The Escort System: A Safety Monitor for People Living with Alzheimer's Disease

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Abstract

People living with Alzheimers and related dementias walk aimlessly for a variety of reasons; unchecked anxiety, little else to do, and boredom. This behavior is labeled "wandering." We present a system to help caregivers ensure the safety of residents who wander in assisted living environments. The Escort™System uses Talking Lights® location-transmitting light beacons and a ZigBee® wireless network to monitor the presence of residents in potentially dangerous areas. When the system learns that the patient is in a potential danger area, it sends a pager- or cellphone-based alert to on-duty caregivers. An evaluation of this system at an operating care facility is presented.

1. Introduction

Walking around the living area is a common physical and emotional outlet for elderly people, whether they live alone, with family or in an assisted living community. In those with dementia, however, walking can become aimless, disoriented and dangerous [22]. Ensuring the safety of these individuals may require near-constant monitoring [21].

Sixty percent of people with Alzheimer's exhibit wandering behavior, and this behavior increases the likelihood of accidents, serious injury, and even death [16]. Wandering has been defined as occurring when anyone with decreased cognitive ability wanders (walks) away from supervised care [9]. Workers in the field differentiate non-goal and goal-directed wandering. In the former, the subject moves about aimlessly with no apparent goal while in the latter the subjects moves toward some type of goal[9].

The Alzheimer's Association estimates that approximately 5.2 million people have Alzheimer's disease and projects that, absent a cure, as many as 16 million people will suffer from it by the middle of the century [1]. Compared to other assays, the clinical identification of "wandering" is an excellent (78% accurate) predictor of fall risk [22]. Wandering is so prevalent [16] that it is of special interest to caregivers [21] and the healthcare organizations that employ them.

In this paper we present and evaluate the Escort™ System, designed to protect wander-prone residents from adverse events. Users wear mesh-networked badges transmitting location information obtained in real-time from a Talking Lights® (TL) optical location setup that uses ordinary light fixtures and other light sources as location beacons. A central server sends real time pager or cellphone Short Messaging Service (SMS) alerts when a user may be at risk, giving caregivers information to address a situation before an adverse event occurs. A trial with residents at a Hearthstone Alzheimer Care Treatment Residence is documented.

2. Related Work

The number of people over 60 years of age worldwide will double by 2050. Some new technologies can improve their quality of care while keeping costs stable [19, 17]. One type of technological assistance enables telemedicine by reading vital signs [11]. These systems are often costly, however, and can have disastrous failure modes [19].

Other technologies enable elderly and disabled people to continue living at home by providing cognitive assistance for everyday tasks or enabling the user to call for help when needed [17, 19, 10]. One proposed system [7] is reported to be cost effective. It requires no wiring and relies on community and family to respond to alerts. The primary interface is a user button, though an accelerometer can detect potential fall patterns. If the detected fall is a false alarm, the user must press a different button to cancel the alert. The need for buttons in addition to an accelerometer supports Mihailidis' assertion that most assistive devices require too much interaction and could use more context awareness [20].

In 2000, Altus et. al. reported an outdoor locator system with transmitter worn by the patient and a portable receiver used to search for the patient. Patient, family and caregiver evaluations are given[8]. ComfortZone, a more modern GPS based system for outdoor locating, is offered by the American Alzheimer Assn[2].

Beckwith discussed an indoor system with multiple sensors in a care facility and user badges which give location by sending IR back to room sensors. He also reviews concerns of privacy and user understanding of the technology[3]. Escort appears to give better resolution of location than Beckwith's system, makes use of existing building infrastructure and so should be lower cost and appears to have much simpler calculations to determine location. Kearns et. al. propose use of Ultra Wideband RFID (UWB RFID) to track dementia patients indoors[16]. Escort appears to be a much simpler system for location than Kearns' system. appears to be more straightforward to qualify and maintain and uses existing infrastructure. Other proposed real-time indoor locating systems include Wi-Fi triangulation and/or intensity mapping [6].

The Escort System is context-aware: that is, it uses knowledge of the physical environment. It does not presently read physiological signals or allow the user to manually call for help. Unlike our earlier studies, which concentrated on building a cognitive orthotic for patients [13, 5], this system creates a sensory adjunct for caregivers, enhancing their capacity to ensure safety of elderly users.

3. System Details

The Escort System features frequent communication of accurate location information in zones selected for alerts; a dependable, low-power wireless infrastructure to communicate location information back to a central server; and a text-capable device to alert caregivers (Figure 1). For location we use a modulated non-flickering illumination-based system provided by Talking Lights LLC. Users wear small badges with capability for location determination and automatic communication with the central server. For this communication we use ZigBee-compliant devices designed by Talking Lights LLC and based on modules obtained from Telegesis Ltd. For caregiver alerts we use commercial off-the-shelf (COTS) Word Messaging pagers from USAMobility Inc, and COTS cellphones with SMS capability. The

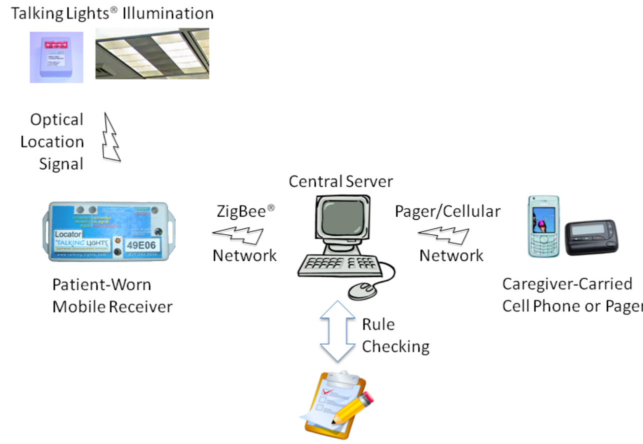

Figure 1. System Overview.

USA Mobility Inc. pagers required 90 -120 seconds or more from transmission to receipt of message. The cellphones typically received a message within 5-10 seconds of transmission. All work at Hearthstone was done with pagers because the cellphone system was not qualified until the Hearthstone work was complete.

3.1. TL Ballasts and Night Lights

Most methods of electromagnetic locating suffer from interference problems; optical methods can require expensive imaging [12]. A challenge of context-aware computing is noisy location data [19]. Since radio waves travel through physical objects [16], radio-based systems may identify two separate rooms as the same location. Ultrasound technology, which requires between 1 and 8 beacons to obtain an accurate fix, is a solution that may provide details about location and intervening obstacles [12].

Escort offers reliable optical location-aware technology using existing lighting infrastructure for beacons. Position information is received by a phototransistor and decoded with a low-cost circuit. We use one TL fixture in each alert location, with potentially seamless integration into existing illumination infrastructure. Each light, whether fluorescent or LED, transmits a unique location identification code.

TL ballasts modulate the drive frequency to transmit digital data through the light itself; a patented two-level Manchester coding scheme enables arbitrary data schemes without flickering [18]. Otherwise, the fluorescent light operates normally, with no visible flicker and no increase in energy consumption.

In other work, we found that multiple TL transmitters in a single room do not present problems [14] [15]. The TL receiver locks onto the nearest, strongest modulated signal. Density of transmitters used is dependent upon spatial resolution desired. We have outfitted buildings with fluorescent

Figure 2. TL Night Light: Location Beacon.

lights every 6-8 feet and observed no problems. The location data from Escort is observed to be accurate, reliable and not noisy. The modulated optical signal has been tested and observed not to cause interference with other systems.

Also in other as yet unpublished work, we demonstrated a system which uses GPS locating outdoors and TL technology indoors. This system can make a transparent transition from one locating technology to another as the user goes from outdoors to indoors or vice versa.

The study reported here was conducted at Hearthstone Alzheimer Care in Woburn, MA. Hearthstone avoids use of institutional lighting for resident comfort. Originally, we planned to use modulated compact fluorescent lights (CFL) for TL location transmitters. However, the funding and resources available for this project did not allow us to design, develop, qualify and obtain regulatory approval on modulated CFLs. Also, many areas with illumination, like patient rooms, must be dark at night. For these reasons we used LED-based TL Night Lights (Figure 2) in most locations. Night Lights are DC powered and modulated at a frequency identical to TL fluorescents. They emit a soft light 24 hours a day, with no reduction in signal strength. Night Lights can be powered by a battery or a plug-in adapter but for safety and reliability all Night Lights were powered by a low-voltage DC line installed in the facility. Future generations of Night Lights will be self contained and will plug directly into a wall socket.

3.2. ZigBee Network

For communication between badges worn by users and the central server, we set up an 802.15.4 ZigBee-compliant network in a mesh configuration. The network has a coordinator node at the server and three repeaters located throughout the residence. Between three and six mobile end devices (MEDs) – patient and caregiver – are operating at any time. We found that commercially available nodes could be lost or dropped from the network when operating as MEDs, so we designed custom nodes with reliability-enhancing protocols. The Escort System communicates badge location to the central server about once every three seconds. Within the scope of this work, we found no practical upper limit to the number of MEDs which could be monitored simultaneously. The only limiting factor is the capability of the ZigBee compliant network as the TL locator technology can support as many MEDs as are on the network. As is, we believe that at least 20-30 mobile nodes could be supported and perhaps more. A more advanced network could support more MEDs.

MEDs for residents have no buttons and are referred to here as “badges.” MEDs for caregivers have two large buttons to facilitate data collection and are called “responders.” MEDs have only rudimentary power-saving modes and thus have a battery life of approximately 48 hours. In this study, caregivers were responsible for keeping them charged, attaching them to residents’ clothing in the morning, and removing them at night. Caregiver and management coverage was much lighter at night, so trials were conducted only during the day to ensure that patient safety was not compromised. Twenty-four hour coverage would likely have required two badges for each patient or a battery with 7-day or longer life. The prototype badge was too large to be worn comfortably while sleeping, so a significant reduction in badge size would be needed for 24 hour service. An alternative is a bed alert to signal the caregiver to attach a badge to the patient when the patient leaves the bed.

3.3. Alerting Caregivers

The Escort System has the capability to communicate alerts using computer, pager, cell phone, and email messages. In this study, all alerts were displayed in the Escort Engine Debug Console, logged to a file, and sent to pagers or cellphones monitored by caregivers.

There is a delicate balance between sending so many messages that caregivers begin ignoring them and sending so few that they miss a true alert. After an alert message, caregivers have between 5 and 10 minutes to respond before the message is re-sent. This ensures that caregivers are reminded of alerts until the patient is checked, but not so often as to be annoying or interfere with other obligations.

3.4. Software Operation

The Escort System has two main software components. The *Escort Configuration Utility* provides an interface to create a database of residents, rules, and assignments, and the *Escort Engine* performs all rules checking and alert dispatching based on this database.

The Configuration Utility generates a separate set of rules for each resident, giving a customized version of a single template rule: e.g. the system may trigger an alert when a resident enters another resident’s bathroom. This can be

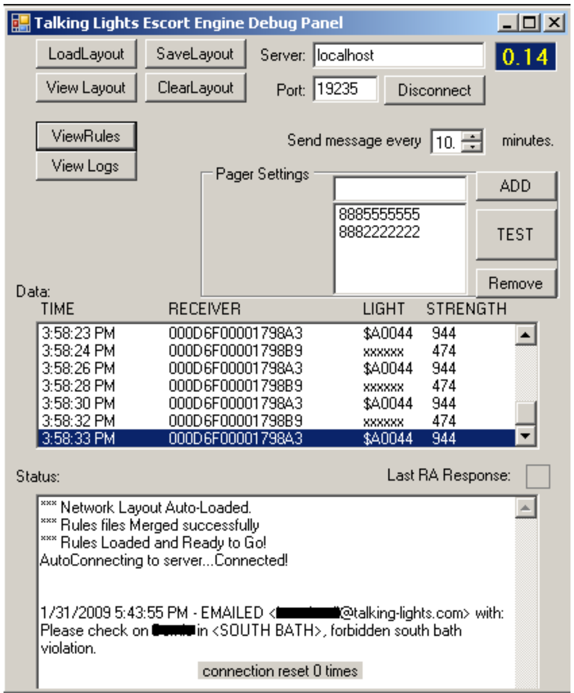

Figure 3. The main window of the Escort Rules Engine.

done by applying a rule forbidding access to resident bathrooms and then enabling an exception for the resident's own room. Rules can also pertain to interaction between residents: if two residents have combative or sexually inappropriate behavior together, their combined presence can trigger an alert and bring the caregiver to their location. Finally, the rule structure supports paging, emailing, and SMS-ing different caregivers for different alerts, though this functionality was not used in the present study.

The Escort Engine automatically starts at Operating System boot time, reads the database files, connects to the ZigBee coordinator's data stream, and begins monitoring location data in real time. The Central Server on which the Engine runs utilizes a number of error-correcting features–including automatic server reconnection and power-outage recovery–to ensure its reliability and eliminate lost or dropped nodes. When the Engine notes a rule match, it dispatches an alert to the pagers specified on the main screen and the email or SMS addresses specified in the rules file (Figure 3). As long as the incoming information matches a given rule, the Engine sends an alert every N minutes. N is five by default, but changing a setting on the main screen changes this repeat rate.

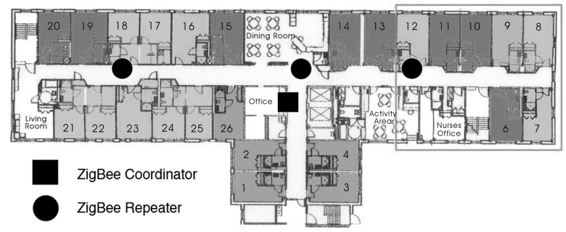

Figure 4. Layout of Hearthstone at Choate in Woburn, MA.

3.5. Data Collection and Logging

When the Escort Engine sends an alert, it also displays the alert on the screen and logs it to a file on the disk. If a caregiver presses a button on the responder, this event is similarly time-stamped and logged in the same file. For this study, a new file was generated each day for the previous day's alerts and responses. The study manager printed this list and asked caregivers to annotate it as described in Section 4.4. Since a typical day had only 5 to 10 alerts, we assumed that caregiver memory of alerts and responses from the previous day was good.

4. The Hearthstone Study

Each Hearthstone Treatment Residence is self-contained. The Hearthstone Alzheimer's Residence at the not-for-profit Choate Community in Woburn, MA is located on the second floor (Figure 4), is specifically designed to make it easy for residents to find their rooms, and is decorated to encourage comfort and familiarity. A distinguishing feature is a specially designed healing garden accessible from the second floor veranda by a ramp.

4.1. Preparations and Planning

Technologies for those with special needs are often rejected or abandoned because of user preference, even if well-designed for a demonstrated need [7]. To guard against this, we met with Hearthstone administrators and senior caregivers in the planning stages to determine the needs of residents and staff. Input from caregivers enabled us to improve both the study and the system. This paper details the second revision of the study, which ran about 12 weeks.

4.2. Alert Conditions

Preliminary conversations with staff gave several areas in which Escort could be effectively tested. We chose the following, listed in order of importance. All, except the exit doors, are accessible to residents:

- Exit doors were the highest priority. Although all exit doors are camouflaged and equipped with magnetic fire system deactivation, they are of obvious concern for exit-seeking behavior. Exit door alerts were the least likely to occur: exits cannot be opened unless a family or staff member enters a pass-code, although residents conceivably can shadow persons exiting or exit when a visitor enters.

- Laundry rooms were the second in priority. Since they are part of daily life at Hearthstone, used by both residents under caregiver supervision and by staff, the door is often left ajar. Detergents (although secured), heavy equipment, soiled clothing, and water spigots all present potential health risks, so the team assigned an alert condition despite the potential for false alarms. Alerts occurred frequently in this area.

- Public bathrooms were next in priority. To reduce incontinence, shared bathroom doors are left open all the time. Residents can use them alone or with a caregiver. When used alone, alerting a caregiver helps avoid the risk of falls or being locked in. In practice, most alerts here were false alarms, and some bathrooms were removed from the ongoing study.

- The healing garden was the lowest priority. Residents enter and use the garden during the day. The path to the courtyard has no stairs, there is no elopement risk, the door is usually locked, and caregivers near the doorway access ramp provide additional security.

  Rules for these alert areas were set in consultation with Hearthstone management and caregivers. As the study progressed, rules were reconsidered and revised in consultation with the caregivers and as a result of our own analysis of data. The elimination of alerts from some public bathrooms is an example of such a rules change.

4.3. Participants

After full IRB approval of the study protocol, the facility director identified participants based on mobility level and incident history, and informed consent was obtained. In cases of relocation or adverse change in mobility level, the participant was removed from the study and an another participant identified. All residents who met participation criteria were enrolled. At any given time, two to four residents were enrolled.

Caregivers were briefed on study objectives and system operation. Six staff members volunteered to collect data and were scheduled to cover both morning and afternoon shifts, Monday through Friday. Additional caregivers enrolled as necessary to cover shift changes or voluntary withdrawal. If no enrolled caregivers were available, data for that day were not considered.

4.4. Caregiver Training and Data Collection

Enrolled caregivers received a 15-minute training session with the responder-pager unit after which they were asked to demonstrate their understanding in a test run. The following instruction was given: when the pager beeps, read the message, check the location indicated, and address the situation. Then hold the responder up to the light and press the red button for a false alarm or the black button for a correct alert.

The first version of the study revealed that the buttons were an inadequate means of data collection. Caregivers had trouble classifying an alert as simply red or black, and often confused the two. For the second version, caregivers suggested handwritten incident reports to supplement the collection of button-press data. Each day, caregivers were asked to comment on a printed list of the previous day's alerts recorded by the system.

During the Hearthstone trials, all caregiver alerts were sent by pager. The faster cellphone alert system was not qualified until the Hearthstone trials were completed.

5. Results and Analysis

This iteration of the study ran for 12 weeks between September 1 and November 22, 2008.

5.1. Data Sets

The Escort system recorded a total of 367 alerts during the trial, 246 between 9am and 5pm when caregivers were actively using the system, and 121 during other hours. The 121 alerts were not considered for analysis because trained caregivers were not consistently available and the experimental conditions could not be verified.

The "raw" data set thus comprises 246 daytime alerts. Of these alerts, 56 were discarded because they could not be matched with entries in the handwritten logbook. Nine intentional test alerts were also discarded.

The remaining 181 data points were designated as the "logged" data set and includes all alerts recorded on days when caregivers filled out the logbook. The "acknowledged" data set is a subset of 73 entries that includes only alerts to which a caregiver responded via button press within five minutes. Note the distinction between acknowledgement (when a caregiver acknowledged receipt of the alert message by pressing a button) and logging (when there

Table 1. Logged Data Summary

	Logged	Acknowledged	Unack'ed
Total	*181*	*73*	*108*
Good	108	63	45
Safe	43	9	34
Excused	3	0	3
Bad	5	1	4
Unmonitored	16	0	16
Empty	6	0	6
Unknown Types	*22*	*0*	*22*

was an entry in the handwritten logs that matched the electronically-recorded data).

5.2. Alert Classification

In evaluating handwritten logs, we classified alerts into six categories based on caregiver comments:

- Good: caregiver commented "good" or "true" or "resident was there."
- Safe: resident was in no danger or the situation had been resolved by the time the the caregiver received and responded to the alert.
- Excused: alert was correct in terms of location, but the badge was not on a resident.
- Bad: alert distracted the caregiver from the actual location of the resident.
- Unmonitored: caregiver did not check on the resident.
- Empty: blank or missing entries on days with otherwise well-annotated reports.

Table 1 summarizes the logged data set. Of 181 alerts, there were 108 (60%) "good" alerts and 43 (24%) "safe" ones. Only five alerts (3%) were labeled "bad" while three (2%) were labeled "excused." The remaining 22 alerts are classified as either "empty" or "unmonitored.

The acknowledged alerts in Table 1 are alerts after which the caregiver pressed one of the buttons on the responder. There were no "empty," "unmonitored" or "excused" entries in this data set. All acknowledged alerts were also confirmed in the logbook.

Of the 73 acknowledged alerts, 63 (86%) were "good," and nine (12%) were "safe." There was only one confirmed "bad" alert. In the original entry in the logbook for this alert, the caregiver wrote "Person X <u>not</u> near laundry room." This data point could have equally been called "safe." The emphasized "<u>not</u>" indicates frustration in responding to the call, so we classified it as "bad." Other caregivers were more tolerant of "safe" alerts but did suggest shortening the time from alert to page to reduce the number of pages in which the patient had moved on.

The principal reason for alerts judged other than "good" was slow response of the paging system: by the time the page was received and the caregiver concluded other tasks and responded, the patient had often moved onto another location. A faster paging system reduces or eliminates this problem.

6. Discussion

The Escort System yielded very satisfactory results. The technical aspects of the system performed well, correctly identifying badge location for acknowledged and unacknowledged alerts 99% and 76% of the time, respectively.

Metsis provides a framework for evaluating assistive environments based on functionality, usability, security and privacy, architecture, and cost [19]. He considers the technical performance, robustness and reliability of the system. Escort responded well to situations we were able to predict when writing software. Some situations required on-site intervention and maintenance: badges going through the wash, MED power failures, and one instance of DC power supply being switched off, turning off all Night Lights. Caregivers contributed to the design process through software suggestions i.e. simplifying rule changes; operational suggestions, i.e. changes in alert rules and areas; and hardware suggestions, i.e. concern about the occasional 90 sec delay before a page was received,.

System faults were primarily of two types: 1) Slow response of the pager so that by the time the caregiver responded, the patient was no longer at the alert location. 2) Transmitter Location: Light fixtures are sufficiently frequent in hallways and meeting rooms that location is rarely a problem. However, in rarely used areas, the light fixture may not be positioned for optimal location transmission.

The former problem was particularly severe if the caregiver missed the initial page and then noted and responded to the repeat 5-10 minutes later. By that time, the patient could be far away.

An example of this latter problem occurred with the laundry room. The TL location transmitter was initially immediately inside the door and so registered on the patient's badge as soon as the room was entered. However, there was spillover of light into the hallway and infrequently the badge would be triggered by a patient walking past and not entering. By the time the caregiver was paged and responded, the subject could be far away. This problem was eliminated by moving the TL transmitter to the back of the laundry room. However, this delayed the paging until the patient was well into the room.

Improving battery life is a simple way to make the system more reliable. Casas et al. suggest using an accelerometer to cut power drain of a ZigBee device [7].

Residents did not object to wearing the small badges. In fact, some were uncomfortable when the badges were removed for charging. Caregivers, however, complained that their responder was bulky.

A further improvement would omit the responder entirely, or combine it with the pager so that a message sent via ZigBee could arrive in a fraction of a second. As Casas observed, users do not wish to carry multiple devices [7]. This apparently applies even when two devices are attached.

Caregivers were able to use Escort without a deep understanding of how it worked. Of nine caregivers, only one asked to be removed from the study. This caregiver felt the alerts and need to respond distracted from other duties.. Caregivers provided very helpful suggestions on changes to patient alert areas and rules. A future version might include a web interface for staff to add and assign new rules, reducing maintenance cost.

Debriefing interviews were conducted with caregivers. Favorable comments related to ability to track patients and know when patients might be in danger, while improvements were suggested in paging response time, need for frequent receiver recharging due to battery life, and ability of the receiver to survive washing.

Privacy options were established at project setup but the Escort software, as is, made them difficult to change. A web interface would address this concern. For this study, resident privacy was maintained by using only first names in messages and logs which met IRB requirements. Privacy could be enhanced by encrypting communication and logging, or by omitting the name entirely, as only the location is necessary for the caregiver to respond to a situation.

7. Conclusions

We have presented a system that uses context-awareness to help protect people living with Alzheimer's in a specialized care residence. The Escort System extends the caregiver's ability to know when a resident is in danger.

Actively powered badges are well known in the pervasive computing community [12], and context-aware systems are increasingly popular in healthcare, usually reporting location, time, and identity [4]. The Escort System appears to be an accurate and non-intrusive means for real-time location/identification in a mobile mesh network.

While technological improvements can always be made to assistive systems, without careful consideration of the system's users [7], functionality, and usability [19], assistive technologies will do no more than increase the communication load on healthcare workers [4]. The Escort System appears to be able to meet these criteria.

This work has demonstrated that an optical, illumination-based locating system can provide accurate, real-time indoor location information. The technology is a strong contender for automated indoor locating applications. Its advantages include simplicity, light weight and small space of the mobile unit, reliability, locating accuracy to spaces much smaller than a room, use of existing essential infrastructure and potentially low cost. The location information is easily integrated into other applications. The Escort System described here demonstrates the capability for indoor monitoring of several persons with dementia simultaneously and for providing caregivers with alerts of potential patient danger which include patient location.

The Escort System is functional, usable, reliable, and reasonably robust. We have identified areas for improvement based on refinements of technology and suggestions of caregivers. We have demonstrated that valuable improvements can be obtained also by iterative design which is evaluated jointly by both heathcare workers and technologists.

We believe that the optical locator based Escort system, with further improvements as suggested, can improve the quality and reduce cost of care in Alzheimers facilities. Caregivers will be able to monitor more patients and provide improved patient oversight. Management and family members will be able to evaluate patient status and caregiver assistance through remote electronic means. Caregiver cost per patient should be reduced. Fewer caregivers will be providing better care.

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References

[1] Alzheimer's Association of America. Online at http://www.alz.org/alzheimers_disease_facts_figures.asp, Accessed in February 2009.

[2] Alzheimer's Association of America. http://www.alz.org/comfortzone/, December 2009.

[3] R. Beckwith. Designing for ubiquity: The perception of privacy. *Pervasive Computing*, 2(2):40–46, April-June 2003.

[4] N. Bricon-Souf and C. R. Newman. Context awareness in health care: A review. *Int'l Journal of Medical Informatics*, 76:2–12, January 2006.

[5] D. Burke, S. Leeb, R. Hinman, E. Lupton, J. Burke, J. Schneider, B. Ahangar, K. Simpson, and E. Kanoalani Mayer. Using talking lights to assist brain-injured patients with daily inpatient therapeutic schedule. *Journal of Head Trauma Rehabilitation*, 16(3):284–291, June 2001.

[6] B.-P. N. C-H Lim, Y. Wan. A real-time indoor wi-fi localization system using smart antennas. *IEEE Trans. on Consumer Elec.*, 53(2):618–622, 2007.

[7] R. Casas, A. Marco, I. Plaza, Y. Garrido, and J. Falco. Zigbee-based alarm system for pervasive healthcare in rural areas. *Communications, IET*, 2(2):208–214, February 2008.

[8] P. X. K. D. E. Altus, R.M. Mathews and B. A. D. Nolan. Evaluating an electronic monitoring system for people who wander. *Am J. Alzheimer's Disease and Other Dementias*, 2000(15):121–125, 2000.

[9] dbS Research. Alzheimer's disease and related disorders sar res.-wandering overview. www.dbs-sar.com/SAR_RESEARCH/wandering.htm, Nov. 2009.

[10] S. Giroux, J. Bauchet, H. Pigot, D. Lussier-Desrochers, and Y. Lachappelle. Pervasive behavior tracking for cognitive assistance. *ACM Int'l Conf. Proc. Series: Proc. of the 1st int'l conf. on Pervasive Tech. Related to Assistive Environments*, 282(86), July 2008.

[11] Y. Hao and R. Foster. Wireless body sensor networks for health-monitoring applications. *Physiological Measurement*, 29:R27–R56, November 2008.

[12] A. Harter, P. Steggles, A. Ward, and P. Webster. The anatomy of a context-aware application. *Proceedings of the Fifth Annual ACM/IEEE International Conference on Mobile Computing and Networking*, pages 59–68, August 1999.

[13] R. Hinman, A. Avestruz, E. Lupton, G. Livshin, J. Rodriguez, S. Leeb, C. Clark, K. Horvath, and L. Volicer. Illumination based locator assists alzheimer's patients. *IEEE Pervasive Computing*, 3(2), 2004.

[14] R. Hinman, S. B. Leeb, A. Avestruz, E. Lupton, B. L. Bentzen, and R. Easton. Dual use lighting for assistive technology. In *2002 NSF Design, Service and Manufacturing Grantees and Research Conference*, 2002.

[15] R. Hinman, G. Livshin, S. B. Leeb, E. C. Lupton, and A. Avestruz. Visible light audio information transfer system. Final Report TL-07-002 for grant 2R44EY12933, Talking Lights LLC, 3 Tremont St. Suite 201, Charlestown, MA 02129, 2007.

[16] W. Kearns and D. Moore. Rfid: A novel measurement of wandering in dementia. *Proc. of FICCDAT/ICTA: the 2nd Int'l. Conf. on Technology and Aging*, June 2007.

[17] S. Lauriks, A. Reinersmann, H. V. der Roest, F. Meiland, R. Davies, F. Moelaert, M. Mulvenna, C. Nugent, and R. Droes. Review of ict-based services for identified unmet needs in people with dementia. *Ageing Research Reviews*, 6:223–246, July 2007.

[18] E. Lupton, S. Leeb, G. Hovorka, D. K. Jackson, and B. L. Bentzen. Communication systems. U.S. Patent, 4 June 2002.

[19] V. Metsis, Z. Le, Y. Lei, and F. Makedon. Towards an evaluation framework for assistive environments. *ACM Int'l Conf. Proc. Series: Proc. of the 1st int'l conf. on Pervasive Tech. Related to Assistive Environments*, 282(12), July 2008.

[20] A. Mihailidis and G. R. Fernie. Context-aware assistive devices for older adults with dementia. *Gerontechnology*, 2(2):173–188, December 2002.

[21] H. Ogawa, Y. Yonezawa, H. Maki, H. Sato, and W. Caldwell. A mobile-phone-based safety support system for wandering elderly persons. *Engineering in Medicine and Biology Society*, 2:3316–3317, September 2004.

[22] M. Vassallo, L. Poynter, J. C. Sharma, J. Kwan, and S. C. Allen. Fall risk-assessment tools compared with clinical judgment: an evaluation in a rehabilitation ward. *Age and Ageing*, 37(3):277–281, 2008.

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