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

The Escort system monitors residents of assisted living communities and alerts caregivers when they walk aimlessly, or "wander," into potentially dangerous situations. The system could help lead to improved care at reduced cost.

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Elderly people, whether they live alone, with family, or in an assisted living community, often walk around their living areas as a physical and emotional outlet. In those with dementia, however, walking can become aimless, disoriented, and dangerous.[1] Ensuring the safety of these individuals can require near-constant monitoring.[2]

Sixty percent of people with Alzheimer's exhibit wandering behavior, and this behavior increases the likelihood of accidents, serious injury, and even death.[3] Wandering occurs when anyone with decreased cognitive ability walks away from supervised care.[4] Workers in the field differentiate nongoal- and goal-directed wandering. In the former, the subject moves about aimlessly with no apparent goal, whereas in the latter, subjects move toward some type of goal.[4]

The Alzheimer's Association estimates that about 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 (see www.alz.org/alzheimers_disease_facts_and_figures.asp). Compared to other assays, the clinical identification of wandering is an excellent (78 percent accurate) predictor of fall risk.[1] Wandering is so prevalent that it is of special interest to caregivers and the healthcare organizations that employ them.[2,3]

The Escort system is designed to protect wander-prone residents from adverse events. Users wear mesh-networked badges that transmit indoor location information obtained in real time from a Talking Lights optical location setup that uses ordinary light fixtures and other light sources as location beacons. A central server sends real-time pager or cell phone short messaging service (SMS) alerts when a user might be at risk, giving caregivers information to address the situation before an adverse event occurs.

System Details

The Escort system features frequent communication of accurate indoor 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 (see Figure 1). For location, we use a modulated nonflickering illumination-based system provided by Talking Lights. Users wear small badges capable of location determination and automatic communication with the central server. For this

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communication, we use Talking Lights' ZigBee-compliant devices, which are based on modules obtained from Telegesis. For caregiver alerts, we use commercial off-the-shelf (COTS) word messaging pagers from USA Mobility, and COTS cell phones with SMS capability. The pagers required 90 to 120 seconds or more from transmission to receipt of message. The cell phones typically receive a message within 5 to 10 seconds of transmission. We performed the work at the Hearthstone Alzheimer Care in Woburn, Massachusetts, using pagers because the cell phone system was not qualified until the Hearthstone work was complete.

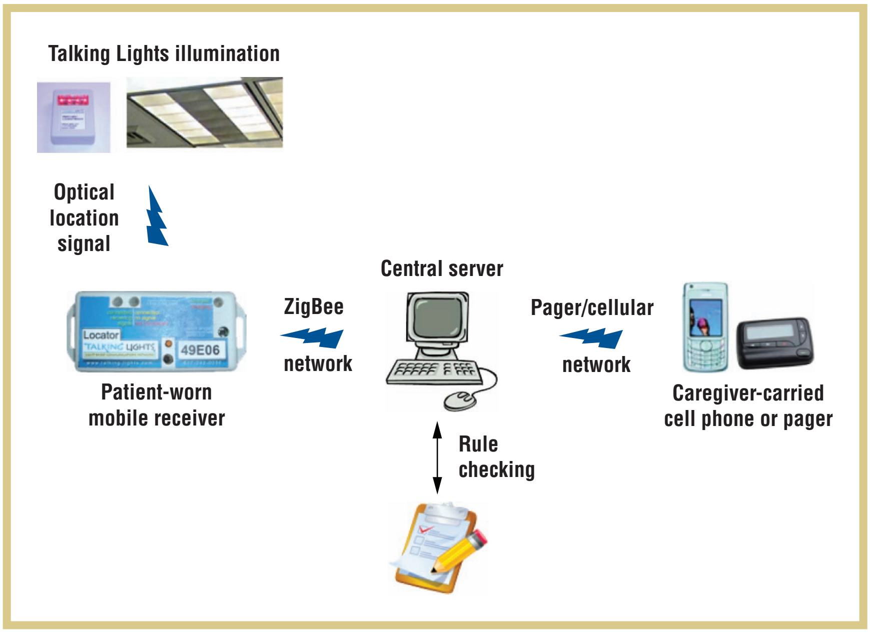

Figure 1. Escort system overview. Optical location information is transmitted from lights to the patient's receiver, and the patient's location is then transmitted via a ZigBee network to a central server. Patient location is compared with predetermined rules and permissions and, if appropriate, an alert is sent via pager or cell phone to a caregiver.

Talking Lights Ballasts and Night Lights

Most methods of electromagnetic indoor locating suffer from interference problems. Some indoor optical methods require expensive imaging.[5] Noisy location data is a difficult challenge in context-aware computing.[6] Because radio waves travel through physical objects,[3] radio-based systems might identify two separate rooms as the same location. Ultrasound technology, which requires between one and eight beacons to obtain an accurate fix, might provide details about location and intervening obstacles.[5] (See the "Related Work in Patient Monitoring" for a discussion of work in this area.)

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 the existing illumination infrastructure. Each light, whether fluorescent or LED, transmits a unique location identification code.

TL ballasts modulate the drive frequency to encode digital data into the light itself. A patented two-level Manchester coding scheme enables arbitrary data schemes without visible flickering.[7] Otherwise, the fluorescent light operates normally, with no visual aberrations and no increase in energy consumption.

In other work, we found that multiple TL transmitters in a single room do not present problems.[8,9] The TL receiver locks onto the nearest, strongest modulated signal. If increased spatial resolution is desired, density of transmitter installations can be increased. We have outfitted buildings with fluorescent lights every 6 to 8 feet and observed no problems. The location data from Escort is accurate, reliable, and very low noise. We tested the modulated optical signal and found no interference with other systems.

In another as yet unpublished work, we demonstrated a system that 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.

Hearthstone avoids the 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 these CFLs. Also, many areas with illumination, such as patient rooms, must be dark at night. For these reasons, we used LED-based TL Night Lights (see 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.

ZigBee Network

For communication between user badges and the central server, we set

Related Work in Patient Monitoring

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.[1,2] One type of technological assistance enables telemedicine by reading vital signs.[3] These systems are often costly, however, and can have disastrous failure modes.[2]

Other technologies allow 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.[1,2,4] One proposed system requires no wiring, relies on community and family to respond to alerts, and is reported to be cost-effective.[5] 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 Alex Mihalidis and Geoffrey Fernie's assertion that most assistive devices require too much interaction and could use more context-awareness.[6]

In 2000, Deborah Altus and her colleagues reported an outdoor locator system with a transmitter worn by the patient and a portable receiver used to search for the patient.[7] ComfortZone (www.alz.org/comfortzone), a more modern GPS-based system for outdoor locating, is offered by the American Alzheimer Association.

Richard Beckwith describes an indoor system with multiple sensors in a care facility and user badges that send IR back to room sensors with location information.[8] William Kearns and his colleagues propose use of ultra wideband RFID to track dementia patients indoors.[9] Other proposed real-time indoor locating systems include Wi-Fi triangulation and/or intensity mapping.[10]

The Escort system is context-aware; that is, it uses knowledge of the physical environment. It does not presently read physiological signals or let the user manually call for help. Unlike our earlier studies, which concentrated on building a cognitive orthotic for patients,[11,12] this system creates a sensory adjunct for caregivers, enhancing their capacity to ensure the safety of elderly users.

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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 that could be monitored simultaneously. The only limiting factor is the wireless network's capability because the TL locator technology can support as many MEDs as are on the network. As is, the technology supports at least 20 to 30 mobile nodes. A more advanced network could support additional MEDs.

Residents' MEDs ("badges") have no buttons. Caregivers' MEDs ("responders") have two large buttons to facilitate data collection. 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 we conducted trials only during the day to avoid compromising patient safety. Twenty-four-hour coverage would likely have required two badges for each patient or a battery with seven-day or longer life. The prototype badge was too large to be worn comfortably while sleeping, so badges would have to be much smaller for 24-hour service. An alternative is a bed alert that signals the caregiver to attach a badge to the patient when the patient leaves the bed.

Alerting Caregivers

The Escort system can communicate alerts using a 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 cell phones monitored by caregivers.

A delicate balance exists between sending so many messages that caregivers begin to ignore 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 resent. This ensures that caregivers are reminded of alerts until they check the patient, but not so often as to be annoying or interfere with other obligations.

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 rule 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. For example, the system might trigger an alert when a resident enters another resident's bathroom. It does this 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, although 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 uses several 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 (see Figure 3). As long as the incoming information matches a given rule, the engine sends an alert every *N* minutes. By default, $N = 5$, but changing a setting on the main screen changes this repeat rate.

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 we describe later. Because a typical day had only 5 to 10 alerts, we assumed that caregiver memory of alerts and responses from the previous day was good.

The Hearthstone Study

Each Hearthstone Treatment Residence is self-contained. The Hearthstone

Figure 2. Talking Lights' Night Light location beacon LED transmitters give an alternative location mechanism. Illumination can be visible or infrared as is appropriate.

Alzheimer's Residence at the not-for-profit Choate Community in Woburn, Massachusetts, is located on the second floor (see 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.

Preparations and Planning

Technologies for people with special needs are often rejected or abandoned because of user preference, even if they are well-designed for a demonstrated need.[10] To guard against this a priori dislike, we met with Hearthstone administrators and senior caregivers in the planning stages to determine the needs of residents and staff. Input from caregivers allowed us to improve both the study and the system. This article details the study's second revision, which ran about 12 weeks.

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.

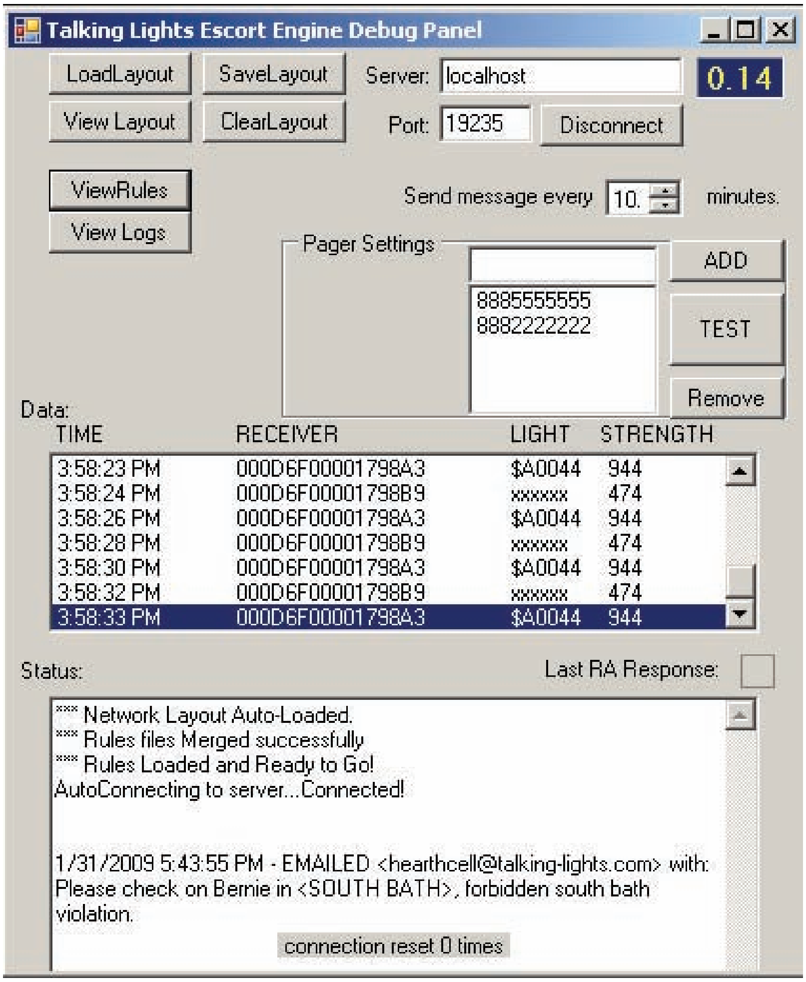

Figure 3. The main window of the Escort rules engine. The *data* box shows real-time data from the ZigBee coordinator. The *status* box displays status messages, including recently dispatched alerts.

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 people exiting or exit when a visitor enters.
- *Laundry rooms* were second in priority. Because 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, because many of the patients could return to their own private bathrooms only slowly and with difficulty, shared bathroom doors are left open all the time. Residents can use them alone or with a caregiver. The caregiver can be alerted when residents enter a shared bathroom alone, in case a patient should fall or be locked in. In practice, most alerts were false alarms, and we removed some bathrooms 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.

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

Participants

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

We briefed caregivers 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 to cover shift changes or voluntary withdrawal. If no enrolled caregivers were available, we did not consider data for that day.

Figure 4. Layout of Hearthstone at Choate in Woburn, Massachusetts, showing ZigBee coordinator and repeater positions.

Caregiver Training and Data Collection

Enrolled caregivers received a 15-minute training session with the responder-pager unit after which we asked them to demonstrate their understanding in a test run. We gave the following instruction: "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 cell phone alert system was not qualified until the Hearthstone trials were completed.

Results and Analysis

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

Data Sets

The Escort system recorded a total of 367 alerts during the trial, 246 between 9 a.m. and 5 p.m., when caregivers were actively using the system, and 121 during other hours. We did not consider the 121 alerts for analysis because trained caregivers were not consistently available and we could not verify the experimental conditions.

The *raw* data set thus comprises 246 daytime alerts. Of these alerts, we discarded 56 because we could not match them with entries in the handwritten logbook. We also discarded nine intentional test alerts.

We designated the remaining 181 data points as the *logged* dataset. This set includes all alerts recorded on days when caregivers filled out the logbook. The *acknowledged* dataset 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 acknowledgment (when a caregiver acknowledged receipt of the alert message by pressing a button) and logging (when an entry in the handwritten logs matched the electronically recorded data).

Alert Classification

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

- *Good*—the caregiver commented "good" or "true" or "resident was there."
- *Safe*—the resident was in no danger or the situation had been resolved by the time the caregiver received and responded to the alert.
- *Excused*—the alert was correct in terms of location, but the badge was not on a resident.
- *Bad*—the alert distracted the caregiver from the resident's actual location.
- *Unmonitored*—the 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 percent) "good" alerts and 43 (24 percent) "safe" alerts. Only five alerts

TABLE 1
Logged data summary.

Classification	Logged	Acknowledged	Unacknowledged
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
Total	181	73	108

(3 percent) were labeled "bad" while three (2 percent) 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 dataset. All acknowledged alerts were also confirmed in the logbook. Of the 73 acknowledged alerts, 63 (86 percent) were "good," and nine (12 percent) were "safe." There was only one confirmed "bad" alert. In the original logbook entry for this alert, the caregiver wrote "Person X not near laundry room." This data point could have equally been called "safe." The emphasized "not" 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.

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

Lessons Learned

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 percent and 76 percent of the time, respectively.

Vangelis Metsis and his colleagues provide a framework for evaluating assistive environments based on functionality, usability, security and privacy, architecture, and cost.[6] They consider the system's technical performance, robustness, and reliability. Escort responded well to situations we could predict when writing software. Some situations required onsite intervention and maintenance—for example, 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 (such as simplifying rule changes), operational suggestions (such as changes in alert rules and areas), and hardware suggestions (such as concern about the occasional 90-second delay before a caregiver received a page).

System faults were primarily of two types. First, as mentioned previously, slow pager response can mean that by the time the caregiver responded, the patient was no longer at the alert location. Transmitter location is another primary problem. Light fixtures are sufficiently frequent in hallways and meeting rooms that location is rarely a problem. However, in rarely used areas, the light fixture might not be positioned for optimal location transmission.

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

An example of the transmitter location 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 patient entered the room. However, there was spillover of light into the hallway, and infrequently the badge was triggered when a patient walked past but did not enter. By the time the caregiver was paged and responded, the subject could be far away. We eliminated this problem by moving the 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 increase the system's reliability. Roberto Casas and his colleagues suggest using an accelerometer to cut power drain of a ZigBee device.[10]

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 and colleagues observed, users do not wish to carry multiple devices.[10] 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 helpful suggestions on changes to patient alert areas and rules.

We conducted debriefing interviews with caregivers. Favorable comments related to the ability to track patients and know when they 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.

We established privacy options at project setup, but the Escort software, as is, made these options difficult to change. A Web interface would address this concern. For this study, we maintained resident privacy by using only first names in messages and logs, which met IRB requirements. We could enhance privacy by encrypting communication and logging, or by omitting the name entirely, because the caregiver only needs the location to respond to a situation.

Optical, illumination-based locating technology is a strong contender for automated indoor locating applications. Its advantages include simplicity, the mobile unit's light weight and small size, reliability, locating accuracy, use of the existing essential infrastructure, and potentially low cost. The location information is easily integrated into other applications.

The optical locator-based Escort system, with further improvements, can enhance the quality and reduce cost of care in Alzheimer's facilities. Caregivers will be able to monitor more patients and provide better 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, with fewer caregivers providing better care.

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