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New directions for pervasive computing in logistics

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Abstract

This paper investigates the new trends in the field of "pervasive" or "ubiquitous" computing in logistics. Over the past two decades, research challenges in pervasive computing have evolved following the rapid progress of information and communication technology. Researchers are working to create an "Internet of Things" that globally interconnects smart devices and sensor networks. Technologies such as wireless communication, ubiquitous sensors, and passive or semi-passive RFID, are essential to monitor the transport chain. "Pervasive adaptation" is a new research challenge that has been recently introduced to describe system's ability to autonomously recognize the situation and adapt to situational changes. For example, it is expected that intelligent parcels that can observe and evaluate current environmental conditions including traffic information, velocity, new orders, temperature, or storage conditions, and decide adaptations such as changing transport route or destination and swapping vehicle. In order modern ubiquitous computing devices to become fully functional they need to overcome compatibility and security problems; these issues as well as potential solutions are explored in this paper. On the other hand, as new technology such as Ultra High Frequency RFID becomes more mature, it is launching into ubiquitous status in commerce and society.

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Keywords: pervasive computing; ubiquitous computing; logistics; RFID; Internet of Things

1. Introduction

Mark Weiser coined the term "ubiquitous computing" in 1988, to describe a future world where invisible computers will be thoroughly embedded in everyday objects to enable everyday activities. When he reported on his vision [1], a new research field opened up. The terms "pervasive computing", "ambient intelligence" and "everyware" are also used equivalently, to focus on a different aspect of the same paradigm. Ubiquitous means

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"present everywhere", while pervasive means "penetrate everywhere". Nowadays pervasive computing matures from a research topic to a commercial reality [2]. Pervasive computing applications include smart homes, health monitoring and assistance, gaming, transportation and logistics. Another concept related with pervasive computing, is the Internet of Things (IoT) [3, 4, 5, 6, 7]. The Things are uniquely identifiable everyday objects that will be gradually connected to the Internet in some way. They will be "readable, recognizable, locatable, addressable, and/or controllable via the Internet—whether via RFID, wireless LAN, wide-area network, or other means" [4]. They will get information about their position in the world and interact with other objects to exchange, compare, and integrate data.

According to Ferscha [8], there are three generations of pervasive computing. The first generation, from late 90s to early 2000s, is characterized by connectedness. New technologies, such as wireless networks, electronics miniaturization and the exponential grow of Internet, could be employed to connect literally everything to everything. During these years appeared special-purpose computing and information appliances that could spontaneously communicate with one another, sensor-actuator systems, and systems with organism-like capabilities such as self-configuration, self-optimization, and self-protection. The second generation, from early to mid 2000s, is characterized by awareness. Things capture data using sensors and interpret them to become aware of their situation. Research focused on context-aware systems. The third generation, from mid 2000s to present, is characterized by smartness. Research is now focused on socio-technical systems, which are complex, large-scale to very-large-scale deployments of pervasive ICT, with concerns on a societal level. Living in a world filled with smart things, have motivated a lot of emerging research areas, such as Embedded Intelligence [6], wearable computing, context-aware homes, mobile phone sensing and smart vehicle systems.

In this paper, we attempt to analyze the emerging research issues, challenges, and new directions for pervasive computing in the domain of logistics. Multiple researches have been developed in an attempt to examine such issues, by using a various set of computational and theoretical techniques [9-23].We give the relation between the Internet of Things and Radio-Frequency IDentification (RFID) technology, and we discuss the opportunities that arise for new types of RFID applications that enable efficient, reliable, and accurate tracking and tracing of delivered materials and storing the inventory until picking, packing, shipping, and delivery of sold products are completed. Since security and privacy issues are of primary concern, we give current trends in the field. Our intention is to give evidence that in the logistics field, the visions of pervasive computing and the Internet of Things are not far away.

2. Implementing the Internet of Things

The Internet of Things is assumed to be one of the main requirements of pervasive computing [24]. The term was first used by Kevin Ashton, a visionary from RFID community, in a presentation that he gave in 1999. Ten years later, Ashton [3] refers that: "If we had computers that knew everything there was to know about things—using data they gathered without any help from us—we would be able to track and count everything, and greatly reduce waste, loss and cost. We would know when things needed replacing, repairing or recalling, and whether they were fresh or past their best". The logistics view sees the Internet of Things as a logistics system [24]. The Things can be palettes and containers or packages that can be automatically directed through internal and external logistics systems, and can demand necessary resources such as a means of transport.

Today the primary conditions necessary for implementing the Internet of Things exist: sensor technology and RFID technology. In the following, we will present the state of the art in these fields and discuss the intensions for the near future, focusing on the area of logistics and the supply chain.

2.1. Sensor technology

Computers can use sensor technology to collect, specify, and comprehend real world data. Then data must be interpreted into a higher-level concept, the "situation". In real world, physical environment sensory data are resolved using situation identification techniques, which can be specification-based (e.g. logic programming, fuzzy logic, ontologies) or learning-based techniques (e.g. neural networks, web mining, decision trees). A detailed analysis and comparison of situation identification techniques in pervasive computing is presented in the survey collected by Ye et al. [2]. In manufacturing and logistics, sensor technology is being adopted in order to control processes and the quality of products. In the transportation of sensitive goods, an important task for the intelligent freight objects is to assess the quality changes by considering environmental conditions. Examples of ubiquitous sensors that measure these conditions include temperature and humidity sensors, thermoelectric flow sensors that check proper ventilation of cooling air, shock and acceleration sensors, and gas, water, or electricity sensors [25]. New sensors have been presented in the last ACM Conference on Ubiquitous Computing [26] that can be applied to a variety of domains, enabling new applications. Advances in sensing include remotely control of on/off state of devices, hand shape recognition, eye tracking, etc. An exceptional approach [27] proposed the use of living organisms as naturally embedded sensors, instead of silicon-based sensors. Among the new applications, we can refer a simple barcode scanner embedded in a shopping cart that can display the distance food traveled [28]. Other applications that use sensors include energy consumption monitoring, home heating control, etc.

2.2. RFID technology

To enable the Internet of Things, the exploitation of connection techniques, such as RFID, is necessary. RFID is a form of object automatic identification that uses communication via radio waves to exchange data between a reader and an electronic tag. RFID technology initially came to replace the standard barcode technology. However, the technology has been evolved so that RFID and barcodes are merging with each other. New RFID printers and scanners can handle both RFID and barcodes. [29]. RFID technology can be deployed for a variety of purposes, since RFID chips can be put not only on a material or product, but also on an everyday object, an animal, or a person.

RFID tags are active, passive or semi-passive, depending on their power source. Active tags have an on-board battery, while passive tags are powered from the signal carried by a RFID reader. Semi-passive tags have a small battery and they are activated by the signal of a RFID reader. The RFID tag broadcast its unique ID serial number, called Electronic Product Code (EPC), via radio frequencies to a nearby RFID reader. RFID systems are designed to operate at a number of designated frequencies, i.e. Low Frequency (LF) in 125 kHz, High Frequency (HF) in 13,56 MHz, Ultra High Frequency (UHF) in 860-960 MHz, and Microwave in 2,45 GHz. UHF tags are suitable for supply chain tracking applications. UHF RFID systems can identify a larger number of tags in the field at a given time, since they can read UHF tags from a greater distance, minimizing collisions. Microwave tags are mostly used in active RFID systems. They offer long range and high data transfer speeds, but they are costly. For this reason, they are mainly used for railroad car tracking and container tracking. A drawback is that microwave transmissions are the most susceptible to performance degradations due to metal and liquids, among other materials [30].

Current UHF RFID readers have become embedded and smaller – at the size of a compact flash card, while their functionality has been expanded from reading a unique ID, to remotely determine the temperature of a product, the direction of travel and velocity, impact and storage conditions and even actuate switches connected to the tag [31]. Recently, innovative passive UHF RFID tags are used for item-level tagging in retail to optimize business performance [32].

Barriers to the wide adoption of RFID technology are firstly the high costs of tags, readers and regional certification for RF emissions, and also the lack of consistent and worldwide standardization. Providers of new RFID readers attempt to reduce time and cost for their customers. For example, ThingMagic [31] provides an application-programming interface that supports UHF RFID modules and finished RFID readers, ensuring RF certification for various countries. Nowadays, supply chain applications adopt the EPC standard in the UHF frequency band, which is different for North America (902-928 MHz) and Europe (868 MHz), while China and Japan does not allow transmission in this band at this time. However, the EPC Global attempts to change this status by implementing global standards for real time identification [30].

2.3. RFID applications in logistics

RFID technology is quite popular in logistics and the supply chain. RFID increases data collection throughput, enhances data storage capabilities, provides immediacy and accuracy of data collection, minimizing human effort. Therefore, companies can identify materials and products in real-time, reducing labor costs and errors. The widespread penetration of RFID in supply chain will come true when each participant decide to invest in RFID technology and be responsible for the corresponding part. RFID technology was initially used within the supply chain to automate identification of cases and pallets. Later on, item-level tagging was adopted, sometimes without the prerequisite case and pallet-level tagging [32]. When retailers deploy item-level tagging, they can improve inventory management, support self-service payment terminals, control missing products, and reduce shoplifting and labor cost [4, 32]. Recent innovations on the retail front include smart shelving and “magic mirrors” in dressing rooms [31]. Distribution and logistics organisations can also take advantage of tagged items, as they can effectively track and trace products, accurately account for received materials, trace assembled products, manage recalls and returns, and speed up processing time and replenishment time.

Four types of integration of RFID and wireless sensor networks are discussed in [33]. Firstly, RFID tags with integrated sensors that provide sensing capabilities to RFID tags are also considered as intelligent RFID tags used to implement embedded intelligence [25]. These RFID sensor-tags use the same protocols and mechanisms for reading IDs and collecting sensed data. Applications of RFID sensor-tags depend on the way the tags are powered up and they include temperature sensing and monitoring, PH value detection, photo detection, vibration detection, rate monitoring, detecting product corruptions, detecting harmful agents, location recording, and vehicle-asset tracking. The second interesting type is the integration of RFID tags with wireless sensor nodes and wireless devices. These tags are able to communicate with each other and with the reader and form a multiple hop network. They have been used for example, to monitor the ambient parameters and total volume of stored chemicals in chemical containers. The third type of integration is the integration of RFID readers with wireless sensor nodes and wireless devices. In this case, readers can communicate with each other wirelessly, read IDs from tags and transmit information to the host. They have been used for asset tracking and inventory management. Finally, RFID tags and readers can be mixed with wireless networks, working independently in the same application.

Active and passive RFID tags have been used to implement Real-Time Location Systems (RTLS) [34]. RTLS enables real-time continuously monitoring of tagged objects in a given local area. RTLS is used to support business decisions such as location management and operation control for logistics and other services.

3. Security and privacy issues

Radio based technologies are subject to various types of attacks as it happens for any technology that utilizes the wireless communication channels. As a result, RFID systems are subject to attacks that threaten system security and user privacy. To overcome security and privacy problems, we have to develop protecting technologies and apply countermeasures that prevent tag misuse. An overview of potential RFID privacy and security threats is reported in [35]. In eavesdropping, the communication channel is used to secretly monitor data transmitted between RFID tag and RFID reader. Data can be encrypted, the distance between the tag and the reader can be limited, and the tag and reader can be shielded during transmission. These techniques can also be used to counter other threats, such as tag cloning and replay attacks. The communication channel can be used by attackers for tag cloning, where attackers make a duplicate RFID tag with the same functionality with the original. Tag authentication can be used to prevent tag cloning additional to the other techniques. Replay attacks are performed when authorized tag carriers' identities are abused by repeating their authentication sequence. Attackers use a clone of a legitimate tag or capture the signal and send it again from their own computer.

In relay attacks, a connection is created between a legitimate reader and a victim's legitimate tag. In order to counter relay attacks, cryptographic techniques have been developed, such as distance bounding, pairings and threshold cryptography. These techniques have been integrated into a novel approach, called threshold-based distance bounding protocol [36], which distributes a user's private key among various personal devices to improve security and reliability. For the future, it is reported [36] that "research is needed to develop a practical, low-cost, dedicated broadcast channel, accessible to all devices".

Concerning unauthorized tag reading threat, consumers need to be protected from unwanted scanning of RFID tags on cloths, shoes or other items they possess. EPC Global has designed a "kill switch" in their tags that lets vendors permanently disable a tag at the point of sale, instead of removing it [37]. This allows the tag to be embedded into the product. However, many applications require the tags to remain active in purchased goods. For example, for returned products, for a recall of specific set of products, for recycling, for store-issued coupons that can be scanned at the checkout counter, for a refrigerator or pantry shelf that need to check expiration date, for airport tickers that allow tracking of passengers within the airport, etc [38]. A better and low cost solution is the "blocker tag" that protect items in the hands of consumers, while at the same time permitting unimpeded reading of tags in commercial environments. As reported in [38], "a blocker tag simulates the full spectrum of possible serial numbers for tags, thereby obscuring the serial numbers of other tags. The blocker tag effectively overwhelms this process by forcing it to sweep the full space of all possible tag identifiers, which is extremely large".

People tracking, tag content changes, physical tag destructions, blocking and jamming are also listed as potential security and privacy treats in [35]. Blocking attack is performed by misusing a blocker tag [38], which causes a denial of service as the reader continuously query tag identifiers that do not exist. Jamming is caused when attackers generate a radio noise at the same frequency as that of the system.

4. Discussion and Conclusions

Pervasive computing and the Internet of Things are still visions, but for the near future. Paul Dourish observed that today the majority of advanced pervasive computing applications are more spectacle than invisible in use [26]. Uckelmann et al [5] describe current state as Intranet/Extranet of Things. As pervasiveness increases, the Internet of Things is expected to become "Internet of Things and People". Actually, this aspect is harmonized with the socio-technical characteristic of the third generation of pervasive computing [8], where people and things can communicate. The Internet of Things can benefit from the current functionalities known as Web 2.0 that connect people with data. However, the usability needs to be improved by providing devices and services that will enable the connection of things and people and will provide data-sharing models. Current applications without social grounds include personal communication (e.g. e-mail, social networks), personal ICT (e.g. smartphones, gadgets), individual mobility (e.g. automotive vehicles), logistics (e.g. transportation of goods, energy) and mass media (e.g. TV, e-paper) [39]. To implement socially interactive computing, we need to consider not each device for itself, but socially collaborating collective [40]. Cook & Das [41] also point out that in order to make technology truly pervasive, there is a need to move from small to massive scale pervasive computing systems. These future large-scale systems will handle massive amounts of data distributed over heterogeneous networking and computing platforms and support a huge number of users.

To be optimist, each day sensor technology and RFID technology becomes more mature and new applications are rising. More industries deploy next-generation technological solutions. UHF RFID technology becomes more commonplace in retail, distribution, and logistics. From the logistics point of view, the Internet of Things can be seen “as a logistics system, in which logistics items can be automatically directed through internal and external logistics system on the basis of their installed intelligence, and can even make requests for necessary resources such as a means of transport” [24]. Supply chain companies still face the challenges of real-time visibility, track-and-trace capabilities of materials and products at every link in the supply chain, as well as timely response to huge amount of “live” data stream that need to be processed for automating supervision of “intelligent parcels”.

Fawcett et al. [42], investigate the mechanisms through which IT investments influence Supply Chain (SC) performance. They believe that despite IT investments, many organizations have failed to obtain improvements in SC performance, and eventually claim that investments in IT make their greatest competitive contribution when they enable a dynamic SC collaboration capability. Grounded in the theory of dynamic capabilities [43], a well established theory in the field of the firms’ business strategy, our future study will focus on the conceptualization of a strategy to guide IT investments in logistics in order to improve SC performance providing competitive advantage. The concept of dynamic capabilities and Resource-Based Theory (RBT) [44] will be used to investigate how the firms’ IT investment in the necessary resources (human, technological, economic, and organizational) for pervasive computing could evolve through time, offering competitive advantage. A series of previous studies will be considered in our research. Jiang and Li [45], study components of the dynamic capabilities of supply chain and enterprise development in turbulent environment and propose that the Supply Chain's Dynamic Capabilities have three Dimensions: flexibility, agility, supply chain coordination. Defee and Fugate [46], review the Logistics and supply chain literature, and provide a model of dynamic supply chain capabilities (DSCCS). They also underline that dynamic capabilities may be extended beyond the traditional single-firm view to exist across the relationships developed by multiple organizations in a supply chain.

According to organizational culture literature and research in dynamic simulation, a great number of problems encountered by firms facing a dynamic and highly competitive environment are due to their ineffectiveness to cultivate the appropriate culture in order to adapt to significant changes of their external environment and align their competitive strategy accordingly [47, 48, 49]. For example, Trivellas and Santouridis [50] empirically concluded that the “hard” TQM elements such as process and quality management, and information analysis facilitate firm’s innovativeness only through job satisfaction which intervenes as a mediator. Under the same logic, the importance of the effective connection between things and people is highlighted by evidence supporting that ISs promoting member dialogue, teamwork, interpersonal communication and cooperation foster task productivity [51]. In particular, their capabilities tend to build or reinforce group collaboration, job satisfaction, involvement and development, and in alignment with organizational culture they may produce a sustainable competitive advantage.

Santouridis et al., in their research [52] contribute to the examination of the four factor structure of E-S-QUAL’s applicability in different settings and to the verification of its factor structure. Moreover, their study provides useful insight into the effect of electronic service quality on customer perceived value and loyalty [53, 54]. In the future, our research will also focus on the examination of the influence of the organisational culture on the quality of services provided in logistics and SC performance. Research data will also be analysed to examine factor structure of E-S-QUAL and its applicability in the context of logistics.

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