

Indirect Wayfinding Navigation System for the Elderly

Full Paper

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Abstract

Difficulty in wayfinding is one of the signs of ageing. Different types of people have the same difficulty in navigation including older people, people with mild dementia, mild cognitive impairment, and head injury. These problems do not only impact the person's life and expose them to different risks, but their caregivers also report personal issues such as depression. This study aims to address this issue by creating a smart phone application called Indirect Wayfinding (IW) that helps affected people and their caregivers by acting as a guide to the elderly person. This paper reviews and summarizes the shortages of the current GPS-based solutions that need to be overcome, and then proposes a solution that mainly uses geofencing technology. This paper outlines the conceptual design, the mobile application, an algorithm to detect the direction of the user, feedback on the design from the caregivers, and an evaluation of the geofencing technology.

Keywords

Elderly, Ageing, Alzheimer, Dementia, Technology, Geofencing, Wayfinding, Mobile health, Design Science Research.

Introduction

The number of elderly people over 60 year-old is expected to increase from 606 million today, to 2 billion by 2050 according to United Nation World Population prospects. According to researchers, major cognitive decline begins after age of 60 (Plassman et al., 1995; Rönnlund et al., 2005; Warner 1994; Zelinski & Burnight, 1997). Getting lost and general navigation difficulties are associated with cognitive decline. A Canadian study found that the prevalence of cognitive impairment no dementia (CIND) is 16.8%, which is 6.8% higher than all types of dementia combined (Graham et al. 1997). Another study investigated CIND in the Italian elderly population and found the prevalence to be 10.7% (Di Carlo et al., 2000). A study on African American shows that the prevalence of CIND is nearly one in four in community-dwelling elders, which is consistent with German (23.5%) and Finland (26.6%). Further, MUML (Medically Unexplained Memory Loss) has prevalence of 12.5% (Unverzagt et al. 2001). Elder population is also exposed to medically explained memory loss due to ageing illness such as Alzheimer Disease (AD).

Topographical disorientation (TD) is defined as "difficulty in orienting to, navigating through, and feeling familiar with one's surroundings" (Cherrier et al. 2001). TD is an early symptom of AD involving damage to hippocampus and parietal structures (Pai and Jacobs 2004). The authors conducted a study on 112 patients, 61 of them currently experiencing TD, 20 of them requiring escorts to their homes by others (EHBO), and 28 having TD as an incipient symptom. In addition, 88% of caregivers reported a high level

of concern when the patient with TD travels alone. Some of the caregivers used methods such as writing the address and name in the coat of the patient or carrying a band with their contact information. Researchers suggest that TD appears in early stages of AD (Henderson VW et al. 1989; Monacelli et al. 2003; Pai and Jacobs 2004; Serino et al. 2014). In addition, (Desai and Grossberg 2005) mention that many AD patients live at home with their older spouse. Age limitations of caregivers could be another factor in GL events, and a motivation in caregiver-patient dependence minimization. The burden of caregivers is not easy even for younger caregivers. According to (Desai and Grossberg 2005), caregivers spend 40-100 hours per week caring for AD patients; 90% of them are affected emotionally and 60% of them report significant depression. Difficulty in navigation is not limited to AD patients but it also includes elderly people, people with mild dementia, mild cognitive impairment, and head injury.

A severe case of wayfinding difficulty is getting lost (GL). According to (Tu and Pai 2006), GL is defined as a situation in which a patient finds himself or herself unable to return home or unable to get to specific destination. EHBO might not be needed if the patient could make a call, hire a cab, or use another method to find their way home. This problem not only affects the person but also their family caregivers. The families have taken different actions after the first GL event including giving the patient map, informing neighbors, or putting him or her on nursing home (Tu and Pai 2006). A study of normal community-dwelling elderly people between 58 and 80 year-old describes the issues of memory loss. One of the issues is forgetting while driving where several participants stated that they forget where they were going (Parsons et al. 2013). Another UK study on wayfinding while driving car on participants aged 21-85 found that elderly and female drivers find wayfinding more difficult while driving than young male drivers (Burns 1998).

GPS-based solutions seem to be a good candidate to address the “Wayfinding” issue. The problem that this study is addressing is the absence of GPS systems that minimize wayfinding difficulty incidents and improves the elderly person’s ability in outdoor wayfinding, taking in to consideration their poor cognitive ability and caregiver burden. In other words, increasing the intelligence of the application and minimizing the actions needed by the elderly person to find a way to the destination. This paper addresses the absence of solutions that address wayfinding difficulty at the individual level by allowing customization (Liu et al. 2008). In addition, the presented solution replaces the physical methods that label elderly people with their names and addresses on their coats or carrying bands with contact information; these methods could have a social impact on the elderly as well as put the patients in dangerous situation by attracting criminals.

In this study, a geo-fencing technique is used in a mobile app to predefine areas in which the person’s receive suggestions and information on the phone as he or she exists or enters a virtual geofence; the caregiver will also receive information when necessary about the elderly person’s situation and position. The proposed design allows each caregiver to use a web portal to make a list of suggested destinations, phone numbers, descriptions, and photos based on the location of the elderly person. Those lists will be sent to the elder’s phone upon existing or entering predefined geo-fences that were specified using a geo-fencing web services. This paper provides the background and motivation for this study, and then details the proposed solution and its main components. Finally, results from an evaluation of the proposed solution are reviewed and the pre-focus gathering requirements are presented as grounds to refine the design.

Background

Wayfinding is a major issue that impacts elderly people and different kinds of disabled people and their caregivers. (Tsai 2007) presented a novel QR code wayfinding system “WADER” in which the user chooses the destination in the beginning. The system has three parts: QR Code tags (2-D barcode that contains an encoded URL), handheld PDAs, and a tracking system. The PDA shows directions in a web browser in photo format. The efforts of (Carmien et al. 2005) focuses on public transportation; it uses GPS to create the “Personal Travel Assistant” prototype. For example, if a user is at a bus station, s/he can choose a destination in the handheld device and receive an update based on the GPS data from buses in the street. “Get ready” messages are sent as bus approaching, “please board now” when the bus arrives, “please get off” at the distention, and “do not forget your back bag.” (Liu et al. 2008) designed an interface in a handheld device that sends directions and prompts to the cognitive impaired users; these messages help them in an indoor wayfinding situation. That paper suggests that there is not a one-size-fit-all

solution; customization and adoptability are the most important aspects in designing guidance systems for people with cognitive impairments.

iWander is an android software that helps elderly wandering people using the mobile phone's GPS; the application is able to detect wandering behavior using pre-defined instructions (Sposaro et al. 2010). Another study has used ultra wide band RFID to precisely locate the elderly individual within 20 cm (Kearns et al. 2008). Sensors have also been used to prevent wandering by sending an alarm when the elderly person left home (Pollack 2005). In addition, a microcomputer device with sensing capability was also used to detect the person's location by communicating with an ultra sound transmitter (LoPresti et al. 2004). Monitoring and assisting the elderly in outdoor activities has been addressed in OutCare, the elderly person can use an easy-to-use phone application interface to obtain an alert like distance from home and/or caregivers on the other side can also request the location of the patient (Wan et al. 2010).

Design

This paper addresses elders' wayfinding issue using the design science research (DSR) methodology. (Hevner and Chatterjee 2010) defined DSR as a "research paradigm in which a designer answers questions relevant to human problems via the creation of innovative artifacts,...". DSR has three cycles: the relevance cycle in which the design is linked to the environment, the rigor cycle in which the design is linked and contributed to the knowledge base, and the design cycle that includes the actual building and evaluation of the artifact (Hevner 2007).

The proposed artifact Indirect Wayfinding (IW) system could help the elderly reach their destinations and guide them with minimal individual intervention. IW is a navigation system for early stages of Alzheimer persons, elderly people, and patients with mild to moderate cognitive impairment; it aims at increasing the elderly person's independence and decreasing the caregiver's burden. The system will use geofencing technology to push messages to the elderly person based on their location. The solution provided is a phone application that acts as smart companion that detects the elderly persons location and suggests possible destinations based on his or her location and heading direction. This research is divided into three stages: 1) the conceptual design of the entire system, 2) the development of the initial components of the system including the geo-fencing enabled mobile app, novel geofencing tessellation architecture as well as novel direction detection algorithm, and 3) a pre-focus requirement gathering to refine and solidify the solution and make it relevant to its environment.

Novelty and Improvement of IW

No current solution has used geofencing techniques as a way of creating wayfinding system for elderly people. There are four advantages of using such a technique. First, the elderly person will be monitored and sent guidance from the moment he or she leaves the home until he or she returns home. This guidance includes warning of dangerous areas or city limit, thereby reducing the elderly person's need to take action steps such as writing a destination or pressing an alarm. Second, the caregivers' burden will be minimized, such that in the case they are not available, their inputs and instructions will be mimicked by the application and the application will be triggered automatically. Third, geofencing applications can work on any Android or iOS device which makes it easier to use, and does not require tracking devices that are expensive or could be a sign of illness. Finally, the elderly person will feel more independent.

In addition to the uniqueness of using geofencing and its advantages, this solution avoids different assumptions found in the previous GPS solutions. These past designs depend on one or more of the following assumptions. First, *caregivers are always present and available for the elderly person*; this is not the case in real life and the number of GL incidents is proof of that (Pai and Jacobs 2004; Tu and Pai 2006). The second assumption is that *the elderly person with cognitive impairment can rely on himself or herself on choosing the destination that they want to go to or can be aware that he is lost or in trouble*. Therefore, some solutions ask the elderly person with dementia to type the destination or to do something to summon help in wayfinding or rescue. However, this assumption is not acceptable as topographical disorientation appears in early stages of patient life (Henderson VW et al. 1989; Monacelli et al. 2003; Pai and Jacobs 2004; Serino et al. 2014). The third assumption is that *battery and reliability are not important when using the GPS in the mobile device*. GPS-based mobile systems should always pay attention to the battery drain and reliability of the system. Increasing the battery life of the mobile

device will make it a proper device to help elderly people because of its cost and availability. GPS drains the battery of the mobile device, which results in an unusable solution. On the other hand, the reliability of the designed solution should also be required because usually battery drain and accuracy are trade-offs. Several studies have tried to solve this issue by developing several location-based mobile services that provide acceptable accuracy while consume less battery (Huang et al. 2013; Lin et al. 2010; Loyola et al. 2013). Similar techniques should be considered in designing a mobile application that uses GPS to help cognitively impaired people. The fourth assumption is that *an optimal solution can be achieved without studying the persons and caregivers requirements and without the need to receive feedback from domain experts*. (Carmien et al. 2005) reports that the standard tool sets often fail because people with mental disability do not have the cognitive requirements needed to run these tools, and encourages the development of specialized tools for those who suffer mental disability that substitute current standard tools. To reach that, elderly people either with dementia or no dementia and/or caregivers should be involved in the design of GPS based solutions to receive the maximum benefit.

Preliminary Design of IW

Elderly people vary in their needs. Therefore, a solution needs to provide the ability to handle wayfinding issues at two levels: for the elderly person herself or himself (*personnel places*) and for the group of elderly people within a particular city (*public places*).

IW consists of three main parts which are mobile app, geofencing service, and web portal. Each city will have general geofences around specific public areas such parks and hospitals. These areas will be “geofenced” for the use of all the users within a city. Caregivers will have the ability to create a list of the places that the elderly person needs at the user level such as home, relatives home, friend home, or bank using a *web portal*. Then, *geofencing server* can be used to create and update these geofences. The elderly person will download an *application on a smart phone*. This application tracks the location, movement, and directions of the elderly person. When the elderly person leaves a geofence, two things will happen. First, it will detect that the user is exiting the geofence, and the system might notify the authorized caregiver via an email, app notification, or text message. Second, the application will detect which direction the elderly person is headed. Based on the direction, the elderly person will obtain a URL that has a list of destination options created in the web portal. The elderly person can click on any destination to activate the turn-by-turn navigation or make on-click call. As the elderly person moves, these options are reduced and become more precise. When the elderly person reaches a destination, the caregiver may be notified. When the elderly person exits this place, again the direction is recalculated and the application will suggest “home” first, along with the recalculated suggested destinations. If the elderly person is headed to another geofence, the same procedures will repeat. However, several mini-artifacts are required to link the three main artifacts of IW and enable them to address wayfinding issue collectively.

Geofencing Tessellation Architecture

Using the personal and general information described above, a city-wide geofencing tessellation architecture will be developed in this section. Four types of geofences are needed. To simplify the understanding of the architecture, each type is denoted with a unique symbol and description (Table 1).

Real Life Scenario Explaining

Elderly person (EP) lives in the city of Rancho Cucamonga, and is being taken care of by caregiver (C). They live together, and C is asked what places does EP visit frequently? (elder’s dependent geofences). They list 3 places X, Y, and Z. The city of the Rancho Cucamonga has five public places (elder’s independent geofences) which are represented by A, B, C, D, and E. The total geofences that EP needs in this case are 10 which include three dependent geofences, five independent geofences, home, and the city limit.

Having identified EP and C required geofences, we can then create these geofences in the map using geofencing editor portal. Figure 1 illustrates all of these geofences in Rancho Cucamonga. The starting point is the elder person’s home, and there are four possible directions that the elderly person can take. The large circle indicates the city limit where existing home means entering the city.





Type	Symbol	Description
Elderly Person's Home		Geofence around the elderly person's home.
Elderly Person's Dependent Geofences		These geofences vary from one elderly person to another.
Elderly Person's Independent Geofences		These geofences are the same for all elderly people in the same city, including city limits.
Control Geofences		Geofences that indicate no specific destination.

Table 1. Geofences' Types and descriptions

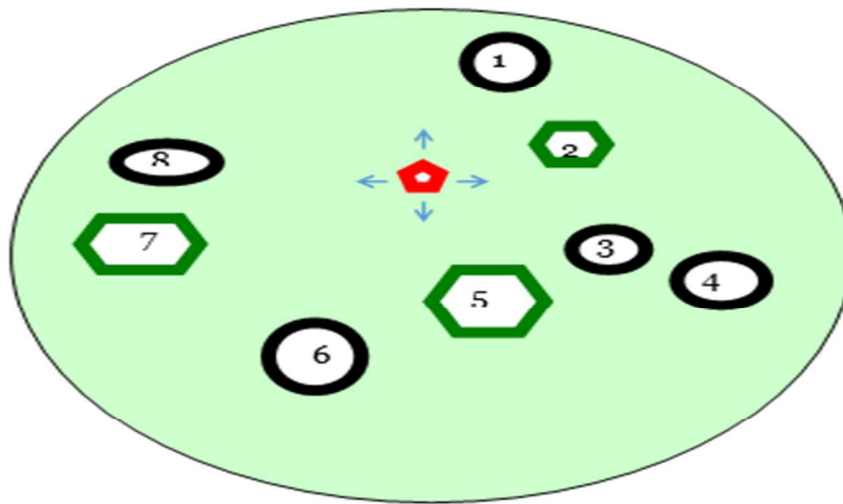


Figure 1: Personnel and public geofences.

Since not all the geofencing services provide the direction of the user, leaving home does not show what direction is the elderly person heading. The difficulty here is how to detect the direction in which the elderly person is exiting a particular geofence? To address this issue, *control geofences* are used; four control CGs will surround each geofence, in this case home. Each CG will be assigned a number from 1 to 4. Figure 2 shows these CGs. In this scenario, when EP exits home and enters CG number 1, the direction of movement is *south*. At this point, C might be notified that EP left home heading south. In addition, EP on the other end should receive all destinations in “south” direction. To overcome the issue of exiting, CGs from the left or right side which means different direction other than south (in this case east or west), even CGs (2 and 4) are stretched over odd control geofences (1 and 3). If EP exits 1 and enters geofence 2 or 4 not the city, the system will detect the change in direction. To make it controllable in the system, if the approached CG is odd then its *neighbors control geofences* (NCG) will be even, and vice versa.

At this point, all the options are addressed when the elderly person leaves home. The direction will be detected and the destinations will be listed. Assume EP has been confirmed as moving south. Mostly EP has a destination in mind. The list of destinations in this case will be geofences 6 and 5. Let's assume that EP is going to geofence 6. Since procedural memory stimulation is encouraged in mild and moderate AD patients (Zanetti et al. 2001), the system will stimulate EP's memory. EP will be provided with information about the two destinations in the system. This information includes names, phone numbers, description, and route map. The system will track EP, whether he or she entered geofence 6 or not. If EP enters geofence 6, a notification message might be sent to C stating that EP is at location 6. When EP exits the geofence 6, the same procedure will be repeated (as if EP exits home), but now home will be the first option since the current geofence is not home. The reason behind the emphasis on home is that most of the getting lost and wayfinding difficulty occurs when trying to return home not to other destinations (Sheehan et al. 2006).

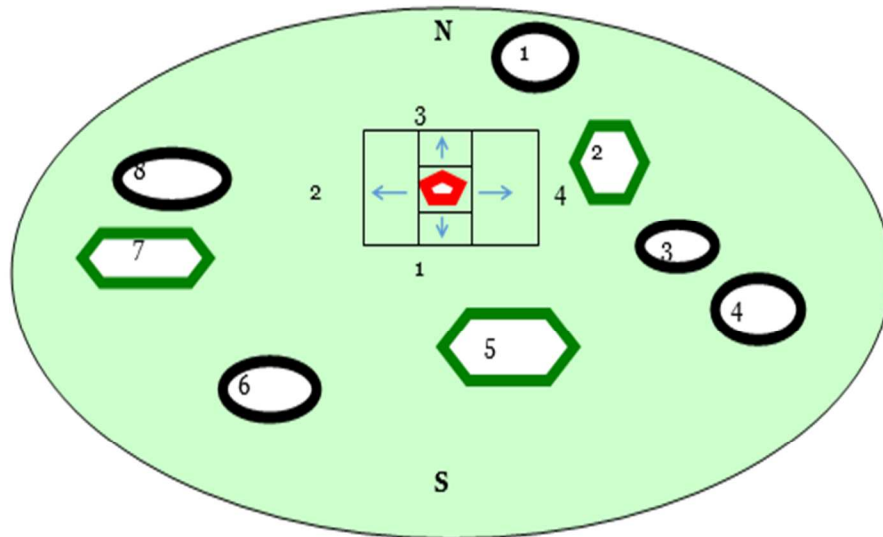


Figure 2: Personal, public, and control geofences.

Computer-aided telephones help cognitively impaired people in making phone calls independently with one click instead of using keys which might be difficult, as well as photos of the caregiver might further facilitate the task (Perilli et al. 2012). Therefore, the application will provide EP with the ability to make a call and/or turn-by-turn guidance.

What if EP did not reach any destination and wandered in the city? To solve this issue in our design, the time needed to reach the Farthest Destination in the Detected Direction (FDDD) is used, $FDDD = \text{Max}(d_1, d_2, d_3, \dots, d_n)$; where d is the estimated time needed to reach the destination. FDDD will be dynamically calculated every time a geofence is exited and direction is confirmed. When EP exceeded FDDD the system will declare emergency and might notify C. At this point, the system will also generate two options to the elderly person which are one-click call and route map to home in addition to the new options based on the new direction, if any. Passing the city limit is another possible option. When EP exits the city limit, the system will notify C and suggest home and phone calls associated with pictures and names. To know which direction the EP left the city, control geofences similar to “home” will be used around the city.

What if EP left home with no specific destination and then decided to go to specific destination? In this case, we will use the CCG (City Control Geofences), these geofences are spread all over the city. CCG will be used along with the CG to detect the direction and show suggestions. When EP enters and exits these CCG, the direction will be recalculated and the option will be updated. Figure 3 shows a map of how the tessellation of CCG will be in the city. The distance between each two CCG should be of the same size and large to avoid frequent recalculation.

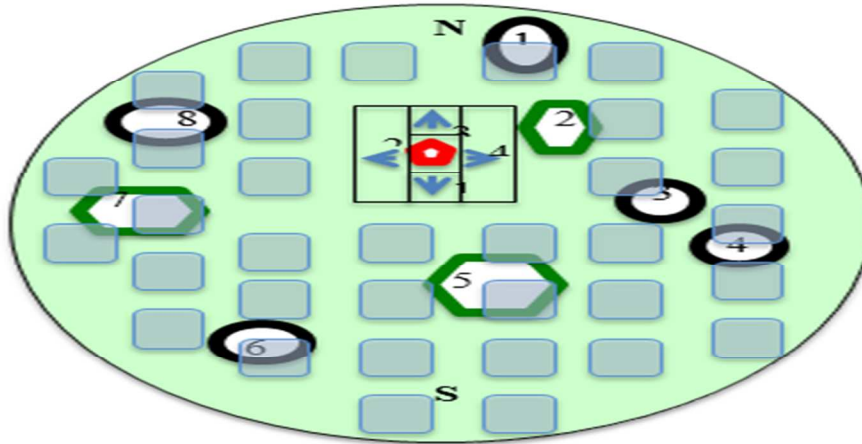


Figure 3: City Control Geofence Tessellation used to correct the direction and detect patient wandering.

Based on the above-proposed framework and architecture components, the next mini-artifact of the final design is pseudopod of *Direction Detection Algorithm (DDA)*:

```

If EP exits home and enters CG 1
{
  Set
    NCG = even
    Possible Direction = South
  Then {
    If EP exits CG 1 and enters home
      EP returned home
    Else if EP exits control geofence and enters control geofence
      2 or 4
      Repeat the procedures: with CG 2 or 4 and set NCG = odd
    Else {
      Confirm direction = south
      Provide EP with suggested destinations
      Calculate FDDD
      If FDDD is exceeded then
        Declare possible emergency
      }
    }
  }
}

```

Notification Structure

Being able to detect the elderly person's direction, we can now assign the triggers in each geofence type that guarantees complete guidance and monitoring (Table 2). The notification structure in IW is divided into two types. The first and main type is the ones that triggers and appears in the elderly persons mobile phone when geofence condition (exit or enter) is satisfied. The second type is the call back notifications that the caregivers receive when there is a need to inform them about an event.

This preliminary design of the notification would use the notification system in the phone device. Since these notifications do not allow much information to be presented, a URL links will be embedded in the message. For example, informing the caregiver that the elderly person has returned home or providing the elderly person with the name of destination reached can be do through the notification message (figure 4). Providing the elderly person with list of destination options and/or picture and information of the caregiver with one click call will be in the embedded URL (figure 5).

Events	Wayfinding Actions (Elder person)	Monitoring Actions (Caregiver)
Elderly person left home and direction confirmed	1. Send list of possible destinations based on the calculated direction	1. Elderly person left home
Elderly person reached X destination	1. Send “You reached X destination”	None
Elderly person could not reach X destination (exceeded FDDD)	1. Recalculate direction and list new destination options. 2. One-click caregiver call and suggest “home” route.	1. Notify caregiver of location
Elderly person reached and left X destination successfully	1. Show Home rout map. 2. Show recalculated destinations.	None
Elderly person passed city limits	1. Home route map 2. One click caregiver call.	1. Send elderly person location. 2. Send elderly person left the city.
Elderly person Returned Home	None	1. Elderly person at home.

Table 2. Notifications and actions per events and per user.

The Instantiation

An iPhone application has been developed to test two things: the functionality of this service in the system and the accuracy and battery efficiency. The functionality of this application included: access to the users’ longitude and latitude, communication with the geo-trigger server, and obtaining push notifications from Apple push notification server. Using the geo-trigger SDK, the tracking profile mode was adjusted from Fine to Adaptive and vice versa.

The application was successful in receiving push notifications when the user enters or exits predefined geofences. A circular geofences have been created to test how the application will work. The application was able to receive notifications when the users enter and leave the geofences. Figure 6 shows the real geofences using “geotrigger editor tool” and the corresponding notifications when these geofences were physically tested using our iPhone application.



Figure 4: Prototype showing the notification.

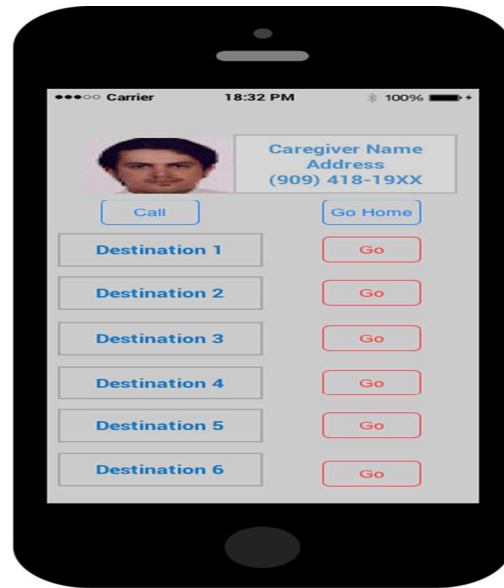


Figure 5: Prototype showing the list of options the patient will receive based on his or her location.

Pre-focus requirement Gathering

The initial parts of the system have been tested. The geofencing service has been evaluated to assess how it should be used to reduce the battery drain while keeping an acceptable level of accuracy. In addition, the problem and solutions were discussed with caregivers to refine the proposed design.

Geofencing Reliability, Accuracy, and Battery Drain

Geofencing is the main technology behind this design. The application was tested physically 240 times in different geofence sizes 20m-70m radii using two different levels of GPS tracking updates. The first level is the most frequent and accurate level of updates, and the second level reduces the tracking updates of the user position to save battery. Results showed 100% accuracy in geofences as small as 20m radius and above when using the most frequent location updates. However, battery consumption at such levels is very high. On the other hand, when location updates are less frequent, savings up to 15.2% of the battery drain are reached with 100% accuracy at 70m geofences radius and above. Therefore, less frequent location updates will be used in this system to track elderly people to save battery life, and the system will only use geofences equal or larger than 70m radius geofences. Thus, reliability and accuracy are achieved.

Caregivers Feedback on the Overall Design

The conceptual design (described above) has been discussed with two family caregivers and an Assistant Professor of neurology who teaches and practices at a university hospital. The family caregivers added no comments to the design, and confirmed that their burden is high and such solutions will be helpful. The doctor mentioned that the system could help AD patients as well as people over 65 years of age. However, the doctor reported that this system should focus only on early stages AD patients as it would be difficult to apply the system in severe cases.

In addition, the doctor offered several important suggestions that could improve the design. First, the doctor suggested that the application should have limited functionality and focus only on necessary functions and that the application should be easy to adopt with short training times. Second, the doctor disagrees with the public location mapping. He asserts that adding too many locations to the system will confuse the elderly person. Therefore, he suggested making location suggestions limited to personal and important locations. Therefore, we will limit the suggested destinations to the personal level and exclude

the public level. Finally, the doctor supported using the direction as a base for the initial suggestion as it limits the suggested destinations and will lessen the elderly person's confusion.

Finally, the doctor affirmed that this system would also help the elderly person in unfamiliar areas when the elderly person moves to a new city or new part of the city; such occurrences cause much confusion. The doctor also supported the use of photos and that they should not be limited to the caregivers but should include every user such as other family members or their doctors.

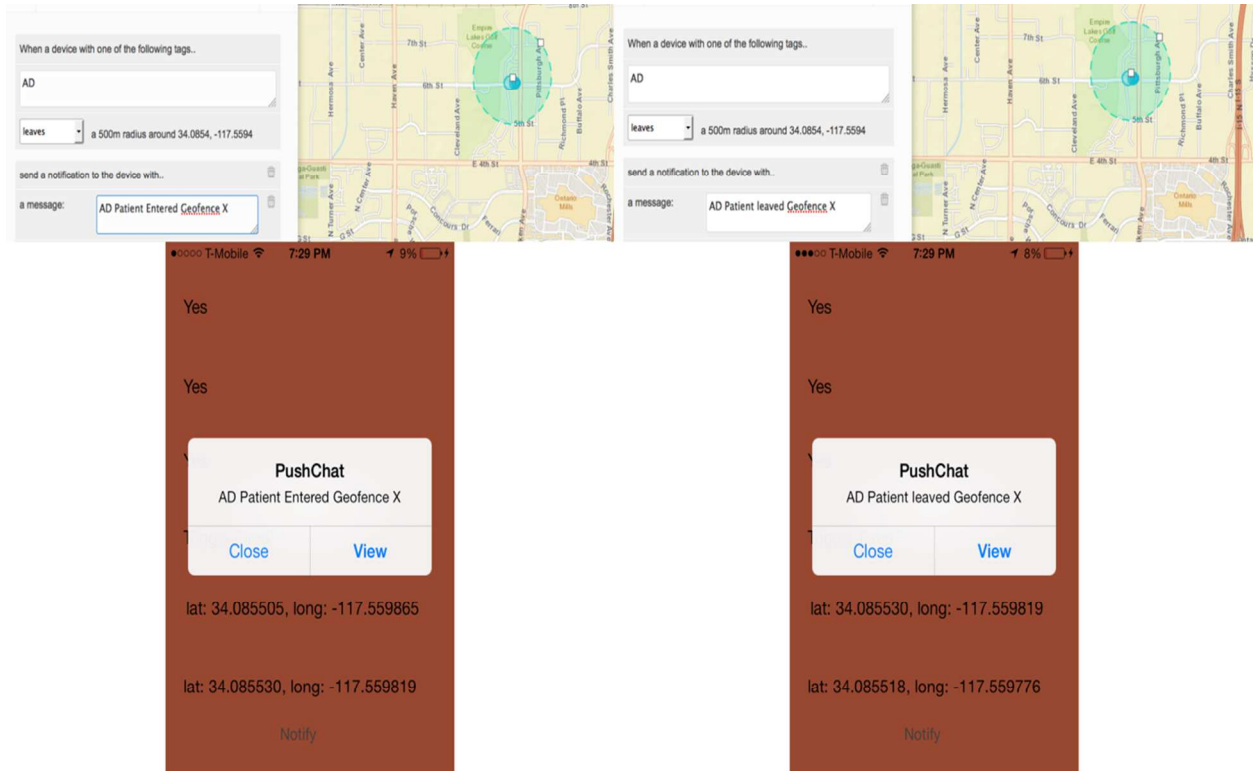


Figure 6: The geo-trigger editor portal and app notifications received when the application was tested in both enter and exit condition; it also shows that the longitude and latitude were obtained.

Conclusion

This paper addresses elders' wayfinding issue using design science research (DSR) methodology. IW is a mobile app that communicates with geofencing server and web server to provide a comprehensive solution to wayfinding problem. The proposed solution aims at reducing the burden of elders' caregivers and increasing the independence of elders. The final deliverable consists of several mini-artifacts and iterations to be built. The components were built in lights of the three DSR cycles. The first cycle is relevance that links the research to the contextual environment. In this study, a doctor and family caregivers have been involved in problem definition and solution, and the technology was evaluated. Secondly, this problem is grounded and examined in the both ageing and technology literature to ground for the problem. Further, this study contributed to the knowledge base by providing a novel way of solving wayfinding issue through technology, evaluation of geofencing service, design specifications of elders' mobile solutions, city geofencing framework and architecture, an algorithm to detect direction in geofencing technology, and surveying the weakness of previous GPS solutions. This grounding and additions to knowledge base are the second cycle of DSR which is rigor cycle.

The third design research cycle is the design cycle; this cycle includes the actual construction of the design and the evaluation. In this study, the entire system has been conceptually designed, several foundation

components were developed, and the required technologies have been evaluated via developing a mobile application. The reliability and accuracy of the geofencing technology have been also tested. The pre-focus gathering requirements indicate that the system design will be as presented with some changes based on the above mentioned caregiver comments. It will use geofences larger than 70m radius with less frequent position tracking updates to save more than 15% of battery with 100% accuracy. If shapes other than circles are needed, the shape in the server will be created in such a way that its size is able to fit in a circle with 70m radii. In addition, designed direction detection algorithm has been constructed and tested. Those components or mini-artifacts along with the web portal are necessary to build the final artifact. The remaining and available components of the proposed system will be put together and evaluated with elderly people to add more rigor and relevance by wayfinding improvement after using the system.

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REFERENCES

- Burns, P. C. 1998. "WAYFINDING ERRORS WHILE DRIVING," *Journal of Environmental Psychology* (18:2), pp. 209–217 (doi: 10.1006/jevp.1998.0077).
- Carmien, S., Dawe, M., Fischer, G., Gorman, A., Kintsch, A., and Sullivan, J. F., JR. 2005. "Socio-technical Environments Supporting People with Cognitive Disabilities Using Public Transportation," *ACM Trans. Comput.-Hum. Interact.* (12:2), pp. 233–262 (doi: 10.1145/1067860.1067865).
- Cherrier, M. M., Mendez, M., and Perryman, K. 2001. "Route learning performance in Alzheimer disease patients," *NEUROPSYCHIATRY NEUROPSYCHOLOGY AND BEHAVIORAL NEUROLOGY* (14:3), pp. 159 – 168.
- Desai, A. K., and Grossberg, G. T. 2005. "Diagnosis and treatment of Alzheimer's disease," *Neurology* (64:12 suppl 3), pp. S34–S39 (doi: 10.1212/WNL.64.12_suppl_3.S34).
- Di Carlo A, Baldereschi M, Amaducci L, Maggi S, Grigoletto F, Scarlato G, and Inzitari D. 2000. "Cognitive impairment without dementia in older people: prevalence, vascular risk factors, impact on disability. The Italian Longitudinal Study on Aging.," *Journal of the American Geriatrics Society* (48:7), pp. 775–782.
- Graham, J. E., Rockwood, K., Beattie, B. L., Eastwood, R., Gauthier, S., Tuokko, H., and McDowell, I. 1997. "Prevalence and severity of cognitive impairment with and without dementia in an elderly population," *The Lancet* (349:9068), pp. 1793–1796 (doi: 10.1016/S0140-6736(97)01007-6).
- Henderson VW, Mack W, and Williams B. 1989. "Spatial disorientation in alzheimer's disease," *Archives of Neurology* (46:4), pp. 391–394 (doi: 10.1001/archneur.1989.00520400045018).
- Hevner, A. 2007. "A Three Cycle View of Design Science Research," *Scandinavian Journal of Information Systems* (19:2) (available at <http://aisel.aisnet.org/sjis/vol19/iss2/4>).
- Hevner, A., and Chatterjee, S. 2010. "Design Science Research in Information Systems," in *Design Research in Information Systems Integrated Series in Information Systems*, Springer US, pp. 9–22 (available at http://link.springer.com/chapter/10.1007/978-1-4419-5653-8_2).
- Huang, Y., Tomasic, A., An, Y., Garrod, C., and Steinfeld, A. 2013. "Energy efficient and accuracy aware (E2A2) location services via crowdsourcing," in *2013 IEEE 9th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob)*, Presented at the 2013 IEEE 9th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), , October, pp. 436–443 (doi: 10.1109/WiMOB.2013.6673396).
- Kearns, W. D., Algase, D., Moore, D. H., and Ahmed, S. 2008. "Ultra wideband radio: A novel method for measuring wandering in persons with dementia," *Gerontechnology* (7:1) (doi: 10.4017/gt.2008.07.01.005.00).
- Lin, K., Kansal, A., Lymberopoulos, D., and Zhao, F. 2010. "Energy-accuracy Trade-off for Continuous Mobile Device Location," in *Proceedings of the 8th International Conference on Mobile Systems, Applications, and Services MobiSys '10*, New York, NY, USA: ACM, pp. 285–298 (doi: 10.1145/1814433.1814462).
- Liu, A. L., Hile, H., Kautz, H., Borriello, G., Brown, P. A., Harniss, M., and Johnson, K. 2008. "Indoor wayfinding: Developing a functional interface for individuals with cognitive impairments,"

- Disability and Rehabilitation: Assistive Technology* (3:1-2), pp. 69–81 (doi: 10.1080/17483100701500173).
- LoPresti, E. F., Mihailidis, A., and Kirsch, N. 2004. “Assistive technology for cognitive rehabilitation: State of the art,” *Neuropsychological Rehabilitation* (14:1/2), pp. 5–40 (doi: 10.1080/09602010343000101).
- Loyola, L., Wong, F., Pereira, D., and Sanson, H. 2013. “Extending Battery Lifetime of Mobile Devices with Geofence Capabilities on Dynamic-speed Urban Environments,” in *Proceedings of the Second ACM SIGSPATIAL International Workshop on Mobile Geographic Information Systems MobiGIS '13*, New York, NY, USA: ACM, pp. 51–58 (doi: 10.1145/2534190.2534193).
- Monacelli, A. M., Cushman, L. A., Kavcic, V., and Duffy, C. J. 2003. “Spatial disorientation in Alzheimer’s disease The remembrance of things passed,” *Neurology* (61:11), pp. 1491–1497 (doi: 10.1212/WNL.61.11.1491).
- Pai, M.-C., and Jacobs, W. J. 2004. “Topographical disorientation in community-residing patients with Alzheimer’s disease,” *International Journal of Geriatric Psychiatry* (19:3), pp. 250–255 (doi: 10.1002/gps.1081).
- Parsons, K., Surprenant, A., Tracey, A.-M., and Godwin, M. 2013. “Community-dwelling older adults with memory loss,” *Canadian Family Physician* (59:3), pp. 278–285.
- Perilli, V., Lancioni, G. E., Singh, N. N., O’Reilly, M. F., Sigafos, J., Cassano, G., Cordiano, N., Pinto, K., Minervini, M. G., and Oliva, D. 2012. “Persons with Alzheimer’s disease make phone calls independently using a computer-aided telephone system,” *Research in Developmental Disabilities* (33:4), pp. 1014–1020 (doi: 10.1016/j.ridd.2012.01.007).
- Plassman, B. L., Welsh, K. A., Helms, M., Brandt, J., Page, W. F., and Breitner, J. C. S. 1995. “Intelligence and education as predictors of cognitive state in late life A 50-year follow-up,” *Neurology* (45:8), pp. 1446–1450 (doi: 10.1212/WNL.45.8.1446).
- Pollack, M. E. 2005. “Intelligent Technology for an Aging Population: The Use of AI to Assist Elders with Cognitive Impairment,” *AI Magazine* (26:2), pp. 9–24.
- Rönnlund, M., Nyberg, L., Bäckman, L., and Nilsson, L.-G. 2005. “Stability, Growth, and Decline in Adult Life Span Development of Declarative Memory: Cross-Sectional and Longitudinal Data From a Population-Based Study,” *Psychology and Aging* (20:1), pp. 3–18 (doi: 10.1037/0882-7974.20.1.3).
- Serino, S., Cipresso, P., Morganti, F., and Riva, G. 2014. “The role of egocentric and allocentric abilities in Alzheimer’s disease: A systematic review,” *Ageing Research Reviews* (16), pp. 32–44 (doi: 10.1016/j.arr.2014.04.004).
- Sheehan, B., Burton, E., and Mitchell, L. 2006. “Outdoor wayfinding in dementia,” *Dementia* (5:2), pp. 271–281 (doi: 10.1177/1471301206062254).
- Sposaro, F., Danielson, J., and Tyson, G. 2010. “iWander: An Android application for dementia patients,” in *2010 Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, Presented at the 2010 Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), , August, pp. 3875–3878 (doi: 10.1109/IEMBS.2010.5627669).
- TSAI, S.-K. 2007. “WADER: A Novel Wayfinding System with Deviation Recovery for Individuals with Cognitive Impairments,” in *Proceedings of the 9th International ACM SIGACCESS Conference on Computers and Accessibility Assets '07*, New York, NY, USA: ACM, pp. 267–268 (doi: 10.1145/1296843.1296906).
- Tu, M.-C., and Pai, M.-C. 2006. “Getting lost for the first time in patients with Alzheimer’s disease,” *International Psychogeriatrics* (18:03), pp. 567–570 (doi: 10.1017/S1041610206224025).
- Unverzagt, F. W., Gao, S., Baiyewu, O., Ogunniyi, A. O., Gureje, O., Perkins, A., Emsley, C. L., Dickens, J., Evans, R., Musick, B., Hall, K. S., Hui, S. L., and Hendrie, H. C. 2001. “Prevalence of cognitive impairment Data from the Indianapolis Study of Health and Aging,” *Neurology* (57:9), pp. 1655–1662 (doi: 10.1212/WNL.57.9.1655).
- Wan, J., Byrne, C., O’Hare, G. M. P., and O’Grady, M. J. 2010. “OutCare: Supporting Dementia Patients in Outdoor Scenarios,” in *Knowledge-Based and Intelligent Information and Engineering Systems Lecture Notes in Computer Science*, R. Setchi, I. Jordanov, R. J. Howlett, and L. C. Jain (eds.), Springer Berlin Heidelberg, pp. 365–374 (available at http://link.springer.com/chapter/10.1007/978-3-642-15384-6_39).
- Warner, K. 1994. “The course of adult intellectual development,” *American Psychologist* (49:4), pp. 304–313 (doi: 10.1037/0003-066X.49.4.304).

- Zanetti, O., Zanieri, G., Giovanni, G. D., Vreese, L. P. D., Pezzini, A., Metitieri, T., and Trabucchi, M. 2001. "Effectiveness of procedural memory stimulation in mild Alzheimer's disease patients: A controlled study," *Neuropsychological Rehabilitation* (11:3-4), pp. 263-272 (doi: 10.1080/09602010042000088).
- Zelinski, E. M., and Burnight, K. P. 1997. "Sixteen-year longitudinal and time lag changes in memory and cognition in older adults," *Psychology and Aging* (12:3), pp. 503-513 (doi: 10.1037/0882-7974.12.3.503).