participants were determined to get all grains off the floor. While all participants except two performed the task without any problems controlling the robot, out of these eight, four participants brought up suggestions for improvement. In this group, two participants described the interaction as mentally taxing in a negative way. The remaining four participants described the interaction as easy. In [6] as well as in this the experimenters noted a discrepancy between the self-reported effort and the way it looked. This shows the importance of using triangulation when evaluating an interaction. By gathering data from different perspectives we are able to validate results and expose contradictions.

The outside perspective on the interaction here appears to paint a brighter picture than the scoring by the test participants. How the interaction is perceived is key in judging an interaction, and should not be taken lightly. The struggling reflected in the self-reporting ties in with the feelings of mental strain or immersiveness that was expressed during the experiments. In the experiments all participants appeared focused on the task of vacuuming the rice and they were busy doing that, but they described the experience in different ways. While some expressed enthusiasm about being so immersed they developed connections with the robot or felt like they were controlling the robot without a smartphone interface, others reported a more negative feeling. They looked as immersed during the experiment, but said that the interaction was mentally taxing. What might be the difference between the felt experiences? Is it the mindset? As expressed in the below quote, it also depends on what moment in the experience we are referring to:

"Once you get the hang of it, it's pretty easy"

All this highlights the challenges of analyzing the user experiences of others.

4.5 Playfulness and Novelty

All participants stated that they found the remote-control functionality very playful, especially compared to the existing Spot cleaning function. This is apparent in the scores where Spot cleaning got an average of 1,7 in contrast to JoyTilt that received an average of 4,6. While all participants perceived the interaction as playful, three participants said that they suspect that there was an element of novelty contributing to the fun. To design for long-term engagement with robots is a known design challenge [10]. This issue could be examined by making a long-term study with JoyTilt, and also by including a more varied group of testers (i.e. children). That type of experiment would require more robust implementation and a lot more time, therefore we can only speculate about long-term usage. Previous long-term studies show that using robot vacuum cleaners becomes routine and that it serves more as a tool when the novelty wears off after the initial phases of users adopting and adapting the robot to their home [20]. That might be an indication that engagement with JoyTilt would be perceived as just another utility, rather than an enriching interaction.

4.6 Utility

In the experiment, JoyTilt was tested as an app alternative to Spot cleaning. Seven participants agreed that JoyTilt would make a good alternative to that function, as a quicker way to clean a spot. However, six participants said that navigating from the station to the spot was impractical. They would prefer to either carry the robot to the spot and then use JoyTilt, or to be able to increase the speed for getting to the spot. It should be noted that the station was only a few meters from the spot during the experiments, meaning that this might be even more of an issue in a typical home setting. To account for this problem, address the question of novelty, and to assess usability further JoyTilt should be tested in a home environment, preferably over a longer period of time. This was not possible because of the technical limitations of this study and the restrictions imposed on social activities due to Covid-19.

A use case that was brought up by 3 participants during the experiments was the ability to override the robot path. A known problem is that sometimes the robot does not find its way to all corners or rooms, or it misses to pick up some dirt. The participants thought it would be a good idea to use the functionality of Joy Tilt to let the user override the robot's path in such situations. This way of interacting with the robot would give the user the freedom to choose when they want control and when they want the robot to clean on its own. This is a suggestion for combining control of the robot with the robot being autonomous which is the theme of the papers about drone control [7, 16].

For further development of JoyTilt more nuanced controls of the robot should be introduced so that there is a possibility to get more control, but also develop mastery in controlling the robot [16]. There is also room for letting the robot be more independent, in line with the sentiment expressed in [7]. So that the robot does not become a "slave". However, this should be investigated further before deciding that independence is a desired feature, the robot vacuum cleaner is after all first and foremost a tool.

4.7 Social context

Two of the participants reflected on their relationship with the robot. One said that normally the robot would do its own thing and that they would be frustrated with the robot if it did not do what they expected or wanted. If it would miss a spot they would even shout at it. During the experiment, they said that it felt like they were collaborating with the robot and that they felt responsible for its actions because they were in control. They said they felt like the cleaning was a collaboration between them and the robot. The other one reflected on their relationship not being good during the times when they are at home during the day.

"Sometimes I shout at it [the robot at home]: 'Why don't you go to the sofa!' [...] This feels quite nice, because usually it's doing its thing and I'm doing my thing and I just shout at it. But now I feel like I can get in there, I feel responsible for it I guess." "You feel responsible for it?" "Yea, yea! I feel responsible because now I'm directing it, right!"

This suggests that JoyTilt provides a more intimate connection between the user and the robot, facilitating some of the responsibility that makes a person bond with an inanimate object [23]. Perhaps JoyTilt would then not be perceived as an annoying feature.

Three participants talked about the robot in a social context with multiple people involved. If this project were to be developed further it would be interesting to let multiple users collaboratively control the robot. It is possible that a multiuser scenario facilitates other types of playful interactions and provides insights about the robot vacuum cleaner as a social player.

As described in this study, in the design of JoyTilt a first-person perspective was used to inform the design choices. Because there was some time to get to know the robot, a sense of how it behaves and what its aesthetics are were obtained. The robot's movements are slow and systematic when it goes around cleaning. It vacuums the corners very carefully and it puts care into the decision to go into another room. By pausing, looking around, and when it is decided, speeding up to make it over the doorsill it gives a sense of care for its job. It can be described as a gentle robot. The aesthetics of the robot are reflected in JoyTilt because tilting is a gentle interaction.

5 CONCLUSION

A mode of gesture-based interaction with robot vacuum cleaners through app design was tested in the prototype JoyTilt. The social role of the robot vacuum cleaner and the control of it as well as its autonomy was discussed. A possible way of balancing autonomy and control was discovered as a way to take over the control of the autonomous robot while it is on its cleaning path.

Three types of physical stances were identified in the participant group, two types of still and one mobile stance. The still stances were either tense or relaxed, and moving only the hand holding the smartphone. All participants kept their gaze on the robot while controlling it. Most participants were happy with the gestures and the design sparked new ideas for other types of interfaces for controlling the robot. This design provides the use-case of overriding the robot's path to get to places that the robot does not reach on its own. The design was viewed as playful by the participants, however, parts of this was probably due to novelty. The robot-human relationship was brought up during the evaluation in reflections on the users' feelings towards the robot, in which the gentle gestures of control provided by JoyTilt could have a positive effect.

In the field of designing mobile apps for IoT contexts, the physical experience of using a mobile phone is often overlooked, with focus placed either on graphical interfaces alone, or on other, more novel gadgets or modes of interaction (e.g. voice assistants). Our study instead proposes that we continue the exploration of the mobile phone as a physical interface for communicating with everyday things.

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