Towards an Evaluation Framework for Assistive Environments

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ABSTRACT

As the world population is aging, there is an increasing need to support independent living of elderly people. Assistive environments incorporate the latest pervasive and ubiquitous technologies and provide a viable alternative to traditional assistive living. In this paper, we propose an evaluation framework to assess the quality of assistive environments. An assistive environment can be successful only if the potential users are willing to adopt it. The proposed framework identifies a set of attributes that are considered critical to user adoption. Sample metrics, as well as possible approaches to measure them, are also suggested to quantify those attributes. The framework is illustrated using an experimental assistive apartment environment that is being built at the University of Texas at Arlington.

Categories and Subject Descriptors

H.4.m [**Information Systems Applications**]: Miscellaneous

General Terms

Measurement, Performance, Design, Reliability, Security, Human Factors, Standardization, Languages, Verification.

Keywords

Assistive environments, assistive living, pervasive computing, metrics.

1. INTRODUCTION

As the domains of Pervasive and Ubiquitous Computing are expanding, there is an increasing quest on how to capitalize the benefit that these technologies can offer. Assistive living and healthcare support can greatly benefit from such technologies provided that they find the ways to effectively adopt and assimilate these technologies according to their needs. The realization of the aforementioned potential by researchers and companies has created an ongoing trend towards the investigation of novel methods and schemes for the application of pervasive technologies into modern approaches of assistive environments for the support of elderly and disabled people.

This trend is also amplified by the fact that the world population is getting older, and thus, there will be an increasing need to support independent living of elderly people. According to the United Nations, Dept. of Economic and Social Affairs Population Division, by 2050, the percentage of people worldwide over the age of 60 is expected to double (to 21.4%), and the percentage of those over the age of 85 will quadruple (to 4.2%) [33]. The aging of the population will increase the needs for healthcare and nursing personnel, which in turn will increase the total cost of the traditional assistive living. The emerging pervasive technologies and computing capabilities can offer a viable alternative which can partly or completely replace the need of continuous monitoring and support to elderly or disabled people. It can also be used to enhance prognosis or tracking of certain conditions such as Dimentia.

Examples of assistive environments such as Elite Care [31] already exist, but they are mainly in experimental phases supported by universities or other institutions. These technologies have to deal with numerous challenges before they become practical and commercially viable in real life. Such challenges include certain functionality and usability issues, security and privacy concerns, architectural difficulties and const-benefit balancing. These challenges can be analyzed from an engineering perspective and suggested solutions can be evaluated on the basis of certain metrics that quantify important attributes of assistive environments.

The need for immediate ways to address the above issues motivates us to propose an evaluation framework which will be used as a starting point for the analysis of future efforts for the creation of viable assistive environments. To help the discussion we will first describe an experimental assistive apartment environment that is being built at the University of Texas at Arlington. We will then identify the attributes that are important for the viability of such an environment in real life. For each attribute, we suggest sample metrics and possible approaches to measure them. Note that some preliminary work toward the establishment of evaluation frameworks for ubiquitous and context-aware pervasive computing applications has been reported in the literature [28]; however, this work does not take into consideration the special characteristics of the assistive environments and the target users.

The rest of the paper is organized as follows. Section 2 gives some general information about pervasive/ubiquitous computing and assistive environments. Section 3 describes the experimental

PETRA 2008, July 15-19,2008, Athens, Greece.

assistive apartment environment. Section 4 presents the proposed evaluation framework. Section 5 provides some concluding remarks.

2. RELATED WORK

In literature the terms Pervasive Computing and Ubiquitous Computing have been used interchangeably to describe a state which involves the availability of many effectively invisible computers throughout the physical environment [35]. In their introduction to an IBM Systems Journal focused on pervasive computing, Ark and Selker [1] note that there are a hugely broad range of areas for pervasive computing research. One of these areas is Pervasive Healthcare. Korhonen [18] has defined pervasive healthcare as 'the application of pervasive computing technologies for healthcare, health and wellness management' and 'as making healthcare available everywhere, anytime, pervasively'.

According to Henricksen and Indulska [15], despite the recent flurry of interest, applications that rely on pervasive computing have not yet made the transition from the laboratory to the marketplace. This is largely a result of high application development overheads, social barriers associated with privacy and usability, and an imperfect understanding of the truly compelling (and commercially viable) uses of pervasive applications. Scientists have examined the possible challenges related to the adoption of pervasive computing by healthcare applications. Such challenges include the need for real world testing, because patients and care-providers are not, as a rule, early adopters [18]. Not all challenges are technical: for example, Korhonen and Bardram [18] note a political issue, which is the need for *de facto* communications standards. Another issue is dependability, which becomes very important in some circumstances, for example when a system is dispensing or regulating medicine [6]. Other work has considered technical, social and pragmatic challenges involved in providing such technologies in the domestic environment [8]. There are also ethical issues associated with this kind of wirelessly-networked, ubiquitous technology [32], and especially the surrounding privacy.

Despite the aforementioned difficulties, there have been substantial efforts for the exploitation of the advantages of pervasive technologies in assistive living. Stanford [31] describes an assistive living complex designed by Elite Care which puts pervasive computing technologies directly in the service of improved quality of life for the elderly, whereas Dowdall[7] analyzes the "Millennium Home" as an example of domestic technology to support independent living of older people.

Scientists have realized that one of the most important factors that will decide the acceptance of the new technologies by the average users and especially the elderly people is to ensure that they are not pressured to take on new systems in which they have no interest. Works on theory of technology acceptance such as the ones by Davis [23] and Venkatesh [34] can help towards this direction. Cheverst [6] has examined and determined many differences between both domestic and care environments compared to workplace environments. Moreover, Newell and Gregor [21] discuss specialist and mainstream design for older and disabled people. They note some differences found in older users – for example, an elderly user is more likely to have one or more disabilities, as well as different wants and needs, than an able-bodied user. The specialties of the users served by assistive environments have created the need for special user interfaces. The kind of disability of the occupant determines the user interface of the control centre. As noted by Nussbaum and Miesenberger [22], in most cases a standard environmental control system (e.g. FST James 2000 [10], SiCare Pilot [13], Proteor Nemo+ [27]) can be used as control centre. But also Tablet PCs and PDAs with special control software (e.g. Autonom [9], SmartX, Pocket Grid [28]) can be used as control centre.

Although there have been some preliminary efforts in the creation of modeling tools to assist designers with the task of exploring and specifying the requirements of general pervasive applications[14], such tools do not yet exist for the specific domain of assistive living. However, the general tools may be adapted to the domain of the assistive living by taking into consideration the unique attributes that define an assistive environment like the ones described in the following sections of this paper.

Finally, one of the most important issues to be addressed by the pervasive technologies for assistive environments is the data mining process and the activity recognition from the collected data. Assistive systems use sensors to monitor a user and obtain information about their location, level of activity, performance of daily activities, etc. Pollack [26] emphasizes that the information collected by such sensors is usually noisy. For this reason, methods of reasoning under uncertainty, such as Hidden Markov Models or Dynamic Bayes Nets, are employed to interpret the sensor data. Examples of this work include [19][20][24]. The collected information can be utilized in several ways. For example, if some deviation from the usual activity pattern is detected, the system can provide an alert to the user and/or to the care givers (e.g., [11]). Extensively, the stored information can be subject to further analysis and inference within compensation or assessment systems. The former assists people in navigating, managing a daily schedule, completing multi-step tasks, locating objects, and so on. Examples include Autominder [25], which uses AI planning technologies to track the activities that a user is expected to perform, and then uses machine learning to induce strategies for interacting with a user when the expected activities have not been performed on time, and Coach [4], which models plan-tracking and reminding as a Markov Decision Process. Although there has been not much work to date on assessment systems, there is an interesting example that uses variations in walking speed as an early indicator of potential cognitive decline [17].

3. AN ASSISTIVE APARTMENT ENVIRONMENT

In this section, we describe an assistive apartment environment that is being built at the Heracleia Lab of the University of Texas at Arlington. We will use this environment as a running example to illustrate our framework. In general, an assistive apartment environment contains intelligent objects, which function both independently and communicatively. Inside an apartment, appliances and objects function in their own right and also exchange messages with or without a central server to give interactive and intelligent responses. In addition, patterns of activity in the apartment are recorded and the accumulated data are used to help diagnosis, anticipate patients' needs, and facilitate other research. Each event has distinct spatial-temporal characteristics where different "players" come into play, similar to a theatric scene. The difference here is that all objects and humans can interrelate and communicate with the environment, receiving and generating different types of data. Appropriate analysis and/or synthesis of such heterogeneous information can derive valuable understanding regarding the needs of the human who is at the center of this activity.

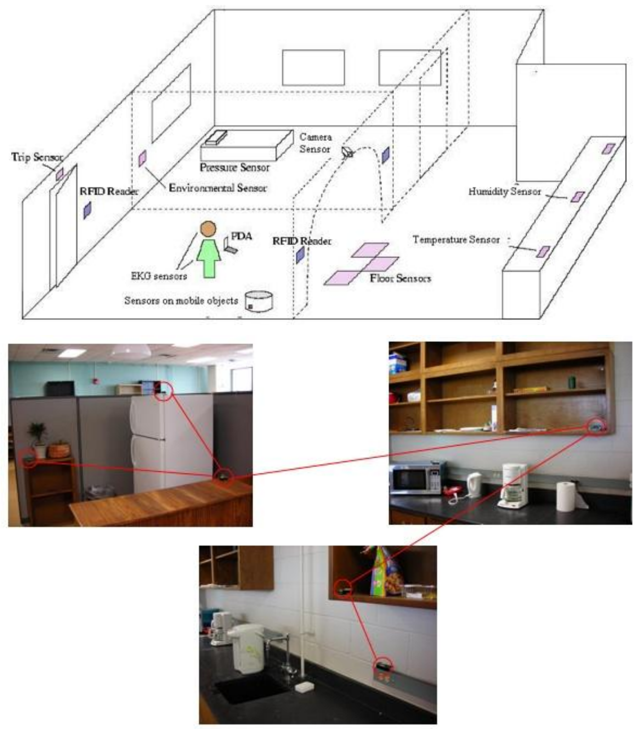

Figure 1: An Assistive Apartment Environment

New materials (e.g. polymer technologies) and technologies that could be applied in assistive apartments may include micro- and nanoelectronics (nanocoatings, polymer actuators), biomicrotechnology (biochips, sensors to measure values like blood pressure, temperature, weight, respiration, urine output and to observe activity patterns nutrition, gait sleep), energy generation and control technologies (energy harvesting), human machine interfaces (display technologies, natural language communication).

General example scenarios (Figure 1) in assistive apartments include noticing unwanted movement (e.g., during a break-in), automatically turning on lights, having a camera record what is happening, raising the alarm and alerting a reporting centre by telephone. A specific example scenario of a cardiac risk patient could be as follows. His electrocardiogram (ECG) is monitored with a small and lightweight chest belt. The ECG is continuously analyzed in the chest belt. In case that an acute event (e.g. Ventricular Fibrillation (VF)) is detected, an emergency signal is automatically sent wirelessly to a base-station. In addition, 20s of the recorded ECG leading to the event are transmitted. At the base-station, an optical and acoustical alarm is generated, so that his caregiver is made aware of this critical situation of the patient. At the same time, the base-station automatically transmits the detected event and the received ECG directly to emergency room through the Internet so that the trained staff gets as much information as possible.

The architecture and major components for our assistive apartment experiment are described in Figure 2. A patient and his apartment are equipped with different types of sensors. The eight major components are listed below.

- *Monitoring/data collecting component:* In this component, different types of sensors including medical sensors will be either physically deployed in an apartment or carried by a patient. The sensors will send data/message to a base station connected to a server.

- *Privacy configuration component:* The patient will set a privacy configuration file before using this system. He or she also can change his or her configuration later. This configuration will let the patient be aware and decide what kind of data about him or her is monitored, such as tracing, video surveillance, sleep pattern, etc, and also what kind of access to the data is granted to whom (caregivers, physicians, and/or other outside researchers).

- *Human computer interface component:* The system will provide a user-friendly interface to help patients, especially those with disability, to interact and tutor caregivers and others. This component may include natural language processing and graphic display of instructions.

- *Authentication component:* The patient should be identified because of security concerns such as sensor capture and impersonation. Voice recognition, heart-beating pattern recognition, or other biometrics will be applied in the system to identify the sensor carrier. In order to securely access data and configure the system will check if its users (patient, caregiver, other data users) have sufficient access privileges or attributes before allowing them to operate.

- *Event recognition component:* The system has some predefined events. The system automatically monitors the medical information and activities of the patient and the environmental data. When there is a match, it will trigger the response component. In addition, it is a self-learning component. It will periodically go through the history and refine the definition of a certain event and create a new one according to the human response it records.

- *Real-time response component:* This component is connected but independent with the recognition component. It will give predefined response instructions according to the type of the events it recognizes. Some of the instructions are given or displayed through the graphic user interface component while others will intrigue other components such as communication component to notify remote entities.

- *Data mining component:* The system will provide an API and tool kit for future extension of data mining methods. For example, feature extraction on motions of certain diseases such as Alzheimer's and Parkinson's.

- *Secure communication component:* This component will provide a secure and efficient communication to remote users such as physicians, researchers, and other related facilities or hospitals. Authentication and access control in Component 4 is built upon this module.

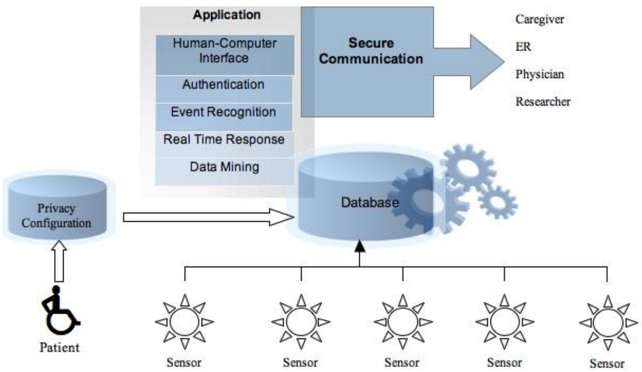

Figure 2: This figure shows the overview of the architecture of an assistive apartment environment. Wireless sensors collect data and share them through a database with related entities such as caregivers and physicians. They securely communicate with the environment in a real-time manner. Data mining tools are provided to analyze the collected data. Patients are allowed to configure a privacy policy on their data.

4. THE FRAMEWORK

In this section, we present an evaluation framework to assess the quality of assistive environments. An assistive environment can be successful only if its potential users are willing to adopt it. This framework identifies a set of attributes that are considered critical to user adoption. Sample metrics, as well as possible approaches to measure them, are suggested to quantify those attributes. In the following, we divide these attributes into the following five categories, namely, functionality, usability, security and privacy, architecture, and cost, and discuss each of them in details.

4.1 Functionality

An assistive environment must perform correctly in order to serve its purpose, i.e., facilitating the patient's independent living. More importantly, failure in an assistive environment could carry severe consequences. For example, in the scenario described in Section 3, if an acute event is detected by the chest belt, an emergency signal must be sent to a base-station, which should further generate an alarm to alert the caregiver and if needed, the staff in an emergency room. If the acute event is not detected, or if the emergency signal is not sent timely, the life of the patient may be in danger. Therefore, the evaluation of whether an assistive environment can perform its tasks correctly is at the very core of the evaluation of an assistive environment.

The proposed framework identifies the following major attributes to be used for functional evaluation.

- *Correctness*: A task is implemented correctly if it delivers the required functionality as specified in the requirement document. Ideally, this attribute can be measured by the ratio of the number of tasks that deliver the expected results over the total number of tasks that can be performed in an assistive environment. In practice, the total number of tasks is often difficult to derive. One possible approach is to generate a set of test scenarios that exercise a representative set of the tasks, e.g. based on the functional requirements, and then check how many of those scenarios can be performed correctly. In addition, feature-specific metrics can be developed. For example, in the assistive apartment environment in Section 3, an important feature is that the event recognition component must be able to correctly identify events that occur in the environment, based on the activities being monitored. A possible metric for this feature is the ratio of the events that are recognized correctly over the total number of events that occur in the environment.

- *Robustness*: This attribute refers to the ability of an assistive environment to deal with unusual situations [3]. In particular, can faults that may occur or exist in the environment be tolerated? There are two major types of faults to consider: (1) User errors, i.e. mistakes that a user may make when performing a task, e.g., a user may have pressed a button that is not supposed to be pressed given his or her situation. Considering that the users are typically not familiar with technology, user errors are particularly common in assistive environments. On the one hand, assistive environments should be designed in a way such that user errors are prevented from happening in the first place as much as possible. On the other hand, the system should be able to continue to operate correctly even in the presence of a user error. (2) Device failures. As illustrated in Section 3, an assistive environment often consists of many small devices that may be subject to failures due to either malfunctions or adverse conditions in the environment. In the case of the assistive apartment environment, a sensor in the data collection component may give an incorrect reading due to some environmental noise or may have gone down due to the depletion of its battery. The failure of one or a few devices should be tolerated, or its impact should be limited as much as possible, in an assistive environment.

  Robustness can be difficult to measure precisely because, for example, there can be an infinite number of ways for a user to make mistakes. One possible approach is to generate a set of test scenarios to exercise failures that have a high probability to occur based on an operational profile or based on a careful analysis of the vulnerability of the devices deployed in an assistive environment. The percentage of those test scenarios that can be tolerated by an environment can be used as a possible indicator of the robustness of the environment.

- *Reliability*: This attribute refers to the sustainability of an assistive environment. That is, how long can the environment operate continuously without breaking down? Many assistive environments are designed to monitor the patients' daily living continuously, where a reset can be very inconvenient. In addition, as discussed earlier, assistive environments can be safety-critical, and unexpected breakdowns may have severe consequences.

One possible metric for reliability is *mean-time-to-failure*, i.e., the average time a system can operate continuously before a failure occurs. The key to measure mean-time-to-failure in an assistive environment is to build an operational profile that is representative of the way in which the environment is used in real life.

4.2 Usability

Usability is one of the most important concerns in assistive environments. There are two major reasons. First, assistive environments target a special group of users who are typically not familiar with technology, and may even have mental and/or physical challenges to learn and memorize instructions [21]. Second, the purpose of assistive environments is to *assist*, rather than create new challenges, in one's daily life. This purpose would be easily defeated if an assistive environment were difficult to use. A key to achieving usability is to make the technology invisible. That is, tasks should be performed in a natural way, i.e., with minimal deviation from how an average person would expect these tasks to be performed by intuition [16]. Related to the above is the fact that an assistive environment should be easy to use for both the patients and the caregivers.

The proposed framework identifies the following major attributes to be used for usability evaluation:

- *Ease of Use:* This attribute consists of several aspects. The user interface of an assistive environment should be easy to navigate. In particular, a user should be able to quickly find commonly used operations. If a sequence of operations needs to be performed to accomplish a given task, then the order in which those operations are performed should be made as straightforward as possible, and the sequence should contain as few operations as possible. If certain input can be derived from context, then it should be done so, instead of asking the user to provide it explicitly [5]. Hints and help should be made readily available, especially for less straightforward operations.

  Note that an assistive environment should be easy to use not only for the patient who lives inside the environment, but also for the operators who help to set up and maintain the environment. That is, ease of use implies easy to set system up, easy to maintain, easy to update and easy to learn how to use it. One possible metric for ease of use is the length of the learning curve for a typical user. That is, how long does it take the user to learn the use of an assistive environment? Metrics like the average length of navigation, the average number of steps required to perform a common task, can also be used. However, as this attribute largely deals with user perception, a completely objective measurement would not be possible. Having a group of testers who is representative of the target user base is the key to mitigate the potential variations in user perception.

- *Accessibility:* Assistive environments target a special user group in which many people have mental and/or physical challenges. The user interface of an assistive environment should be made accessible to accommodate the special needs of those people. For example, if the user has difficulties to read the screen, then an audio-based interface may be employed to better interact with the user.

  Some metrics that can be used to measure accessibility include the number of available accessible options, the number of transformations that are available between different options, and the degree of transparency between those transformations.

- *Non-obtrusiveness:* To maximize the utility of an assistive environment, it is often necessary to be proactive. For example, it is desirable to remind a person who suffers Alzheimer's disease of taking medicine at a regular interval. However, there is a fine line between being proactive and obtrusive. People tend to reject systems that they consider to be obtrusive [18].

  This attribute depends on user perception to a large degree, and is thus difficult to measure on a purely objective basis. In particular, the same operation might be considered obtrusive by some people but not by other people. One possible approach to measure obtrusiveness is to identify a group of testers who are representative of the user base and then collect feedback from them.

4.3 Security and Privacy

Security and privacy attract more attention when a system involves remote users and when data are shared with other institutions, even for the research purpose. Secure communication, data access control, and robustness against certain attacks are among the most important aspects to be evaluated.

The proposed framework identifies the following major attributes to be used for security and privacy evaluation:

- *Violation reports:* The number of security violation reports (or breaches) and the number of privacy violations could be used to measure the accomplished strength of security and privacy protection.

- *Configurable privacy/access control:* Users can customize policy agreements to grant access and release data; they configure setting files to choose what types of data are sharable with his physicians and other researchers and what types of access they can have.

- *Encryption strength:* Robustness of security & privacy control against cryptanalysis depends on the encryption strength. The length of common module for public/private key pairs can be used for measuring the strength. The password setting could be measured by weak, fair, and strong according to the combination of characters against off-line dictionary attack.

4.4 Architecture

Architecture refers to the interconnection of the major components in an assistive environment [30]. As shown in the assistive apartment environment in Section 3, an assistive environment often consists of a number of hardware components, e.g. various types of sensors, that are heterogeneous in nature. This calls for an open architecture that allows those components to work together in a seamless manner and in a way that can be easily configured and extended.

The proposed framework identifies the following attributes to be used for architecture evaluation:

- *Modularity*: Modularity is one of the most fundamental principles underlying modern system designs [2]. The idea is to make each component a relatively independent module by reducing the coupling between different components. Doing so makes it easier to change or replace individual modules with minimal effect on the rest of the system. For example, in the assistive apartment environment in Section 3, a modular architecture would allow a data mining component to be easily replaced by another one that employs a different algorithm, or a different type of sensor to be added into the environment.

  Modularity can be measured by the average number of other modules with which each modular has a direct or indirect dependency relation. The dependency relation between modules can be derived either by analyzing the source code, if available, or by conducting experiments.

- *Interoperability:* An assistive environment may interoperate with other systems. For example, in the assistive apartment environment in Section 3, the base station needs to interact with the server in the emergency room. In addition, within an assistive environment, different components need to interact with each other, and those components may come from different vendors. For example, in the assistive apartment example, the data collection component needs to work with different types of sensors.

  The key to achieve interoperability is to define a standard interface (or protocol) so that different parties can speak the same language. Interoperability can be measured by the number of interfaces that conform to a standard. One way to check if an interface of an assistive environment conforms to a standard is to perform conformance testing, i.e., having the environment actually work, at the interface point, with a third-party component or system that is known to be conforming to the standard.

Note that modularity and interoperability are orthogonal attributes, in terms that the former characterizes an assistive environment from a static perspective while the latter does so from a dynamic perspective.

4.5 Cost

The cost of an assistive environment must be controlled so that it is affordable to its user base. An assistive environment typically consists of many software and hardware components. The way in which those components are integrated can significantly affect the overall performance, and thus must be managed carefully. In particular, the most expensive components put together may not always deliver the best performance system-wide. Cost can also be controlled by seeking a balance between optimal performance and affordability. Note that the cost of an assistive environment does not only include the purchase price, but also the cost of maintenance.

The proposed framework identifies the following major attributes to be used for cost evaluation.

- *Installation Cost*: This is the cost that has to be paid to set up an assistive environment. It includes both the cost of purchasing the necessary hardware and software components, and the cost of putting them together and installing them in the physical space.

- *Maintenance Cost*: Maintenance activities are often necessary to keep an assistive environment up and running. Examples of such activities include regular replacement of sensor batteries, system reset after a breakdown, hardware and software components upgrade, and such.

Note that both installation and maintenance costs contribute to the overall cost of an assistive environment. In addition, there is often an interplay between the two types of cost. For example, some sensors cost more but are more robust and have a longer lifespan, which reduces the cost of maintenance in the long run. Therefore, the two types of cost should be considered in an integrative manner.

5. CONCLUSIONS

Assistive environments are unique in that they target a special group of users who are typically not familiar with technologies. Thus, user adoption is the key to the success of those environments. Our framework identifies a set of attributes that are considered critical to user adoption. Those attributes are classified into five categories, namely functionality, usability, security and privacy, architecture, and cost. The framework also suggests sample metrics, as well as possible approaches to measuring them, to quantify those attributes.

This work is part of a larger effort in building an infrastructure for evaluating assistive environments. The infrastructure will consist of hardware components that are commonly needed to deploy an assistive environment, and a collection of software tools that help to automate the evaluation process. We plan to build a database of operation and user profiles that are representative of real life scenarios that may occur in assistive environments. Those profiles will provide us with a more realistic assessment of those environments.

6. ACKNOWLEDGMENTS
This work was supported in part by the National Science Foundation under award number IDM 0733673, ITR 0733674, and CT-ISG 0716261. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

7. REFERENCES
[1] Ark, W. & Selker, T. A Look at Human Interaction with Pervasive Computers IBM Systems Journal, 1999, 38, 504-507

[2] Baldwin C., Clark K.., Design Rules: The Power of Modularity Volume 1. MIT Press, 2000.

[3] Boehm B., Brown J., Lipow M., Quantitative evaluation of software quality, Proceedings of 2nd International Conference on Software Engineering, pp. 592-605, 1976**.**

[4] Boger, J.; Hoey, J.; Poupart, P.; Boutilier, C.; Fernie, G. & Mihailidis, A. A Planning System Based on Markov Decision Processes to Guide People With Dementia Through Activities of Daily Living

[5] Chen G., Kotz D., A Survey of Context-Aware Mobile Computing Research. Technical Report TR2000-381, Dartmouth College, 2000.

[6] Cheverst, K.; Clarke, K.; Dewsbury, G.; Hemmings, T.; Kember, S.; Rodden, T. & Rouncefield, M. Designing assistive technologies for medication regimes in care settings Universal Access in the Information Society, Springer, 2003, 2, 235-242

[7] Dowdall, A. & Perry, M. The Millennium Home: domestic technology to support independent-living older people Proceedings of the 1 stEquator IRC Workshop, 2001, 1-15

[8] Edwards, W. & Grinter, R. At Home with Ubiquitous Computing: Seven Challenges Ubicomp 2001: Ubiquitous Computing: International Coference, Atlanta, Georgia, USA, September 30-October 2, 2001: Proceedings, Springer, 2001

[9] Flachberger, C., Panek, P., Zagler, W.L.: Autonomy - A Flexible and Easy-to-Use Assistive System to Support the Independence of Handicapped and Elderly Persons, Proc. 4th International Conference on Computers for Handicapped Persons (ICCHP), Vienna, Austria, Sept. 1994, 65 - 75.

[10] FST – Fondation Suisse Pour Les Teletheses – Stiftung fur Elektronische Hilfsmittel: James 2000. http://www.fst.ch/FST2/CATALOGUE/fiches_produits_details/James2_D.pdf. Oktober 2002

[11] Glascock, A. & Kutzik, D. The Impact of Behavioral Monitoring Technology on the Provision of Health Care in the Home Journal of Universal Computer Science, 2006, 12, 59-79

[12] Grudin, J. Why CSCW applications fail: problems in the design and evaluation of organization of organizational interfaces ACM Press New York, NY, USA, 1988

[13] Dr. Hein GmbH: SiCare Pilot. http://www.sicare.de/sicarepilot.html. Nurnberg 2002

[14] Henricksen K., Indulska J., and Rakotonirainy A. Modeling context information in pervasive computing systems. In 1st International Conference on Pervasive Computing (Pervasive), volume 2414 of Lecture Notes in Computer Science, pages 167–180. Springer, 2002.

[15] Henricksen, K. & Indulska, J., A software engineering framework for context-aware pervasive computing, Pervasive Computing and Communications, 2004. PerCom 2004. Proceedings of the Second IEEE Annual Conference on, 2004, 77-86

[16] Ivory M., Hearst M., The state of the art in automating usability evaluation of user interfaces, ACM Computing Surveys, 33(4):470-516, 2001.

[17] Jimison, H.; Pavel, M.; McKanna, J. & Pavel, J. Unobtrusive monitoring of computer interactions to detect cognitive status infielders Information Technology in Biomedicine, IEEE Transactions on, 2004, 8, 248-252

[18] Korhonen, I. & Bardram, J. Guest Editorial Introduction to the Special Section on Pervasive Healthcare Information Technology in Biomedicine, IEEE Transactions on, 2004, 8, 229-234

[19] Liao, L., Fox, D., Kautz, H.: Location-based activity recognition using relational Markov networks. In: Proc. of the Intl. Joint Conf. on Artificial Intelligence, pp. 773–778 (2005)

[20] Munguia-Tapia, E., Intille, S.S., Larson, K.: Activity recognition in the home setting using simple and ubiquitous sensors. In: Ganzinger, H. (ed.) ESOP 1988. LNCS, vol. 300, pp. 158–175. Springer, Heidelberg (1988)

[21] Newell, A. & Gregor, P. Design for older and disabled people-where do we go from here? Universal Access in the Information Society, Springer, 2002, 2, 3-7

[22] Nussbaum, G. & Miesenberger, K. The Assistive Home--More than Just Another Approach to Independent Living Computer Helping People with Special Needs: 9th International Conference (ICCHP 2004). Proceedings, Springer, , 1

[23] Davis, F.D., Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology MIS Quarterly, JSTOR, 1989, 13, 319-340

[24] Philipose, M., Fishkin, K.P., Perkowitz, M., Patterson, D.J., Fox, D., Kautz, H., Hahnel, D.: Inferring activities from interactions with objects. In: IEEE Pervasive Computing 3(4), 50–57 (2004)

[25] Pollack, M.; Brown, L.; Colbry, D.; McCarthy, C.; Orosz, C.; Peintner, B.; Ramakrishnan, S. & Tsamardinos, I. Autominder: an intelligent cognitive orthotic system for people with memory impairment Robotics and Autonomous Systems, Elsevier, 2003, 44, 273-282

[26] Pollack, M. Intelligent Assistive Technology: The Present and the Future LECTURE NOTES IN COMPUTER SCIENCE, Springer, 2007, 4511, 5

[27] Proteor Group: Nemo+. http://www.proteor.com/proteor/uk/ht/index_cata.htm

[28] Sensory Software International Ltd: Pocket Grid. Software for Windows CE Computers.

http://www.sensorysoftware.com/software/pocketgrid/index.html

[29] Scholtz, J., and Consolvo, S.. Toward a framework for evaluating ubiquitous computing applications. Pervasive Computing, IEEE 3(2004): 82-88.

[30] Shaw M., Garlan D. Software architecture: perspectives on an emerging discipline. Prentice-Hall, 1996.

[31] Stanford V 2002 Using Pervasive Computing to Deliver Elder Care IEEE Pervasive Computing 1 10-3 http://www.elitecare.com/

[32] Stone, A. The dark side of pervasive computing Pervasive Computing, IEEE, 2003, 2, 4-8

[33] United Nations Dept. of Economic and Social Affairs Population Division http://www.un.org/esa/population/unpop.htm

[34] Venkatesh, V. & Davis, F. A Theoretical Extension of the Technology Acceptance Model: Four Longitudinal Field Studies Management Science, JSTOR, 2000, 46, 186-204

[35] Weiser, M. Some computer science issues in ubiquitous computing ACM SIGMOBILE Mobile Computing and Communications Review, ACM Press New York, NY, USA, 1999, 3