TigerPlace: An Innovative Educational and Research Environment

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Abstract

A one of a kind project based on the concept of aging in place is in progress at the University of Missouri (MU). This project required legislation in 1999 and 2001 to be fully realized. A specialized home health agency was developed by the MU Sinclair School of Nursing specifically to help older adults age in place. In 2004, TigerPlace, a specially designed independent living environment, was built by Americare Corporation of Sikeston, Missouri, a leading long-term care company. TigerPlace was developed as a true partnership between the University of Missouri and Americare Corporation. This partnership allows for unique student and research projects.

Introduction

A cutting edge project to serve older adults is underway in Columbia, MO, TigerPlace, an independent senior living setting designed for aging in place. The project was developed as an academic and private business partnership between the University of Missouri (MU) and a major long term care corporation, Americare Corporation of Sikeston, Missouri. This endeavor involves the diverse talents of many different academic disciplines including: nursing, electrical and computer engineering, social work, physical therapy, occupational therapy, environmental design, landscape architecture, health informatics, and business. The only long-term care facility in the country to be licensed as an aging in place building, TigerPlace provides top quality care to its residents and provides unique research and educational opportunities to the faculty and students of MU.

An interdisciplinary research team is investigating the use of sensor technology to monitor and assess potential problems in mobility and cognition of elders in their homes at TigerPlace. The collaboration between TigerPlace, Sinclair Home Care, researchers from a variety of MU schools and colleges, elderly participants, and students makes this research in elder care technology possible. The elderly participants allow sensors to be installed in their homes for real world testing. The input from experts in gerontology nursing and the residents allows for the development of clinically relevant technology. Access to medical records maintained by Sinclair Home Care, a home health agency, allows researchers to evaluate the long-term impact of the technology on the health of the participants. A variety of factors have come together to make this collaboration possible.

The Aging in Place Model

Traditionally as people age and their health status deteriorates, they may be forced to move from their homes to an assisted living facility and as they become more frail to a nursing home. However, older adults want to remain at home as long as possible; they fear moving to a nursing home (Marek and Rantz 2000; Rantz et al. 2005b). With good reason, forced relocation causes mental deterioration, physical decline, and even premature death (Johnson, 1999; Manion and Rantz 1995).

In contrast to this traditional model, the concept of aging in place is to allow older adults to remain in the environment of their choice for as long as possible with supportive services as needed (Marek and Rantz 2000). The goal of aging in place is to maximize older adults' independence and dignity while helping them stay as healthy as possible.

Historical Prospective

In 1996, faculty and the dean of the MU Sinclair School of Nursing (SSON) envisioned a new model of long-term care based on the concept of aging in place. The SSON faculty met with an interdisciplinary group of health care providers, community leaders, and researchers to define this new model of care. However, the faculty soon realized that Missouri regulations restricted the development of a facility based on this new paradigm.

Faculty members worked with Missouri legislators, health care professionals, and state officials to enact legislation that would make aging in place possible within the highly regulated health care 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 aging in place pilot sites were created to evaluate the effectiveness of the aging in place model. The MU SSON applied for and was designated as a demonstration site.

The aging in place project consists of two parts: a home care agency focused on the care of older adults and a unique senior living facility, TigerPlace.

Sinclair Home Care, an innovative home care agency

Sinclair Home Care was developed to support the aging in place model. The agency is a certified Medicare home health agency and an in-home provider of supportive services. The agency provides services to residents in private congregate senior housing, public senior housing, and private homes in six counties in mid-Missouri. The MU SSON received a $2 million from the Centers for Medicare and Medicaid Services to start the agency and evaluate Aging in Place. In 1999, the agency opened as a department of the MU SSON. From the beginning, the agency was designed to serve older adults and provide services to TigerPlace. (Rantz et al. 2005a)

Care coordination by a registered nurse is the key to aging in place. Residents receive a comprehensive health assessment upon admission and every 6 months. Ongoing care coordination is centered on the wellness center. Sinclair Home Care operates a wellness center at TigerPlace three days a week. Residents may have their vital signs checked, get assistance with medications, or consult with a registered nurse (RN) on any health care issues or other problems. Additionally, a Sinclair Home Care nurse is on call 24-hours a day by phone for questions or assistance with problems. If a problem is identified, the nurse care coordinator works with the resident's physicians and other health care providers to ensure that the resident receives the needed care and the various health care providers involved have the information necessary to provide the best care possible. Many residents and their family members have found RN care coordination especially appealing as many have had serious health consequences with uncoordinated care in the past. In addition, this case management approach allows couples to stay together who might otherwise have to be separated to receive the care they needed, for example, when a spouse moves to a nursing home. Care coordination has allowed couples to stay together throughout the hospice and dying process of a spouse at TigerPlace, true aging in place success stories.

In addition to care coordination, Sinclair Home Care provides a range of services to the residents of TigerPlace. Every resident has access to four private home visits to assess problems as they arise. A variety of private pay services are available to assist with medication management and activities of daily living such as bathing, dressing or grooming. Exercise classes are offered five times per week. Medicare services are also offered on a short-term basis as residents need and are qualified for, such as after a hospitalization to assist with recovery.

Sinclair Home Care maintains electronic medical records on every client. In addition, logs of significant health events (hospitalizations, emergency room visits, and falls) are kept on the residents of TigerPlace. A database administrator is creating de-identified datasets for use in the research projects. All of the participants signed informed consent for the use of their health and sensor data.

Sinclair Home Care supplies the health care and health promotion services to TigerPlace. These services are the first essential component of the MU SSON's aging in place project. The second component is TigerPlace itself.

TigerPlace, a unique sensor living community

To really evaluate and implement the aging in place model an innovative independent living facility was developed in partnership with Americare of Sikeston, Missouri. Americare shared the vision of the University of Missouri and TigerPlace was founded on the principles of aging in place; to maximize older adults' independence and dignity while helping them stay as healthy as possible.

TigerPlace (www.tigerplace.net) was developed as a true partnership. Detailed services agreements were executed to establish the responsibilities of each partner. Americare staff are responsible for maintenance, housekeeping, transportation, social activities, and dining services. MU staff are responsible for the health care services, health promotion, exercise program, and linking residents with the faculty and students of MU as well as the numerous recreational and educational activities at MU. This partnership is marketed to perspective residents and is an important factor for residents and their family when choosing TigerPlace.

TigerPlace was designed to maximize the independence of the residents while supporting research. An interdisciplinary group of nurses, physical therapists, occupational therapists, environmental design specialists, and other experts in gerontology were involved in the design of TigerPlace to ensure a supportive environment. In addition, faculty from computer engineering participated in the building planning to ensure the infrastructure would support technological advances so that new technology could easily be installed throughout the building.

From the beginning, TigerPlace was envisioned to be an educational and research venue for the University of Missouri. Student and faculty have been involved at TigerPlace since its inception and have truly benefited from the experience.

Student Opportunities

TigerPlace serves as an educational center for students from many different departments on campus. Since TigerPlace opened in June 2004, over 300 students have had experiences at TigerPlace. Business and engineering students have collaborated to develop new products for older adults, for example, a walker with automatic breaks. Horticultural students have designed individual gardens for

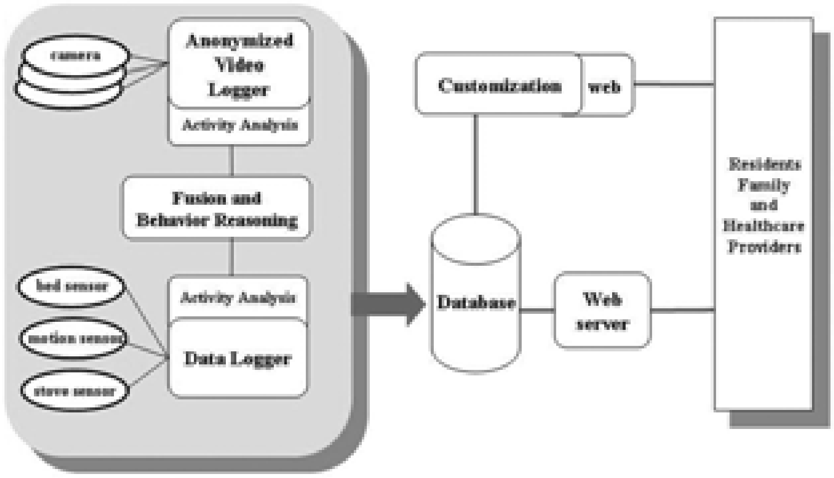


Figure 1: The Integrated Sensor Network

residents and a new courtyard feature. Nursing students interview older adults, participate in designing social activities, and do weekly foot care and massage to learn assessment and communication skills with older people. Occupation therapy students apply their message techniques, a service the residents truly enjoy. Students from social work, medicine, health informatics, and many other departments interact with the residents of TigerPlace.

Research at TigerPlace

Faculty from nursing, electrical and computer engineering, social work, and health informatics are investigating ways to use technology to monitor and access potential problems in mobility and cognition of elders. The purpose of the research is to detect the beginning of changes in a person's function so that health care services can be targeted to help the person early with health problems before small problems become larger ones. We believe technology has the potential to detect changes before people are actually aware of them and seek traditional health care. To accomplish the research purpose, our interdisciplinary group is developing an integrated sensor network. This network as shown in figure 1 contains three main components: (1) a data logger with motion, bed, and stove sensors; (2) an event-driven, anonymized video sensor network; and (3) a behavioral reasoning system.

The first component of the integrated network is the in-home monitoring system (IMS) developed by collaborators at the University of Virginia's Medical Automation Research Center. The IMS consists of a set of wireless motion sensors, a stove temperature sensor, and pneumatic bed sensors that can be used to infer specific activities (Alwan et al. 2003). Motion sensors are installed to detect presence in a room or specific activities. For example, a motion detector installed above the shower indicates bathing activity (figure 2). A bed sensor is used to detect presence as well as measure restlessness (movement in bed), breathing and pulse. A stove temperature sensor detects cooking activity and can be used to send a safety alert if the stove as been on too long. The motion sensors used are commercially available passive infrared (PIR) sensors which transmit using the wireless X10 protocol (Yuejun & Minghuang, 2005). The bed sensor is a pneumatic strip (installed under the bed linens) which detects presence in the bed, qualitative pulse and respiration, and bed restlessness (Mack et al. 2006). A low pulse event is sent if the detected pulse is less than 30 beats per minute; a high pulse event is generated at greater than 100 beats per minute. A normal pulse event is generated for 30-100 beats per minute. Similarly, a low respiration event is sent if the detected breathing rate is less than 6 times per minute, and a high respiration event is sent for rates greater than 30 times per minute. A normal respiration rate is generated for 6-30 times per minute. Four levels of bed restlessness are reported. A level one event is generated for movement up to 3 seconds in duration. A level two event is sent for movement from 3-6 seconds in duration. If movement persists from 6-9 seconds, a level three event is generated, and if continuous movement persists longer than 9 seconds, a level 4 event is sent. Together, these different levels provide a measure of restlessness in bed which is used to determine the quality of sleep. All of the output of the bed sensor contributes to the general pattern of the resident.

Figure 2: Motion sensor installed above the shower to detect bathing activity.

Currently, all of the sensor data is transmitted wirelessly via the X10 protocol to a data monitor PC which is located in each resident's apartment. The data monitor adds a date-time stamp for each sensor event and logs it into a file that is periodically sent to a dedicated central server which stores the data in a relational database. The data monitors are connected to the central server through a dedicated local network, for security purposes. In addition, as a precaution, identifiers are stripped from the data before transmission.

To date, we have installed sensors in 17 resident apartments. Data collection has been ongoing for two years in some apartments. This longevity in sensor data is allowing researchers to develop and test algorithms to detect emergency situations such as falls. In addition, normal activity patterns can be established and deviations recognized to alert staff to possible changes in condition. Several methods for displaying the data including a web-based interface and motion density maps have been investigated in an effort to interpret the data and explore possible correlations to the health data provided by Sinclair Home Care.

Using both health and sensor data collected longitudinally for years is one of the key factors that separates the TigerPlace research environment from other university technology testing environments. Not only can we explore a variety of analytic methods due to the large volume of sensor data, we have the opportunity to use the sensor data to make a difference in the lives of the residents, helping them to improve health and well-being through informing health care providers of changes they are experiencing. Never before have health care providers had information on activity and function in every day life activities (other than often unreliable or sketchy self-report). This has huge potential to advance technology rapidly from concept to actual use in ways that can really make a difference for people.

The engineering faculty enjoy the challenge of developing and testing their work in the real world environment of TigerPlace, tailoring ideas with feedback from residents and families to better fit the needs, and seeing immediate implications of their research. The nursing, health professions, social work, and medical faculty are inspired by the potential to create new solutions to sometimes "old" persistent health care problems for older adults that their traditional approaches have sometimes failed to fully address.

A secured web-based interface was developed to display the sensor data for health care providers, researchers, and residents. The web interface was refined with input from nursing, health informatics, social work, and residents to ensure it was user friendly, easy to use, and clinically meaningful. The interface allows users to select a specific participant and a date range. Sensor data is grouped by category: motion, pulse, breathing, and restlessness in bed. Users can drill down in the interface to see data from individual sensors. Data can be displayed in a variety of ways including histograms, pie charts, and line graphs. The total number of sensor firings can be aggregated in units ranging from 15 minutes to daily. An example of the web based interface is shown in figure 3.

In addition to the web-based visualization, work is also underway to develop automated reasoning techniques for processing the sensor data. Much of the strategy is based on identifying the typical pattern of activity for an individual and then recognizing when the pattern changes. These pattern deviations may take the form of a sudden change as a result of a specific health event, or in the form of a gradual change as a result of a deteriorating condition. One approach for detecting such changes is a new algorithm for temporal clustering (Sledge, Keller, and Alexander 2008; Sledge and Keller 2008).

Monthly activity density maps (figure 4) have also been created to track activity levels over time. Each line on the vertical axis represents the activity density for one day each month. Each block on the horizontal axis represents one hour of the day. All motion sensor firings per hour are total and color is used to indicate the level of activity in the apartment. Darker colors are used to indicate higher density (more activity). Black areas designate when the resident was out of the apartment. The maps are usually shown in color. Figure 4 is shown in grayscale with darker shading indicating more activity.

The two monthly activity density maps in figure 4 are generated from two different residents and clearly show two different lifestyles. From the maps you can track when the participant left the apartment for breakfast, lunch and dinner in the common dinning room as well as for other activities. Figure 4a show a very active resident who leaves the apartment many times a day (numerous black areas) and is very active in the apartment (more

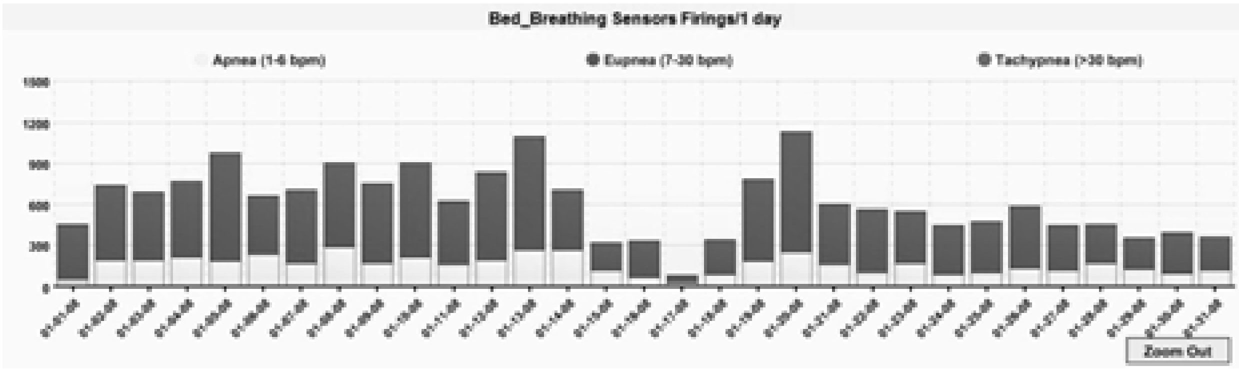
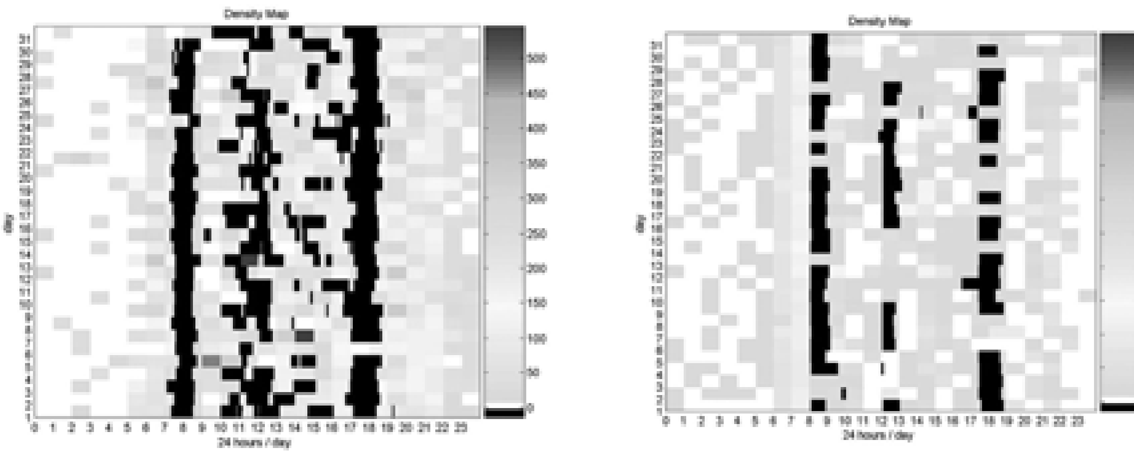


Figure 3: Web-based interface showing data from the bed breathing sensor with the total number of sensor firings aggregated to the daily level.



(a) *(b)*

Figure 4: Monthly activity density maps generated using motion sensors data from two different residents showing very different activity levels.

shading). This resident has cognitive issues which contribute to an active lifestyle. Figure 4b shows a resident with fewer black areas (less time out of the apartment) and less shading (less activity while in the apartment). We are especially interested in tracking the residents' densities over time to look for changes in activity patterns which may indicate a change in health status, so that health care providers may intervene to prevent or delay functional decline.

The second component the research team is developing is an event driven anonymized video sensor network to track relevant data on gait and range of motion and to detect falls. The system compliments the IMS by reducing false alarms generated by the motion sensors. To preserve the privacy of the residents, algorithms are being developed to find a moving person in the image and generate a silhouette. (Chen, He, Anderson, Keller, and Skubic 2006; Wang, Tan, Ning, and Hu 2003). Important features are then extracted from the silhouette and a hidden Markov model (HMM) is trained to recognize known activities (Anderson, Keller, Skubic, Chen, and He 2006).

The final component of the integrated system is a behavioral reasoning system that uses the motion sensor data to establish normal patterns of activity and recognizes deviations from the established patterns. Several methods of behavioral reasoning using fuzzy logic rules (Wang, Keller, Burks, Skubic, and Tyrer 2006) and a hierarchical HMM are being investigated. Fuzzy rules can be expressed in simple, non-technical language, which is helpful when discussing these methods in interdisciplinary team meetings.

The network minus the anonymized video has been installed in 17 residents' apartments at TigerPlace. All of the participants volunteered to be monitored and have signed informed consent. For some participants, we have collected more than two years of continuous sensor data.

Improving the lives of the residents of TigerPlace has always been the focus of the research and their input is invaluable to developing useful technology. Several focus groups were conducted early in the research to assess the residents' attitude and perceptions of the technology. The analysis revealed that technologies which would benefit older adults included monitoring activity level and sleep patterns, preventing or detecting falls, and alerting caregivers to emergency situations. The participants emphasized that the system should not be burdensome or obtrusive; it should be user-friendly (Demiris et al. 2004). These results were used in choosing which technologies to develop at TigerPlace. The opinions and perceptions of the participants are constantly sought and respected as the technology development evolves.

An unexpected benefit of this research has been the response of the residents. The residents enjoy participating in focus groups and other research activities. They feel they have a voice and are true partners in the research projects. The residents take pride in knowing that they are helping to improve the quality of life for other older adults. The residents' collaboration in and attitudes toward the research have made it very successful.

Family Involvement

As TigerPlace was envisioned, we anticipated that families would enjoy the university connections and experiences with students. We hoped they would be intrigued with research we hoped to develop. Their reaction and support of the research initiatives and technology has been nothing less than remarkable. Families are willing to help students and faculty by participating in interviews, focus groups, and informal feedback as the sensor research has evolved over the years. Their willingness to give freely of their time and share their honest views has been so important to keep our research on track, developing technologies to enhance aging in place, not requiring people to wear sensors, assuring privacy and dignity, while addressing the health concerns of older adults.

Families have shared with us that a key reason they were interested in TigerPlace is the technology research in progress. They want to see these technologies developed and want to participate if they can in some way to see technology used to help people remain at home as independent as possible.

Challenges and Lessons Learned

One of the challenges of this project has been that we have moved out of the lab setting and into people's homes. Unlike demonstration smart homes that can be specially configured with numerous sensors and computers, we wanted a system that could be installed in any home with minimal time and effort and especially with minimal wires and cables. In addition, we have observed that people care very much about the looks of their homes, and they do not want extraneous sensors, wires, and computers cluttering up their space. Thus, using small, wireless sensors was an important consideration. In addition, there is the question of how many sensors to use, where to place them, and how to mount them securely. We had to balance the engineering tendency to put sensors everywhere with more practical considerations of installing and maintaining them (e.g., replacing batteries). In addition, we wanted the residents to resume their normal behavior without feeling like they were being watched by sensors everywhere. Our interviews have shown that we have been mostly successful with this goal; residents go through 3 stages in adjustment to the sensors. By the end of the first month, they are already in the third stage and report that they do not consciously think about the sensors (Demiris et al. 2008).

The commercial PIR motion sensors have proven to be practical for this application. They are small, wireless, and lightweight enough to be mounted on the wall or ceiling with double-sided foam adhesive. They can be placed in cabinets, drawers, closets, and the refrigerator to indicate various activities, and they don't show on the outside. The apartments at TigerPlace are not all the same size so a custom configuration is necessary for each apartment. Bigger apartments have more sensors than the smaller apartments.

We have tried other sensors but have discontinued their use. Initially, we used a binary floor mat which provided specific location information of the resident, i.e., an event was transmitted when the resident was standing on the mat and another event signaled when the resident left the mat. We discontinued use of the floor mat when it became apparent that this provided a trip hazard for some older adults. In addition, we tried a binary chair pad which signaled when the resident was sitting on a chair. We discontinued use of the chair pad because residents found it awkward to have to continuously readjust the pad for comfort. A floor vibration sensor (Alwan et al. 2006) was also tried in TigerPlace. We had hoped to identify falls from floor vibration signals, as well as qualitative gait patterns, e.g., walking in a limp or a shuffle. However, TigerPlace, like other typical U.S. eldercare facilities, is built on a concrete slab foundation, on the ground floor. Although we could detect floor vibration signals from walking or falling, other activities would also generate similar signals such that classification results were poor. For example, in recognizing falls, it is important that the sensing mechanism detect falls reliably but not generate false alarms. This did not appear feasible using the floor vibration sensor on a concrete slab foundation.

We have also had to consider where to place the computer which provides the data monitor functions. This computer is a small PC with no monitor or keyboard attached. However, for security and reliability considerations, we had decided to use a wired network port, and thus the position of the computer was constrained by the location of the network port. All of the apartments at TigerPlace have a network port in the living/dining area. At first, the computers were simply placed on the floor typically behind a large piece of furniture. While this generally worked fine, there were occasional problems. Sometimes, a resident would unplug the computer because he or she wanted to use the power outlet. Eventually, we decided to dedicate a cabinet to the computer. Cabinets were installed above the refrigerator in each apartment with holes in the cabinet for ventilation. A power outlet and network port to a dedicated local area network were installed inside the cabinet so that all wires and cables are concealed.

Another challenge has been keeping all of the sensors and computers operating continuously. We addressed this challenge by first doing a week-long validation test in the lab with a computer and sensors configured for a specific apartment. This identified some problems and eliminated unnecessary trips to TigerPlace. After the system was installed, there were still instances in which sensors stopped transmitting and computers stopped logging, resulting in gaps in the data. For example, sensors occasionally fell down. A stove sensor failed probably due to excessive heat. Power spikes from thunderstorms caused computers to reboot and sometimes required manual intervention to bring them back on-line. Eventually, we implemented an automated monitoring system which emails the system administrator daily on the status on each network, so that problems can be addressed in a timely manner.

Finally, the biggest challenge has been trying to connect sensor data to medically relevant events. Although we have access to electronic health records, these are not in a form that easily accommodates data mining. Thus, our current studies have necessitated manual extraction of health data and comparison to logged sensor data. In addition, we have found that the sporadic collection of vital signs is not frequent enough to match the continuous collection of sensor data. To address this, we plan to make telemedicine equipment available to the residents and ask that they collect their vital signs daily. The data will go into an internal database, which will include other pertinent data on sentinel health events such as hospitalizations and falls.

Summary

This collaboration between TigerPlace, Sinclair Home Care, residents, researchers and students from a variety of disciplines is a model for others interested in doing research in elder care technology. While TigerPlace is truly a unique facility enabled by legislation to demonstrate a new model of long term care, these kinds of partnerships easily could be formed in other venues with the goal of providing a real-world setting for education and research in gerontology and elder care technology.

TigerPlace is built on the principles of aging in place and a spirit of cooperation, TigerPlace offers an innovative educational and research venue. Students have experiences with older adults and learn valuable skills. The interdisciplinary research taking place in this real world setting is providing invaluable information for elder care technology. Most importantly, the men and women of TigerPlace receive top-notch care and have stimulating interactions with faculty and students.

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