A Survey of Research on Context-Aware Homes

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Abstract. The seamless integration of people, devices and computation will soon become part of our daily life. Sensors, actuators, wireless networks and ubiquitous devices powered by intelligent computation will blend into future environments in which people will live. Despite showing great promise, research into future computing technologies is often far removed from the needs of users. The nature of such future systems is often too obtrusive, seemingly denying their purpose. Furthermore, most research on context-aware environments and ubiquitous computing conducted so far has concentrated on supporting people while at work. This paper presents research issues that need to be addressed to enhance the quality of life for people living in context-aware homes. We survey current research and present strategies that facilitate the diffusion of information technology into homes in order to inspire positive emotions, encourage effortless exploration of content and help occupants to achieve tasks at hand.

Keywords. Pervasive, ubiquitous computing, smart context-aware homes, environments, smart sensors, user-experience, privacy

1 Introduction

The invention of graphical user interfaces and mouse-style pointing devices by Xerox PARC some 20 years ago greatly simplified the use of computers. It was no longer necessary to remember and type in “cryptic” commands and as a result, the personal computer became an astonishing success, with hundreds of millions of devices being sold worldwide.

In 1991 Mark Weiser stated that “Such machines cannot truly make computing an integral, invisible part of the way people live their lives.” (Weiser 1991). He initiated research on ubiquitous computing at Xerox PARC in the late 1980’s (Weiser, Gold and Brown 1999) and suggested “integrating computers seamlessly into the world at large”, letting users communicate directly with their computer-equipped objects and the environment. Weiser’s idea was that computer systems should become invisible to the user and disappear from conscious thought. Users should not be distracted any more from their tasks by concentrating on a particular computer interface. Instead, they should be able to communicate in a more intuitive manner, directly with a context-aware environment, thus enabling them to achieve their goals more easily and freeing their minds to think even further ahead of their current tasks and problems.

The goal of ubiquitous computing is to bring computation into the real physical world and to allow people to interact with them in a more natural way: by talking, by moving, pointing, and gesturing (Coen 1998).

Most research that has been conducted on ubiquitous computing and context-aware environments has concentrated on supporting people at work. Most people spend more time at home than in any other place. Little research has been conducted so far on how they can be supported in their everyday life. This paper will present some research work relevant to context-aware homes.

Section 2 gives scenarios on how people could benefit from living in a context-aware home. Section 3 addresses why context-aware homes need to be different from context-aware offices. In Section 4 we introduce the notion of context and identify the research dimensions that need to be addressed, which are Instrumentation, Middleware and Frameworks for context-aware Homes and User Experience. They are presented in Section 5, 6 and 7 respectively. We conclude in section 8.

2 Context-aware home scenarios

The goal of research on context-aware buildings is to offer an unobtrusive and appealing environment embedded with pervasive devices that help its occupants to achieve their tasks at hand; technology that interacts closely with its occupants in the most natural ways to the point where such interaction becomes implicit.

A multitude of futuristic scenarios have been prophesied in magazines, movies and research papers. Researchers and technologists are often very cautious in predicting the future shape of our technological landscape but the following simple scenarios are among the recurring visions:

- Lights, chairs and tables automatically adjust as soon as the family gathers in the living room to watch TV.
- Phones only ring in rooms where the addressee is actually present, preventing other people being disturbed by useless ringing.
- The music being played in a room adapts automatically to the people within and the pictures in the frames on the desk change depending on which person is working there.

- Interactive play spaces are created for children where images, music, narration, light and sound effects are used to transform a normal child's bedroom into a fantasy land (Bobick, Intille, Davis et al. 1999).
- In-house context-aware communication systems allow family members to speak to each other as if they were in the same room, even when they are in different rooms. (Hindus, Mainwaring, Leduc et al. 2001) (Nagel, Kidd, O'Connell et al. 2001).
- Elderly people will be supported in their daily life by context-aware homes, allowing them to age in their own home or familiar environment (Mynatt, Essa and Rogers 2000) (Lines and Hone 2002).
- Complete security systems including emergency call out alarms for burglars, fire, or injury with a complete awareness of the home owners wherever they are.
- In assisted living complexes, context-aware systems monitor the state of the elderly occupants, freeing the nursing staff from the task of constantly supervising them, thus giving them more time to care about those who actually need their support most (Stanford 2002).

More scenarios and applications may be thought of and even more will likely be discovered as soon as people are able to move into context-aware homes and can explore the possibilities themselves. "*Neither an explication of the principles of ubiquitous computing nor a list of the technologies involved really gives a sense of what it would be like to live in a world full of invisible widgets*" (Weiser 1991)

3 Characteristics of Context-aware homes and why they are different from offices

The scenarios described above reflect the pervasiveness of sensors, actuators, wireless networks and ubiquitous devices powered by intelligent computation blended into the user's surrounding. The scenarios show that the nature of interactions and the relationships between humans and machines will change radically. The scenarios are characterized by the existence of technology and computation which:

- is aware of its own state and that of related systems
- is aware of users intentions, tasks and feelings
- can autonomously adapt its behaviour spontaneously on context changes

Social activities in offices differ from home activities. Generally speaking office activities are more formal, more structured, task-oriented and geared to optimize productivity. The types of social interactions at work are different from those that occur at home. The scale of the technology that supports work interaction is larger than that which would support homes. The scale of infrastructure to support social interaction within a home is often reduced to a small LAN (Local Area Network). This is mainly due to cost containment or a fear of bringing disturbing technology into the home. Home activities are informal, not necessarily structured and focus on tasks that will make the occupants' lives more:

- safe
- supportive
- convenient
- pleasant
- enjoyable
- entertaining
- relaxing

Quite a few context-aware office-style research environments have been developed so far to support people while at work. In a laboratory environment there are likely to be enough technologically educated people to administrate computer systems and to fix faulty hardware and software right on the spot. Cost will likely not be a significant issue and people may be interested in using an application just because it is fun to play with, even (or especially) if it is not easy to use. Additionally, privacy might also not be very important at the research stage, as long as no real sensitive data is being acquired and processed by the system.

When setting up a context-aware environment for business use, more care has to be taken. System administrators should still be available to keep the system up and running, but investments will only be made if the system delivers real cost savings or productivity gains. It has to be easy to use and useful, so that users do not waste their time figuring out how to complete a certain task and get real benefit out of using it. Because the systems will be used in a business environment, security measures have to be taken to protect valuable data and intellectual property from competitors. Though every effort should be made to make the use of a system desirable to the users, its usage may simply be imposed by the management if they think it will be advantageous for the company.

Developing context-aware environments for people at home creates additional challenges. In contrast to the task-oriented offices, people at home decide freely for themselves how they organize space and time, what activities they undertake, when, where, how often and who they involve. For a private home environment, even more care has to be taken to make it desirable to the occupants. Despite giving them a real personal additional value, special care has to be taken to fulfil their requirements for

- usability
- usefulness (even if it is just wasting time)
- social acceptance
- privacy protection
- low cost
- zero administration

Debby Hindus and others from the now-defunct Interval Corp. have been studying domestic spaces, through ethnographic enquiry and focus groups. In (Hindus 1999) they state that “homes are fundamentally different from workplaces”, “customers are not knowledge workers” and that “families are not organizations”. They suggest that products which have been found to be useful in an office environment will not necessarily be desirable at home and that therefore thorough user studies should be conducted while developing technologies for homes. We believe that a family living in the same house has a tight and complex structure. Privacy from other family members is not as big an issue as it is for an enterprise. Family members share a large amount of context, such as cultural or historical context. They also know each other’s personality and share artefacts or home appliances.

4 Context Awareness Research Dimensions

In order to enable natural and meaningful interactions between the context-aware home and its occupants, the home has to be aware of its occupants' context, their desires, whereabouts, activities, needs, emotions and situations. Such context will help the home to adapt or customize the interaction with its occupants. By context, we refer to the circumstances or situations in which a computing task takes place. Context of an entity A is any measurable and relevant information that can affect the behaviour of A. Context can be considered and exploited at different levels of abstraction.

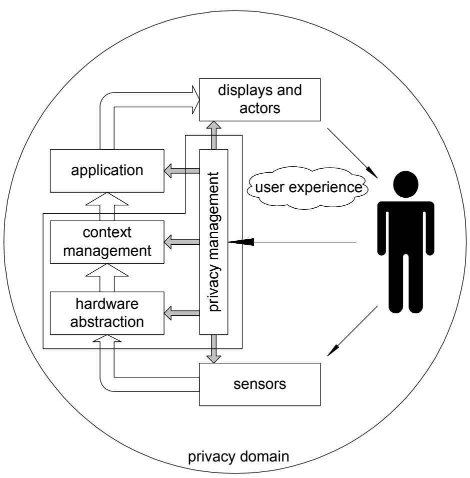

Figure 1

Figure 1 shows the basic components of a context-aware system interacting with a user. Listed below are the most important research dimensions that need to be addressed, while taking the special requirements of context-aware homes and their occupants into account:

- Instrumentation: Technological building blocks such as smart sensors, wireless networks and (tangible) user interfaces to gather context information and enable new types of human-computer interactions. This covers the sensor, actuator and information presentation hardware itself, as well as microcontrollers, their software and wireless networks to let them communicate with each other and higher-level systems.

- Middleware: The whole system infrastructure to gather context information, process it and derive meaningful (re)actions from it. The main building blocks are a hardware abstraction layer to provide decoupling from the actual implementation of the sensors and networks, a context manager to process the context information and a privacy manager.

- Applications: These use the gathered contextual knowledge to infer what the user expects and then delivers the expected services.

- User experience: Everything felt, observed, perceived and learned through awareness and interaction. A good user experience is one that exactly meets the expectation of the users, with minimal frustration and as enjoyably as possible.

- Privacy: In an environment full of sensors that are keeping track of everybody and everything that is happening, privacy becomes an important issue which can not be added at the end of the development process. Privacy must be taken into account from the beginning.

5 Instrumentation

In this chapter we will mainly discuss the sensors for gathering context information, leaving information displays and actuators aside. We will (1) mention what to consider when sensing context information, (2) present a survey of research trends in the area of sensor instrumentation and (3) discuss privacy issues which have to be considered when selecting sensors.

5.1 Instrumentation requirements

Context information can be sensed, profiled or derived (Henricksen, Indulska and Rakotonirainy 2002). The goal of a context-aware home is to gather the information necessary to perform its tasks as unobtrusively as possible and with the least amount of effort from the occupants. Therefore as much context information as possible should be gathered implicitly by sensors, as opposed to requiring the user to explicitly enter it. In the ideal case, sensors should provide context information that reflects the “real world” situation, but context is an abstract concept and therefore difficult to capture directly (Schmidt and Van Laerhoven 2001). Nevertheless, it is feasible to gather information about a real-world situation that is a close-enough approximation of the context as to be useful as a basis for further actions.
It is unlikely that one kind of sensor will be perfectly suitable for all types of applications, or even perfect for one application. Combining the data of multiple sensors increases the meaningfulness of the derived context and improves error detection and correction. Multimodal user interfaces can make use of different types of sensors such

as microphones, video cameras or pen-based devices to permit flexible use of input modes and increased capability to understand the users' intention.

5.2 Instrumentation trends

One of the main recent developments in sensor technology is to make the sensors "smart" by combining them with microprocessors. This allows them to pre-process acquired data and communicate directly with other sensors.

The Telecooperation Office (TecO) of the University of Karlsruhe has developed *Smart-Its*, small-scale embedded devices equipped with sensing, processing, and communication capabilities which can be attached to everyday objects to let them establish dynamic digital relationships with their environment and users, the best known of which is the *MediaCup* (Beigl, Gellersen and Schmidt 2001). More on sensors and what kind of information they can provide can also be found in (Schmidt and Van Laerhoven 2001).

Similar devices are the *MOTES* (Hill, Szewczyk, Woo et al. 2000), which have been developed at the University of Berkeley as part of the *Smart Dust* project, with the final goal being to make then as small as a grain of sand (Warneke, Last, Liebowitz and Pister 2001).

The location of objects and people has been found to be one of the most valuable types of context information. Substantial research has been conducted on which types and combinations of smart sensors to use to gather location information. The Cricket Indoor Location System, developed at MIT, uses a combination of RF and ultrasound technologies. Wall and ceiling-mounted *beacons* are spread through buildings, publishing information on an RF signal and concurrently sending an ultrasonic pulse. The mobile receivers of these signals can determine their positions due to their different propagation times (Priyantha, Chakraborty and Balakrishnan 2000). The AT&T Cambridge Bat location sensor system uses the same technologies, though their mobile *bats* send ultrasound pulses instead of receiving them (Addlesee, Curwen, Hodges et al. 2001). The RADAR system developed at Microsoft Research (Bahl and Padmanabhan 2000) and the UCLA Nibble system (Castro, Chiu, Kremenek and Muntz 2001) both use an existing WLAN (802.11b) infrastructure to derive location information from received signal strength. More can be found in the survey of location systems for ubiquitous computing (Hightower and Borriello 2001).

Some information might not be gained without direct user interaction. New tangible interfaces have been developed which present and gather information in a more natural way using physical objects. They are therefore more suitable for home use by children and the elderly. They can give direct feedback, present information in a more natural way and allow the users to take control literally into their own hands. One of the most well known examples have been developed at the MIT tangible media group lead by Hiroshi Ishii (Ishii 1997) (Ullmer and Ishii 2000). Saul Greenberg from the University of Calgary developed physical widgets, which he called *Phidgets*, as building blocks to help developers to construct physical user interfaces (Greenberg and Fitchett 2001).

As sensors may number into the hundreds per home, connecting them by wires can become impractical and expensive, as the cost of running wire for sensors in buildings is 50%-90% of the cost of the sensor (Center for the Build Environment 2002). This is especially the case for existing homes, as they will likely not have cable conduits like modern office buildings. It also does not make sense to equip an object which has been wireless so far, with a sensor that has to be connected by wires. Therefore sensors which communicate over wireless networks are ideal for deployment in existing homes. Smart devices with sensors, which use Bluetooth for wireless communication, have been developed at the ETH Zürich (Mattern 2001). To support local communication between their smart devices a spatially aware communication infrastructure has been developed at the University of Karlsruhe (Beigl 1999) (Hupfeld and Beigl 2000).

All aforementioned systems rely on sensors directly attached to people and objects. An alternative solution is to monitor the occupants, objects and their environment unobtrusively and passively using video cameras. Humans acquire a large amount of information about their environment through vision. It allows them to determine where they are, as well as who and what is around them. By using digital cameras and appropriate image sequence analysis software, context-aware environments can derive useful context information from video data. Even when they are not connected wirelessly, cameras have the advantage that a few of them, installed at fixed positions, might be enough to gain sufficient context information.

Video camera based systems to track people moving around in a room have been developed by the Vision Interfaces Group at MIT (Darrell, Demirdjian, Checka and Felzenszwalb 2001) and at Microsoft for their *EasyLiving* project (Krumm, Harris, Meyers et al. 2000). Research at Microsoft also revealed that users prefer to communicate with their environment through gestures and speech (Brumitt and Cadiz 2001) which could be realized by using the cameras in combination with microphones.

5.3 Privacy Issues to consider when choosing Sensors for a context-aware Home

Pervasive computing will deeply affect most aspects of the way that we live and work. It will undoubtedly have an unprecedented impact on personal privacy. Security and privacy are prerequisites for consumer acceptance of context-aware homes. Lots has been written on privacy in stationary or mobile environments but less so on ubiquitous/pervasive environments (Bellotti and Sellen 1993). In an environment infused by invisible gadgets, it is impossible to have perfect protection for personal information (Langheinrich 2002), but care must be taken to minimize privacy threats. One possible way to achieve this is to give users more control and awareness over the use of personal information. If they are in control of their data, they might be willing to choose to sacrifice parts of their privacy for an easier life. The W3C P3P is a web standard policy specification on how a site handles personal information about its users (W3C-Consortium

2001), which might be used as a basis for a home privacy policy.

Looking at the number of smart sensors which may soon end up in our homes, we recognize that privacy becomes an important issue. People are already providing personal information for increased convenience in other digital domains, but this practice should be kept to the minimum. With every use of a credit card they add more information to an ever increasing personal shopping profile. From the type and amount of goods and services a person is buying with their credit card, a lot of information can be inferred about their personal behaviour and preferences. In addition, people who carry a switched-on mobile phone with them give the mobile network operator the potential to track their location and movements over time.

If people prefer to live in a context-aware home to gain extra convenience, every measure should be taken to prevent that information about their private life being accessed by anybody else. There are two main approaches towards ensuring privacy. The more common approach is to try to make sure that as little information as possible gets outside the system, the second interesting alternative is to restrict the amount of information being acquired and stored to the absolute minimum right from the beginning.

We think that privacy and security should already be addressed at the sensor-level, integrating appropriate mechanisms from the beginning. Smart sensors with their own processing capabilities through embedded microprocessors enable us to implement this. If the amount of private data being disseminated can be reduced at this stage, then this would offer the best protection. Once the information is spread across an interconnected, distributed system it becomes much more vulnerable to eavesdropping and hacker attacks.

If video cameras are being used to acquire information about occupants of a house and their environment, then we are reaching a point of a completely supervised life like never before. It would even exceed what Orwell envisioned in his novel “1984”, but with the surprising difference that the occupants themselves would freely install the surveillance systems in their homes in order to gain convenience.

Installing video cameras and intelligent image-processing systems has many advantages. Just a few cameras are enough to cover the whole house and its surroundings. There is no need to attach a smart sensor to every object and to every person. Cameras can be easily installed in new and existing houses (especially if combined with wireless networks) and they can each gather a large amount of information simultaneously. Using automatic face recognition, the identity of a person and their position can be tracked and gestures can be interpreted as commands without the need for any other additional input device. Also, dangerous situations (e.g. person falls down a staircase) might be detected as well.

The drawback is that more private information ends up in the system than the system actually needs to perform its tasks. We would not care if we could be sure that nobody else will be able to gain access to the data, but it would be even more secure if the data were not collected in the first place. For example, it should be sufficient to determine that the parents are in the bedroom, but no actual video footage of what is happening is necessary.

One solution might be not using video cameras at all, but relying on other (non-imaging) sensors to gather the needed information about the environment and the people within it. The problem is that the installation of many sensors might be very cumbersome or even impractical.

Another alternative would be to let the environment stay “dumb” and use smart mobile devices or wearable computing equipment to gather and process contextual information, and then let these devices instruct the environment to perform certain tasks. It would also allow people feel to be more in control of what is happening. A person would be able to go totally offline by simply switching off their mobile device or by not wearing their wearable computer.

To overcome privacy concerns when using video cameras, the cameras could be equipped with high-level image-analysis capabilities on the same chip. The smart camera would be provided with all the necessary information to recognize relevant objects and individuals and would only return descriptive information (e.g., parents are in the bedroom). In order to be still able to perform security surveillance tasks, the camera could send full-scene-pictures to a user for further analysis whenever an unknown face was detected.

As already mentioned special care has to be taken to prevent people from hacking into the private home network to gain access to personal information. This is especially the case when wireless networks are deployed, as there is no longer physical protection to prevent authorized access.

Today, people might still bear with the security flaws in their PCs, but that will likely change when their computers get to know much more about their private life. Though people might be willing to sacrifice a little bit more of their privacy for added convenience, we strongly suggest taking privacy issues seriously and designing ubiquitous computing as securely as possible from the beginning.

6 Middleware and Frameworks for context-aware Homes

Figure 1 shows the components, which should as a minimum be available in a context-aware system:

- A hardware abstraction layer which decouples the software from the actual implementation of the sensors and the communication infra-structure.
- A context manager which derives basic context information from the raw sensor data, maps it to a suitable context model and derives higher level context-information from lower ones.
- A privacy manager which makes sure that only selected information leaves the privacy domain and otherwise ensures that as little as possible gets outside.

Most parts of these components will likely be realized in middleware and/or some kind of framework to make them reusable for all kinds of context-aware applications. The applications themselves will make use of the context-information processed by the middleware and will likely not reside in one place, but will be distributed over servers, smart sensors and actuators.
We don't think that the components of the middleware have to be specifically developed for home use, as their functions will be quite similar to other context-aware systems. One noticeable exception though, is the management of the middleware. Today's systems are far too complex to be manageable by the average user and there is still quite some work to do to make them "self-manageable".

6.1 Hardware Abstraction Layer

The task of the hardware abstraction layer is to decouple the higher level software from the actual sensor hardware, its software and the communication network.
The context manager should not be affected by the type of sensor, type of network (wired or wireless), transfer protocol or if the data has been encrypted during transmission or not.
As we envision context-aware environments to be highly dynamic, with sensors, networks and environments changing constantly, we expect the addition of previously unknown sensors and transmission modes to be possible at any time during runtime. New smart sensors and actuators should be discovered automatically and they should form ad-hoc networks when there is a need to communicate.

6.2 Context Manager

Meaningful context information has to be derived from raw data acquired by sensors. This context processing aims at building concepts (knowledge) from environmental information sensed by sensors. Information can be also provided directly by users - we call such information profiled information. This intelligence processing is also known as context interpretation. It should contain two separated sub-steps:

- Modelling: Raw data is modelled to reflect physical entities which could be manipulated and interpreted. Part of the modelling consists of (i) representing the complex structure of a situation in the environment (e.g. representing a room) (ii) correlating raw data from different sensors (e.g. temperature measurement must be associated with the location of the temperature sensor) (iii) defining relationships between entities (e.g. a room is within a building). The output of this module could be considered as a set of propositions about the physical environment (e.g. Paul is absent).

- Evaluation: Propositions from the modelling module are relative to a particular situation (McCarthy and Buvac 1997). They need to be evaluated against a particular context. McCarthy defined a relation *isTrue(c;p)* which means that the proposition *p* is true only in the context *c*. Hence, the interpretation through different space and time could significantly change the results. Therefore the evaluation of a proposition must be associated with a context (c). The evaluation produces assertions (e.g. it's true that Paul is absent from his desk and Paul is not absent from home). Evaluation mechanisms often use artificial intelligence techniques.

The context manager should be able, by means of some sort of description, to combine lower level context information to higher level constructs not conceived of at design time.
As a basis for a context management infrastructure which is currently under development (Rakotonirainy, Indulska, Loke and Zaslavsky 2001), Karen Henricksen developed a context model that overcomes problems associated with previous models and improves their generality. It also tackles issues such as wide variations in information quality, the existence of complex relationships amongst context information and temporal aspects of context (Henricksen, Indulska and Rakotonirainy 2002).

6.3 Privacy Manager

With sensors being ubiquitous in the home, substantial private information will be collected. The residents should be confident that sensitive, private data does not leave the privacy domain and fall into the wrong hands. Otherwise they will not find life in a context-aware house pleasant. They might be willing to sacrifice some of their privacy for easier living, but they should be given the opportunity to define privacy policies with which they are comfortable in an easy way themselves. Users should be given the opportunity to explicitly grant or reject certain rights to other family members, visitors, foreign persons or their smart objects in the house. The privacy manager has responsibility for controlling what data might go where. Unfortunately, today's systems for privacy management are still far too complicated to be managed by the average user. There is definitely more research necessary on how privacy policies for a context-aware home can be implemented and managed in an easy way.

6.4 Current Research on Middleware and Frameworks for Context-Aware Homes

Schmidt and Van Laerhoven introduce the concept of *cues* for their framework for building distributed context-aware systems. *Cues* provide an abstraction of the actual sensor implementation and also allow the pre-processing of samples taken at different times. Context is being derived from the *cues* by Kohonen Self-Organizing Maps and K-Means clustering (Schmidt and Van Laerhoven 2001).
Anind K. Dey developed a conceptual framework and a toolkit for supporting the rapid prototyping of context-aware applications (Dey, Abowd and Salber 2001). He introduces three components for acquiring context and delivering it to interested applications. C*ontext widgets* insulate applications from the actual sensors and context

acquisition concerns and *context interpreters* derive higher abstractions of context from lower levels or multiple other pieces of context information. *Aggregators* help to collect multiple pieces of context information that are logically related into a common repository.

He also introduces *context services* which are an analogue of the context widgets, but which abstract the output and allow the control of actuators or the change of state information in the environment. *Discoverers* are the final component in his conceptual framework. They are responsible for maintaining a registry of what capabilities exist in the framework.

At Cambridge University (UK) QoSDream has been developed, a research platform and framework for the construction and management of context-aware multimedia applications (Bobick, Intille, Davis et al. 1999). Based on this, FLAME, an open application framework for location-aware systems, has been implemented (Coulouris, Naguib and Sanmugalingam 2002).

More information on context-aware middleware can be found in (Abowd, Atkeson, Hong et al. 1997) (Brown 1995) and (Chen and Kotz 2000; Rakotonirainy, Indulska, Loke and Zaslavsky 2001).

A few context-aware homes are also already under development, though little information about their system architectures has been provided: (Kidd, Orr, Abowd et al. 1999) (Miller 2001) (Brumitt, Meyers, Krumm et al. 2000) (Heierman 2000) (Phillips 2001).

7 User Experience

One of the goals of context-aware homes is to increase the appeal of using technology to people who otherwise would not use it. A context-aware home should feature usable and useful technology that users want to use, with technology that fits with the context-aware home lifestyle.

7.1 User Experience Requirements

Aside from making the context-aware home space pleasant, personalised and easy to use, it must also be a solution to real problems and not another added burden that fails to support the user's achievement of the task at hand. Assessment studies about consumers' needs have been conducted (Internet Home Alliance 2002). They show that the most appealing aspect of the connected home is the time-saving associated with the ability to control a variety of devices from a central system. The least appealing aspect is the presumption that the technology will be too complicated.

The studies demonstrated that usability in software and user interface is of the utmost importance in software lifecycle development. According to ISO9241, usability is the *effectiveness*, *efficiency*, and *satisfaction* with which specified users achieve specified goals in particular environments. Based on such a definition the HCI research community has developed empirical studies such as suitability for the task, appropriateness for trained users, learn ability and error tolerance to measure usability.

7.2 Trends: User Experiences

Most usability research focuses on human-centred perception of machines (Nielsen 1993), and can be summarized by Norman Donald "*I'm a technology enthusiast annoyed by unnecessary complexity of today's products. My goal is to humanize technology, to make it disappear from sight, replaced by a human-centred, activity-based family of information appliances. Easy to learn, easy to use. Powerful, enjoyable*" (Norman 1998). The Disappearing Computing is an EU funded initiative studying how pervasive environments can lead to new ways of supporting and enhancing people's lives that go above and beyond what has been realized with the computer until today (Disappearing Computer Initiative 2001). The above research needs to be complemented with the

- Identification of a set of user requirements that fit, both functionally and aesthetically, with the context-aware home occupants' lifestyles.
- Identification and understanding of occupant's pattern of behaviour evolving in a context-aware home environment from social and economic perspectives (Bellotti and Edwards 2001).

We also believe that the usability community has not paid enough attention to beauty, to fun, or to pleasure. There is a need to study beyond usability by looking at design parameters that influence the happiness and comfort of users (Jordan June 2001). This dimension reaches psychology research on emotion and affect. The idea is to communicate emotional/affective information to machines so that they can adapt and improve their interaction with users (MIT Media Lab 2002). Improvement of interaction can manifest itself by the involvement or absorption of the user in a *flow* of activity for its own sake (Csikszentmihalyi 1990). The use of computer game design theory in order to have affective user interfaces impacting on concentration, enjoyment and absorption in an activity is one way to increase the involvement of users. Some empirical studies are still needed to validate this approach.

8 Conclusions

The sensors for acquiring relevant context information for context-aware homes and other hardware to present information and execute actions are largely available, but have to be carefully chosen to meet the special requirements of home residents. Privacy and ease of use are definitely important topics to be examined.

Systems to derive meaningful context information from sensor data are becoming available, though there is still some work to be done. Computer vision systems for example, still require powerful hardware for the time consuming computations. Though current research has already provided systems which largely meet the desired requirements, they still have to become smaller and cheaper before they can be deployed ubiquitously in context-aware homes. More work also has to be done on generic platforms and frameworks for developing context-aware environments. They have to support modelling, handling, storing and disseminating context, as well as deriving higher level context information from lower levels in constantly changing, dynamic, distributed systems.

A very challenging research topic is the development of smart applications which will likely require some sort of artificial intelligence systems to enable them to derive meaningful responses, as desired by the occupants of context-aware homes, from the context information. If they will not act as expected in most of the cases, they will likely not be accepted. Preventing this does not only require solving the technological problems, but also a better understanding of the residents desires through user studies in a context-aware home.

Furthermore, components for context-aware systems have to be developed which need (close to) zero administration and can be managed by non-experts.

To put the residents in control of what happens to their private data, they must be made aware of what happens with it and they must be enabled to specify privacy policies in an easy way.

Finally, there is also a need to think about the social and economic impact of ubiquitous computing (Marc Langheinrich April 2002).

We have presented examples of how people could benefit from living in context-aware homes and outlined issues to keep in mind during their development. We introduced the notion of context and identified the research dimensions that need to be addressed in order to make the vision of "context-aware homes" a reality. We surveyed systems for acquiring and interpreting context information and addressed privacy problems related to the ubiquitous deployment of in-house sensors.

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