**Proceedings of the 1st Distributed Diagnosis and Home Healthcare (D2H2) Conference
Arlington, Virginia, USA, April 2-4, 2006**

Impact of Passive In-Home Health Status Monitoring Technology in Home Health: Outcome Pilot

Majd Alwan, *Senior Member, IEEE*, David C. Mack, Siddharth Dalal, *Member, IEEE*, Steve Kell, Beverely Turner, Robin A. Felder

Abstract— **This paper describes a study designed to assess the impacts of passive health status monitoring technology in home health. Monitoring systems were installed in the homes of 13 home health clients to track physiological parameters (heart rate, breathing rate, and gait), the activities of daily living (ADLs) and key alert conditions of residents, such as falls. Activity reports and alert notifications were sent to professional caregivers in order to refine and target the care administered to clients participating in the study. Informal caregivers of participants were provided with access to the ongoing wellness status of their loved ones. The potential diagnostic utility of the monitoring data, the subjects' quality of life and health related quality of life, as well as the quality of life, strain and burden levels of the informal caregivers were assessed. Pre- and post-installation scores were compared. The results suggest that monitoring technologies could provide care coordination tools that have a positive impact on the perceived quality of life of monitored individuals, as well as a reduction in the strain levels of their informal caregivers, and may have a positive impact on the participants' health related quality of life.**

Index Terms— **Telemedicine, In-Home Health Status Monitoring, Quality of Life, Health Related Quality of Life, Informal Caregiver Strain, Home Health Care.**

I. Introduction

Recent advances in telemedicine, including sensor, communication, and information technologies have created opportunities to develop novel tools enabling remote management and monitoring of chronic disease, emergency conditions, and the delivery of health care. In-home monitoring has the added benefit of measuring individualized health status and reporting it to the primary care providers and caregivers alike, allowing timelier and targeted preventive interventions [1]. In-home monitoring may be one key solution that addresses efficient and effective means of care delivery to the world's growing elder population.

Health monitoring in home environments can be accomplished by a) ambulatory monitors that utilize wearable sensors and devices to record physiological signals (reviewed in [2]); b) sensors embedded in the home environment and furnishings to unobtrusively collect behavioral and physiological data; or c) a combination of the two [2]. In our review of non-hospital monitoring, we focus on unobtrusive systems similar to technologies tested in this study.

One of the pioneering telehealth research projects was conducted at the University of New South Wales, Australia, aiming to explore whether functional health status amongst the elderly could be accurately determined remotely by continuously monitoring relatively simple parameters that measured the interaction between participants and their environment [3]. The researchers reported a high level of acceptance by both the participants and their primary care providers, since the system was easy to use, effective, and potentially increased the efficiency of chronic disease management. Glascock and Kutzik [4] described a non-intrusive system that is similar in principle and basic hardware components to one of the technologies used in this study. In the proof of concept phase, this system was validated in the ADL suite of an urban hospital where a video camera and recorder captured the actual activities carried out by participants. An in-home testing phase was sequentially conducted in 1998 in several homes, with the longest monitoring data collected representing 13 consecutive days. The system applied simple statistics to the first motion sensor firing in the morning, indicating wake-up time, and the last sensor firing at night, signifying the bed-time. It also applied these statistics to the frequency and times of access to medications, which was monitored by an instrumented medication caddy; the paper also presented and examined trends of these variables [4].

In this paper, we present the results of a pilot study conducted in collaboration with the Evangelical Lutheran Good Samaritan Society. A number of In-home Monitoring Systems (IMS) were deployed in the homes of home health clients. The system, together with its activity inference algorithms, was initially tested for 18 months under an institutional review board (IRB) approved study in a private home that served as our "living laboratory". In these

Manuscript received December 24, 2005. This work was supported in part by a grant from the Evangelical Lutheran Good Samaritan Society.

M. Alwan is with the Medical Automation Research Center at the University of Virginia, Charlottesville, VA 22908 USA (phone: 434-924-2265; fax: 434-924-5718; e-mail: ma5x@virginia.edu).

D. C. Mack is with the Medical Automation Research Center at the University of Virginia, Charlottesville, VA 22908 USA (e-mail: dcm5a@virginia.edu).

S. Dalal is with the Medical Automation Research Center at the University of Virginia, Charlottesville, VA 22908 USA (e-mail: dalal@virginia.edu).

S. Kell is with the Medical Automation Research Center at the University of Virginia, Charlottesville, VA 22908 USA (e-mail: swk3f@virginia.edu).

B. Turner is with the Medical Automation Research Center at the University of Virginia, Charlottesville, VA 22908 USA (e-mail: bt2h@virginia.edu).

R. A. Felder is the Director of the Medical Automation Research Center at the University of Virginia, Charlottesville, VA 22908 USA (e-mail: rfelder@virginia.edu).

preliminary studies, the activity data of a normal healthy middle-aged participant was logged and analyzed using several data analysis techniques, including clustering, mixture models [5] and a rule-based approach, where spatial-temporal relationships among sensor events are exploited to infer the occurrence of activities with a high degree of confidence. The latter approach was adopted for the inference of the activities of interest. The system's rule-based inference methods were validated against 37 days of the subject's self-report, recorded in real-time using a Personal Digital Assistant (PDA) based electronic diary developed specifically for the validation study. A detailed description of the activity inference rules and validation results are reported in [6]. The acceptance, utility, and impact of the system, particularly on monitored older adults quality of life in assisted living were evaluated and presented in [7].

The objective of the current study was to assess the impact of the system on the quality of life of an older adult population, and the quality of life as well as strain and burden levels of their informal caregivers in a pre- and post-assessment study conducted in a home care setting. In what follows, we describe the technical enhancements made to the monitoring system, evaluation approach, the statistical methods used, and results of this outcome pilot.

II. Methods

A. Subjects

Thirteen in-home monitoring systems were assembled and installed in the homes of clients of a home health care agency managed in rural southwest Minnesota. The total sample size was 13 participants, five males, and eight females. All participants but one were over the age of 65 (mean age 84.85 years, median age 88, minimum age 63, and maximum age 100). All subjects were white. Inclusion criteria required the subjects to be ambulatory, be able to provide for their own hygiene except for bathing (some participants received assistance from home health aides in bathing), be able to prepare meals and eat autonomously, be eligible for home health and have a friend or relative who acted as an informal caregiver who was also willing to participate in the study. Exclusion criteria included subject refusal to being monitored, inability to get out of bed, the requirement for extensive outside assistance in the activities of daily living, and not having an informal caregiver who was willing to participate.

A total of 13 informal caregivers were recruited, six males, and seven females, mean age 56.38 years, median age 59, minimum age 34, and maximum age 75. All informal caregivers were white.

Home health clients and informal caregivers interested in participating in the study signed an IRB approved informed consent.

B. Measurements

The quality of life of the monitored residents was assessed using the Satisfaction With Life Scale (SWLS) instrument [8], as well as the CDC Health Related Quality of Life instrument known as CDC HRQOL-4 [9] before and after the monitoring. The SWLS consists of five questions dealing with general satisfaction (e.g., I am satisfied with my life); responses are made using a 7-point Likert scale. In contrast, the CDC HRQOL-4 asks the participant to rate their general health (Excellent, Very Good, Good, Fair, or Poor), and asks about physically unhealthy days, mentally unhealthy days, and number of days where physical or mental health condition prevented the respondent for carrying out normal activities in the previous month. During the pilot, older adults were monitored for four months.

Informal Caregivers were provided access to wellness and activity monitoring reports of their loved ones. The Satisfaction With Life Scale (SWLS), Caregiver Strain Index (CSI) [10], and Caregiver Burden Interview (CBI) [11] were administered before and after Informal Caregivers were provided with access to reports. The CSI consists of 13 questions (dichotomous response) designed to assess various types of strain experienced by live-in informal caregivers; the CBI is a 22-item self-administered inventory originally designed for Alzheimer patient family caregivers. Questions are answered with a five point Likert scale.

C. Technical Information

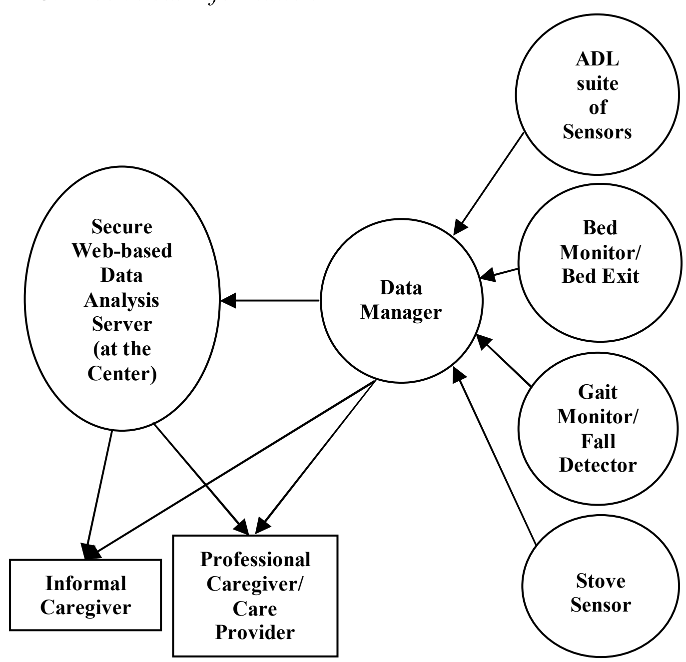

Fig. 1. The Common Modular Architecture of the In-Home Monitoring System evaluated in this study.

The piloted In-Home Monitoring System was described in detail in [7]; in this pilot, the system (see Fig. 1) has been augmented with a passive floor-vibration based gait monitor and fall detector placed underneath the bed (for more information about this gait monitor and fall detector, see [12, 13]). Consequently, an "impact fall" alert condition, indicated by high frequency high amplitude signal from the fall detector followed by lack of motion activity for 20 minutes, was added to the monitored possible fall, low-pulse, high-pulse, and forgotten stove alerts.

D. Statistics

Descriptive statistics including means and variance comparisons were applied to the SWLS, CDC HRQOL-4, CSI, and CBI data.

III. Results

A. Outcome Evaluation

There was a statistically significant increase in quality of life scores for the monitored older adults after four months of monitoring from a mean of 24.39 ± 5.39 pre-monitoring to 25.69 ± 4.16 post-monitoring (one-tailed paired t-test for means, p=0.0326). The one-tailed t-test for means was used because the direction of change was anticipated *a priori* due to previous evidence of tendency for such an increase in prior research [see 10]. There was also a reduction in the variance of the collected data, indicating that after monitoring, the perceived quality of life of the monitored sample population has become more homogenous.

There was a decrease in the number of physically unhealthy days (mean of 12.12 ± 12.38 pre-monitoring and 6.77 ± 9.74 post-monitoring), a slight increase in the number of mentally unhealthy days (mean of 4.85 ± 8.32 pre-monitoring and 6.38 ± 11.40 post-monitoring) and a decrease in the number of physically and mentally unhealthy days that kept the participant from usual activities after monitoring (mean of 5.62 ± 9.78 pre-monitoring and 1.77 ± 3.52 post-monitoring); although these changes were not statistically significant, the results show a trend that the integration of the monitoring system's data in the care planning and delivery process may result in reducing the number of physically unhealthy days as well as the number of physically and mentally unhealthy days that keep the participant from usual activities.

Thirteen individual accounts were created for the informal caregivers. However, only 10 informal caregivers accessed their accounts (77%). Each informal caregiver accessed the site 2.8 times on average over the period of the pilot (SD=2.10, Min=1, Median=2.5, Max=8).

There was no change in the quality of life of informal caregivers (mean of 28.92 ± 4.13 pre-monitoring and 28.85 ± 3.00 post-monitoring).

There was a slight decrease in the score of informal caregivers of monitored individuals on the Caregiver Burden Interview instrument after monitoring (mean of 18.92 ± 14.13 pre-monitoring and 15.10 ± 11.37 post-monitoring); nonetheless, the change was not statistically significant**.**

There was a statistically significant decrease in the score of informal caregivers of monitored individuals on the Caregiver Strain Index instrument after monitoring (mean of 2.46 ± 3.46 pre-monitoring and 0.39 ± 0.77 post-monitoring, p=0.0336 two-tailed paired t-test), indicating that the use of the technology could result in reduction in the informal caregivers' strain levels.

B. Diagnostic Use of Collected Health Status Data- Case Study

In one case study, a 69 year old woman who was selected as a candidate for the study because of a history of Gastro-Intestinal (GI) problems, was hospitalized on April 1st and once again on April 16th as a result of bowel obstructions. Retrospective inspection of her reports showed interesting variations in the number of bathroom visits during the days preceding hospitalization. The average daily bathroom visits frequency (in 24 hrs) changed from 8, a few days prior to hospitalization, to 4 on March 28th, up to 14 on the 29th, then it remained around 11 until April 1st. She returned home from the first hospitalization on April 11th. On April 12th she had 15 bathroom visits, and then she had an average of 8 bathroom visits for a couple of days. This was followed by only 2 bathroom visits on the 15th. She was re-admitted into the hospital on April 16th. This change in bathroom visit frequency made the research team initially suspect improper self-medication using over the counter laxatives and anti-diarrhea agents. However, further dialogue with the site nurses revealed that the client had reported loose stool, and that she had been removed from her medications, Reglan and Zelnorm, upon the orders of one of her physicians about 2 weeks prior to her first bowel obstruction. (Reglan helps move food through the GI track by increasing peristalsis; Zelnorm, which is prescribed for chronic constipation, synchronizes the GI peristalsis to effectively move food through the GI.) At about the same time, a different doctor had her start on Zaroxlyn due to a 14 pound weight gain in a very short time period. Zaroxlyn, a metolazone drug, is a diuretic. The diuretic increased this individual's water loss until she was dehydrated, which further exacerbated her chronic constipation and resulted in dangerous complications. If the data and monitoring reports were available to the physicians, and if the physicians were sharing information about the patient's current medications, these hospitalizations could have possibly been avoided.

This case study highlights the importance of using such a system to connect physicians and home health agencies; not only to have access to this objective health status data, but also to have shared access to all of the patient's current medications to immediately track the effect a change of medication regimen has on the patient's activity patterns, symptoms, as well as identifying any adverse reactions or complications at the earliest possible opportunity. The MARC system is implemented on an OpenSource Electronic Medical Record (EMR) extended to include the wellness information, such as key ADLs and sleep quality, which allows sharing such information among provides.

C. Emergency Response

During this pilot study, the system did not detect any true emergency conditions. One participant fell outside the home during the pilot, and no alerts were generated by the system since all alert conditions were only monitored inside the home. No high pulse alerts were generated by the system. There were a few low pulse alerts generated by an obese participant whose weight seemed to negatively impact the performance of the bed monitor. Stove alerts were deactivated early in the study, as the temperature threshold was set too low, which caused many false alerts. There were also a few false "possible fall" alerts generated. Software customizations of the alert rules were necessary to adjust for unique layouts of some participants' homes that caused these false alerts. Thus, alerting sub-system development will have to be iterative and continuous in order to reduce false alerts, reduce the detection time, and improve the detection rate. The performance of the floor-vibration based fall detector has recently been enhanced [13] and the improved version will be integrated into the system for future field trials.

IV. Conclusions

This study indicated that the use of passive health status monitoring could result in a statistically significant improvement in the perceived quality of life of the monitored older adults. This improvement can be attributed to better quality of care, due to the availability of wellness reports to caregivers in general, and professional caregivers in particular, and/or to increased sense of security.

Moreover, there was an appreciable decrease in the number of both physically and combined physically and mentally unhealthy days after monitoring, which is another indicator of potential improvement in the quality of home health care as a result of using the monitoring technology. Although this decrease was not statistically significant, it showed an encouraging trend indicating that the integration of the monitoring system's data in the care planning and delivery process may result in reducing the number of unhealthy days for the monitored older adults. Statistical significance may be attained by a larger sample size and/or a longer pilot.

Additionally, there was a statistically significant decrease in Caregiver Strain Index for informal caregivers of monitored individuals, indicating that the use of the technology may have reduced the informal caregivers' strain levels.

Qualitative assessment of the system's utility in a home health setting by the staff indicated that the system's data reports, including the bed sensor's data, could be useful in care coordination, care planning and could help in the early detection of health issues resulting from changes and/or anomalies in the data collected by the system. Reports may allow health care providers to initiate appropriate and timely interventions that might not seem appropriate or necessary in absence of monitoring data.

Emergency alerts require careful refinement to reduce the rate of false alerts.

In summary, the noninvasive health status monitoring technologies, presented here and piloted in this outcome study, could provide effective care coordination tools that have a positive impact on the perceived quality of life of monitored individuals, as well as the strain levels of their informal caregivers, and may have a positive impact on the participants' health related quality of life.

Acknowledgment

We would like to thank the Lutheran Evangelical Good Samaritan Society, their home health staff, the home health participants, and the informal caregivers who participated in this study. We acknowledge Bill Holman for helping setup and remotely maintaining the systems. This research was conducted under a research license agreement of US Patents 5,629,215 and 6,108,685.

References

[1] BG Celler, NH Lovell, DK Chan. The Potential Impact of Home Telecare on Clinical Practice. *MJA*. 1999; 171:518-521

[2] I Korhonen, J Parkka, M Van Gils. Health Monitoring in the Home of the Future- Infrastructure and Usage Models for Wearable Sensors that Measure Health Data in the Daily Environment of the Users. *IEEE Engineering in Medicine and Biology Magazine*. May/June 2003; 22(3):66-73.

[3] BG Celler, W Earnshaw, ED Ilsar, et al. Remote Monitoring of Health Status of the Elderly at Home: A Multidisciplinary Project on Aging at the University of South Walse. *International Journal on Biomedical Computing*. 1995; 40:147-155.

[4] AP Glascock, DM Kutzik. Behavioral Telemedicine: A New Approach to the Continuous Nonintrusive Monitoring of Activities of Daily Living. *Telemedicine Journal*. 2000; 6(3):33-44.

[5] T Barger, D Brown, M Alwan. Health Status Monitoring Through Analysis of Behavioral Patterns. *IEEE Trans. on Systems, Man and Cybernetics (Part A: Systems and Humans)*, 2005; Vol. 35, No. 1, pp 22-27.

[6] M Alwan, J Leachtenauer, S Dalal, et al. Validation of Rule-Based Inference of Selected Independent ADLs. Accepted for publication in the *Journal of Telemedicine and E-Health*, Oct. 2005, Vol. 11, No. 5: 594-599.

[7] M Alwan, S Dalal, D Mack, S Kell, B Turner, J Leachtenauer, R Felder. Impact of Monitoring Technology in Assisted Living: Outcome Pilot. Accepted for publication in the *IEEE Transaction on Information Technology in BioMedicine*.

[8] E Diener, R Emmons, J Larsen, et al. The Satisfaction with Life Scale. *Journal of Personality Assessment*. 1985; 49(1): 71-75.

[9] http://www.cdc.gov/hrqol/hrqol14_measure.htm, last accessed on Dec. 20th 2005.

[10] BC Robinson. Validation of a Caregiver Strain Index. *Journal of Gerontology*. 1983; 38:344-348.

[11] SH Zarit, NK Orr, JM Zarit. The hidden Victims of Alzheimer's Disease: Families Under Stress. 1985; New York: New York University Press.

[12] M. Alwan, S. Dalal, S. Kell, R. Felder. Derivation of Basic Human Gait Characteristics from Floor Vibrations. 2003 Summer Bioengineering Conference, June 25-29, Sonesta Beach Resort in Key Biscayne, Florida.

[13] P. Rajendran, M. Alwan, S. Kell, et al. A Passive Floor-Vibration Based Fall Detector, Accepted in the International Conference on Aging, Disability and Independence, to be held in Florida Feb. 2006.