Potential of pervasive computing through embedded systems and Internet technologies: Research of customer perspective

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***Abstract*—**During the recent economic recession software industry has shown a high level of resilience to negative economic trends by initiating a substantial innovation cycle. In turn, European commission recognized software industry and consumer electronics to be key industries that were able to change the course of economic trends. Most of these innovative endeavors relied on technologies that are the basis of pervasive computing, such as mobile applications, consumer electronics, embedded systems and Internet technologies. In order to create significant economic benefits it is not sufficient to have technological capacity to produce these innovations, but there are equally challenging issues of targeting the customer markets so that these innovations get accepted and absorbed by the market. Better understanding of how the demand for these services is created and what are its main features.

In this paper we will present the research of market potential for advanced services that combine best practices in embedded systems with Internet computing, its success in implementation through the perspective of users that are the targeted customers of these services.

Goal of the paper is to investigate users' understanding and awareness of the underlying technologies on one hand and to understand the level of adoption of currently available services as well as to estimate the potential of implementing future services based on pervasive computing concepts.

Results of the research show that there is a significant lack of understanding of these technologies by the end users. Nonetheless, this fact does not present an obstacle nor does it reduce the interest for using the services associated with these technologies.

***Keywords*—**Consumer electronics markets, Embedded systems, Innovation, Internet technologies, Mobile computing, Pervasive computing, Ubiquitous computing.

I. Introduction

RECENT global economic crises has initiated a very successful technological innovation cycle that has introduces a variety of new products and services in the customer electronics, software services, mobile services and internet market segments. The industries that supply these market segments have presented a high level of resilience to negative economic trends. Even though the purchasing power has been decreased newly established customer habits as well as new economic and business models managed to alleviate negative trends and open new opportunities. One of most interesting segments that have been under development is the pervasive computing and its applications. These applications offer high level of convenience for their users, and make the devices that they already invested in even more useful. On the other hand there is a number of potential drawbacks and issues arising from the intensive use of the underlying technologies, such as security and privacy issues.

In this paper we will take a look at recent technological developments from the customer perspective and try to understand how customers decide to accept new products and services offered through embedded and mobile systems that make up the backbone of future pervasive computing applications. Since pervasive computing creates applications and services that have additional level of autonomous operation many of technological facts about these technologies are hidden from users. It is fair to ask whether the lack of customer involvement in understanding the technology also creates additional incentive to use such products and services. On the other hand the high dynamics of contemporary life styles may be overwhelming for customers so that they may accept new trends, fads and services without assessing potential risks or even that the customers' level of tolerance to risk has grown due to thrust in new reliable technologies. It is also fir to ask where is the limit of this new thrust and what is the potential of new pervasive computing technologies in the future.

Goal of this paper is twofold: firstly, we want to estimate the level of understanding of recent technological developments by the individuals who are target audience for the products and services produced using these innovations. Secondly, we wish to estimate the potential interest in currently available services that fall under the pervasive computing paradigm as well as to investigate the interest of potential customers to new and innovative services that are currently either being developed or being designed. When we acquire this information we will be able to discuss the relation between the knowledge about technology and readiness of customers to use resulting products and services, which may serve as invaluable indicator for the development of future innovative projects in the underlying industries.

The structure of the paper is organized in six Sections. After the introduction in Section I, an overview of pervasive and ubiquitous computing is given in Section II. The emphasis is on the recent developments concerning primarily embedded systems, Internet technologies and mobile technologies. In Section III overview of the economic aspects and customer markets where products and services based on technologies and areas of pervasive computing will be presented. In the following Section, a research about the potential of embedded systems, mobile applications and Internet applications from the customer perspective will be presented. In Section V a

discussion of the research results will be given. Here the relation between the understanding of technologies and usage will be investigated. Finally in Section VI conclusions will be given as well as the remarks for future work.

II. Overview of Recent Developments in Pervasive Computing

Pervasive or ubiquitous computing is a general term describing the new conceptual paradigm where most of the devices and their environment have particular computing capabilities. This term is meant to contrast the term desktop computing in the sense that computing is available from any device, any location using any computing aspect or technology.

Goal of pervasive computing is to provide users with proactive and self-tuning environments and devices that can augment personal knowledge and decision making abilities, while requiring as little direct user interaction as possible [1].

Pervasive paradigm relies primarily on embedded systems, mobile technologies and Internet technologies to supply everyday devices with computing capabilities. Devices include electronics that have microprocessors by definition, but also everyday objects or mechanical devices that traditionally did not contain computing capabilities.

Pervasive environment is based on creating hybrid ubiquitous networks resulting in augmented reality models based primarily on wireless technologies, mobile technologies in particular and internet technologies. These networks are highly dynamic such as Near Area Networks (NANs) or Body Area Networks (BANs), but also incorporate a reasonable degree of intelligence, allowing for autonomous decision making, self-organization [25] etc. Environment that can react to the presence of people is also referred to as the ambient intelligence.

Other technologies are also used, primarily RFID technology GPS technology and other sensor and actuator technologies.

Development of pervasive systems is an ongoing process resulting in a number of applications spanning from very simple control/indicator systems to more elaborate applications including mobile devices and electronic business models etc.

We will present some of the current research for future applications below. One of the most studied applications is the development of smart homes that use ambient intelligence to provide comfortable, assistive and secure environment for their residents [10, 13, 14]. Sentient computing systems that brings various services to the user using virtual networks such as redirecting phone calls to the phone nearest to the user or teleporting user's desktop to the nearest available computer, etc… [12]. Exploritorium project applied pervasive computing to museums and other exhibition venues augmenting the visitor experience by adding the additional layer of interaction with the exhibits [8]. For computation intensive scientific research a pervasive computing project e-Science was employed to automatically capture and publish data from ongoing experiments in laboratories [21]. One of few implementations that were active in the real world situations is the iHospital system that supported the coordination of operations in a large hospital [11]. Other notable research examples include pervasive computing in automobiles [9, 20] and outdoor applications for both civic and military implementations [17].

In order to efficiently construct and use pervasive environments, devices should be enabled to perform basic computing tasks and participate in networking. In the rest of this section we will make an overview of the most important technologies used for this purpose, embedded systems and Internet and mobile technologies.

A. Embedded systems

Embedded systems are computer systems created to perform few very specific tasks. Due to their conceptual dedication to solving a particular set of problems and tasks they are not easy to change. They may include both software and hardware components, but they do not resemble general purpose computer systems. They are mostly added to mechanical or electronic devices as permanent part providing these devices with additional capabilities and improving their initial properties and efficiency. They are used to enable these devices to process information in real-time or process and exchange data with other systems. Embedded systems are used to control most of devices common to contemporaneity. Key part of all embedded systems is software component that cannot be changed once deployed within the device. Some devices though, have gone through a process of evolving from basic embedded systems towards more general purpose devices such as mobile phones and other mobile devices that may periodically update their software components called firmware.

Embedded systems have become commonly used in most application areas. The fact that 98% of all the microprocessors produced in the world use embedded systems [7] supports the importance of the development and evolution of embedded systems.

Due to their presence and improved capabilities embedded systems provide new solutions in the way that user may not perceive and be aware of them so the gap between the users active understanding and the rate of usage of these systems is increasing. This characteristic is also translated from embedded systems to pervasive computing where providing innovative and convenient new functionality does not require the user to understand the inner working [1]. While this may be an advantage in terms of user interaction and convenience, it may also pose a reasonable threat in terms of security, privacy and device failure scenarios.

B. Internet and mobile technologies

Internet usage is increasing every day because of its huge potential and benefits to the end users [6]. Internet technologies are changing our everyday life and they become ubiquitous in private and business life [19]. Development and adoption of Internet technology has positive impact on competitiveness and social-economic growth of countries, firms and individuals [4]. In 2014 there was 454.2% more Internet users in Europe than in 2000 year and worldwide

growth of Internet users from 2000 to 2014 year was 741.0% [16].

Mobile technologies are closely related to the Internet and they change the way individuals manipulate information and how they are connected with each other. Mobile technologies consist of hardware, software, and network infrastructure and offer wide spectrum of functionality to the users [5]. Mobile phones provide information regardless time and place constraints [22] and they offer the potential to different private and business activities. There are many mobile applications that come pre-installed or can be added to mobile phones, e.g. video, photography, high-speed internet access, social networking, Bluetooth, email, games, GPS location services [5, 22]. In many countries, more and more individuals use smart mobile phones more than laptop or personal computers. In the USA 58% of adults use mobile phones in order to check their electronic mail, communicate or manipulate with data.

There are many individuals who uses different Internet and mobile technologies and devices which include embedded system but who are not understanding their functions and do not use all possibilities they offer. In this article we want to estimate the level of understanding of technologies by individuals who use them at daily basis.

III. Customer Markets and Pervasive Computing Capabilities

Innovation in ICT industry is feasible only if the end user market can absorb newly developed products and services. Same is true for goods and services rooted in pervasive computing. Understanding the current state of customer markets that are related to pervasive computing is of utmost importance. Here, we will take a closer look at the consumer electronic markets and their current states in terms of revenue and structure. Also we will take a closer look at the performance of mobile application distribution platforms that present a key component in distribution of current customized applications of various products and services that originate in embedded systems, mobile technologies or other networking technologies that are the basis of pervasive computing.

Consumer electronic market includes all the markets of electronic equipment used by individuals on daily basis either for personal or official use. Consumer electronic market contains several market segments: (1) digital media boxes, which include home video game consoles, blu-ray video players and recorders and digital media adapters or multimedia gateways; (2) computers, that include desktop computers and laptop computers, but also other sub segments such as netbooks and notebooks; (3) Televisions; (4) Set-top boxes, subdivided according to external signal technology such as cable, satellite, terrestrial or IPTV signal; (5) portable media devices that include sub segments such as smartphones, handheld game consoles and media tablets.

According to World Consumer Electronics Market 2014-2018 Research Report [15] the market is expected to grow further due to favorable conditions. The report further details four most important influences which are active technological innovation cycle, availability of new services and positive response by the end users in adoption of new customer habits. Mobile devices are bestsellers worldwide. There is an increase in the sales of connectable devices, and there is a shift from stationary desktop computer sales towards more mobile technologies and devices such as tablet computers.

The sales of these products are mainly determined by the technology used in these products, the pricing, availability of different variants, and the level of after-sales support given to customers. In addition, global economic conditions also influence the sales of consumer electronics because they directly affect the purchasing power of customers.

During the recent years of global economic recession most of the segments of consumer markets showed high resilience to economic fluctuations, counteracting negative trends through technological innovation cycle that has been active since 2009.

This means that availability of innovative information devices has not decreased and that through everyday use individuals have already accepted new habit of everyday use which is also a positive indication for further innovations such as pervasive computing.

Closely related to customer electronics markets is the software market. Global software sales have not experienced a significant drop in revenues during the recent global economic crises [23]. Software industry trends are showing an increasing share of mobile application products being distributed to customer markets. The importance of this segment is also recognized by software developers and new software development methodologies are being employed in the development processes, e.g. Mobile-D [2, 18].

Mobile application distribution platforms play a major role in providing availability and accessibility of new mobile applications. Additionally they are a readily available distribution channel for after-sales support for customers that strongly influence the creation of new customer habits and expectations.

The revenue shares of products and services in mobile computing are steadily increasing since its first appearance. Recent study estimates that in the EU region revenues from mobile applications have reached over 10 billion euros in 2013, while creating over half a million jobs in 28 EU countries [24]. This segment has gained in economic significance as the market shares have risen, not only by the revenue attained through the realization of products and services but also by creating jobs, and establishing new service industries with related supporting service industries. This is why this market segment, taken as a whole, both the customer side and supplier side, is being referred to as the App Economy. The role of App Economy will be crucial in further development of products and services of the pervasive computing paradigm.

Takin into account the positive market trends in accepting new product and services and the fact that pervasive computing is eliminating the need to understand the underlying

technologies in these products and services we will present a research that tries to explain if there is the lack of understanding of technologies used today and how this may affect future trends from customer perspective.

IV. Research of Pervasive Computing Potential Supported by Embedded Systems and Internet Technologies Form the Customer Perspective

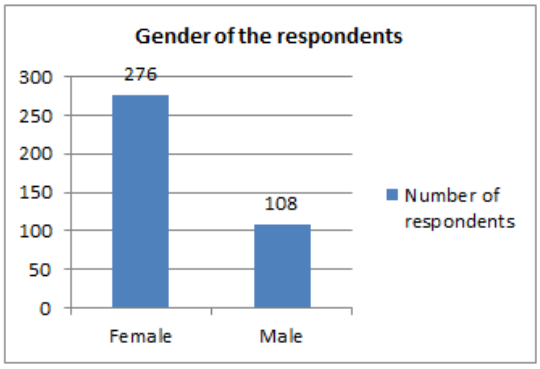
Pervasive computing through embedded systems and internet technologies is developing every day and its usage is growing constantly. However, there is still lack of research and studies dealing with this topic especially regarding users. In this article we want to estimate the level of understanding of using internet technologies by the individuals and to investigate the interest of individuals to new and innovative Internet technology services. In order to achieve these two goals a simple close-ended questionnaire was conducted.

A. Methodology and data

In May 2013 the empirical research on usage of ubiquitous computing supported by embedded systems and internet technologies was conducted among the third year students from the Faculty of Economics and Business Zagreb. Students were engaged in the course Business Information Systems. There were 384 students who participated in the survey.

The survey consists of two main parts. The first part of the survey is about embedded systems and how students are informed regarding their usage. In the second part of the survey participants named which of various devices and service which comprise embedded systems they use. While fulfilling the survey, the respondents can choose one or more offered answers. The questionnaire was distributed among students through mail in google docs format. The questionnaire was analyzed using descriptive statistics methods and techniques with the Statistica software.

Demographic characteristics of the respondents show that most of the students are female who are 21 year old. They are attending obligatory course Business Information Systems at the Faculty of Economics and Business Zagreb (Figure 1).



Source: Authors' analysis

Fig. 1 Demographic characteristics of the respondents

B. Research Results

Table 1 shows what respondents consider an embedded system is. They could choose more than one answer, e.g. POS devices, Smartphone, Data base, ATM, Personal computers, Safe alarms, Peacemaker, SIM cards, eBooks, Traffic lights, Video games, MP3, Console for playing video games, Presentation pointer and Dishwasher machine. The highest percentage of respondents consider that POS device (48,57%), Smartphone (45,19%) and Data base (42,08%) present embedded systems. One quarter of the respondents believe that Personal computers (25,19%) and Safe alarms (24,16%) present embedded systems. The lowest percentage of respondents choose MP3, Console for playing video games, Presentation pointer and Dish machine as devices with embedded systems.

In your opinion, what present embedded system?	Number of respondents	%
POS devices	187	48,57%
Smartphone	174	45,19%
Data base	162	42,08%
ATM	141	36,62%
Personal computers	97	25,19%
Safe alarms	93	24,16%
Peacemaker	84	21,82%
SIM cards	84	21,82%
eBooks	64	16,62%
Traffic lights	63	16,36%
Video games	59	15,32%
MP3	49	12,73%
Console for playing video games	46	11,95%
Presentation pointer	46	11,95%
Dish machine	35	9,09%

Source: Authors' analysis

Table 1 Devices that present embedded systems

Table 2 presents different usage of GPS technology for the city sightseeing. The respondents could choose more than one answer while answering the questionnaire, e.g. Defining route between two addresses in the city; Discovering city sights close to your location; Monitoring and forecasting dense traffic and View of all restaurants on selected city area. Most of the respondents (83,12%) stated that defining route between two addresses in the city is one of the most important usage of the GPS technology for the city sightseeing. Half of the respondents excerpt that usage of the GPS technology is important in discovering city sights close to your location (47,01%). The lowest percentage of respondents named that usage of GPS technology can be useful for monitoring and forecasting dense traffic (23,12%) and finding restaurants on selected city (21,82%).

In table 3 Possession and usage of different devices is described. Respondents could choose more than one offered answer, e.g. Smartphone, Laptop, WIFI device, MP3, GPRS, Tablet, Playing console, SmartTV, Cyclocomputer and eReader. Almost all respondents (94,03%) have smartphone.

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Usage of GPS technology	Number of respondents	%
Defining route between two addresses in the city	320	83,12%
Discovering city sights close to your location	181	47,01%
Monitoring and forecasting dense traffic	89	23,12%
View of all restaurants on selected city area	84	21,82%

Source: Authors' analysis

Table 2 Usage of GPS technology

Possession and usage of different devices	Number of respondents	%
Smartphone	362	94,03%
Laptop	304	78,96%
WIFI device	278	72,21%
MP3	202	52,47%
GPRS	90	23,38%
Tablet	79	20,52%
Playing console	74	19,22%
SmartTV	54	14,03%
Computer for the bicycle	24	6,23%
eReader	15	3,90%
Nothing	6	1,56%

Source: Authors' analysis

Table 3 Possession and usage of different devices

Laptop (78,96%) and WIFI device (72,21%) are also used by high percentage of students. Half of respondents have MP3 device (52,47%). GPRS, Tablet and Playing console are devices that around 20% of respondents possess and use. Cyclocomputers (6,23%) and eReaders (3,90%) are really rarely used.

Figure 2 shows results about students' knowledge regarding RFID technology. Most of them stated that they are not familiar with RFID technology (69,79%). Only 30,21% respondents know what is RFID technology.

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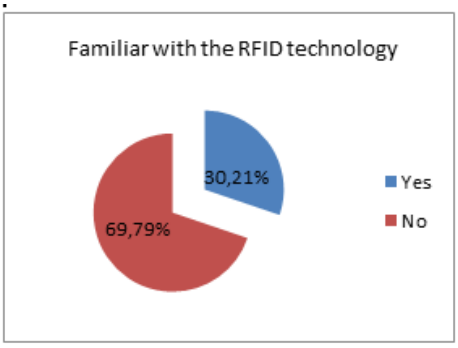


Source: Authors' analysis

Fig. 2 Respondents' knowledge about RFID technology

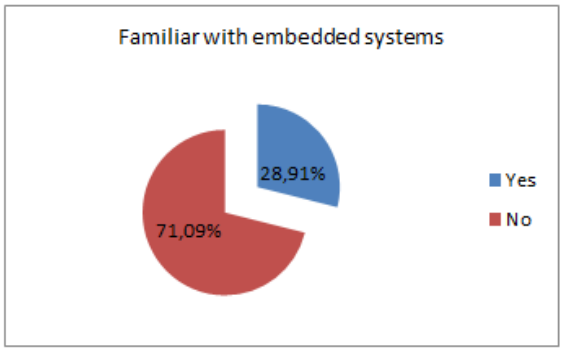
Although, respondents do not know what RFID technology is, most of them estimate that RFID is mostly used in Logistics and transport industry (66,23%) (Table 4). Just 18,44% of respondents consider that RFID is widely used in Tourism industry. The lowest percentage of respondents believe that RFID technology is primarily used in Construction industry (5,71) and in Textile industry (2,34%).

Industries	Number of respondents	%
Logistics and transport industry	255	66,23%
Tourism industry	71	18,44%
Food industry	27	7,01%
Construction industry	22	5,71%
Textile industry	9	2,34%
TOTAL	**384**	**100%**

Source: Authors' analysis

Table 4 Usage of RFID in different industries

Figure 3 shows results about students' knowledge regarding embedded systems. Most of them stated that they are not familiar with embedded systems (71,09%). Only 28,91% respondents know what embedded systems are.



Source: Authors' analysis

Fig. 3 Respondents' knowledge about embedded systems

In Table 5, data about usage of embedded systems by individuals is presented. The respondents could choose more than one offered answer, e.g. Digital thermometer, Parking sensors, eReader, Blood Glucose Monitoring Device, Peacemaker, 3D printer and Robot vacuum cleaner. The highest percentage of respondents use digital thermometer (60,00%) and parking sensors (47,79). Quarter of all respondents use also eReader (27,53%) and Blood Glucose Monitoring Device (23,38%). The lowest percentage of respondents indicates that they use 3D printer (11,95%) and Robot vacuum cleaner (11,69%).

Usage of other embedded systems	Number of respondents	%
Digital thermometer	231	60,00%
Parking sensors	184	47,79%
eReader	106	27,53%
Blood Glucose Monitoring Device	90	23,38%
Peacemaker	62	16,10%
3D printer	46	11,95%
Robot vacuum cleaner	45	11,69%

Source: Authors' analysis

Table 5 Usage of embedded systems

V. Discussion

A. Estimating awareness and understanding of pervasive computing technology

The conducted research was aimed at young highly educated demographic so when interpreting the presented results we

should take into account that the targeted demographics had better access to information about the current state of the art in economics, business and partially to IT and consumer electronics. From table 3 we can also conclude that this targeted demographic is well involved in the trends in electronics since 94,03% of them own and use smartphones. It is safe to presume that due to these characteristics the targeted segment of users are in better position than most of the other demographics that have somewhat lesser access to information through academic channels. This is why we presumed that the results will show adequate understanding and knowledge about technology, and at least some knowledge about various technologies used for pervasive computing.

This is the reason why the first part of the survey resembled an examination test where some of the possible answers were correct and others incorrect. This is why in Table 1 there are correct and incorrect options to choose an answer from to the question what is considered an embedded system. The correct devices that contain or present themselves as embedded systems are POS devices, smartphones, ATMs, safe alarms, pacemakers, SIM cards, traffic lights, video games consoles, presenter pointers and dishwashers. Unfortunately, none of these devices was recognized by majority of respondents as embedded systems. Best scores for POS devices and smartphones are below 50%. It is encouraging, though, that most of the incorrect answers were recognized as incorrect in much greater extent, except from databases that had the highest score of 25% as misidentified embedded system. This means term embedded systems is not overly familiar to the surveyed demographics as they are not able to recognize its real world implementations. Further evidence for this is given in Figure 3 where less than a third of responses claim that they are familiar with embedded systems. Similar results are found for presented RFID technology shown in Figure 2.

If we take a look at more factographic questions that are being taught at various courses during their studies, results are much better as expected. An example is the question of where RFID technology is mostly used with results shown in table 4. This is a piece of information taken from the obligatory undergraduate course Business information systems that all of the respondents took part in that same year. Two thirds of respondents have recognized the most typical industry RFID technology is used in. Usage of GPS technology yielded similar results, where over 80% of students recognized one typical applications of this technology, while other correct uses (discovering city sights in vicinity and traffic density maps) were less recognized. Finally viewing static data on a map that does not require GPS technology was recognized as non GPS application by similar number of students.

Overall, we may conclude that students have some overall declarative knowledge about the mentioned technologies but do not have enough understanding to recognize their usage in real world applications, which may also indicate the lack of awareness of their availability, advantages and disadvantages and potentials.

B. Usage of products and services containing embedded systems, Internet and mobile technologies

Finally, in order to estimate the level of usage of products and services that rely on pervasive computing technologies and principles we focused on what devices students possess and use (shown in Table 3) and what other devices they use or know how to operate (shown in Table 5).

If we take a look at the devices and consumer electronics that respondents own we can see that all of the market segments discussed in Section III are represented. This means that there is a good foundation for development of additional services related to any of the customer electronic devices present on the market which is one of the bases of pervasive computing. Even lesser used devices with very particular purposes are represented as we can see in Table 5. Most important is the use of smartphones and laptops with over 90% and almost 80% of respondents use them, respectively.

Since smartphones present an intermediary form between embedded systems and general-purpose devices [26] it is safe to presume that potential for further use of pervasive computing is significant. Earlier studies [27, 28] have shown that student use various mobile applications and innovative mobile services. This is why better understanding of underlying technologies is called for, or in the case of pervasive computing, implementations that will minimize the risks of technologies used thus increasing further the use of applications and services.

VI. Conclusions

Pervasive computing is a computing paradigm where most of devices have some computing capability and interconnectivity which results in creation of proactive and self-tuning environments and devices that can augment personal knowledge and decision making abilities of its users, while requiring as little direct user interaction as possible. In the recent years various examples of pervasive computing implementations have been created which is partly a result of technological innovation cycle which was initiated during the latest global economics crisis in 2008. All of the related markets have shown high level of resilience to economic fluctuations, both customer electronics markets, software markets etc.

In this paper we investigated this phenomenon from the customers' standpoint trying to find the explanation for the positive trends in related industries and the incentive that customers through market absorption supported the process of innovation and development of various segments of pervasive computing.

The goal of this paper was twofold. Firstly, by using the survey targeted at highly educated young demographics investigate the level of technological understanding, and secondly to investigate practical involvement of this demographic in increasing trends of using products and services related to embedded systems, mobile technologies and Internet technologies.

The results have shown that there is insufficient level of in-depth understanding of used technologies, but this lack of awareness does not diminish the level of practical involvement and interest for products and services these technologies offer. This is in accordance with one of guidelines of pervasive computing where providing innovative and convenient new functionality does not require the user to understand the inner working. This opens a number of challenges concerning security, privacy, trustworthiness and disaster recovery issues. The incentive to deal with these issues is on the pervasive computing solutions.

Still, correlation between understanding of underlying technologies and rate of acceptance of products and services it enables remain for future investigation. Also, understanding the limitations of customer acceptance needs to be further explored.

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