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Smart home technology solution for night-time wandering in persons with dementia

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Abstract

Introduction: More than half of persons with dementia will experience night-time wandering, increasing their risk of falls and unattended home exits. This is a major predictor of caregiver burnout and one of the major causes of early institutionalization.

Methods: Using smart home technologies such as sensors, smart bulbs, pressure mats and speakers, the Night-time Wandering Detection and Diversion system is designed to assist caregivers and persons with dementia that are at risk of wandering at night. Being placed in homes around Ottawa for a 12-week trial, the system allows caregivers to rest peacefully in the night, as it detects when the person with dementia gets out of bed and automatically provides cue lighting to guide them safely to the washroom. The system also uses prerecorded audio prompts, if they venture from the bedroom, only waking the caregiver when the person with dementia opens an exit door.

Results: Thus far, the average depression and anxiety in caregivers have been improved after the 12 weeks, and most have said that they sleep more peacefully.

Conclusion: The system has proven successful in supporting the safety of persons with dementia as well as their caregivers.

Keywords

Age in place, sensor design, sensors/sensor applications, smart homes, telehealth

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Introduction

With the growth of the aging population, there is a concern that an increase in the prevalence of dementia will result in large demands on caregivers and supportive services. As of 2016, in Canada, there are approximately 564,000 persons with diagnosed dementia, with an expected two-fold increase in this number by the year 2031.[1]

Persons with dementia (PWD) prefer to remain in their homes for as long as possible in order to maintain the integrity of their social networks, preserve environmental landmarks and maintain their quality-of-life.[1] In addition, institutionalization usually means a high-economic burden for the family and/or the taxpayers.[2] However, caring for PWD is associated with high levels of stress, and this burden on the caregivers can jeopardize the viability of continuing to provide care at home.[3]

One of the common symptoms of advancing disease in PWD is night-time wandering, which is related to disturbances in the internal biological clock (e.g. circadian rhythm) that regulates the periods of sleepiness at

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night and wakefulness throughout the day.[4] The loss of visual cues at night reduce sense of direction.[4] By affecting quality of sleep, night-time wandering can further impact the cognition of a PWD, in particular attention, orientation, and memory performances.[5] At the same time, wandering becomes a dangerous behavior itself, increasing the risk of injuries and elopement (wandering away from the home).[6] Night-time wandering is a major predictor of caregiver burnout and subsequently one of the major causes of institutionalization of PWD.[7]

The idea of using technology to monitor a PWD is not new. Vuong et al.[8] provided a thorough review of technologies that geo-fence and prevent elopement, track and locate PWD and provide information services to assist caregivers. Teipel et al.[9] review the literature on Information and Communication Technologies (ICT) studies relating to dementia outcomes and propose the use of smart home technology for clinical trial use. A couple of groups are moving the smart home systems from pure monitoring to monitoring with actions. Boumpa et al.[10] propose a system that provides audio cues for a PWD to help them identify a familiar visitor, but the system has not been field tested. Finally, Radziszewski et al.[11] describe a custom-assembled system that operates in two phases: two weeks of "analyzing" night-time behavior, followed by an "assistive phase" that is purported to decrease the stress associated with wandering. They suggest the system was field tested but do not provide clinical results. Thus far, there have not been any studies that have tested off-the-shelf technology to actively reduce the impact of night-time wandering in dementia. Hence, the purpose of this pilot study is two-fold: (1) to determine if repurposed, off-the-shelf technology providing light and sound cues can (re)direct a PWD that is wandering at night and (2) to determine if this facilitates caregiver sleep and decreases caregiver stress.

Methods

This 12-week pilot study was approved by the Research Ethics Boards of Bruyère Continuing Care and Carleton University, Ottawa, Canada. To participate in this pilot study, participants must live in the greater Ottawa area, experience episodes of night-time wandering and live with a caregiver. Because of the advanced level of dementia associated with wandering, consent for participation was obtained from the Substitute Decision-Maker, who was also the live-in caregiver in all cases.

Defining the problem/developing the partnership

TAFETA Smart Systems for Health is a partnership between the Bruyère Research Institute and Carleton University in Ottawa, Canada, and its coleaders are scientists with the AGEWELL NCE Inc. TAFETA has been studying the use of sensors to support aging in place for a dozen years. The coleaders contacted the Alzheimer's Society of Ottawa and Renfrew County (ASORC—now known as DSORC—Dementia Society of Ottawa and Renfrew County) to discuss what issues their community of caregivers and PWD were experiencing. The Champlain Local Health Integrated Network (LHIN) funds home care services in the greater Ottawa area and their Innovation Centre: Innovation Empowering Patients and Caregivers Through Technology provided assistance in this pilot study by assembling and testing the components of the NWDD system prior to home study trials. Members of these three entities worked together for some 18 months to develop this pilot study.

DSORC has close ties to caregivers and support staff for PWD. They identified the issue of night-time wandering in PWD as a significant priority issue for PWD and caregivers. Night-time wandering affects caregiver sleep and results in increasing stress, ultimately leading to caregiver burnout and premature institutionalization. This led to the idea of using smart home technologies to support caregivers, by helping improve their sleep and thereby reducing their stress.

The participants

The initial goal of the pilot study was to include 40 dyads of community-living older adults self-identifying with moderate to severe dementia who have experienced instances of night-time wandering and their main caregiver. Wandering typically occurs in later stages of dementia, so for this pilot, no further diagnostic clarity was sought. After struggling with recruitment, and receiving help from DSORC and the Champlain LHIN, the goal was adjusted to 20 participants. To further improve recruitment, persons living within assisted living communities were also included. This paper presents the data for the first five participants within the study.

The technology

The NWDD system is an assembly of components from Samsung Smart Things,[12] SONOS, and Ideal Security and Ecolink Sensors. The sensors include Samsung Smart Things Motion Sensor F-IRM_US-2, Smart Things Multipurpose Sensor F-MLT-US-2, Ecolink Z-Wave Plus Door and Window Sensor DWZWAVE2.5-ECO which is connected to an Ideal Security Pressure Mat SK630. The pressure mat is deployed under the mattress of the bed on the side the PWD sleeps and acts as the on/off switch within

the system. The output is "open," meaning that there is no pressure on the mat, and "closed," meaning that there is pressure on the mat. The mat will trigger when more than one pound per square inch (PSI) is exerted and is suitable for a maximum weight of 350 lbs. These sensors connect to the Samsung Smart Things Home Hub STH-ETH-250. This hub connects to the Internet via wireless 3 G/LTE Internet Router. The WebCoRE rule engine allows the NWDD system to be personalized by creating advanced rule logic for the system in the cloud. These rules trigger activation of Sylvania Smart Home Dimmable White A19 lightbulbs, Samsung Smart Things Outlet F-CEN-APP-1, a SONOS model PLAY1US1 smart speaker, or a message is sent to a connected personal device.

The NWDD system setup

The system is designed with the caregiver's need for rest in mind and functions in the following way: when the PWD gets out of bed, the pressure on the bed mat decreases and instantly a message is sent wirelessly from the mat to the hub and ultimately to the cloud. The rule in the cloud is "if the pressure sensitive mat returns the value of 'open', meaning there is no longer pressure on the mat, and thus the condition of no one on bed, then turns on the light." Hence, a command is sent from the cloud to the hub and ultimately to the smart light in the hall/bathroom/bedside table: to turn the light on. This light is used as a guidance tool to guide the PWD to the bathroom destination and back, as bathroom need is typically the cause for wakening during the night hours.[13] Once the PWD returns to bed, the pressure sensitive bed mat reads the increase in pressure where the condition of a person being on the bed then sends a message to the cloud, which then turns the lights off again, allowing the PWD and the caregiver to continue to sleep.

If the PWD does not return to bed, and instead wanders toward other areas in the house that are not unsafe but not appropriate at night, motion sensors in those spaces detect movement and trigger redirection of the PWD back to bed, again via the cloud. In this case, the rules could be "if this motion sensor detects movement, and there is no pressure on the bed mat, and it is night-time, creating the condition of someone being in the room but no longer in bed then plays a predetermined message through the speaker." The message is a prerecorded voice message, typically in the voice of the caregiver, played through the SONOS speaker, informing the PWD that it is night-time and asking them to return to bed.

If the message does not bring the PWD back to bed, they may continue to wander toward an exit. Samsung Smart Things contact sensors are placed on all exit doorways. Once the contact is open, the condition of the door has been opened becomes true, a message is sent to the cloud, and the rule for the contact sensors is to send a text message to the phone number of the caregiver, informing them which door was opened, provided it is night time, and there is no pressure on the bed mat. This alert can also be an alarm sound through the SONOS speaker or lights could flash on and off, if the caregiver does not have a phone. The notification is customizable to the individual caregiver to what they think would result in waking them, taking into account personal challenges such as hearing.

The system has a flexible design allowing it to be adapted to meet the needs of diverse residences and users, such as protection for multiple exit doors, coverage for higher risk areas of the residence such as a kitchen or stairs, and relationships where the caregiver and PWD share a bed/bedroom and other cases where the caregiver sleeps in a different room. The only requirement for this study was that the caregiver and PWD live in the same house. This system places no requirement on the PWD or the caregiver, as it is fully functional without any form of wearable device on either participant. All of this allows the caregiver to sleep comfortably, knowing they will only need to wake up should they receive a text message informing them that their PWD has opened an exit door.

Measures of wandering

The system collects and outputs a record of all sensor activity. The method of data capture and archiving, including sampling method, has been previously described.[14] This has the potential to allow the research team to determine the number of times a PWD leaves their bed at night (bed sensor), and monitor their movement and travel throughout the house (motion detectors and door sensors). This gives the ability to determine if the bed exit has purpose or not. For instance, whether they got up and went to the bathroom and returned, or if they got up and went to the kitchen then proceeded to head toward the front door and then returned to bed as some examples. With the contact sensors, this provides insight into the number of times the doors are opened, giving the ability to determine how many times a PWD attempts to exit from the household and at what hours in the night this occurs. This data were collected for 12 weeks.

Measures of caregiver anxiety/depression

The Hospital Anxiety and Depression Scale (HADS) is a self-assessment scale developed by Zigmond and Snaith,[15] and it has been validated as reviewed by Djall et al.[16] for use in both clinical and research

settings. It is a 14-item scale that generates ordinal data: seven of the items relate to anxiety and seven relate to depression and takes 2 to 5 min to complete. This test is administered the day the NWDD system is installed and then again at the end of the 12-week pilot study.

Measures of caregiver sleep quality

The Mini Sleep Questionnaire is based on a mini sleep test[17] with a few added questionnaires to fit the needs of the pilot study. Questions about the sleep habits of the caregiver are asked at the beginning of the pilot study to determine how much sleep they usually get, how often they get up in the night for their own needs and how often they need to get up in the night to support their PWD. These questions are also asked at the end of the 12-week pilot study to assess the system's effectiveness in allowing the caregiver to sleep more peacefully.

Installation

After a participant has agreed to partake in the pilot study, our research team drives to their house and installs the motion and contact sensors (Figure 1), bed mat sensor, speaker and smart bulbs according to the layout of the house and the needs of the participants. After the installation, the research team monitors battery life and sensor connectivity remotely, giving the ability to know immediately if over the 12-week pilot study, a team member needs to contact and visit the participant for a new battery or sensor replacement. The participant is called on a biweekly basis to check that the system is working properly and is then asked questions regarding if the PWD has had any negative reactions to the technology. This gives the research team an opportunity to adjust any rules with the system should the caregiver need anything altered or added, and this is when visits for technology maintenance are planned. After 12 weeks, the research assistant visits the participant to complete the poststudy questionnaires and gather feedback regarding the technology. It is also at this time the technology is removed from the participant's house. There are two reasons for this, first, the research team would not have been able to maintain the service to support the system after the end of the research, and removal was required by the Research Ethics Board.

Figure 1. Research assistant installing a contact door sensor.

Results

This paper presents the data from the first five participant dyads, with participant IDs P1–P5. To obtain the first 5 participants, a total of 11 potential participants were called, where 5 had declined to participate due to reasons regarding their concerns regarding technology. The other participant was not included in the study due to not meeting the eligibility criteria of episodes of night-time wandering, as the PWD was taking sleeping medications.

The participants

The first five PWD consisted of two women and three men with a mean age of 82.6 years (range: 59 to 94) and a mean years of education of 15.0 (range: 13 to 16). The caregivers were three women and two men with a mean age of 62.6 (range: 47 to 78). Of these five households, three were spousal pair relationships, and the other two were parent–child where the parent had been moved into the child's house. Three dyads lived in the City of Ottawa, and two within 15 km of the city limits. There was an assumption that dyads that self-selected for this project consisted of one PWD and one healthy caregiver and that wandering was a challenge they were facing. The diagnosis of the PWD was not verified nor did the type of dementia get recorded, as it was not necessary for the purposes of this pilot study. The research assistant verified that the caregiver was able to provide consent and noted that all five PWD actually had cognitive issues.

The technology

Since the technology had been extensively tested at the Champlain LHIN, Carleton University and the Elisabeth-Bruyère Hospital, overall, it worked well in participants' homes. However, some minor issues arose. For instance, the pressure sensitive bed mat functioning was variable, as in one case, it caused lights to turn on when the PWD rolled over in bed. The pressure sensitive bed mat was more fragile than anticipated and experienced failures during the pilot study as the pressure sensors inside were easily damaged. Other failures occurred due to the placement of the pressure sensitive bed mat, and the thickness of the participants' mattresses. In one case, a very thick mattress distributed the participant's weight in such a way that the pressure sensitive mat was unable to detect pressure. Of the five homes, two homes required new pressure sensitive mat installations. All other technological components worked to their expected abilities, and other visits were due to battery changes for the motion and contact sensors. This only occurred 1–2 times per participant during their 12-week pilot study. Since the rules were accessible in the cloud, it was possible to turn off sensors or change rules immediately, and go to homes to replace broken parts within a few days of issues arising.

There were no failures regarding the programming of the rules, once a rule was programmed in place, the system worked as expected.

Both the caregivers and the PWD hardly noticed the technology that was placed in their homes. The caregivers were more aware of the technology, but said that it was never a bother, and when asked, they felt that the PWD generally did not seem to notice the technology. However, the few who did notice pieces of the technology, and when asked, the caregivers would remind them of the pilot study details. The pressure mat was never noticed, and the speaker message often made the PWD feel as though their caregiver was up at night with them. There was no report of the speaker message startling the PWD in the moment; however considering their condition, this is difficult to verify as the caregivers were meant to be asleep during these events. Overall, caregivers never reported negative reactions to the technology.

PWD sensor data integrity

There was only a small amount of data loss in the first five dyads. This occurred during a short power outage at the data recording center, in which the server was not restarted to continue collecting data from the cloud. Thus, there was a short period of time in which data were lost. However, other than this event, no other data were lost, and importantly, the loss did not affect the system functioning at the residence. The sensor data can be converted into daily graphical images (Figure 2), showing which motion sensors were triggered, and if at the time, the pressure sensitive bed mat had pressure (i.e. PWD was in bed) or not. All the sensors in the home send a time stamped data point for each change in their status. If there is no change in their status, they send a time stamped data point with the current status every 10 min.

PWD sensor data–case example

Figure 2 illustrates a 24-h period of data from one participant. It can be seen that just before midnight, the PWD went to bed. Around 2 a.m., the PWD got out of bed, and the bedroom motion sensors were triggered. This was followed by a trigger in the hallway sensor and finally a bathroom sensor. Then the hallway motion sensor was triggered again, followed by the two motion sensors in the bedroom and then pressure reappeared on the bed mat. This sequence suggests the PWD went to the bathroom and returned to bed, allowing the caregiver to continue to sleep. Around 7 a.m. on the same day, a similar motion sensor trigger

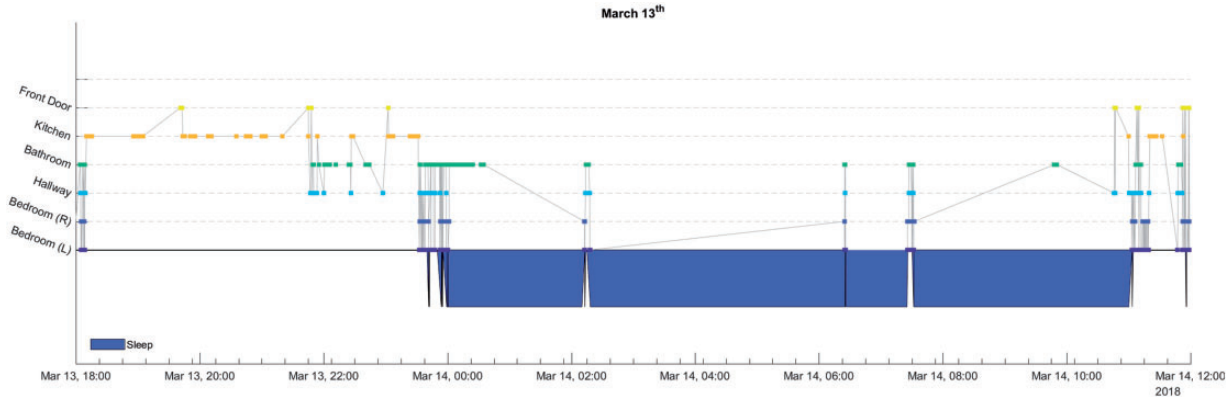

Figure 2. A 24-h representation of the NWDD system and its outputs.

sequence is observed; however, after the return to bed, a number of motion sensors are triggered: hallway, bathroom, hallway and kitchen. Since the bed sensor is indicating "occupancy," this likely represents the caregiver getting up for the day. This illustrates the importance of the bed mat in helping identify who is triggering the motion sensors. Looking at the graph further, it can be seen that the PWD woke up for the day around 11 a.m.

PWD clinical results

The pilot was not designed to determine if the light and sound triggers functioned, but there was anecdotal information from caregivers that they saw the light go on and heard the speaker. Unfortunately, at the time of writing, automation to determine the number of bed exits and the impact of the light and auditory supports has not been accomplished.

Caregiver anxiety/depression

The second main purpose of this study was to qualitatively collect information and data based on the caregiver experiences, in hopes of reducing caregiver stress and burden, while increasing caregiver nightly sleep. Across the five participants who have completed the pilot study, the average baseline depression score was 5.2 (range: 0–12), and the average anxiety score was 6.8 (range: 2–10). After 12 weeks had passed, the average depression score decreased to 3.6 (range: 0–7), while the average anxiety decreased to a 5.8 (range: 0–10). A decrease in these scores would suggest a positive change as the numbers reflect less depression and less anxiety were reported in the caregivers. Below, Figures 3 and 4 show the depression and anxiety scores respectively for each participant from the start of their 12 weeks to the end of the pilot study.

Investigating the depression scores, it was found that three participants reported lower depression scores after the 12-week pilot study was complete, while one participant indicated being more depressed and one participant remained the same. With respect to the anxiety scores, two participants reported less anxiety, one participant indicated a higher value of anxiety and two participants remained the same across the 12-week pilot study. Further investigation on the cases where depression and anxiety increased or remained the same were completed, and in the case of P3, it was clarified that the increased score found in Figure 3 was due to other life events unrelated to this pilot study. The scores found in Figures 3 and 4 for P5 indicated that they were more accepting of the situation of living with their PWD.

Caregiver sleep quality

The average hours of sleep per night for all caregivers was calculated to be 6.1 h (range: 2–8) at the beginning of the pilot study. This number decreased to 5.8 h (range: 3–7) by the end of 12 weeks. Of the five participants, three reported an increase, or no change, in hours of sleep per night, while two reported decreased sleep hours, one of whom was reporting around 3 h of sleep per night at the end of the pilot study. The second caregiver decreased their hours of sleep per night by 1 h, starting with 8 h of sleep in a night and ending with 7 h of sleep.

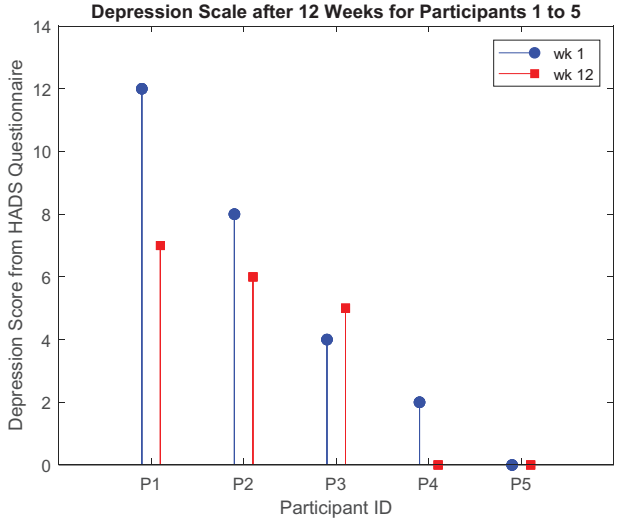

Figure 3. Depression scores across the five completed participants before and after the pilot study.

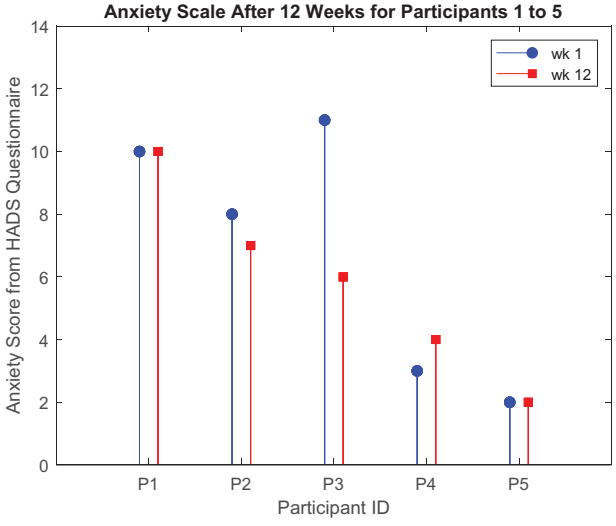

Figure 4. Anxiety scores across the five completed participants before and after the pilot study.

Overall feedback at trial end

When removing the NWDD system from participants' homes, the caregivers were asked to provide their feedback, in hopes of further improving the system. Even those who experienced minor technical difficulties, such as faulty hardware resulting in a few more visits to rectify these, felt that the system would keep their PWD/loved one safe, and notify them only when an action was needed. A number of the dyads would have been happy to keep the system after the pilot.

Discussion

This system is the first off-the-shelf technology based solution that has been adapted for the use of detecting when a PWD is out of bed in the middle of the night, redirecting them back to bed if they enter parts of the home that are not usually visited in the night hours, and then notifying the caregiver if the PWD does attempt an elopement.

Pilot results from the first five participants suggested that the system was helpful not only in the redirection and safety of the PWD but allowing the caregiver to feel more at ease in the night hours. During the post-pilot study questionnaire, administered to the caregivers, there were trends to decreases in symptoms of depression and anxiety, and there was positive anecdotal feedback saying that they were able to sleep comfortably in the night knowing they would be woken if and when their assistance was needed. Three of the caregivers increased their number of hours of sleep per night. In the cases where the caregiver appeared to have worse outcomes toward the end of the trial—family and other factors outside the use of the system appeared to be the cause, an example being medical conditions of the caregiver.

While the system functions well, there were a few technical issues to work on, such as how to handle a power outage and recovery in reference to data collection as a small amount of data were lost. The in-home technology functioned as desired, with the exception to the bed mat that was used. This suggests future work will also involve testing other pressure sensitive mats.

There are a number of limitations of this work. First, it presents pilot data from a very small set of participants limited to one community (Ottawa). More data need to be analyzed, and the trial needs to be replicated with other populations. Furthermore, this pilot only focuses on one brand of technology. Finally the amount of data collected from the pilot was substantial, preventing manual analysis of the clinical outcomes. Future work should compare different brands of devices for ease of installation/use and reliability and develop automated clinical data analytic techniques.

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