AT EASE: Automated Technology for Elder Assessment, Safety, and Environmental monitoring

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D.F. Mahoney, E.L. Mahoney, E. Liss. AT EASE: Automated Technology for Elder Assessment, Safety, and Environmental monitoring. Gerontechnology 2009; 8(1):11-25; doi 10.4017/gt.2009.08.01.003.00. **Background**: Independent Living Residences (ILRs) for elders are becoming a popular and less expensive option than assisted living facilities. ILRs, however, operate with minimal professional staffing and new ways are needed to provide oversight of increasingly frail and/or confused elders who live alone. **Objective**: To gain an understanding of the elders, families and staff concerns in ILRs and to investigate whether remote residential monitoring, using off-the-shelf wireless sensors, might address these concerns. **Methods**: Mixed methods approach. Phase 1 qualitative research involved eight sets of focus groups comprised of either elderly residents from ILRs, relatives of residents, building managers and superintendents, or affiliated nurse practitioners (NPs) providing residential services. Phase 2 implementation built the system in response to end users input. Detailed testing of signal reliability and validity occurred. Phase 3 involved an 18 month implementation period with 10 sets of end users using the system for at least 4 months each. End user sets –residents, family members, building staff and nurse practitioners were assessed pre and post implementations. **Results**: Across the end user subgroups concerns varied but they all shared in common worries about the safety and well-being of the residents. Specific memory related issues included medications, meals, and shutting off the toilet/bath water. The Automated Technology for Elder Assessment, Safety and Environment (AT EASE) remote home monitoring system was developed to uniquely tailor the type of sensor and activities monitored to the individual's particular concern(s). Initial reliability trials uncovered severe signal interference for the X10 based wireless sensor system. This resulted in a redesign and successful deployment of a Zigbee based system. Moreover for the first time alert information was triaged to multiple parties, authorized as recipients, and occurred without any data security breaches. For example, only the building superintendent would receive the toilet overflow alert, the family member the missed meal or medication alert and the nurse practitioner when several medications were missed. **Conclusions**: Multiple safety and well being concerns arose that could be addressed through sensor based residential monitoring but most residents underestimated their personal vulnerability. Key to acceptance was the residents' perceived need and usefulness of the system to maintain independence and prevent being relocated to a more restrictive environment. Families found the system easy to use and were very satisfied. Building staff highly valued the water overflow alerts and having an additional means to oversee residents' safety that did not increase their workload. NPs were non-adopters (feared information overload) favoring personal interaction with residents to medication compliance monitoring. End users favored passive alert notices (over proactively monitoring the website for residents' status), that were few in number, and valid. They did not want to monitor the monitoring data and believed that accurate alerting was critical and achieved.

Keywords: telehealth, Zigbee wireless technology, senior housing, smart home

By 2030 the number of Americans aged 65 and older will more than double to 71.5 million or approximately 20% of the U.S. population[1]. Between 2007 and 2015, Americans' 85 years and older, those considered most at risk for chronic and acute care health problems, will increase by 40%[2]. Although vulnerable, research has consistently shown that older adults in America overwhelmingly prefer to remain living in their home and age-in-place as independently as possible. Homes are modified to promote self sufficiency and if this is not feasible elders then seek non-institutional residences with home like environments that enable them to maintain their daily activities.

Given the increasing number of older adults now seeking supportive housing, the market responded by offering innovations in elderly housing. Over two decades ago, US major hotel corporations (Hyatt & Marriott) were early entrants into this market, applying their hospitality model to residences for older consumers[3]. Facilities were designed with private residences and accoutrements such as formal dining in restaurant-like settings to clearly distinguish them from institutional models. As residents aged in place these facilities were unable to accommodate personal care needs. Thereafter the boom in assisted living (AL) facilities developed. The assisted living model embraces several key components, namely: personal privacy providing both private bedroom units with small living spaces and larger public spaces for socialization and shared meals and offers elders choice and control over their daily routines with specialized services to help maintain elder functioning. There has been explosive growth in this market and currently there are 39,500 AL facilities serving 900,000 residents in the US[2]. For comprehensive coverage of AL's evolution and contemporary critical issues the reader is referred to two special reports in the literature[4,5]. The latest type of elder housing to evolve is Independent Living Residences (ILRs). ILRs offer elders a more economical way to live in a senior apartment facility than AL. They accomplish this by not only eliminating an entrance fee, but also by limiting the services, not providing seven day a week professional staff for twenty four hours a day and relying on the elders to perform their activities of daily living or manage with help from their families and friends. However, helping elders remain independent in the setting of their choice is a complex, multifactor endeavor[6]. Anecdotal evidence is growing that elders may appear intact during ILRs pre-admission interviews but upon relocation become confused. Others as they age-in-place are at risk for physical as well as cognitive impairments. Given the limited staffing in ILRs, monitoring technologies may offer a means to oversee residents' safety, but research is critically needed to inform application development.

Previously this research team conducted the first USA trials that successfully proved the feasibility of using a completely wireless remote elder monitoring system in 'the real world' that encompassed a variety of private residential housing designs across New England over a two year period[7,8]. The WIN system integrated X10 motion sensor readings with cellular communications to link via the Internet to the project's Web server wherein customized software algorithms directed the monitoring aspects and posted reports on the Website. Password approved caregivers could log on to proactively see and/or passively receive informational notices via their cell phone, or computer. The X10 sensors were readily available at a low retail cost but they did require careful placement away from magnetic electric fields to ensure valid signal transmission. Unknown but of research and practical interest was whether this system could adapt to the needs of elders in ILRs and function reliably in that environment. We approached the ILR research in three phases, each guided by a research question:

Phase 1: What types of concerns do residents, their families, and staff have in ILRs that might be addressed by our monitoring approach?

Phase 2: Would the density and electrical complexity of the ILRs environment generate too much signal interference for the X10 sensors?
Phase 3: Could we adapt our system to tailor to the concerns expressed by multiple types of end users, manage huge volumes of system data generated from 18 months of around the clock postings without security breaks, posting problems and invalid alert notices?

ILR housing sites for research

The research occurred at three ILRs for people age sixty and over residing in Massachusetts, USA. The facilities were all high rise apartment buildings, each offering elevator access to over three hundred predominantly one bedroom rental units at an average cost of US$1,200/mo for qualified low income elders to US$1,960/mo market rate. If two meals per day were included, the cost would increase an additional US$450/mo. Each apartment building offered a day-time receptionist, activity staff, maintenance staff, building manager, part-time nurse practitioners for wellness management consults and part-time social workers for counseling. In the evening and weekends, an on-call building superintendent covered the three buildings and was the only staff person routinely available. Optional housekeeping and personal care services were available at an additional cost. The buildings were owned and operated by the same non-profit organization that maintained an excellent reputation in the region for elder long term care and their facilities were chosen as exemplars. The research protocol was submitted both to the investigators' Institutional Review Board for human subject study as well as the housing sites' research review committee and received dual approval before study commencement.

Phase 1-3 methods and results

Phase 1: Concerns and monitoring needs

We used qualitative focus group methodology with content and thematic analysis as our approach. Bandura's theory of perceived self-efficacy provided the conceptual framework for the research by directing attention to the key stakeholders' understanding of independent living and behavioral responses necessary to maintain elder independence[9]. The analysis used a grounded theory approach, an inductive analytic method that is guided by broad research questions designed to stimulate discussion among the focus group participants[10].

Focus groups

In total 26 participants were enrolled: 13 residents of ILRs, 4 family members, and 9 staff members. Overall, the average age of the residents was 79, the majority was female, widowed, and moved to the ILRs within the last two years to be near family. The majority of the staff was middle aged and female except for the 3 building superintendents who were males in their early thirties. Family members included two adult children, a brother, and a niece. Each of the subgroups was interviewed in separate group sessions that were audio-taped. On average the sessions lasted approximately 1.5 hours and were conducted in 2005. Participants received a US$20 honorarium. Subsequently, the moderator entered the transcribed data into a computer assisted qualitative analytic program, WinMax-95. This program facilitates standardized implementation of qualitative analytic practices and systematic analysis. Investigators searched for relationships between categories and developed concepts. Findings related to the tensions that arise from differing expectations and interpretations of the meaning of independent living among the elders, families, and staff are presented elsewhere[11].

Technology related findings are reported here and include staff requests for ways to help new residents' transition into ILRs, mitigate their confusion or provide continued oversight if confusion persists. They also expressed concerns about residents who aged in place and became increasingly confused over time. From analyses of their concerns and insights into residents' patterns of confusion a Timing of Technology

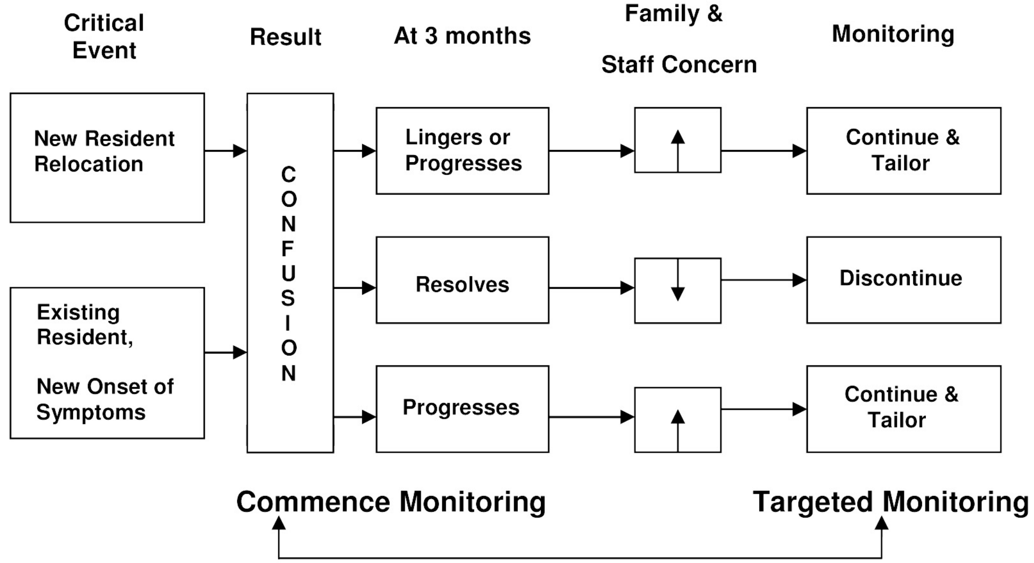

Figure 1. Timing for technology in a cognitive concern model; ©D. Mahoney, 2007 reprinted with permission

Model emerged that offers guidance to the most advantageous implementation of monitoring technology for new and confused residents (*Figure 1*). The three month point arose as the pivotal time to reassess 'confusion' to determine whether it was a resolvable confusion or a progressive state in need of monitoring. This model offers owners of residential complexes a pro-active means of responding to residents with confusion and can serve to stimulate the market for this technology.

Residents had more difficulty envisioning personal usages for the monitoring technology but all could identify frail neighbors whom they felt needed it. Families expressed the desire for the technology to let them know their family member was 'ok' when they wanted to know it without being 'spammed' or bothered by non-essential messaging. At the end of the session, participants viewed the system prototype and provided positive feedback on the human factors aspects and report elements, and affirmed its user friendly aspects. We have learned to readily build off our accumulating knowledge of geriatric user friendly design from previous evaluations. However, this application was the first to triage messaging across multiple types of participants and we needed to gain insights into the participants' preferences for communication and design accordingly. Message alert preferences varied with families favoring cell phone messages, administrative staff preferring e-mail messaging, and building superintendents requiring paging notification.

Phase 2: Architecture, reliability & validity

The WIN system had already been designed to address the major concerns from Phase 1 involving elder activity and event oversight such as medication timing. The only concern that arose from the focus groups that we did not yet have was the capability to monitor toilet overflows. Building superintendents reported that elders were not used to the low flow (1.3L) toilets and overflows occurred commonly at a rate of 2-3 per month and at a cost from US$8,000 to US$12,000, depending on floor, subfloor, and damage to the ceiling below. We tested several models and finally were able to obtain a water sensor that was interoperable with our system.

In prior research we had found that complex regimens such as taking multiple pills at multiple times were an issue. We had managed that in WIN by using a box we retrofitted to hold multiple sensors linked to sections each holding a different medication. In this project we piloted medication taking using a video camera to record the event and linked it to the end users' website so an authorized caregiver or nurse could view the actual medication taking or retrospectively check it when convenient. The data load and storage for this streaming media was so high during our 5 minute, 3 minute, and 2 minute testing periods that it was only feasible to tape for 1 minute. This did not guarantee that we would capture the actual swallowing of the medication, the activity we were most interested in viewing. Therefore, we deferred further video camera work until advances in video technology and cost reductions make it more practical.

Our prototype was pilot tested in our research office, located in one of the senior residences. We then conducted a second series of testing in a vacant apartment to ensure that the unit would perform accurately in the 'real world'. Motion sensors were placed in each room and the hallway. We established a 'pass criterion' of 100%, for 1 week wherein we triggered and tracked each sensor and its reports multiple times to ensure signal validity and reliability. The first three days of sensor monitoring demonstrated report congruence with our movement. Day 4 showed unexpected sensor signals in the bedroom. Day 5 we conducted a controlled movement study, dual observing both our staff member and the sensor recordings. Not only was the staff members' movement noted but also several extraneous signals were again noted from the bedroom. Our computer programmer ran a signal diagnostic program for 24 hours and the printout revealed 149 competing X10 signals! Further investigation found that signals were being emitted from the buildings heat and ventilation systems, wireless telephones and microwave ovens.

Consequently we determined that our X10 wireless system would not be feasible for use in this senior housing complex. We were able to connect with a new vendor who developed the first Zigbee based commercial remote home monitoring system in the US. Zigbee is a wireless network protocol in compliance with IEEE 802.15.4 specifications that optimizes low cost, long battery life, reliable, and secure connections between devices. Unfortunately the commercial system did not allow the degree of tailoring that we needed nor could it import our customized software and algorithms. Consequently our programmer had to write new coding to configure this system which then required debugging. We also tested the hardware capabilities such as the battery life of the new lithium battery powered sensors and the radius of their signals to prevent overlap and dead areas. We installed the Zigbee based test unit and repeated our validity and reliability testing with 100% success; no signal interference from any source. We subsequently converted and deployed the remainder of our systems using this platform.

Final system technology

The monitoring system consisted of motion sensors in each room, an additional water sensor in the bathroom, a system remote to enable/disable the system, a processing unit (with both Ethernet and Modem Network Internet Connections (NICs), a Zigbee computer interface and custom automation software application to operate the processing unit. Additional sensors available but not desired by participants in this setting included contact sensors for doors, pressure sensors for beds and chairs, and appliance on/off sensors. Each sensor was mounted via a special non-damaging strip of removable adhesive, activated by movement and wirelessly transmitted its signal to a base unit connected to a Personal Computer (PC). Time delay between motion events was set at 2 minutes. Motion data was sent to the project server via the Internet every 15 minutes starting at the top of the hour with alerts sent immediately. These parameters were chosen based on prior experience, system data management capacity, and battery life. The server processed and posted the data to our Website reports. The water sensor consisted of a disc attached to the bathroom floor and hard wired to a wireless sensor placed on the side of the vanity. This sensor only transmitted if there was a water overflow event. The system (resident) status, based on level of activity registered, was coded as: disabled intentionally = yellow, OK = green, watch = orange, and attention = red. Algorithms tailored to the participants' concerns and residents functional health status directed whether and when a red posting would be converted into an alert notice and to whom it would be sent.

Our system utilized remote embedded PCs, off-the-shelf automation components, broadband Internet service, Windows XP/2000 server application and a web based application with secured access for case management of the home monitoring systems (*Figure 2*). Our service application received incoming alert information from residences, updated the Structured Query Language (SQL) database with alert information, sent priority alerts to appropriate personnel or family members through pagers and emails, downloaded new configuration parameters of the systems and exported reports and data to research staff. The Application Service Provider (ASP) web site provided a secure interface to family members and research personnel and provided a configuration screen to manage the residential monitoring systems. Secure access to the application was available 24 hours a day and 7 days a week over the Internet to valid system users, and was easily accessed using the Web Browser. The AT-EASE system baseline functionality was derived from the WIN system hardware and software. However, it shifted from centralized processing performed on the server down to Central Processing Units (CPUs) located in the residence. This move to distributed processing minimized the bandwidth requirements for the Internet connection between residence and the service provider.

Embedded window application
This residential automation processor is a dedicated program operating on the embedded PC which operates as an automation controller within the resident's home. This module was configurable and allowed the service running on the server to push down new configuration and alert schedules. This module performed all logic and timing associated with the motion and water sensors. After determining that an alert was required the embedded application pushed up the alert notification to the server. The embedded application also performed system diagnostics and sent system status messages at set intervals. This module allowed a broadband connection to the Internet.

Database application
This application consisted of security/system login tables, alert/notification tables and residential system/configuration tables.

Web interface application
This web application was client accessible through web browsers. The application was served through a secure HTTPS protocol and had a Health Insurance Portability and Accountability Act of 1996 (HIPAA) compliant login structure. The security structure provided the appropriate pages and controls to the user after login. The application had an automatic and manual logout feature and was the main user interface for the system and supported all the operator roles of the system.

Phase 3: AT EASE intervention methods
Participants and study protocol
In Phase 3 we conducted a pilot intervention study to test system operations using the Independent Living setting and the AT EASE technology described previously. Residents and family members were recruited by posters, presentations, and notices in their mail about the study. In addition, the staff identified 20 residents with safety and health concerns; and although they recommended the project to them, 13 refused to consider participation. The clinical staff reported that the residents they knew had dementia were in this group, which raises the possibility that the families and/or residents did not want

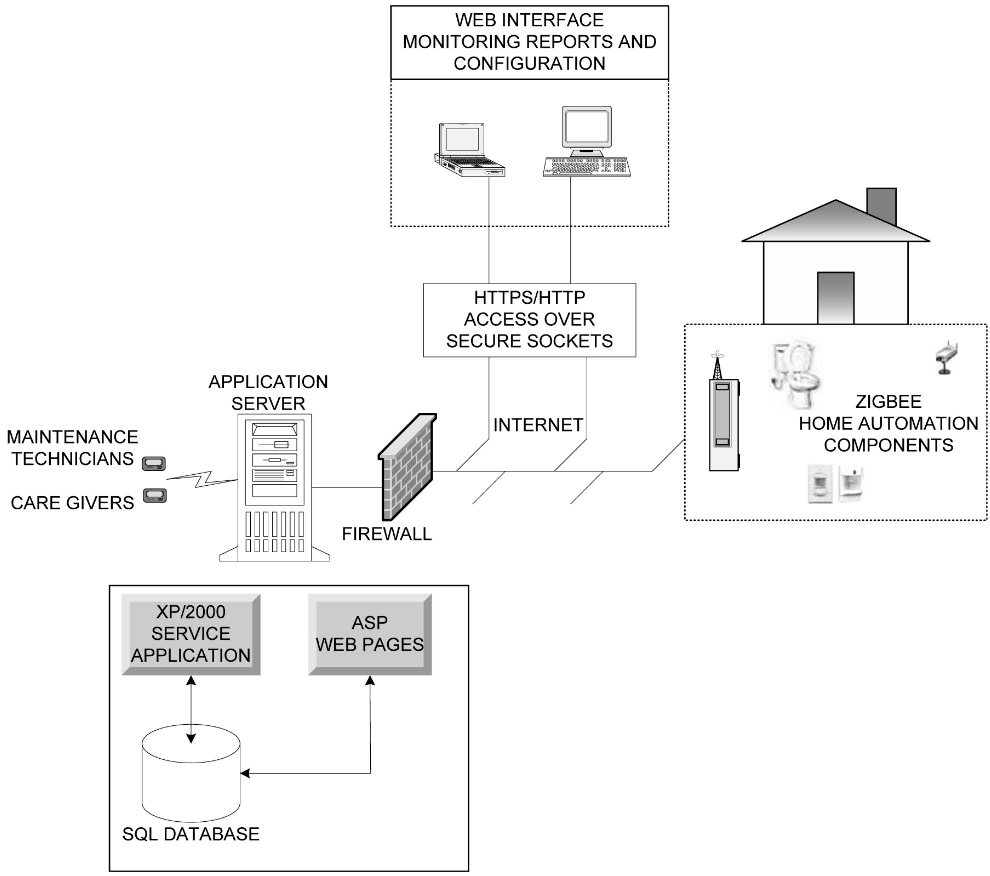

Figure 2. AT-EASE system architecture; ©D. Mahoney reprinted with permission

a monitoring intervention out of fear of being identified as impaired and not suitable for independent living. The project director telephoned elders and family members who signed our contact permission sheet and assessed their eligibility. Participants were eligible if they were residents, family members of residents, or staff in the ILRs. Because of potentially recruiting residents with dementia, related ethical issues were addressed[12]. We used Callahan's et al validated Six-Item screening tool to identify residents with cognitive impairment and thus unable to consent[13]. Two residents failed the screening and their legal guardians provided consent while the elders gave their assent. Subsequently the project director made an appointment for a home visit to re-explain the study and obtain written consents, administer the baseline interview, customize the installation, and train the family member. Staff were consented and trained separately.

Eleven resident-family member dyads were enrolled and ten completed the study. One dyad dropped out due to aggravation over several aborted cable modem installations by an outside vendor. Among the ten participating dyads, there was no attrition over the course of the study.

Measures and analyses

Baseline measures included socio-demographic characteristics of the residents and family members. Measures of elders' emotional, physical health, and activity levels were collected pre and post intervention. Technology related outcomes included system recordings of end user usage by feature accessed. Alert validity was determined by the project director checking each alert with the targeted end user to discern accuracy and relevance. All end users were asked (yes/no) whether the system addressed their need(s), was intrusive, substituted for staff, and rated on a 5 point scale (from 1 low, to 5 high), how satisfied they were with the technology and the helpfulness of the technology training. In addition elders were asked if it made them feel secure using a similar rating scale. Family members also rated their level of security and their worry/concern level about their relative on a 1-5 scale. In addition, family members were asked post intervention about their willingness to pay for the technology using four different price point scenarios. Staff was queried about their level of satisfaction and perception of this technology increasing their workload (yes/no). Quantitative analyses were limited by the small sample size to descriptive reporting. Open ended comments about system impressions are reported verbatim.

AT EASE INTERVENTION RESULTS

Sample characteristics

Overall there were 29 participants, 10 residents, 10 family members and 9 staff members. Of the 10 participating residents, six were female, all were Caucasian, their mean age was 83 (range 70-91), and they were predominantly widows (n=7) who all lived alone (n=10). They averaged 14 years of education and the majority (n=7) rated their current physical health only as fair, the remainder as good. Psychologically the vast majority (n=9) rated their emotional health as very good or good. When asked about their health and safety concerns all rated them as important to very important to them. Overwhelmingly (n=10) the primary reason for relocating to these premises was to be near family after loss of spouse.

Similarly, of the 10 family caregivers the majority (n=6) were female and all were Caucasian. However, their mean age was 56 (range 40-76) and they were predominantly married (n=8).They averaged 17 yrs of education, all being college graduates, one with a Master's degree and two held doctorates. The majority were employed (n=9), in very good to excellent health (n=10), but less expressed very good to excellent emotional health (n=7). They were primarily the adult children of the resident (n=6) or another blood relative (n=4). They viewed the residents' physical health as good (n=5), fair (n=4) or poor (n=1), which was lower than the residents' self assessment. Similarly they rated the residents' emotional health lower than did the residents with only three rating it as fair. The vast majority (n=9) felt it was likely to possible that their relative would experience a serious illness or accident within the next year. Getting out of bed, moving about the house safely and taking medications were their prime concerns. No one reported concerns about bathroom safety or meal preparation. They spent, on average, half an hour a day checking in on their relative by telephone or email. All reported being highly skilled with computers. The need for in person visits ranged widely from none to 90 minutes per day.

Of the ten family members half (n=5) participated in the hands on twenty minute training given at installation by the project director (PD) in their relative's apartment and rated it as very helpful. Four preferred a telephone training session with the PD consisting of an explanation of the user log-on, navigation and review of the sensor information pages while on-line at their home or work computers. Everyone rated the training time period as about right. The majority (n=8) rated the system as being very easy to learn, with one noting it as easy and the one remaining family member who had refused training reporting it as just ok (n=1). None took advantage of the helpline available during the course of project but they rated it as helpful to offer but not necessary because navigation was so intuitive.

Usage

Six systems were used over the course of the 18 month field period that included testing and then implementation. Five of these systems were rotated among the 10 participants, each of whom had a system for at least a four month period. The sixth system was used continuously over the 18 months for testing and monitoring system operations. Each system recorded data from four motion sensors placed in the residence according to desired monitoring activities. Motion data was sent to the project server every 15 minutes, starting at the top of the hour. All activities picked up by the sensors were recorded by the system (*Table 1*). Expected variation across resident activity levels occurred, however the systems were consistent and accurate within each residence: no 'wild fluctuations' were noted in motion detection within or across days throughout the intervention period. The systems with the highest average readings (Systems 2, 7 and 10) were located in residences with frequent regular visitors, who added motion picked-up by the sensors. And, the resident using System 6 had to be transferred to a nursing home, reducing the total number of days this elder could be monitored at home. System 7 was down for approximately 28 days, thus all of that system's data for the time period were dropped for analysis. Sensors were also available to monitor medication usage, but surprisingly none of the 10 residents or their caregivers chose to have this activity monitored. However, the use (opening/closing) of a medication drawer was tested at one residence (System 4) using a contact sensor for approximately 100 days of the intervention, successfully recording an average of 7 events per day.

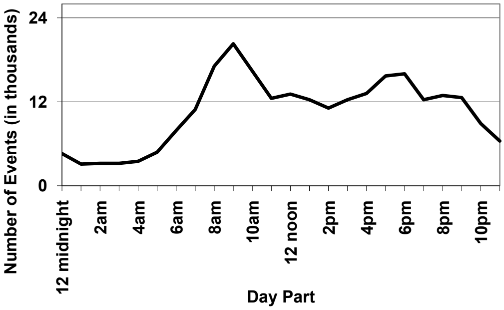

Figure 3. Number of events (in thousands) across 24-hr parts

The AT-EASE web site enabled caregivers to log-in (to a secure and password-protected page) to check the status of their family-member's sensors/activity and patient records. In a post-intervention interview, caregivers said they did not log into the system very often. Half (n=5) reported visiting the site less than once or twice a week. One caregiver reported daily use of the website, but others logged in less often (3-4 times a week, n=2; 1-2 times a week, n=2). System session records (*Table 2*) confirm these reports, showing most caregivers did not log in very often. Session records show that two caregivers did not log-in at all, while five others logged-in fewer than 10 times across the four-month intervention. Three caregivers (using Systems 4, 9 and 2) logged in most frequently. Virtually each time a caregiver logged in, they clicked on the Activity View and/or the Patient Summary pages.

*Table 1. Average number of events per day by system; *= system down or sensor intentionally disabled*

Events	**System #**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Residence average/day	160	298	173	146	146	221	279	160	186	288
Bathroom	12	40	72	26	16	7	14	22	29	49
Bedroom	54	122	24	43	56	50	105	60	23	46
Kitchen	52	80	50	34	3	89	24	22	47	67
Living room	42	56	27	43	71	75	136	56	87	126
Total days of intervention	156	176	178	169	130	86	163	123	126	112
Days monitored	133	145	158	146	130	86	120	120	124	110
Days off line*	23	31	20	23	0	0	43	3	2	2

Table 2. Caregiver log-ins to AT-EASE site and number of days viewed with marked motion sensor report

System	Total Log-ins	# of Days	Description of log-ins
1	9	0	6 days in November
2	42	16	24 days November through March; reduction from once every couple of days down to once a week; only once in February
3	6	0	In November, once in December; none in the following months
4	120	63	Almost daily in November, every 2 days in December; almost daily in January, every other day in February; once in April. Caregiver loved system - her husband was hospitalized with brain aneurism, she drove her 3 children to school; would check on resident with PDA during wait time. She was out straight, couldn't get in to visit and felt bad because she was aunt's only living relative
5	4	0	3 days in February
6	2	0	Twice in March
7	0	0	Caregiver lived only 2 blocks away and visited resident almost daily; took him to adult day-care 3 times/week. She was single mother with 2 kids in school and worked as Real Estate Broker (no time to use system)
8	3	0	3 log-ins in June across 2 days
9	20	18	7-8 times in June and July; 3 times in August, once in September
10	0	0	-

The graph in Figure 3 shows the total number of motion events captured by the AT-EASE system (for the ten residents in the study) across hour parts (one hour each across 24 hours). As an illustration of the system's accuracy, the linear pattern of the graph follows closely what one might expect across a typical day, with little activity in the early morning hours, a steady increase from 6:00am through 10:00am, a slight tapering around lunchtime, and a plateau in the afternoon hours. We see a slight increase in activity around dinnertime (5:00-7:00pm) and then a steady drop in action as residents head into bedtime.

Alert postings and accuracy

As Table 3 indicates the system tracks and posts on the Internet both status indicators and alerts. We found that about one-third (33%) of the postings indicated that everything was as expected or ´OK´, half (52%) triggered a watch state but only a minority (16%) proceeded to the attention level which indicated an area of concern arose and was being monitored for progress to an alert. As indicated on the table, for our ten residents, each of whom was monitored for four months, 5,304 postings were generated. The triggered alert notices sent to the caregivers however, were only 189, primarily generated by a global no activity by the resident alert (n=50). We analyzed each of the alerts to determine whether they were spurious (0%) in error (0%) or true (100%). True alerts reflected an accurate reason for the trigger primarily low activity due to oversleeping, or forgetfulness to shut the system off when hospitalized or away with family. In addition three of the ten systems issued a water alert, one each for: System 3 (sink), System 9 (toilet) and System 7. This last water alert detected water on the floor but the water came from a toilet overflow in the non-monitored apartment above. This was the second instance this participant experienced the neighbor's overflow and it necessitated relocation to allow for extensive renovations. Water alerts went directly to the building manager/superintendent.

System effects per subgroup
Residents reported no change post intervention on their assessments of whether the system addressed their needs (yes), was intrusive (no), or would substitute for staff (no). Unexpectedly, there was a categorical drop from a pre-intervention of 'strongly agree' to post intervention 'somewhat agree' that using the system made them feel more secure. The data show that the participants had positive expectations, which is probably why they enrolled, and while the intervention met some it could not meet all of their security needs because we had no visual component to see if they were in need of assistance.

Family members reported a slight worsening of their relatives' health, a significantly different worsening of their emotional health, and a slight increase in their level of concern at post interview. The time needed to check on their relative however decreased slightly. And the major focus group issue of family concern – whether their family member was OK – moving about the house safely dropped from a pre-concern worry rate of 50% to 20% post intervention. Of note, while there were no changes from the pre-intervention ratings of the system addressing their needs (yes), being intrusive (no) or would substitute for staff (no), within group changes did occur. One respondent was more negative post intervention while the others remained the same or rated more positively. This respondent became the outlier in the usage analyses, reporting no worry about mother's safety, too busy to use the system, and trouble navigating the pages; notably this respondent had declined any training and never used the help line. Interestingly, family members' level of security associated with system usage did not significantly change but their reporting of whether the system made their relative feel more secure did drop from somewhat agree to somewhat disagree post intervention similar to the resident's response. Open ended responses indicated that family members also desired to be able to see if the 'no activity' alert was due to sitting or sleeping too long or an injurious fall. Family members usage varied widely ranging from one who checked daily, two who checked 3-4 times per week, two 1-2 times per week and five less often. Only the one caregiver mentioned above reported any difficulty in performing the program tasks. The remaining nine reported it was easy to connect to the report page, read it, view details and log out. Only two had changed the report and alert times and also reported that easy to do; the remainder did not use this function. Open ended queries about unasked problems revealed that the server went down occasionally and that then one couldn't see the day's activities on the screen, and that sometimes there was difficulty in going form the Home page to the Activity page. The former was known to us, the latter was not. Caregivers, although they had the Project Director's contact information, never reported this problem. In terms of alerts, a small minority of (n=2) chose not to receive any. The remainder chose to receive them by e-mail notice, and all reported that the number was just about right and were helpful.

Program satisfaction
Family members (n=6) who reported a good to very high match with their relatives health or safety needs correspondingly found AT EASE very useful. Those reporting it was somewhat (n=1) to not very useful (n=2) did not see a match to their particular needs. "X was hospitalized and when he came home he had to have a homemaker who was in the apartment almost full time so his daughter did not use system very often after that". "Health care worker [there now] every morning (bathing and dressing)".

Overall, the majority (n=6) would recommend AT EASE to other elders, the remainder felt it depends on the situation. Open ended comments are reported in entirety add further insight. Each quote represents a different participant and they are classified in three categories of impressions:
(i) On the positive side: "Alert was very helpful". "Great to help elders stay in Independent Living in their own apartment longer".

Table 3. Detailed breakdown of total postings by system

System	Number of postings: OK	Watch	Attention	Totals	Emails to caregiver	No activity alert	Description	Elder situation
1	236	216	75	527	6	1	6 red alerts on one day, sensors read about half the number of motion events as compared to other days, especially in bathroom	1 day in hospital
2	80	410	105	595	3	1	Motion sensor readings average; 3 red alerts on one day, 3 days after trigger	At relative's home
3	42	534	56	632	9	3	Readings were very low on the 2nd and 4th, no motion on the 3rd; red alert; 6 messages on the 1st day, followed by 1 and 2 on the following days; 1 water alert	Visited family for holidays
4	209	309	186	704	0	0	Per request, no emails were sent to caregivers	
5	151	274	95	520	0	0		
6	224	84	36	344	5	3	Reduced activity in kitchen and living room (1/3 of norm); 1 day triggered only, all emails sent that day	Overslept
7	311	154	79	544	70	12	No motion detected on noted days in April; red alert and 6 messages sent each day (Soon after the system was down for a number of days); Other notices in June across 6 days; Water damage from unit above (water alert); Couldn't get access to unit	Forgot to shut off ; moved to new unit after flood damage
8	98	372	22	492	10	4	No report registering on sensors; 2 days triggered; 6 emails sent same day as first trigger; 4 emails sent same day as second	2 days in hospital
9	200	136	160	496	50	20	Minimal activity being sensed across all rooms; red alert and emails sent (6 each day for 6 days, then 1 each day for 14 days); system then shut down at server until resident returned; 1 water alert	2 weeks in hospital, then rehabilitation; system not shut off
10	175	257	18	450	36	6	6 days with triggers; 6 emails sent same day of each; sensors did not record on September 17 and 18	Overslept and low activity
Tot.	1,726	2,746	832	5,304	189	50		
%	33	52	16					

"Least intrusive with biggest gain in knowledge". "Very helpful in providing oversight and felt more secure with system in place".

"Very satisfied with the program". "Very pleased – could log on from any location; very willing to pay US$60/mo or more to

continue with AT EASE". "Didn't log on very frequently but the one alert received was very helpful because brother had a serious incident and I was able to respond".
(ii) Neutral: "Useful in right circumstances". "Would like the system to include a tracking device because [resident] tends to wander at times".
(iii) Negative: "Not unless their relative had less mobility or in poorer health …or difficulty remembering or taking care of herself". "Would be better for someone without daily home health aide; no one to check on them regularly".

Half of the ten family members were willing to pay US$60 per month to use the AT EASE program, four at US$30 per month, and 1 did not answer. We also queried to see if there was interest in adding a camera feature and if they would pay additional for it. Fewer (n=4) agreed to do so at US$90 per month and four agreed at costs ranging between US$10-75 per month. Two did not reply. And finally we offered an enhanced system with interactive features and nurse oversight at US$130 per month. This received support by three family members, and greater interest (n=5) at US$100 per month.

All of the staff rated their concern for resident wellness and safety at a moderate level with the majority (n=6) rating the AT EASE system as high to very high in addressing their concerns. We queried to see if the alerts would be seen as adding work. Surprisingly, one respondent reported that the system reduced workload while the majority (n=8) noted no change. Using this technology as a substitute for staff was not of concern to any of the staff. Staff also rated the system as non-intrusive (n=6) or didn't know (n=4). The majority would recommend this system (n=8) with one maybe. Comments indicated the system was one more measure of security for residents that the staff had concerns about.

Discussion

The Timing for Technology Model reflects the findings from Phase 1 that not everyone wants or needs monitoring technology and its utility occurs at specific time points. Other researchers have noted an adaptive denial that makes some elder interventions difficult to accept[14]. The focus group findings indicated that a profile of the resident who would most benefit from home monitoring would be a recently relocated older adult and/or one with new onset cognitive impairment who exhibits forgetfulness, a proclivity to fall, not take their medications, and/or walk enough. Residents who indicate some type of vulnerability or at-risk situation that generates family or professional caregivers' concern also fit the profile. It is at that point that technology seems to become a favorable means to allow / prolong independent living.

Medication taking devices claim to boost compliance and allow elders to remain in their homes[15]. We found that although medication taking was an issue, the clinicians preferred to do a personal visit that not only encompassed the task of medication supervision but also allowed them to integrate a personal assessment of other factors influencing health and well-being. This is something technology cannot do at this time, capture the gestalt that a provider in a therapeutic long term relationship can assess and detect that something is wrong before biometric and/ or home monitoring detection. Moreover, the clinicians reported being overloaded by non-critical computer messaging and did not want to add another source of input despite our assurances of only critical medication event reporting. The water overflow issue, however, was uniquely addressed by the water sensor at a low cost and high convenience so that has been strongly endorsed by the building managers. A stand alone water sensor costs less than US$100 creating a very positive return on investment

Those most satisfied with home monitoring are end users who perceive a good fit with their needs and if it addresses their concerns. The majority of family and professional caregivers reported being very busy and preferred a passive role depending on system-generated alerts to notify them of variances. Consequently, the multiple formats and in-depth real time reporting features were generally underutilized and future costs may be lessened by not providing such details. Technologists tend to relay as much data as possible and caution is advised to know your end users preferences[16,17] and capacity especially with dementia[18]. Families expressed a willingness to pay but were sensitive to price and feature offerings.

AT EASE advanced the field by being the first study to implement stratified reporting of residents' functional health and well being data 24hours a day/7days a week to family, professional and non-professional caregivers. We were the first to formally study and report usage of the Zigbee wireless platform for remote home monitoring and the first to demonstrate the feasibility of incorporating water sensors into activity monitoring. Although not using personal health data, our approach collected resident activity data via the Internet, stored it and managed it over the Web with on-line reporting and e-mail notices that parsed different data securely to varying levels of authorizations and can serve as a model example to support secure exchanges of health applications. It should be noted that we also broke the commercial barrier of two hour data transmission time and report updating by lowering it to every 15 minutes, or essentially real time, critical to water overflow alerts.

As more and different types of monitoring devices become common, there will be increasing competition for power sources, telephone line usage and compatibility issues. In one resident's apartment our system wirelessly connected to the Internet but needed to maintain a power source while another system in the same apartment transmitted blood pressure readings via the telephone line and also needed to be plugged into a power source. The cleaning staff intermittently used the same electrical sources for their vacuuming. We identified a need to develop a method of remote system rebooting to reduce the need for on-site visits. And despite rhetoric of low power source demands, battery life remained problematic. Twelve month (expected life) lithium batteries were used based on expectations of at least six months of reliability. Yet, approximately 15% of motion sensor batteries did not last the full 4 month operational period.

Future research

Retrofitting the residences, having to get Internet installed by outside Internet Service Providers, conducting screening visits then visits to consent the participants all added another layer and degree of artificiality imposed by clinical research. How different would the situation be if the technology was already installed and supported by the housing facility in a situation where the residents' cognitive impairment was known and accepted? And when the field evolves to make it realistic and affordable, large scale evidence based outcome and cost effectiveness studies are needed to inform healthcare and housing policymakers.

Conclusion

ILR monitoring technologies need to be able to customize to the concerns of the key stakeholders in order to promote adoption and buy-in. Intervention data reveal that participants preferred easily accessible and readable reports, with passive observation and reporting. Users preferred few alert functions, and limited but significant alert notifications. They don't want to monitor the monitoring data and accurate alerting is critical. Overall we found that tailoring technologies to the resident and facility is feasible and recommended. We also demonstrated for the first time that stratified Internet based reporting targeted to multiple family and staff authorized end users was achievable while maintaining confidentiality and privacy. Given our trial TV monitoring, we recommend waiting until the technology has advanced in its broadband/Internet and viewing tracking capacity and lowers costs before it becomes practical enough for monitoring medication taking or specific tasks on a widespread basis. The problem of signal interference will only increase as more products go wireless. Vendors of wireless technologies should be asked to report on the sensitivity and specificity of their signals and related alerts. Testing in the "real world", in the situations the technology systems are designed to function in, was critical to detect and rectify wireless implementation problems, demonstrate validity, and practical utility.

Acknowledgment
This work was supported in part by the NIH National Institute of Nursing Research (NR009262), the Alzheimer's Association of America (ETAC 1023) and the Jacque Mohr Professorship in Geriatric Nursing Research. The authors wish to thank Brian Lisiewski and the participants for their facilitation of this research. A preliminary version of this research was presented in a poster session at the ISG08 June 2008 Pisa Italy meeting.

References

1. US Census Bureau. The older population in the United States: March 2000; www/census.gov/population/www/socdemo/age/ppl-147.html; retrieved May 9, 2008
2. American Association of Homes and Services for Aging (AAHSA); www.aahsa.org/aging; retrieved April 20, 2008
3. Wilson KB. Historical evolution of assisted living in the United States, 1979 to present. The Gerontologist 2007;47(III):8-22
4. Hughes S. Improving practice through research in and about Assisted Living: Implications for a research agenda. The Gerontologist, 2007;47(III):4-154
5. Commission on Affordable Health Facility Needs for Seniors in the 21st Century. A Quiet Crisis in America; June 28, 2008; http://govinfo.library.unt.edu/seniorscomission/pages/final_report/keydemo.html; retrieved October 17, 2008
6. Rantz M, Dorman K, Aud M, Tyrer H, Demeris G, Hussam AA. Technology and Nursing Collaboration to Help Older Adults Age in Place. Nursing Outlook 2005;53(1):40-45; doi 10.1016/j.physletb.2003.10.071
7. Mahoney DF. Linking home care and the workplace through innovative wireless technology: The worker interactive networking (WIN) project. Home Health Care Management & Practice 2004;16(5):417-428; doi 10.1177/1084822304264616
8. Mahoney DF, Mutschler P, Tarlow B, Liss E. Real world implementation lessons and outcomes from the worker interactive networking (WIN) project. Telemedicine and e-HEALTH 2008;14(3)224-234; doi10.1089/tmj.2007.0046
9. Bandura A. Self-efficacy: toward a unifying theory of behavioral change. Psychology Review 1977;84(2):191-215
10. Morgan D. Focus groups as qualitative research. Thousand Oaks: Sage; 1977
11. Mahoney D, Goc K. Concerns about vulnerable elders residing alone in Independent Living Facilities: Views of Elders, Families, Building Staff, and Nurse Practitioner Consultants. Journal of Housing and the Elderly 2009;23(3)
12. Mahoney D, Purtilo R, Webbe F, Alwan M, Bharucha A, Adlam T, Jimison H, Turner B, Becker A. In-home monitoring of persons with dementia: Ethical guidelines for technology research and development. Alzheimer's and Dementia 2007;3(3):217-226; doi 10.1016/j.jalz.2007.04.388
13. Callahan C, Unverzagt F, Hui S, Perkins A, Hendrie H. Six-item screener to identify cognitive impairment among potential subjects for clinical research. Medical Care 2002;40(9):771-781
14. Roberts S, Plowman T, Prendergast D. The Global Aging Experience Project Ethnographic Research 2006. Santa Clara: Intel Corporation; 2007
15. iHealthbeat. Medication compliance improved through use of tracking tools; March 20, 2008; www.ihealthbeat.org; retrieved March 25, 2008
16. Lee H, Kim Y, Jung JW, Park KH, Kim DJ, Bang B, Bien Z. A 24-hour health monitoring system in a smart house. Gerontechnology 2008;7(1):22-35; doi: 10.4017/gt.2008.07.01.003.00
17. Sixsmith AJ, Gibson G, Orpwood R, Torrington J. Developing a technology 'wish-list' to enhance the quality of life of people with dementia. Gerontechnology 2006;6(1):2-19; doi: 10.4017/gt.2007.06.01.002.00
18. Rahimi M, Vaughn-Cooke M. Information architecture for an Alzheimer's communication monitoring system (ACMS). Gerontechnology 2007;6(1):42-55; doi: 10.4017/gt.2007.06.01.006.00