Smart Home Sensors for the Elderly: A Model for Participatory Formative Evaluation

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***Abstract*—This paper describes an evaluation framework for a smart home project that utilizes sensor technologies to detect activity levels and monitor older adults. The study setting is TigerPlace, an independent retirement community designed to follow the model of aging in place. Technologies used include a stove sensor, a bed sensor, a gait monitor and a video sensor network. The evaluation framework includes focus groups with end users (older adults and health care providers) as well as observations. Preliminary findings indicate an overall positive attitude of older adults towards smart home sensors and a valid and reliable performance. End users need to be included in all stages of a smart home development (design. Implementation and testing) and become actively involved in a formative evaluation of the technology.**

I. Introduction

Older adults are living longer and more fulfilled lives, and they desire to live as independently as possible. But independent lifestyles come with risks and challenges. Mobility and cognitive impairments among the elderly lead to functional decline [1]. Interventions to improve function include both evidence-based nursing approaches and innovative technologies. Crucial to successful intervention is early identification of changing conditions that are precursors of impairments so that interventions can be offered at the earliest indications of need. Customized monitoring can enable the early detection of deteriorating health conditions, such as a shuffling gait, restless sleep, rapid change in activity level, or an unusual change in one's typical routine.

To address these issues, researchers are developing "smart home" technologies to enhance residents' safety and monitor health conditions using sensors and other devices. Several pilot projects have introduced smart home technologies for frail elders in the United States, Europe and Asia:. The SmartBo project in Sweden, for example, includes a two-room ground floor demonstration apartment containing technology for elders with mobility impairments and cognitive disabilities, such as dementia and developmental disability. Devices and sensors control lighting, windows, doors, locks, water outlets, electrical power, stove, as well as visual and tactile signaling devices, speech synthesizers, and Braille displays [2](. The PROSAFE project in France examines devices and sensors that identify abnormal behavior that can be interpreted as an accident and collect representative data on patients' nocturnal and daily activity [3]. The experimental room has been designed to accommodate patients with Alzheimer's disease. It is equipped with a set of infrared motion sensors connected to either a wireless or wired network. The Hospital Without Walls is a home telecare project in Australia that includes a wireless fall monitoring system in which patients wear small sensors that measure heart rate and body movement. A home computer records data from several sensors and uploads to a remote assessment center [4]. Finally, the Aware Home developed by Georgia Tech in the USA is developed within two identical independent living spaces allow for controlled experiments with technology and enable inhabitants to live on one floor while demonstrating prototypes of assistive technologies on the other floor [5].

Although these projects have advanced research, most are primarily demonstrations of technological possibilities or provide visual displays that are not customized for elderly users nor do they provide comprehensive information about activities of daily living but rather graphs and charts that depict numeric information obtained from the vital sign assessment. Much work still needs to be done in addressing fundamental issues on the usability and effectiveness for older adults. The needs of elders are different from the general population and the groups typically investigated in human-computer interaction studies [6,7].

Smart home technology can help keep older adults independent while controlling costs. However, it is essential that the solution be driven not by the technological possibilities but rather by the needs of the older adult population. Furthermore, it is important to design

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applications that address the specific needs of their end-users and follow 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. The aim of this paper is to present an evaluation framework for a formative and participatory evaluation of a smart home application. This framework has been developed and tested with an actual smart home project that is implemented in a real world setting rather than a laboratory or demonstration site.

II. METHODS

The study setting is an independent retirement facility in Columbia, Missouri called TigerPlace. It opened its doors in 2004 and is based on the Aging in Place model as it offers varied services as needed at the time these are needed rather than forcing elders to move as their health care needs change [8]. This model also supports residents to maintain their health status and activity levels for longer periods of time by providing ongoing assessment, early illness recognition and health promotion activities. Ultimately, the aging in place model aims to help residents avoid expensive and debilitating hospitalizations and relocation to a nursing home.

The facility includes 32 independent one and two bedroom apartment and a wellness clinic staffed by a nurse three days a week. Furthermore, clinical staff are on call 24 hours a day, 7 days a week. Currently, TigerPlace has 34 residents ranging in age from about 70 to 90 years.

Technology has become an integral part of TigerPlace due to an ongoing project that investigate the use of sensor technology to monitor and assess potential problems in mobility and cognition of elders. The focus is on sensing alert conditions such as falls, and changes in daily patterns that may indicate abnormalities. The smart home system that is in place inclues an in-home monitoring system, an event-driven anonymized video sensor, and a component that conducts activity analysis and behavior reasoning.

The In-Home Monitoring System (IMS) [9] consists of a set of wireless infrared proximity sensors to detect motion, as well as pressure switch pads (sensor mats) that can be used to infer specific activities based on the position of the mat. The system also includes a stove temperature sensor, switches on cabinet doors and a bed sensor capable of detecting presence, respiration (normal/ abnormal), pulse (low, normal or high) 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 to a secure server as binary streams stripped of identifiers. The system exploits low-cost X10 technologies coupled with specialized filtering and analysis.

The system includes a passive gait monitor developed by the University of Virginia that relies on a highly sensitive displacement sensor [10]. This sensor detects small deflections in the floor induced by a person walking ten feet away from the sensor on both carpeted and uncarpeted wooden and concrete floors. The gait monitor processes the raw vibration signal, extracts features of significance, and analyzes the extracted data to provide basic gait characteristics [10].

The video sensor network complements the IMS by collecting more detailed information that is not available by the other sensors. Thus, the video sensor network reduces false alarms by providing visual information about human motion. It is called "anonymized" as it uses algorithms to identify a person in the image and extract a silhouette [11].

The system aims to not only detect emergencies but also support ongoing monitoring of residents. In this context, activities are analyzed on multiple time scales. Relatively short-term observations of events are used to infer activities such as cooking, getting ready for bed, etc. These short-term observations are made in the *Activity Analysis* components. By observing a sequence of these activities over time, we can infer a typical daytime pattern of behavior, such as getting out of bed, cooking, etc. This type of longer-term behavior reasoning is represented in the *Behavior Reasoning* component.

The value of an intelligent monitoring system is to distinguish a typical pattern for an individual from what would be an abnormal pattern for this specific individual. For this purpose we are exploring Hidden Markov Models (HMMs) for learning and recognizing short-term activity patterns fusing data from the IMS and the video sensors. The output of each Activity Analysis process is a descriptor or a set of descriptors that report the likelihood of an activity. Fuzzy rules can also be trained when the data is sufficient, but more importantly, can be modified by the experts (in this case, the nurses) who can insert specific domain knowledge. Events that are highly improbable but nonetheless possible and important to detect are very difficult to "learn" but easy to incorporate in rules.

The formative evaluation approach described in this paper involved end-users in both the design and implementation of the system. End-users are broadly defined to capture the actual residents, their family members and health care providers. The design of a usable information system for healthy users who are familiar with computer technology is a challenge. When a system needs to address age-related constraints and the functional limitations of inexperienced users, it becomes even more difficult. The aim of the formative evaluation is to increase its functional accessibility. The term "accessible design" refers to maximizing the number of potential customers who can readily use a product [12]. A "functional limitation" describes a "reduced sensory, cognitive, or motor capability associated with human aging, temporary injury, or permanent disability that prevents a person from communicating, working, playing, or simply functioning in an environment where other people in the population can function" [12]. For both the design and evaluation of the displays of activity levels and other monitoring data we followed design guidelines for elderly patients. Specifically, we integrated published guidelines for the design of a web-based clinical monitoring and educational system for elderly patients [13] into this work. These guidelines cover four areas: system interface, training, user support, content and security. The specific guidelines pertain to simplicity, clear navigation mechanism, selection of appropriate colors, elimination of distracting features or sound effects, and inclusion of end users in the design process. The formative evaluation approach involves the end users in all phases of the system design and implementation and aims to integrate feedback assessed via quantitative and qualitative methods into the design in order to increase usability.

The evaluation model includes observations, focus groups and interviews with representative users. Focus group sessions with TigerPlace residents addressed many items, including the resident's operation of the system and specifically ease of use, adjusting to changing needs, and maintenance, impact of the information on lifestyle, psychological factors, including confidence in using the interface, reliability of the system, trust in its accuracy and performance, sense of control and concern for violation of privacy.

Focus group sessions were also conducted with health care providers, namely home care nurses of Senior Care, the agency that operates in TigerPlace, to assess their perception of visual displays and whether these can be integrated into the patient monitoring plan, the level of clinical utility and the extent to which they can be tools for effective monitoring, early detection and/or prevention of disease and emergency situations.

Finally, as part of the formative evaluation prlan research team members made a series of heuristic observations on-site to identify problems and usability issues of the proposed applications and the implemented technology. We employed 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. The observation sessions were also useful in validating the sensor technology. 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 portable data 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.

III. RESULTS

We conducted three focus group sessions with a total of fourteen older adults over the age of 65 (five male and nine female). Each session lasted approximately one hour. Overall, participants had a positive attitude towards smart home technologies. Their perceptions of the potential of the technology focused on a reactive role (detecting emergencies) rather than a proactive one (monitoring a situation to detect trends or predict issues or concerns) [14]. Fall detection was a function that appeared to be uniformly supported as important. Participants felt that none of the technologies presented to them would interfere with daily activities.

Overall, participants saw a balance to be struck between the benefits of such monitoring, determined by level of need, and the concomitant perceived intrusion into privacy at home. Participants also emphasized the need to customize how the information resulting from the monitoring systems would be handled.

Furthermore, we conducted one focus group session with health care providers, namely, four gerontology nurses and one social worker. The session was facilitated by a member of the research team. The focus group protocol included questions about participants' preferences in accessing patient related data, their critique of suggested interfaces and additional questions about types of display and alerts that will be useful in monitoring and caring for senior residents.

Specific examples of interfaces were displayed and comments were solicited in terms of advantages and disadvantages. Participants stated that non-emergency data sets should be available on a secure website allowing for providers to access the data at their own discretion and from several points. Emergency alerts triggered by the system indicating a situation that requires immediate attention should be sent in *multiple formats*, such as email messages, pager messages, phone calls etc. Participants also provided specific feedback to examples of interfaces stating a preference for graphic displays (e.g. pie charts, bar graphs), use of colors and figures that allow users to zoom in or obtain more in-depth information if they choose to [15].

All participants expressed preference for a *web-based application* that would allow for *remote access* to the datasets. Most participants stated that the interface should allow users to enter interpretations and other notes and provide a platform for communication with other health care providers. *Visual summaries* and *overall trends* were perceived as very useful in managing large data sets. Most participants emphasized the need for *internal* and *external consistency* of the interfaces and *interoperability* of this application with other applications and specifically, the electronic medical record software (regardless of whether these datasets end up becoming part of the record system).

Finally, we conducted three observation sessions in apartments of residents who had allowed the installation of the smart home sensors. 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, use of stove etc.) The aim of the observation sessions was not only to validate the sensors but also 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.

IV. Conclusion

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 non-obtrusive monitoring of residents and there are different levels of sophistication of the technology involved, ranging from stand-alone intelligent devices to homes that continuously monitor residents' activities and physical status and adopt to residents' needs, often providing proactive measures.

Several ethical issues and challenges 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. A further concern is that of transfer of personal information to third parties, without proper consent. Specifically, and in relation to the first concern, there are fears that smart homes may result in a reduction of social interaction, or may provide tools that substitute personal forms of care and communication.

In order to address these and other challenges, smart home applications have to be evaluated on an ongoing basis and have to include the end-users in all stages. The evaluation framework presented here was tested in a residential care facility and demonstrates the potential of smart homes. Health care providers appreciate the additional information that sensor systems provide but have specific expectations of the system interface. Similarly, older adults have an overall positive perception of smart homes but have some concerns.

Smart home technologies can potentially revolutionize home care. Their success depends not only on the technical feasibility of specific devices and sensors but also on the level of successful integration into every day life and health care services. Thus, extensive and ongoing evaluation can reveal challenges and allow for participants to provide feedback and improve the overall system.

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