FEATURE ARTICLE

# Improving Nurse Care Coordination With Technology

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Technology offers potential solutions to the pending crisis of healthcare for older adults, while healthcare workers are in short supply. Technology can enable remote monitoring of individuals and early detection of potential problems, so that early interventions can help older adults remain as healthy and independent as possible. Research is under way with passive monitoring technology in senior housing that is finding patterns in the data that can enhance nurse care coordination through early illness detection. With early detection, interventions can be more effective and reduce hospitalization and other healthcare expenses. Case studies are presented, and implications are discussed.

KEY WORDS

Aging • Assisted living • Care coordination • Senior housing • Technology

In 2000, there were 35 million people 65 years or older. By 2030, this number will more than double to 71.5 million.[1] This dramatic increase, coupled with a looming shortage of nurses, primary care physicians, and other geriatric healthcare workers, means that new models of healthcare are desperately needed to be able to care for older adults. Technology offers potential solutions to this pending crisis by enabling remote monitoring of individuals and early detection of potential problems, so that early interventions can help older adults remain as healthy and independent as possible. This technology can be active, requiring the person to wear a sensor, pull a cord, or push an alarm; or be passive, embedded in the environment and programmed automatically to detect potential problems. The purpose of this article was to describe our experience with passive monitoring technology in senior housing with services and discuss the potential of this technology to enhance nurse care coordination through early illness detection.

Older adults are dissatisfied with traditional long-term care options; they want to remain at home and independent for as long as possible. They want to age in place with services delivered to them in the setting of their choice.[2–5] The aging-in-place (AIP) concept, allowing older adults to remain in the environment of their choice with supportive services as needed, is being evaluated and tested in a real-world setting, TigerPlace, a special independent housing with services (both hospitality and care as needed) facility in Columbia, MO. Researchers at the University of Missouri (MU) are using inexpensive sensor technology to monitor older adults' health status, augment traditional nursing care, enhance care coordination, and help older adults age in place.

## TIGERPLACE

Planning for TigerPlace began in 1996, when faculty and the dean of the MU Sinclair School of Nursing (SSON)

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envisioned a new model of long-term care based on the concept of AIP. They met with healthcare providers from many different disciplines, community leaders, and researchers to define this new model of care. However, they soon realized that Missouri regulations restricted the development of a facility based on AIP principles. Although seniors prefer to remain in apartment-style independent living, the regulations do not allow them to remain there as their care needs increase, and they are forced to move from independent senior housing to residential care or assisted living and to nursing homes.

Faculty members worked with Missouri legislators, healthcare professionals, and state officials to enact legislation that would make AIP possible within the highly regulated healthcare industry. Two rounds of legislation were passed in 1999 and 2001 to define the rules and survey process for this new model of care. Four AIP pilot sites were created to assess the effectiveness of the AIP model and TigerPlace was designated as an AIP pilot.

A specially designed independent senior living community, TigerPlace is built to nursing home standards, licensed as an intermediate-care facility with several waivers for traditional operations, and operated as independent senior housing with hospitality services and care services as needed. With the legislation, residents can remain in private apartments and receive care and services up to and including hospice and skilled nursing services as needed. Private insurance, Medicare, and private pay are the sources for payment for necessary care services.

TigerPlace offers an environment with health promotion and care services to help residents maintain their independence and remain as healthy as possible. TigerPlace was developed by Americare Systems, Inc (Sikeston, MO), a leading elder-care company, in cooperation with the MU SSON. Nurses, physical therapists, environmental design specialists, and other gerontological experts were consulted on the design of TigerPlace to ensure an accessible, supportive environment for aging. Residents live in independent apartments with basic services such as housekeeping, transportation, and two meals per day provided.

Residents of TigerPlace also have access to health promotion activities including exercise classes 5 days per week, RN care coordination, a wellness center staffed by an RN care coordinator three mornings a week, ongoing comprehensive nursing assessment (at least every 6 months), and four private nurse visits (in addition to unlimited nurse access in the wellness center) per year as requested to evaluate and assist with problems. An RN is on call 24 hours per day, 7 days per week, to answer health questions or assess problems as needed. Residents are encouraged to take part in a variety of social activities at TigerPlace as well as events at the MU such as concerts, community lectures, classes, sporting events, and other festivities of campus life.

TigerPlace residents are typical of older adults living in congregate senior housing or assisted living. There are 34 TigerPlace residents, nine men and 25 women, ranging in age from 69 to 95 years (median age, 86.2 ± 5.4 years). All of the current residents are white. There are three married couples, and the remaining residents are single. About 80% of the residents have at least one chronic disease, and many have more than one. Common chronic diseases include diabetes, heart disease, and arthritis. A few have early-stage Alzheimer's disease. Two residents use wheelchairs, and many of the residents use walkers or canes.

## SINCLAIR HOME CARE

Sinclair Home Care, a Medicare-certified home health agency developed by the MU SSON, supports the AIP project by providing services to TigerPlace, other congregate senior housing both public and private, and community-dwelling seniors. Before the construction of TigerPlace, the SSON received a $2 million grant from the Centers for Medicare & Medicaid Services for Sinclair Home Care to evaluate the effectiveness of the AIP model.[2] Results from the initial evaluation of AIP indicate that community care with RN care coordination improves clinical outcomes when compared with individuals of similar case mix in institutional long-term care.[6]

Based on these results, when TigerPlace opened in 2004, the care was designed with the RN care coordination model and is centered on the wellness center. Centrally located near the dining room, the wellness center is open for 2 hours three mornings per week and usually staffed by the RN care coordinator. At the wellness center, residents may have their vital signs monitored, receive assistance with medications, discuss health issues with the RN care coordinator, and have health problems assessed. If needed, the RN care coordinator will recommend additional assessments or services and coordinate these services with the residents' physician(s) and family members.

Residents living at TigerPlace appear to be quite willing to discuss their health issues with the RN care coordinator who has an established relationship with each of the residents. This seems to help her and other staff detect deviations in a person's normal behavior and health status. Another likely reason for openness about health concerns is that residents of TigerPlace do not have to fear being forced to move as health needs increase as in traditional senior housing or assisted living due to state and federal regulations of long-term-care settings. Living in TigerPlace with its state AIP designation enables people to live there through the end of life, receiving care and services as they are needed. The RN care coordinator is able to intervene to help residents get care and treatment of health issues, typically earlier rather than later as things develop. A comprehensive healthcare assessment is completed on admission and at least every 6 months by the RN care coordinator to track health status and determine if there are issues not detected during visits to the wellness center.

The four private visits each year help residents when they experience acute illnesses so they can get rapid personal assessment and referral as needed. The 24-hour on-call nurse service also helps residents deal with immediate concerns. In the event of an emergency, residents are encouraged to call TigerPlace staff who are available 24 hours per day as well as by telephoning 911 emergency response. Sinclair Home Care provides additional private pay services to assist residents with medication management or personal care activities of daily living such as bathing, grooming, and dressing. In addition, Medicare services are available when residents need and qualify for the service such as after a hospitalization to assist with recovery and the transition back to their home at TigerPlace.

## HEALTH DATA SETS

Sinclair Home Care maintains electronic medical records on every resident of TigerPlace with nurses, physical therapists, and the social worker documenting assessments, care, and other healthcare data. Electronic medical records are vital to the care coordination process so that every clinician (including the 24-hour on-call nurse service) has access to current, updated health information on every client. In addition, with the resident's informed consent, researchers can easily obtain the needed health information without needing access to individual paper records. Significant health events such as hospitalizations, falls, and emergency room (ER) visits are also logged at TigerPlace. A database administrator creates deidentified health data sets from the medical records and other adverse event records maintained by Sinclair Home Care for use by the research team, with the university's institutional review board approval.

Precautions are taken to ensure the privacy and confidentiality of the residents' medical records. Access to identifiable medical records is restricted to the Sinclair Home Care clinical staff and the database administrator. Each participant has provided separate informed consent to have their medical records and sensor data used in research projects, and all residents have consented to the use of their healthcare data for evaluation of AIP when admitted to TigerPlace.

## THE INTEGRATED SENSOR NETWORK

The integrated sensor network under development is shown in Figure 1. The network includes six main components: (1) a passive physiological sensor network with data monitor and activity analysis of stove sensors, water flow sensors, bed sensor (developed by collaborators at the University of Virginia),[7,8] and motion sensors; (2) an event-driven, video sensor network that hides identifying features of the residents; (3) a reasoning engine that combines sensor and video data and analyzes patterns of behavioral activity; (4) a component for providing customization of sensor configuration, alert specification, and data access for each resident; (5) a flexible alert manager, and (6) a database server and Web interface that provide interactive retrieval and visualization of the sensor data.[9]

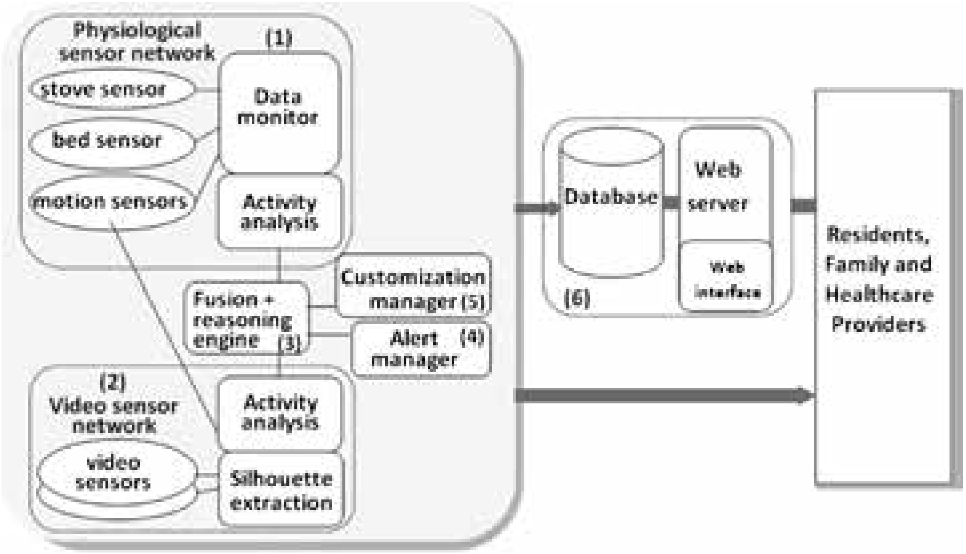


**FIGURE 1.** Integrated sensor network.

Inexpensive passive infrared motion sensors using low-cost, wireless X10 technology, which specifies a standard protocol for the data transmission, are installed in residents' apartments to detect presence and activity. Motion sensors are also installed in targeted locations to infer specific activities. For example, a motion sensor is installed above the shower to detect bathing activity, and sensors are installed in kitchen cabinets and the refrigerator to detect activity in the kitchen. In addition, a stove temperature sensor detects cooking activity and can be used to send an alert if the stove has been on too long by a forgetful resident. Water flow sensors will eventually be used to monitor water usage in the kitchen and bathroom, for example, for monitoring kitchen activity and toilet use.

A bed sensor detects presence in bed as well as restlessness, breathing, and pulse rates while sleeping. The bed sensor is a pneumatic strip that lies on top of the mattress and under the linens. The pneumatic tube displaces air as a person lies in bed. Displacement varies for movement, breathing, and pulse; with signal processing, the bed sensor distinguishes between different levels of restlessness, breathing, and pulse. Continuous movement of 1 to 3 seconds triggers a low restlessness event; 4 to 6 seconds is a medium restlessness event; 7 to 9 seconds is classified as a high event; and the very high level is greater than 9 seconds of continuous movement. Similarly, breathing is classified in three levels: low (apnea) (1–6 breaths/min), normal (7–30 breaths/min), and rapid (tachypnea) (>30 breaths/min). A slow pulse event (bradycardia) is triggered for a pulse rate of 1 to 30 beats/min, and 31 to 100 beats/min activates a normal event. Greater than 100 beats/min generates a high-pulse-rate event (tachycardia).

A data monitor collects the motion and bed sensor data, time-date stamps each event, and generates a file, which is regularly transmitted via a deidentified binary stream to a central server. The data are then assembled in a MySQL database (Microsoft, Redmond, WA) for use by researchers, healthcare providers, and the participants.

To complement the data monitor and motion sensors, an anonymized video network is under development. The ultimate goal of the video network is to collect more detailed information than is available in the physiological sensor suite, such as detecting falls and gathering diagnostic gait information.[10,11] Several strategies have been investigated to preserve the privacy of the individuals in the video including segmenting the person in the image and generating a silhouette.[12–14]

Early in the research, focus groups were conducted to determine older adults' attitudes toward technology. The participants emphasized the need for the technology to be reliable and user-friendly, require no or minimal action on the part of the user, and be unobtrusive.[15] Based on these results, a design decision was made to implement sensors only in the environment, rather than requiring participants to wear sensors. Residents report that, after an initial adjustment period, they no longer consciously think about the sensors but rather go about their regular daily activities.[16] This is essential in capturing the daily patterns that may indicate early signs of potential problems.

The monitoring technology is offered to everyone who lives at TigerPlace. Since the beginning of the monitoring study in fall 2005, a total of 56 individuals have been approached to participate in the study. To date, a total of 16 individuals have volunteered to be monitored, for a 28.5% recruitment rate. Recruitment is ongoing, and three additional people have recently decided to participate. The first integrated sensor network was installed on September 27, 2005, so data collection has continued in some apartments for over 3 years.

The monitored group consists of 16 individuals (11 women and five men) All participants are older than 65 years (median age, 88.44 ± 6.16 years; range, 70–96 years). Four participants have been discharged (two moved to a nursing home and two died).

A Web-based interface was developed to display the data for use by researchers, healthcare providers, residents, and family members.[17] Four nurses and a social worker with expertise in gerontology participated in the design of the interface to ensure that it was user-friendly, clinically relevant, and accessible to healthcare providers.[18] The Web-based interface was implemented and refined with input from users as well as residents and their families who have access to their own individual data.

Using the Web-based interface, users may select start and end dates and a time interval in hours or days to display sensor data for an individual study participant. Sensor data are grouped by category: motion, bed restlessness, bed breathing, bed pulse, and stove-top temperature. Users may drill down to see data from individual sensors, such as in the shower or kitchen. Data may be aggregated in increments ranging from 15 minutes to daily and displayed in a variety of ways including histograms, line graphs, and pie charts.

## CASE-STUDY ANALYSIS OF SENSOR DATA AND HEALTH EVENTS

Using the Web-based interface, sensor data were retrospectively viewed and analyzed for periods before and after health events such as hospitalizations, falls, and ER visits. The purpose of this review was to determine if predictive patterns before the health event were evident in the sensor data. Our goal is to establish alert conditions from the sensor data and develop automated methods to monitor ongoing health status. A retrospective exploratory multiple case-study methodology was used because the analysis focused on linkages traced

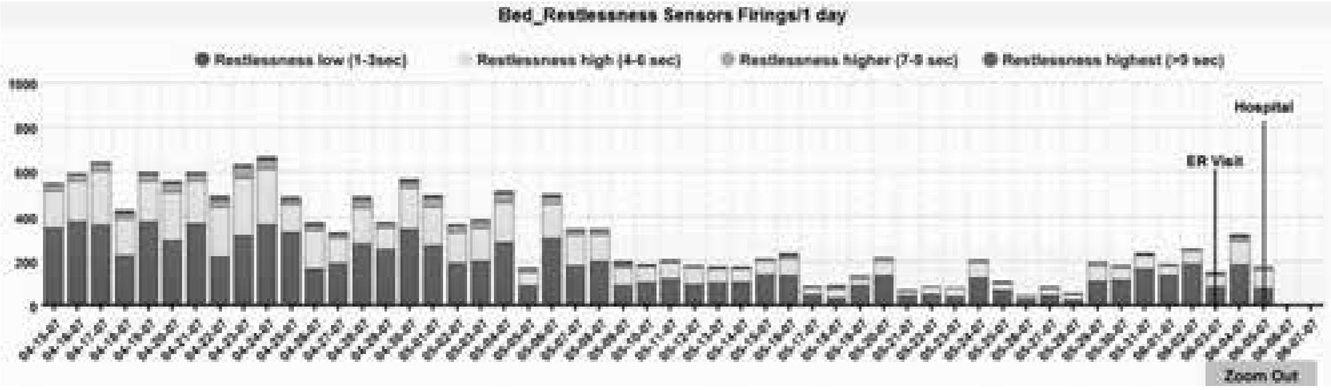


**FIGURE 2.** Web-based interface showing the frequency of bed restlessness sensor firings per day, April 15, 2007, to June 7, 2007. Annotations indicate time of ER visit and hospital admission.

over time rather than mere frequency or incidences.[19] Patterns began to emerge when the data were aggregated to a daily level rather than in smaller time frames.

All significant health events from the period September 27, 2005, to April 30, 2008, were examined (n = 74 events for 16 participants). In 31 cases (41.9%), patterns in the data prompted further review. Results of this initial analysis are being used to refine algorithms and test automated strategies for detecting abnormalities that may require healthcare intervention. In a few cases, important changes were detected that are being used to establish alert conditions.

## CASE STUDY 1

A 96-year-old woman who lived alone in her apartment had a significant cardiac event and was transported to the ER. She was hospitalized 2 days later and subsequently died. She had a history of cardiac problems including a diagnosis of congestive heart failure (CHF). She was leading a normal, relatively active life before the cardiac event with some assistance from her family and a daily home health aide in the morning to assist with bathing and dressing.

A retrospective analysis of the sensor data revealed a change in her overall bed restlessness (Figure 2) and slow pulse rate (bradycardia) while in bed prior to the cardiac event (Figure 3). Figure 2 displays the bed restlessness sensor firings for each day; bars have three colors of the firings of high, medium, and low bed restlessness. Figure 3 displays only the sensor firings of slow pulse for the same period. Note the decline in overall bed restlessness (Figure 2), particularly from May 9 to May 28. Also note the increasing bradycardia (Figure 3) that started on May 9.

The sensor data indicated changes in her health status that traditional healthcare assessment did not detect. Traditional physical assessment and observation by the RN care coordinator did not detect changes in her health status, nor did daily observation by the home health aide who was providing personal assistance in the morning. She did not frequent the wellness center for vital sign checks so that information is sparse. Her medications and diagnosis indicated cardiac problems, but simply the use of these medications would not predict this cardiac

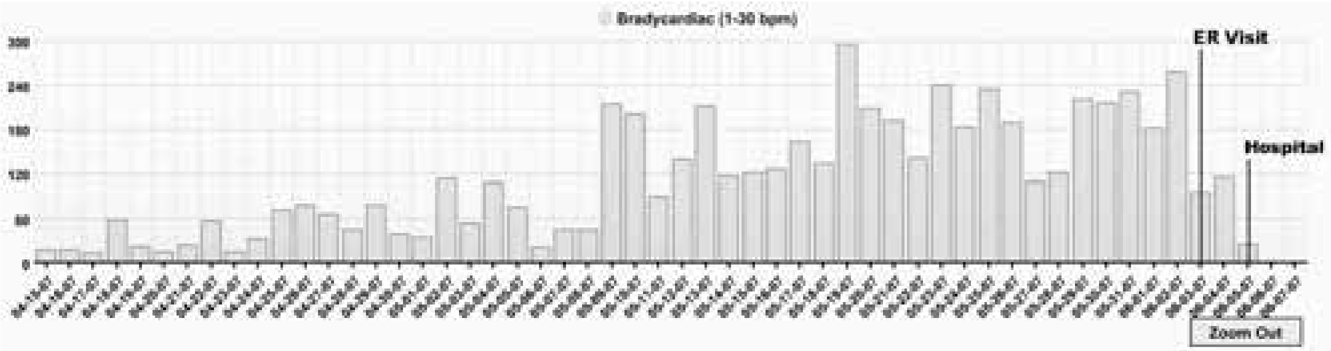


**FIGURE 3.** Web-based interface showing the frequency of bradycardia (slow pulse rate) bed sensor firings per day April 15, 2007, to June 7, 2007. Annotations indicate time of ER visit and hospital admission.

event. In this case, the sensor data could have been used to alert healthcare providers of changes in her health status triggering an assessment and possibly intervention or support through the changes.

## CASE STUDY 2

An 89-year-old woman who lived alone in her apartment fell and broke her nose on December 16, 2007. She was hospitalized for a few days for observation of a possible head injury and pain control. She was then discharged on several new medications for pain control. This participant has a history of falls, chronic kidney disease, and heart disease including a diagnosis of CHF. Upon returning to TigerPlace, she was admitted to home health for pain control and instruction regarding her new medications. She recovered well and was discharged from home health on January 4. Almost 2 weeks later (January 16, 2008), she was hospitalized again for dehydration, renal failure, and elevated potassium levels (hyperkalemia). Prior to this hospitalization, she complained of “just not feeling well” and sought assistance from the RN care coordinator, who contacted her physician. The physician instructed the client to restart her diuretic. A retrospective analysis of her sensor data revealed an increasing trend in her overall bed restlessness prior to her second hospitalization, but after being discharged from home health (Figure 4).

Upon return from the hospital, she was closely followed by home health and had several follow-up visits with her doctor. Nonetheless, she was hospitalized again for exacerbation of CHF and eventually required nursing home care to stabilize her condition. She finally returned to TigerPlace in April 2008 and was placed on medication management for ongoing supervision of her CHF. She is managing very well with this assistance.

Before the second hospitalization, the client contacted the RN care coordinator who did a traditional healthcare assessment and contacted her physician, who ordered a medication change. Because the sensors detected changes a few days earlier than symptoms were reported to the RN care coordinator, if the care coordinator had been able to use the sensor information, evaluated the client’s situation sooner, and coordinated care to address the changes with the client’s physician, the second hospitalization and subsequent complications may have been avoided.

## CASE STUDY 3

An 86-year-old woman who lives alone in her apartment has a history of cardiac problems including hypertension, orthostatic hypotension, chronic obstructive pulmonary disease (COPD), and CHF. Because of her cardiac problems, she sometimes has trouble breathing while lying down and often sleeps in a chair. To better monitor her health status, a sensor was installed in her favorite chair.

She was hospitalized from March 14 to March 21, 2007, for pneumonia and exacerbation of her COPD and CHF. Upon discharge, she was admitted to home health for ongoing monitoring, medication management, and instruction for her new medication regimen.

After her hospital stay, she was weak and became fatigued easily. She had several episodes of hypotension (low blood pressure), which the RN care coordinator/home health nurse was monitoring closely. She was taken to the ER on March 30 for a hypotensive episode during which she became unresponsive.

A retrospective analysis of sensor data from her chair revealed an increase in restlessness while sleeping after her hospitalization and prior to her ER visit, then a gradual return to normal (prehospitalization) levels several weeks later (Figure 5). In this case, the sensor data could have been combined with traditional healthcare assessment to better track her recovery. The sensor data could have

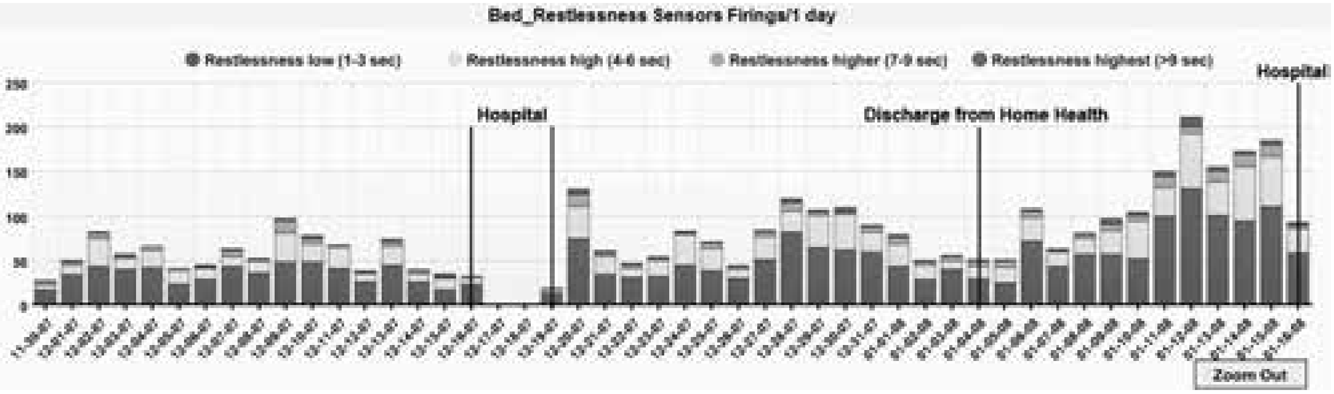


**FIGURE 4.** Web-based interface showing the frequency of bed restlessness sensor firings per day November 30, 2007, to January 16, 2008. Annotations indicate time of hospital stay, discharge from home health, and subsequent hospital admission.

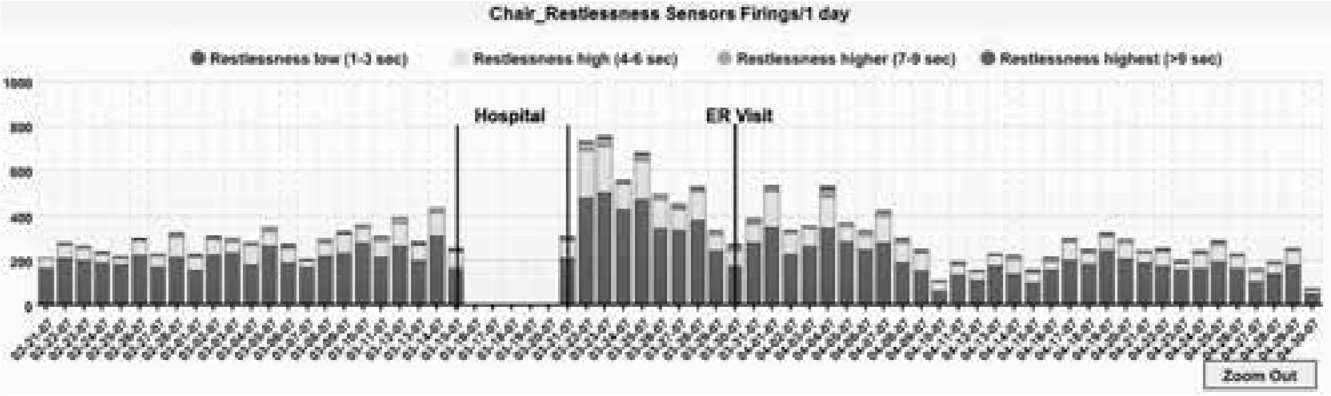


**FIGURE 5.** Web-based interface showing the frequency of chair restlessness sensor firings per day February 21, 2007, to April 30, 2007. Annotations indicate time of hospital stay and ER visit.

been used as an additional assessment tool to provide a clearer picture of her overall health status.

## OTHER CASES

Additional health events retrospectively analyzed include planned surgeries, ER visits, acute illnesses, falls, and exacerbations of chronic illnesses. In the analyses, changes in bed restlessness, pulse, respiration, or activity level appeared a few days before and reoccur for a few days after some health events happen to participants as illustrated in the three case studies presented and others examined in the analyses. It appears that the sensors are detecting some degree of changes that are not reported to the RN care coordinator or are not even perceived before health events.

## DISCUSSION

These case studies illustrate the potential of sensing technology to augment traditional healthcare assessment and nurse care coordination. As shown in the case studies, the sensors provide additional information that traditional healthcare assessment and observation often missed. In these cases, changes were seen in the physiological sensor data days or weeks before the health event, specifically bed restlessness, pulse, or respiration. These changes could have been used to provide an early warning to prompt healthcare providers to assess the clients in more depth and hopefully intervene to prevent or delay substantial changes in health status. The sensor network could also be used to monitor recovery after a hospitalization or significant health event.

Several limitations with this study must be addressed. First, the health events that were studied are self-reported or reported by facility staff. Falls are one of the health events that are often self-reported and could easily have occurred on a different day or time than was reported by the older participant. In addition, falls are probably underreported because some older adults may be embarrassed and do not want to appear frail.[20,21] A more reliable method for detecting falls and tracking health events is needed. Second, this pilot study had a very small sample size of 16 monitored individuals. A larger, statistically valid study is needed to corroborate the results of these case studies, establish meaningful alert conditions, refine the Web-based interface to make it clinically relevant, and prospectively use the sensor data to monitor the participants with a goal of preventing or delaying significant health events.

A current challenge with these data are that patterns in sensor activity signify that "an event" may be about to happen. Larger studies and more data may help to address the lack of specificity of these alerts. The sensor data and case studies show promise as an early detection system; however, accumulation of more data and the examination of combinations of data from multiple sensors may help to identify specific conditions that associate with specific patterns from single or multiple sensors inputs. This would give clinicians not only an early warning system, but also a sense of what type of event might be forthcoming, enabling the link between early alert and potential event prevention.

With additional study, potential benefits of an early detection system of passive sensor data could be increased sensitivity to identifying physiological or clinical condition changes. Additionally, such a system could provide early warnings of impending changes or health events in older adults who are monitored.

Older adults want to remain at home. Community-based services with RN care coordination have been proven an effective strategy for improving clinical outcomes.[6] Technology has the potential to dramatically improve the efficiency of this model. Once prospectively validated in a larger sample, this approach could be implemented in a variety of settings including independent senior housing, long-term care, and homes of the elderly or disabled individuals in the community. Physicians, RN care coordinators, and other healthcare providers could potentially monitor older adults at home, thus avoiding the need for traditional long-term-care placement; this is exactly what older adults want.

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