Sensor Systems for Monitoring Functional Status in Assisted Living Facility Residents

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ABSTRACT

This article provides results of an expert review of data displays for a sensor system used to monitor functional abilities in older adults. The research took place at TigerPlace, an assisted living facility where the sensor system is currently being evaluated. A checklist of 16 heuristic criteria was used to evaluate the sensor data displays, with consideration to the users of the system: residents, their families, and health care providers. Results of this expert review indicate that flexibility and efficiency of use, help and documentation, navigation, and skills were not well developed in the sensor data displays. Conversely, sensor data displays were rated highly for their aesthetic value and the ample visual contrast on the main display components. Through the use of a sensor system, new ways of detecting functional decline in elderly residents of assisted living facilities can be accomplished.

Demand for assisted living facilities is expected to increase during the next 25 years as the Baby Boomer generation ages and the percentage of older Americans increases. Older adults prefer aging in place; if they cannot live at home, a second choice might be the homelike environment of an assisted living facility, rather than a more restrictive nursing home environment (Chapin & Dobbs-Kepper, 2001). One factor limiting aging in place in an assisted living environment is age-related functional decline (i.e., decline in performance of basic and instrumental activities of daily living and increased need of caregiver assistance) (Aud, 2004; Hawes, Phillips, Rose, Holan, & Sherman, 2003; Kissam, Gifford, Vor, & Patry, 2003). Thus, although older adults prefer to remain in the least restrictive environment possible, increasing dependence and functional decline often result in transfer to a nursing home.

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With the assistance of technology, early recognition of functional decline, and prompt treatment of acute illnesses or exacerbations of chronic illnesses, older adults are anticipated to be able to remain in assisted living longer, improving their quality of life and independence. The pilot study reported in this article describes preliminary results of an expert review of computer interfaces for a sensor system installed in TigerPlace, an assisted living facility at the University of Missouri.

To date, 9 residents have sensor systems installed in their apartments; data on 14 residents have been collected since the study started. Inclusion criteria included living at TigerPlace and living alone. These residents, their families, and health care providers are participating in ongoing interviews to further aid researchers' understanding of how sensors can help monitor individuals in such settings and why residents would choose to use these devices. Clinical implications for how these data can be used to monitor for increasing dependence and functional decline will be discussed.

BACKGROUND

Detecting Functional Decline in Older Adults

Clinicians have anecdotally reported for many years that decline in function is often an early indicator of an impending acute illness or an exacerbation of a chronic illness. Researchers have confirmed these observations and have identified risk factors to detect those older adults most at risk of experiencing decline in physical function (Fried, Bandeen-Roche, Chaves, & Johnson, 2000; Onder et al., 2005; Wolinsky, Miller, Andresen, Malmstrom, & Miller, 2005). Early illness recognition and early treatment are not only key to improved health status, with more rapid recovery after an acute illness or exacerbation of a chronic illness, but is also essential to reducing morbidity and mortality in older adults (Boockvar & Lachs, 2003; Hogan, 2006; Ridley, 2005).

Although traditional assessments by health care providers often reveal signs of impending or early functional decline, in most cases, patients must either be physically present with the health care provider or connected via expensive telemedicine equipment (Alexander et al., 2000; Wolinsky et al., 2005). Self-report of functional performance and early decline is relied on to predict actual functional performance and decline (Fried, Young, Rubin, Bandeen-Roche, & WHAS II Collaborative Research Group, 2001; Wakefield & Holman, 2007).

However, researchers have concluded that asking older adults to self-report functional limitations or disability "captures only the tip of the iceberg" (Wolinsky et al., 2005, p. S146). New ways of detecting decline in physical function are needed, including those that:

- Are unobtrusive, yet accurately assess physical function and detect declines from an individual's normal functional performance.
- Do not require face-to-face assessment of the individual by a health care provider.
- Can use individuals' normal daily activities of living to reveal changes in physical function and alert health care providers of these changes.

We believe the use of a sensor system can accomplish these new ways of detecting decline in physical function. Using and evaluating the impact of such a sensor system is especially critical, given the rapidly expanding elderly population.

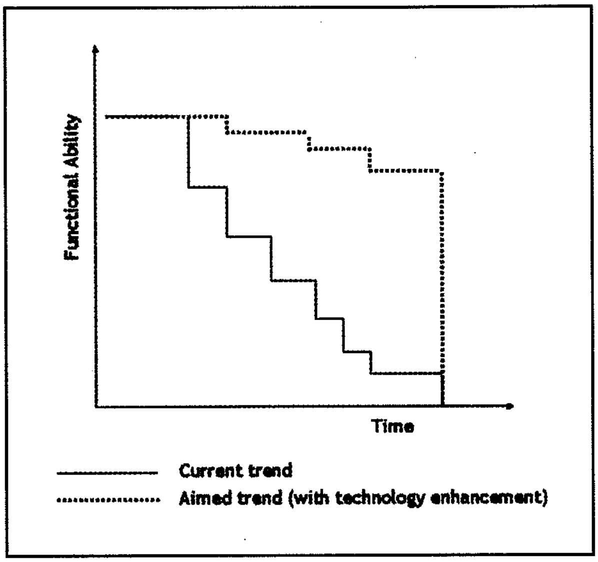

Figure 1. Trajectory of functional decline with (aimed) and without (current) sensor technology.

Sensor Technology to Detect Functional Decline in Older Adults

Our research team is searching for opportunities to use technology to enhance the quality of life of assisted living facility residents who may be nearing the end of life. The pilot study reported in this article is part of a larger study evaluating use of passive sensor technology to assess activity levels of such individuals.

A model used by the research team (Rantz et al., 2005) shows the trajectory of functional decline in a current trend (without sensor technology) and an aimed trend (with sensor technology) (**Figure 1**). **Figure 1** illustrates that older adults' overall function remains fairly constant for a

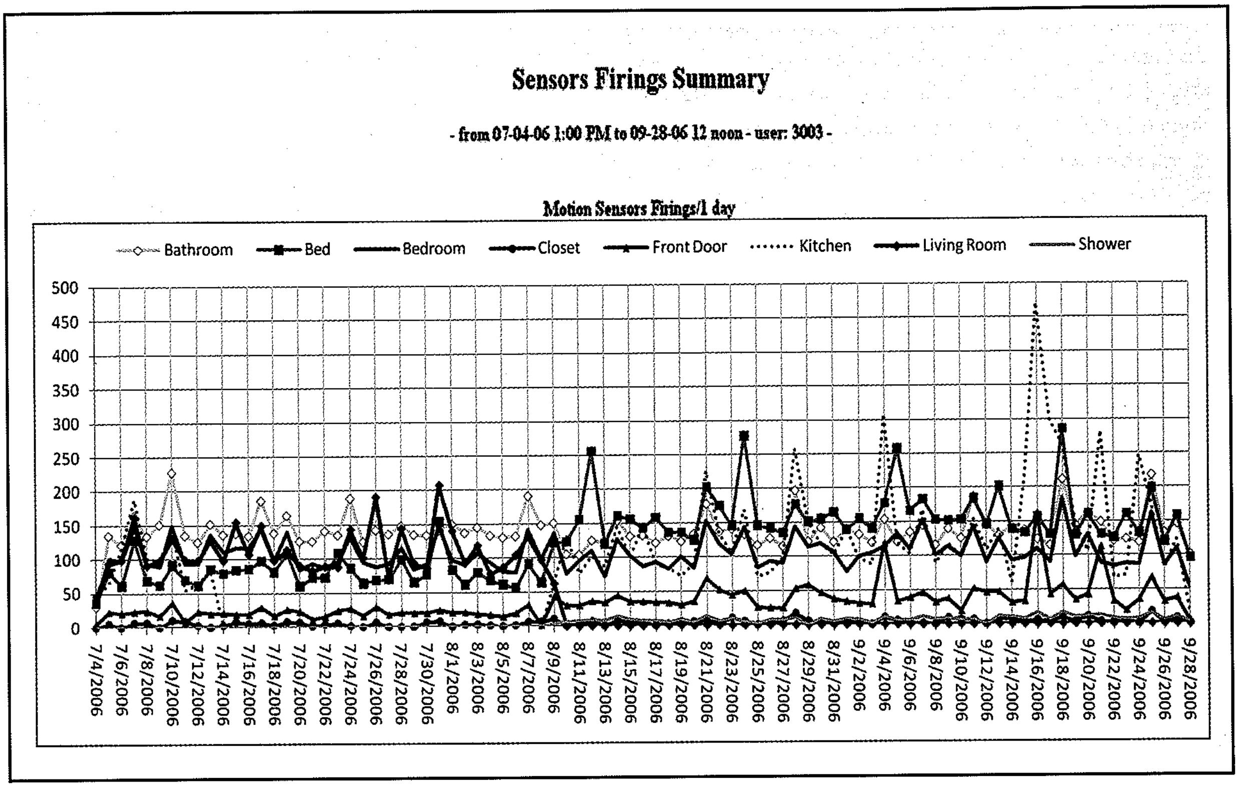

Figure 2. Sensor data display of motion sensors in an assisted living facility residential apartment. The graph was modified from its original colored line graphs to the current black and white version to meet publication guidelines.

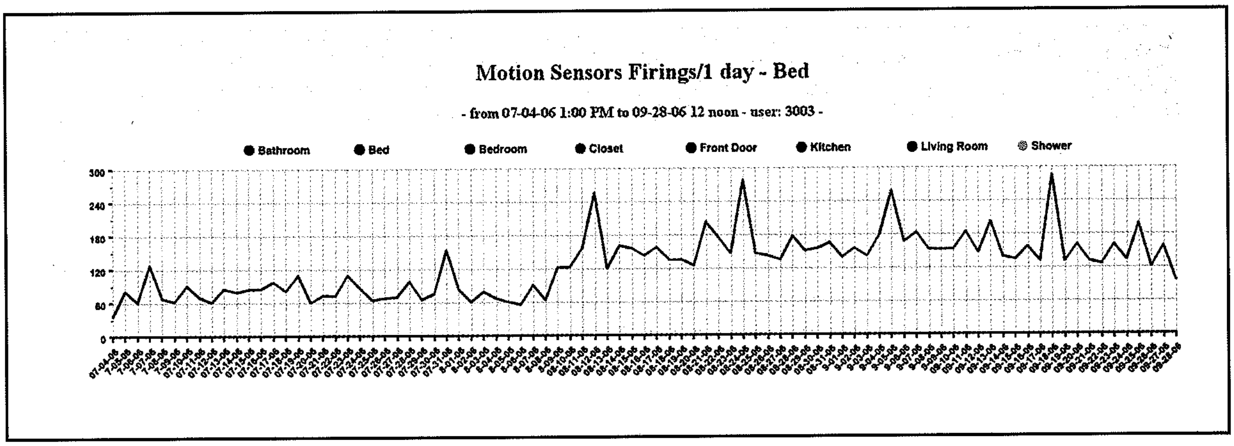

Figure 3. Sensor data display specifically of motion sensors on a resident's bed.

period of time until some change in mobility, cognition, or sensation alters their functional status. In the current trend, these changes are not detected as quickly, and interventions that could prevent functional deterioration are delayed. In our ideal scenario (aimed trend), technology should enhance formal and informal caregivers' ability to sooner detect fluctuations in activity levels from the older adult's baseline activity. This early warning system will enable caregivers to implement necessary assistive interventions, such as medication management, fall-risk protection measures, and assistance in daily living requirements sooner, thereby delaying residents' functional decline.

METHOD

Sensor Data Displays

The University of Missouri Institutional Research Board approved all research procedures before the study was conducted. Our research team's multidisciplinary task force has been meeting weekly since April 2007 to develop sensor data displays. The data display, or *interface*, is a connection between two systems through which information is exchanged. For example, a bed sensor or a wall-mounted room sensor are hardware interfaces that detect resident motion. Other sensors can detect stove temperature, restlessness in bed (measured by the frequency of fidgeting while lying down in bed), and physiological parameters, such as pulse and breathing rates. The sensors are connected to small computers to produce a sensor network (Rantz et al., 2005). In our sensor network, the information captured through the sensor hardware was stored on a computer until software programs, in the form of data displays, were developed, allowing individuals to interact with the data for decision making purposes.

The team has used data captured from the sensors (hardware) since 2004 to develop data displays (software), as shown in **Figure 2**. The data displayed in **Figure 2** provide a detailed account of the activity frequency for one resident from July to September 2006. An activity graph is shown for each sensor installed in this resident's apartment. These sensors are located in the bathroom, bed, bedroom, closet, front door, kitchen, living room, and shower. To develop these displays, experts from multiple disciplines (i.e., gerontological nursing, informatics, computer science, physical/occupational therapy, and health management) convened and iteratively reviewed the data and displays, offered suggestions for improvement, participated in development and refinement of each version, and studied changes in activity patterns as the data were displayed.

The data display has many functions that users can use to monitor the activities of those who have sensors installed in their apartments. For example, each individual graph within **Figure 2** can be viewed separately. This enables the system user to get a better understanding of individual activities throughout the apartment, which can be more revealing. A nurse interested in the amount of time a resident was in bed can view the line graph specifically depicting the bed sensor, as shown in **Figure 3**. These data show only a section of the graph from **Figure 2** for this resident's bed activity during the same time frame. In **Figure 3**, the increase in the baseline data during the first week of August indicates that a change had occurred in the activation frequency of the resident's bed sensor. This increase of time in bed might warrant further investigation.

A health care provider or family member might also want to know whether the resident was experiencing more restlessness during this increased time in bed. Therefore, our team established a scale for restlessness that ranges from low (lasting 1 to 3 seconds) to highest (lasting more than 9 seconds) while the resident is lying in bed. This scale allows detection of periodic changes in restlessness while residents are sleeping.

In some situations, the research team has modified the use of the sensors to accommodate a resident's activity habits. For example, one resident who had poor heart function was having difficulty sleeping while lying flat in bed, and we noted from sensor data that the resident was spending a majority of time sleeping while sitting in a chair. After further investigation, we found this was a normal activity for the resident. Knowing this allowed us to redefine how we used the sensor system in the apartment to better monitor the resident while sleeping.

Sensor Data Display Expert Usability Review

In August 2007, the task force hired an outside expert review panel (three reviewers trained in usability evaluation) to conduct a review of the TigerPlace sensor data display (partially illustrated in **Figures 2 and 3**). A heuristic evaluation checklist (**Table**) was specially created to consider the interface's users: residents, their families, and health care providers.

A heuristic evaluation is a commonly used usability evaluation method. It is performed by a small set of evaluators examining a user interface and judging its compliance with a set of usability principles, or *heuristics*. The checklist consisted of 16 heuristics (Pierotti, n.d.; Sharp, Rogers, & Preece, 2007). For example, visibility of system status is improved if the data display provides the user with feedback about progress through the data or the data's current location in the system. For each of the heuristic criteria, a rating of 1 (*least important*) to 4 (*most important*) was given to identify potential problems in the data display. The focus of the evaluation was the usability of the data displays. Two specific audience groups were considered in the evaluation: nurses, older residents, and their family members. Individual reviews were conducted separately before the reviewers convened for a negotiation meeting to discuss each of the items under the criteria.

RESULTS

A total of 96 items were distributed under the 16 heuristic criteria. Thirty of these items were not applicable to the interface because it is in a very nascent stage. The percentage agreement with the applicable criteria was 33%, and disagreement was 66%. A summary of the percentage disagreement of each criterion is included in the **Table** .

TABLE

Findings from Sensor Data Display Expert Usability Review

Heuristic	Number of Criteria	Meets Heuristics	Does Not Meet Heuristics	Heuristics Not Applicable	Agreement with Heuristic Criteria	Reviewer Rating[a]
1. Visibility of system status	10	2	7	1	22%	3
2. Match between system and the real world	5	0	3	2	0%	2
3. User control and freedom	8	2	3	3	40%	3
4. Consistency and standards	4	2	2	0	50%	2
5. Help users recognize, diagnose, and recover from errors	2	0	1	1	0%	3
6. Error prevention	4	0	2	2	0%	3
7. Recognition rather than recall	16	7	4	5	64%	2
8. Flexibility and efficiency of use	5	0	3	2	0%	4
9. Aesthetic and minimalist design	4	2	0	2	100%	1
10. Help and documentation	9	0	5	4	0%	4
11. Skills	4	0	2	2	0%	4
12. Pleasurable and respectful interaction with the user	13	5	7	1	42%	3
13. Privacy	1	1	0	0	100%	1
14. Navigation	2	0	2	0	0%	4
15. Structure of information	6	1	2	3	33%	3
16. Extraordinary users	3	0	1	2	0%	3
TOTAL	96	22	44	30	33%	

[a] Rating values: 1 (*least important*) to 4 (*most important*).

Heuristics recognized as having the most potential problems for users (i.e., rating of 4) were flexibility and efficiency of use, help and documentation, skills, and navigation. Flexibility and efficiency of use of the sensor displays was rated poorly for the lack of support and guidance documentation provided to both novice and expert users. Adequate support and guidance documentation would include important information about how to navigate through the display, descriptions of functions available to users of the sensor display, and other information about how to use the displays. The availability of help and documentation data included instructions that allow users to focus on specific areas within the data they want to assess. Skills deficiencies were noted because the data interface did not support all skill levels necessary for the nurse and resident users. Navigation of the system was rated poorly because users were provided with little feedback as to where they were in the system and where they needed to go to efficiently access other information. In addition, too many windows opened up in the interface, often causing users to get lost and close the main window, resulting in the need to reopen the Web site to continue browsing.

The highest ratings (i.e., 1) were given for heuristics related to aesthetic and minimalist design and recognition rather than recall. Aesthetic and minimalist design was given a positive rating because the essential information for decision making was displayed prominently on the screens; icons used in the displays were clearly understood by reviewers; and data entry screens had short, simple, clear, and distinctive titles directing users to choose the graphs they needed to view. The displays met the heuristic for recognition rather than recall because of ample visual contrast for the main components of the Web site, use of visual cues (e.g., colors and graphs), features emphasizing quantity with graphic displays, grouping of related items, consistency of color coding, and contrast between images and background. These areas are especially important for residents who may have decreased color discrimination and poorer depth perception due to normal aging processes.

DISCUSSION

Usability assessment for these kinds of systems is valuable because such systems are often designed, marketed, and implemented with little or no input from end users, especially health care consumers. The purpose of this article was to describe an approach to usability assessment and to show how, even after the researchers met several times to design the sensor displays, the product still did not measure up to recommended guidelines. Our task force is using the results of this expert review to improve the sensor display by focusing on the areas recognized as having the most potential for problems (i.e., ratings of 3 and 4). Future research will include more usability assessments of this interface with a focus on its end users, including health care providers of older adults, residents' family members, and residents themselves who are eager to see what data are captured by the sensors.

Especially important for this study will be the development of help screens and documentation to train users on using the information system. Help documentation will support both nurse and resident users with both novice and expert skill levels. Also, including better design features for users of all ages and skill levels would contribute to improvements in the flexibility and efficiency of use of the data interface. In addition, to support users' skill levels, we will be developing better designs, such as more distinct color variations, so older adults with poor vision will be able to distinguish colors on the charts' line graphs. We will also focus on developing better navigational feedback for interface users to let them know of their current location in the system and where they should go to efficiently access other information.

User Feedback

In a separate but related study, a total of 75 interview sessions were completed with 9 residents to discuss their experiences living with the sensors. These experiences are important because they inform researchers about resident interactions with the technology and how to assess sensor data.

Interviews lasted no longer than 20 minutes, and residents' overall perceptions of the sensor interface have been positive. Residents were encouraged to describe interactions with technology (i.e., how the technology affected their daily activities, whether the technology was noticed by their visitors) and to share any suggestions with the research team (Demiris et al., 2004). Overall, positive perceptions of the sensor technology were reported, with no reports of interference with daily activities.

During the interviews, research team members identified three phases the residents experienced with the technology:

- *Familiarization.* Familiarization occurred when residents familiarized themselves with the installed technology and identified any issues or concerns. For example, a few residents reported that the bed sensors were noticeable when they slept; the research team addressed this issue by developing a new sheath that covered the sensor so it was softer to lie on in bed. This familiarization phase lasted 2 to 3 weeks, and the novelty of the technology was obvious as residents showed it to other residents.
- *Adjustment and Curiosity.* This second phase also lasted approximately 2 to 3 weeks. During this period, residents continued to express curiosity about the sensor functions. One resident reported, "I try to see if the lights are blinking.... I often forget it is there, and then I will look." Residents reported that they did not show the technology to visitors, and most people did not notice it.
- *Integration.* During the third phase, residents stated they forgot about the technology, expressed no privacy concerns, and believed the sensor monitoring provided a certain ease of mind and/or the sense of contributing to generation of new knowledge (Demiris, Parker-Oliver, Dickey, Skubic, & Rantz, 2008).

Interviewing residents and assessing their perceptions, concerns, and attitudes over time helps increase understanding and acceptance of technology and empowers end users, as these concerns and suggestions are being addressed by the system designers (Demiris, Finkelstein, & Speedie, 2001). During the final phases of research now underway, the team is again including users' perceptions of the sensor technology. However, we are taking this approach one step further by considering the visualization of sensor data by older residents and their families on the newly developed computer displays.

GAPS IN CURRENT KNOWLEDGE

During preliminary work, we learned that residents using the sensor network identified positive experiences with the technology; that residents and their families are eager to see the sensor data; that the sensor system works reliably, continually detecting motion activities in residents' apartments; and, on a few occasions, that sensor data may have changed during a sentinel health event. However, we are unable to verify the relationship between the sensor data changes and sentinel health events because residents have not been involved in the actual sensor data review during these events. It is critical now that residents become involved in this evaluation process by identifying when sentinel health events occur and discussing their perceptions of the sensor data. This will provide the means for us to validate the sensor network before further evaluating its usefulness and disseminating it widely to other settings.

CONCLUSION

The goal of this research is to expand on the integration of sensor systems for monitoring older residents of assisted living facilities. To accomplish our aims, we are planning to use usability methods to help us understand how health care providers, residents, and family members can use sensor networks to evaluate functional status by observing daily activity patterns recorded by sensors. We are interested in using the sensor activity to help enhance the monitoring of residents' functional status and activity levels. Eventually, we plan to use the sensor data system and interfaces to assist in the prediction of sentinel health events in older residents who wish to age in place.

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