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Using Sensor Technology to Augment Traditional Healthcare

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Abstract—**Sensor networks have been installed in the apartments of volunteer residents at TigerPlace, a specially designed retirement community helping residents aging in place. Researchers are investigating methods to interpret the sensor data to detect early signs of illness or functional decline in older adults and alert health care providers to these changes. Two case studies are included to illustrate the potential of the sensor networks to augment traditional health care assessment.**

I. Introduction

Technology provides the key to long-term remote monitoring of older adults, early detection of impending problems and early intervention to help older adults manage chronic illnesses and remain as healthy and independent as possible. Researchers at the University of Missouri are developing passive sensor networks, installing sensors in apartments of elderly volunteers at TigerPlace, and investigating methods to interpret the sensor data to detect changes in health status and help residents age in place.

TigerPlace, developed around the concept of aging in place, offers a unique real world environment in which to test sensor technology. The concept of aging in place is to allow older adults to remain in the environment of their choice with supportive services as needed [1]. Sinclair Home Care, a licensed home care agency, provides home care services and coordinates all of the residents' medical care with their physician, family members, and other providers to ensure their care needs are met, allowing residents to remain as long as they wish.

To enhance the care provided by Sinclair Home Care, we are investigating the use of sensor technology to monitor and detect changes in the residents' health status. We are interested in detecting emergency situations such as falls or dramatic health changes as well as more subtle changes in health condition which may be a sign of impending illness or exacerbations of chronic disease.

Small investigative studies of sensor networks for eldercare have been conducted. Glascock and Kutzik successfully tested a system of motion sensors to infer activities of daily living for 13 days in the home of a 71-year-old male [2]. Ogawa et al. documented a pilot study monitoring two individual participants in their homes for motion activity, sleep time, and appliance use (through wattmeters) continuously for over a year. Researchers concluded that daily monitoring of elders could contribute to maintaining the health of older adults [3]. Beckwith describes a study in an assisted living facility with 9 residents of varying degrees of dementia. Residents and staff each wore a badge for location tracking. The system included motion, door sensors and load cells on the bed [4]. A monitoring system of 8 passive motion sensors was installed in one elderly volunteer's home to infer a person's behavioral patterns using probabilistic mixture model analysis [5]. Another pilot study used motion and door sensors to extract a 24 hour activity profile; an alert could be generated if newly logged data deviated from the stored profile [6]. Heart and breathing rates of 21 assisted living residents were monitored as well as activities of daily living (through motion sensors) and key alert conditions. The results of this case controlled study demonstrated reduced hospital days, cost of care, and had a positive impact on caregivers' efficiency [7].

The collaboration between the University of Missouri, TigerPlace, Sinclair Home Care, and the elderly participants makes this research possible. The sensor networks are installed in the apartments of elderly residents who volunteer to participate in our research. Based on resident interviews, our research is focused on ambient monitoring, i.e. the participants do not wear any sensors, monitors, or other devices. [8] We have longitudinal data sets, electronic medical records and sensor data, spanning years. We are correlating the sensor data and health records in an attempt to detect health status changes early to prompt early interventions to prevent or delay physical and/or mental deterioration. This clinical focus particularly separates this research from other projects [9].

II. Research Components

A. TigerPlace

TigerPlace was developed by Americare Systems, Inc, a leading long-term care company, in partnership with the University of Missouri. The building was built to nursing home standards, but is specially designed to promote independence. Residents live in independent apartments with basic services such as housekeeping, transportation, and 2 meals per day provided.

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TigerPlace residents are similar to other seniors in Missouri and the United States. Currently, TigerPlace has 39 residents ranging in age from 70 to 98 (mean 87.93 ± 5.26). There are 4 couples and the remaining residents are single. 18 residents (46.15%) use walkers, 2 residents employ canes, and 4 residents rely on wheelchairs. About 90% of the residents have a chronic disease; 60% have multiple chronic diseases. Common illnesses include arthritis, heart disease, and diabetes. A few residents have early stage Alzheimer's disease, but continue to function normally with the help of family, TigerPlace staff, and Sinclair Home Care.

B. *Sinclair Home Care*

Sinclair Home Care was opened in 1999 to provide health care services to TigerPlace. While living at TigerPlace, residents receive a comprehensive health assessment at least every 6 months, 4 visits per year to evaluate problems, access to a wellness center 3 day per week where they may have their vital signs checked or discuss health issues with the registered nurse (RN) care coordinator, and health promotion activities including exercise classes 5 days per week. A RN is on call 24 hours a day, 7 days a week. Residents may also pay privately for additional health care services, such as medication management or personal care assistance.

Sinclair Home Care maintains electronic health records for all the residents of TigerPlace. In addition, TigerPlace keeps a daily communication log for staff where information is recorded about the residents including significant health events such as falls, hospitalizations, and emergency room (ER) visits. De-identified datasets were constructed from the electronic health records and paper logs. Residents provide informed consents for use of their medical records and sensor data.

C. *Integrated Sensor Neworks*

The integrated sensor network (fig. 1) consists of 1) a physiological sensor network with data monitor and a stove sensor, motion sensors and a bed sensor developed by colleagues at the University of Virginia [10]; 2) a video sensor network which focuses on protecting the privacy of the residents by extracting a silhouette; 3) a fusing and reasoning engine to combine the sensor and video data and analyze patterns; 4) an alert manager which notifies clinical staff if a problem is detected; 5) a component for customizing sensor configurations, alert specifications, and data access for each resident; and 6) a database, web server, and secure web-based interface for graphically displaying the sensor data [11]. The motion sensors are used as a proxy for activity level. The physiological sensor network consisting of the motion sensors and the bed sensor has been installed in 19 apartments at TigerPlace. The other components of the network are under development at the University of Missouri and have not yet been installed.

Inexpensive passive infrared motion sensors, which transmit via the wireless X10 protocol [12], are installed to detect presence in various rooms in the apartment as well as to infer certain activities. For example, a motion sensor installed above the shower detects bathing activity.

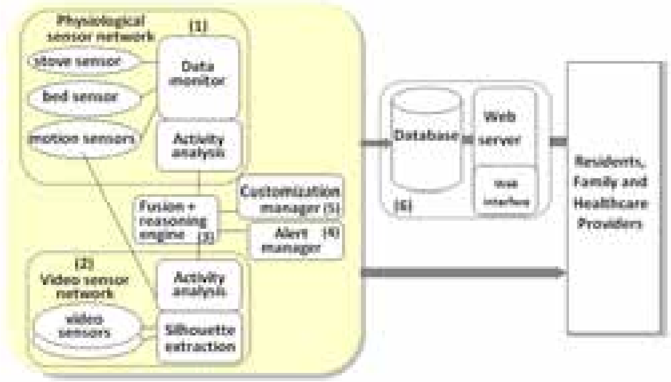

Fig. 1: Integrated Sensor Network

The bed sensor is a pneumatic strip which is installed between the mattress and the bed linens. The bed sensor detects presence in bed and measures restlessness as well as qualitative (high, low, or normal) pulse and respiration [13].

An interactive secure web-based interface was developed to display the sensor data for the health care providers, researchers, and the volunteer participants. The interface was refined with input from nursing, physical therapy, occupational therapy, and informatics as well as residents and their families to ensure that it presents the data in a way that is easy to interpret and clinically relevant [14]. The interface allows users to select a specific resident and a date range. The sensor data are grouped by category (motion, restlessness, pulse and respiration) and may be displayed in a variety of formats including histograms, bar graphs, and pie charts. The data may be aggregated in increments ranging from 15 minutes to daily and displayed for time periods from hours to months.

20 residents (7 male, 13 female) have agreed to be monitored with the physiological sensor network. The participants range in age from 70 to 96 (mean 87.2 ± 6.07). Five participants have been discharged; two subjects died; two moved to a nursing home, and one moved to an assisted living facility. The first sensor network was installed on September 1, 2005, so there are continuous data for over 3 years. The average length of monitoring with the sensor network is 15 months.

III. METHODOLOGY

A non-clinical research associate examined sensor data using the web-based interface before and after known health events such as falls, hospitalizations, and ER visits with a goal of detecting patterns which could be used to generate alerts and monitor on-going health status. A total of 104 health events (22 ER visits, 63 falls, and 19 hospitalizations) from Sept. 1, 2005 to Dec. 31, 2008 were retrospectively analyzed using the web-based interface. An exploratory multiple case-study methodology was used because the analyses focused on trends over time instead mere frequencies or incidences [15]. In a few cases, obvious trends in the data were located which could have better informed the health care providers.

IV. CASE STUDIES

A. Case Study #1

A 90-year-old female living alone in her apartment fell out of bed on December 12, 2008. She was not injured in the fall and later self-reported the event to her home health aide (HHA). She had a history of falls and heart disease including congestive heart failure and hypertension (high blood pressure). She manages quite well in her apartment with the help of a HHA to assist with bathing and personal care. When retrospectively reviewing her sensor data using the web-based interface before this fall, an increase in all levels of bed restlessness was visually located (fig. 2).

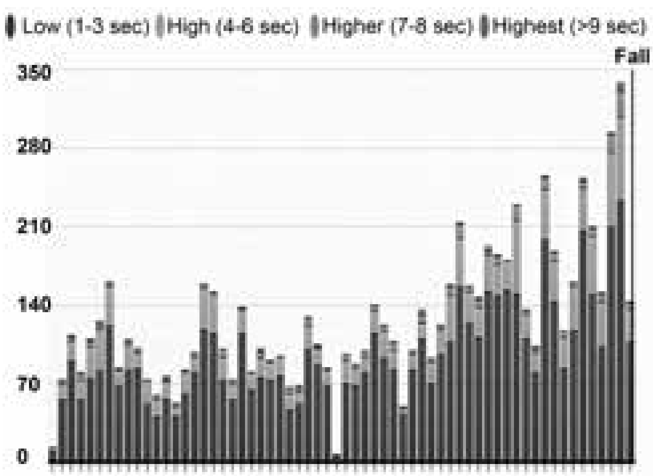

Fig. 2: Graph of web-based interface with the addition of a mark denoting the fall showing bed restlessness sensor firings (all levels) aggregated to a daily level for the period from 10/12/2008 to 12/12/208.

The HHA visit notes indicate a problem before this event which the sensor data confirms. Her HHA had noted that she wasn't feeling well and not sleeping well several days prior to this event. The bed restlessness sensor data also indicate that she was not sleeping well. The aide notified the RN care coordinator of the resident's deteriorating condition on December 10th. Had the RN seen the sensor data in conjunction with report from the aide, the RN may have taken additional action and assessed the resident further. In this case, the sensor data could have been used as an additional assessment tool and provided a better overall picture of the client's health status.

B. Case Study #2

In addition to the web-based interface, different methodologies are being investigated to display and interpret the sensor data such as density maps, which show computed motion density data over a one month period. Densities are calculated as the number of all motion sensor hits during an hour divided by time at home during that hour [16]. Colors are used to represent different densities as illustrated on the scale on the right of the map. The X axis signifies time of day and the Y axis indicates day of the month. Black is used to represent time out of the apartment. By examining the motion densities over time, typical patterns may be established and variation from the norm used to monitor potential changes in health status.

An 87 year-old women who lived alone in her apartment was cognitively impaired. The sensor network consisting of the bed sensor and 8 passive motion sensors was installed in her apartment in January 2006. At the beginning of her stay at TigerPlace, she was managing well with the assistance of family. As seen in fig. 3 from July 2006, she has a very active lifestyle leaving the apartment quite frequently sometime for very brief periods. She would wander in her apartment and around the common areas of the building. She regularly attended dinner in the common dining room.

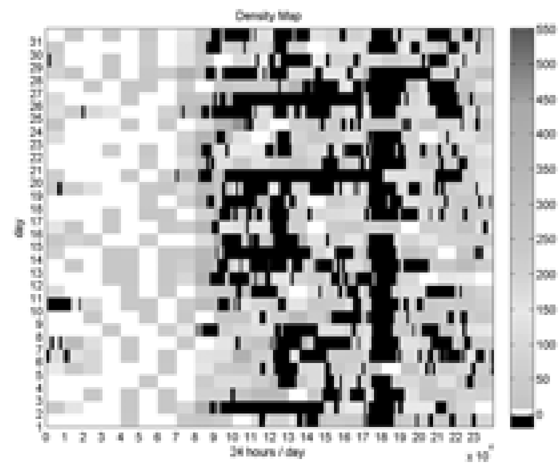

Fig. 3: Density map from July 2006.

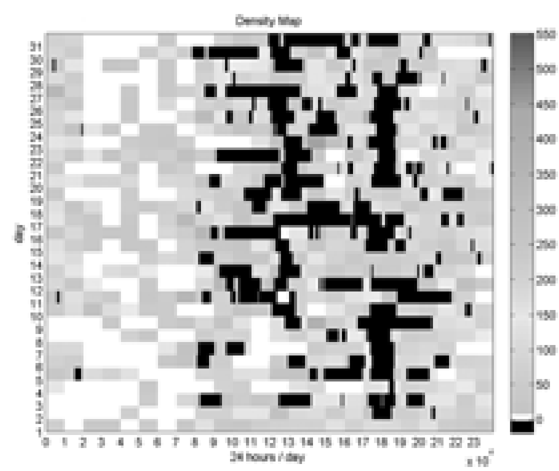

Fig. 4: Density Map from July 2007.

She steadily declined over the next year. As seen in fig. 4 from July 2007, her overall activity level decreased and she was spending less time out of the apartment (fewer black areas). She was also not sleeping well as indicated by several nights of increased activity.

In this case, the density maps could have been used to track the client's overall progress by providing a picture of activity level and change from month to month.

V. Discussion

These case studies illustrate the potential of the sensor network to augment traditional health care assessment and RN care coordination. In several other cases the sensor network detected changes in the resident's condition that were not detected by conventional health care assessment [17], [18]. The sensor data could be used to prompt health care providers to assess the situation in more depth or watch for potential complications. In addition, the sensors have the potential to alert health care providers to an emergency situation, such as a fall, when the resident is unable to call for help. The goal is to develop an early warning system that uses the sensor data to detect early signs of illness or functional decline in older adults and alert health care providers to these changes.

While the case studies presented here were obvious to the non clinical research associate, only a few of the retrospective case studies using the web-based interface yielded clear results. Of the 104 health events examined, only 38 (36.5%) prompted a closer inspection. Many of the visual data patterns were subtle and ambiguous to the non-clinical researcher.

Additional work is underway to refine the web-base interface and develop new methods to detect health status changes. Computer engineers are developing algorithms to alert clinical staff of early signs of illness or functional decline. In addition, clinical staff familiar with the residents being monitored may have additional insights which help them more clearly interpret the sensor data. Plans are underway to have interdisciplinary clinical staff use the web-based sensor interface prospectively on a routine basis to enhance their understanding of the residents' conditions. Input from clinical staff familiar with the residents is critical in the development of a meaningful and useful system.

With additional work refining and using the sensor data, the goal of an early warning system will be met. Eventually, this type of system could be deployed in other community-based settings, senior housing, long-term care, and private homes helping the increasing number of older adults manage their chronic diseases and remain healthy and independent longer.

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