

Findings from a participatory evaluation of a smart home application for older adults

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Abstract. The aim of this paper is to present a participatory evaluation of an actual “smart home” project implemented in an independent retirement facility. Using the participatory evaluation process, residents guided the research team through development and implementation of the initial phase of a smart home project designed to assist residents to remain functionally independent and age in place. We recruited nine residents who provided permission to install the technology in their apartments. We conducted a total of 75 interviews and three observational sessions. Residents expressed overall positive perceptions of the sensor technologies and did not feel that these interfered with their daily activities. The process of adoption and acceptance of the sensors included three phases, familiarization, adjustment and curiosity, and full integration. Residents did not express privacy concerns. They provided detailed feedback and suggestions that were integrated into the redesign of the system. They also reported a sense of control resulting from their active involvement in the evaluation process. Observational sessions confirmed that the sensors were not noticeable and residents did not change their routines. The participatory evaluation approach not only empowers end-users but it also allows for the implementation of smart home systems that address residents’ needs.

Keywords: Participatory evaluation, sensors, smart home, long term care facility, aging in place

1. Introduction

As life expectancy increases, older adults are living longer, more fulfilled lives aiming to maintain their independence for as long as possible. As mobility and cognitive impairments among the elderly lead to functional decline [15], information technology can become a useful tool for early identification of changing conditions and early intervention, as well as for ongoing customized monitoring. So-called “smart home” applications use sensors and other devices and telecommunication features to enhance residents’ safety and monitor their health condition and overall well-being. Several pilot projects worldwide have explored smart home technologies for the elderly. The SmartBo project in Sweden, for example, explores home-based technology for elders with mobility impairments and cognitive disabilities,

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including devices and sensors that control lighting, windows and water outlets, as well as visual and tactile signaling devices and speech synthesizers [6]. In France, a smart home initiative examines the use of infrared motion sensors connected to a wireless network to identify abnormal behavior of patients with Alzheimer's disease [5]. In the US, the Aware Home is exploring the use of sensors and assistive technologies to enable older adults to live independently [13].

These and many other projects have advanced the research agenda of ambient assisted living and have explored principles of ubiquitous computing for the home environment and older adults. However, most initiatives are primarily demonstrations of technological possibilities. Much work still needs to be done in addressing the potential end-users' needs and expectations. The needs of elders are different from the general population and the groups typically investigated in human-computer interaction studies [19, 8]. While the premise is that smart home technology can help keep older adults independent while controlling costs, it is essential that the solution be driven not by the technological possibilities alone but rather by the needs of the older adult population. The success of smart home applications will rely on the extent to which their design and implementation follows a model that empowers elders, making them active participants in the health care process and in the monitoring of their condition rather than passive recipients of care services. This requires a participatory evaluation approach, defined as the learning process for the end-users "that will help them in their effort to reach desired goals [7]." Participatory evaluation is a process controlled by the people in the program, a "reflective process for their own development and empowerment [16]." This process leads to collective knowledge production and cooperative action in which all stakeholders participate substantively in the identification of the evaluation issues and the action taken as a result of the evaluation findings [11].

The aim of this paper is to present a participatory evaluation developed and tested with an actual smart home project implemented in a real world setting (rather than a laboratory or demonstration site). The purpose of the evaluation was to assess resident response and the validity of sensor data, on an ongoing basis. Using the participatory evaluation process, residents guided the research team through development and implementation of the initial phase of a smart home project designed to assist residents to remain functionally independent and age in place.

2. Methods

The study setting is an independent retirement facility in the United States (in Missouri) called TigerPlace. This facility was developed based on the principle of Aging in Place, namely it offers varied services as needed to enable elders to stay at the residence of their choice for as long as possible rather than transfer to a different facility of care each time their health care needs increase [17]. The facility includes 31 independent apartments (studios, one and two bedroom) and a wellness clinic staffed by a nurse three days a week. The smart home technology implemented in this facility uses sensor technology to monitor and assess potential problems in mobility and cognition of elders. The focus is on sensing alert conditions and changes in daily patterns that may indicate abnormalities. The smart home system includes an in-home monitoring system and a component that conducts activity analysis and behavior reasoning. An event-driven video sensor network is currently under development and was not included in this study.

The In-Home Monitoring System (IMS) [1] consists of a set of wireless infrared proximity sensors to detect motion and pressure switch pads (sensor mats), a stove temperature sensor, sensors on cabinet doors and a bed sensor capable of detecting presence, respiration, pulse and movement in the bed. The Data Manager collects data from the sensors, date-time stamps the data and logs it into a file that is sent

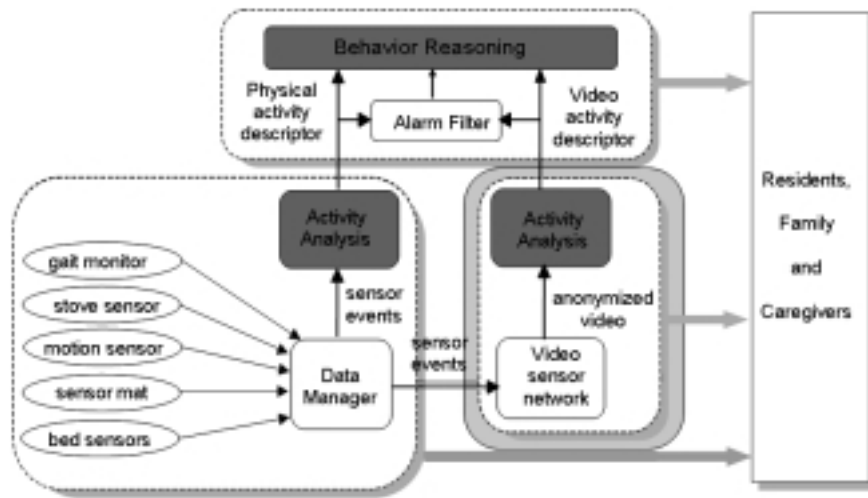


Fig. 1. The smart home architecture.



Fig. 2. A bed sensor.

to a secure server as binary streams stripped of identifiers. The IMS exploits low-cost X10 technologies coupled with specialized filtering and analysis. Figure 1 shows the overall architecture of the system (including a video sensor network that is currently under development and was not installed in the initial phase of this project presented here). Figures 2 and 3 show a bed sensor and a stove sensor in one of the apartments where the system was installed.



Fig. 3. A stove sensor.

Algorithm development for processing the sensor data has been ongoing throughout the project. We are especially investigating algorithms to detect three types of conditions. First, we aim to detect alert conditions that demand immediate attention include situations such as detecting a fall in the home or detecting that a stove has been left on (with no cooking activity in the kitchen being sensed). Secondly, we aim to identify a sudden change in some sensor data pattern that may correlate with a medical event. We have observed a change in bed restlessness due to cardiac events. In one case, a resident's bed restlessness increased to a much higher level for several weeks after a heart attack until a pacemaker was implanted, at which time, the bed restlessness dramatically lowered to the pre-heart attack level. We have also observed a change in the number of bathroom visits after a medication modification. Finally, the third type of condition studied is a gradual change in some sensor pattern indicating a possible medical related trend. For example, a gradual decline in overall activity level may indicate a deteriorating health.

We have used a variety of methods for feature extraction and pattern recognition, most of which fall under the general area of computational intelligence. Fuzzy set theory and fuzzy rule-based systems have been particularly good for modeling the inherent uncertainty [3,18]. In addition, we are using the fuzzy C-Means [4] and possibilistic C-means [14] clustering algorithms, as well as Hidden Markov Models [2] and particle swarms [12].

A Graduate Research Assistant (GRA) approached residents of the facility and explained the nature and purpose of the smart home technology. Details of the study and an informed consent form were reviewed allowing residents and their family members time to decide whether to enroll in the study or not. Once a subject enrolled in the study, members of the research team installed the set of sensors in the subject's apartment. The GRA then visited the resident on a regular basis and reported findings to the research team.

The participatory evaluation framework was designed to adopt several key principles of community-based participatory research by Israel et al. [10], namely place an emphasis on:

- recognizing the independent retirement community as a unit of identity
- building on strengths and resources within the community
- facilitating collaborative, equitable involvement of all partners in all phases of the research
- integrating knowledge and action for mutual benefit of all partners
- involving a cyclical and iterative process
- disseminating findings to all partners
- involving a long term commitment by all partners.

The specific methodology for this approach included interviews and observations. These interviews were originally conducted by the GRA on a weekly basis and then (six months into the study) on a bi-weekly basis. The interview protocol addressed overall perceptions of the sensor technologies and allowed for residents to report any problems or concerns, whether the technology interfered with daily activities, whether the resident thought of the technology or whether visitors had noticed the sensors. Furthermore, during these interview sessions residents were encouraged to identify any suggestions they had for the research team, to describe their priorities for this project and drive the evaluation questions following the participatory evaluation tradition. Thus, the interviewer acted as the facilitator for the interviewee to drive the evaluation agenda. The interview protocol was reviewed for face validity by experts in gerontology research and survey development. Time, date and duration of each session were recorded.

Finally, as part of the formative evaluation plan, research team members made a series of observations on-site in residents' apartments to identify potential interference problems of the sensor set with daily activities and confirm its validity. We employed these observations as part of a heuristic evaluation, a usability inspection method, which refers to a class of techniques in which evaluators examine an interface for usability issues. Observation is considered an informal method of evaluating usability because observers rely on heuristics along with their experience and the knowledge. During these sessions residents were asked to carry out certain activities (for example, meal preparation) while being observed by two research assistants who made notes and timed tasks using a personal digital assistant (PDA). The notes were compared with the sensor data to validate the collected data sets. Furthermore, the observations aimed to identify whether the installed technology becomes obtrusive during regular daily activities in the home.

3. Results

In the period January 2005 to August 2007 we recruited nine residents who provided permission to install the smart home applications in their apartments. All residents were over the age of 65 years. We conducted a total of 75 interview sessions with these residents. These interviews were originally conducted on a weekly basis and then (six months into the study) on a bi-weekly basis. Each interview session did not last more than 20 minutes. Residents expressed overall positive perceptions of the sensor technologies and did not feel that they interfered with their daily activities.

Findings indicate that the process of adoption and acceptance of the sensor technologies included three phases. The initial phase, **familiarization**, is the one where residents familiarized themselves with the installed technology and identified any issues or concerns, as well as assessed for themselves how technology integrates into their daily living. In individual cases when residents provided feedback about problems or concerns (e.g., one resident reported that the original bed sensor was noticeable when lying on the bed, another resident expressed the wish to have a smaller sensor mat) this information was then forwarded by the GRA to the research team. The team would then address these issues (e.g., replacing the original bed sensor with an improved version, providing the resident with a different sensor mat) allowing for a truly participatory evaluation of the technology as residents were the drivers for any changes or design approaches for new technologies. This initial phase lasted 2 to 3 weeks and residents responded during that phase that they do think of the technology frequently, look at the sensors and try to figure out if they are working or not. The novelty of the technology was obvious as they made their participation in the research study known, showing the sensors to other residents in the facility, family members and other visitors. For example, one resident stated "*I have shown them [sensors] to everybody*

who comes in, they are hard to see if you don't know they are there, I point them out and tell them all about the study."

During the second phase, that of **adjustment and curiosity**, which lasted also about 2–3 weeks, residents continued to express curiosity about the sensors' functions and thought of the technology occasionally. One resident said: *"I try and see if the lights are blinking, I will move back and forth to see if it will pick it up. I often forget it is there, and then I will look at the (sensor) mat, and remember I have this system in my home."* During that phase residents reported they did not show the technology to visitors and most people did not notice the technology was there unless they pointed it out to them.

The third phase was that of full **integration**. During that phase residents reported that they forget the technology is there and that it does not interfere with their daily activities. One resident stated: *"I completely forget it is there. When you stop by for these interviews, I remember, yes I have them (sensors) in my apartment."* During this phase, residents reported that both they and their visitors do not notice them in the apartment.

Residents did not express privacy concerns. The belief that a balance needs to be struck between the benefits of such monitoring, determined by level of need, and the concomitant perceived intrusion into privacy at home, was key in their decision to participate in the smart home project and allow the installation of the technology in their apartments. Throughout the study, residents stated that they had no privacy concerns and felt that allowing for monitoring of their daily activities was providing ease of mind and/or the sense of contributing to generating of new knowledge by participating in a research study.

As part of the participatory evaluation approach, interview sessions encouraged residents to identify evaluation questions and drive the technology assessment efforts. Residents provided feedback on the location of the sensors and ways to share data generated by the sensors with residents' family members and health care providers. A few concerns were expressed by residents which guided the team to make changes. For example, it was discovered that when one resident did not have bed sensor readings through the night an interview revealed she spent the night sleeping in her favorite chair. When this was reported to the research team, a bed sensor was adapted to fit her chair permitting the team to continue gathering bed sensor data, without changing the daily pattern of the resident. This was discovered with yet another resident as well, changing the team to regularly ask questions related to sleep patterns during initial installation and consecutive interviews. Likewise, a new bed sensor was developed and installed in the apartment of one resident. She reported that the new thicker sensor strip was bothersome at night and asked that it be removed. The sensor was immediately removed and the report given to the development team. The new sensor pad was returned to the apartment and the resident had no further complaints.

The ongoing interviews provided residents with a sense of control and the feeling of being actively involved in the research and evaluation of the system design and performance. Many reported they wanted to see the data sets triggered from the sensors and would not object to additional sensors or other technologies installed in their residence.

Finally, we conducted three observation sessions in apartments of residents as a way to check the validity of the motion sensor firings and assess how the technology integrates into daily activities. For these sessions, residents were asked to prepare a meal. Two observers took notes and timed tasks during the sessions without interacting or instructing residents. The notes were then compared with the datasets that were stored in the server (triggered from the sensor firings) and in all cases it could be confirmed that the activities recorded on paper were also recorded via the sensors (opening and closing of cupboards, drawers, refrigerators, stove usage etc.) In addition to validating the sensors, the observation sessions aimed to determine whether the different sensors installed in the kitchen (stove sensor, motion sensors on refrigerator door, cupboards and drawers) were interfering with daily activities or were perceived as obtrusive. In all cases residents confirmed that the sensors were not noticeable and that they did not change their routines because of the system.

4. Discussion

The concept of smart homes places the technology within the residence in order to increase functionality, security and quality of life. A smart home enables monitoring of residents with different levels of sophistication of the technology, ranging from stand-alone intelligent devices to wired homes that adopt to or even proactively address residents' needs. In this context, ethical considerations need to be addressed, for example, the possibility of such technologies removing choice and control from the users as they learn to rely on automation. Furthermore, obtrusiveness, namely the subjective evaluation of the end user of the extent to which features of the home-based technology are prominently undesirable [9], needs to be explored.

In order to address these and other challenges, smart home applications have to be evaluated on an ongoing basis and have to include end-users in all stages. The participatory evaluation framework presented here was tested in a residential care facility and demonstrates the potential of smart homes as well as the usefulness of this form of evaluation. One advantage of the participatory evaluation approach is that it adds a temporal dimension to the findings, as it allows for assessment of residents' perceptions, concerns and attitudes over time. This provides a better understanding of the diffusion and acceptance process of the technology. It also empowers end users as they see their concerns and suggestions being addressed by the system designers. This iterative process is essential for smart home applications since their success does not only depend on the technical feasibility of specific devices and sensors but also on the level of successful technology integration into every day life and health care services.

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