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ORIGINAL ARTICLE

Implementing technology-based embedded assessment in the home and community life of individuals aging with disabilities: a participatory research and development study

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Abstract

Purpose: The goal of the study was to investigate the accuracy, feasibility and acceptability of implementing an embedded assessment system in the homes of individuals aging with disabilities. *Method*: We developed and studied a location tracking system, *UbiTrack*, which can be used for both indoor and outdoor location sensing. The system was deployed in the homes of five participants with spinal cord injuries, muscular dystrophy, multiple sclerosis and late effects of polio. We collected sensor data throughout the deployment, conducted pre and post interviews and collected weekly diaries to measure ground truth. *Results*: The system was deployed successfully although there were challenges related to system installation and calibration. System accuracy ranged from 62% to 87% depending upon room configuration and number of wireless access points installed. In general, participants reported that the system was easy to use, did not require significant effort on their part and did not interfere with their daily lives. *Conclusions*: Embedded assessment has great potential as a mechanism to gather ongoing information about the health of individuals aging with disabilities; however, there are significant challenges to its implementation in real-world settings with people with disabilities that will need to be resolved before it can be practically implemented.

Keywords

Aging, disability, embedded assessment, indoor–outdoor combined, location sensing, rehabilitation, smart home

History

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➤ Implications for Rehabilitation

- Technology-based embedded assessment has the potential to promote health for adults with disabilities and allow for aging in place. It may also reduce the difficulty, cost and intrusiveness of health measurement.
- Many new commercial and non-commercial products are available to support embedded assessment; however, most products have not been well-tested in real-world environments with individuals aging with disability.
- Community settings and diverse population of people with disabilities pose significant challenges to the implementation of embedded assessment systems.

Introduction and motivation

Embedded assessment is an approach to monitoring, preventing and compensating for age or disability related health changes [1]. Sensors and software systems embedded in home and community automate data capture, provide objective measures of an individual's behavior and detect meaningful changes over time. Embedded assessment is an outgrowth of developments in pervasive and ubiquitous computing as well as developments in health sciences that are being driven by the development of low-powered, low cost sensors and sophisticated algorithms for behavior recognition. Examples of embedded assessment range from smart homes to consumer personal health technologies. Embedded assessment has been used to measure a wide range of variables including location and movement, task completion, activities of daily living (e.g. brushing teeth, getting out of bed), physiologic measures (e.g. heart rate, galvanic skin response, pulse), sleep and falls and rehabilitation specific tasks such as back training and stroke rehabilitation [2,3].

Embedded assessment has been proposed as a means for leveraging technology to promote health for aging adults and to allow for aging in place [4,5]. Embedded assessment can serve several functions including: (a) monitoring (e.g. to measure current functional performance and positive and negative changes or to support early identification of disease and monitor disease progression), (b) prevention (e.g. to use data gathered to plan interventions that will promote health and (c) compensation (e.g. to provide compensatory support for memory loss or to make caregiving more efficient and manageable) [1].

The development and implementation of these technologies is particularly important to people aging with disabilities. These individuals may experience conditions that are related to their

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Table 1. Participant demographics and home characteristics.

Participant	Gender	Age	Diagnosis	Mobility aids used	Home size (ft^2/m^2)	Style/# of rooms in home	Weeks of study
1	M	81	LEP	Cane	1350/120	House/8	6
2	F	69	SCI	Powered and manual wheelchair/2 canes	520/50	1 Bed Apt/4	6
3	M	69	SCI	Manual wheelchair	700/68	House/5	3
4	F	46	MD	Powered wheelchair	1390/128	House/13	3
5	F	60	MS	None	1185/110	House/9	3

primary diagnosis including, but not limited to fatigue, pain, sleep disorders, reduction of mobility and falls [6]. If left untreated, these secondary conditions can lead to worsening of symptoms or other complications, such as broken bones from falls or pressure ulcers from lack of movement. While there are many evidence-based strategies available to help reduce the onset, intensity and duration of secondary conditions, most of these are implemented after problems have already developed. If these problems were dealt with or anticipated earlier, then complications and worsening of symptoms could be avoided [7–9]. As individuals with disabilities age, they have an increase in symptoms and therefore secondary conditions, which highlights the importance of preventative care [10–12]. The use of continuous monitoring and self-management techniques are ways to encourage preventative care to reduce the incidence or impact of possible secondary conditions.

Although many new forms of embedded assessment have been developed and tested in research environments, very few have been implemented in community settings. In this study, we designed, developed and field-tested an indoor–outdoor-combined location sensing system, *UbiTrack*, with community dwelling individuals who are aging with disabilities. Location is a good measure of life space mobility, that is, the extent to which individuals venture out into their community and the assistance they require to do so [13–15]. The indoor/outdoor nature of our system facilitates measurement of the full range of an individual's life space. Location is also an important element of a system for measuring physical activity. As Chen et al. [16] note, there are three different classes of sensors that have been used in activity monitoring, including movement sensors (e.g. accelerometers, pedometers, gyroscopes), physiological sensors (e.g. heart rate, blood pressure, breathing frequency) and contextual sensors [e.g. Global Position System (GPS), RFID, measures of ambient conditions such as light/sound]. These types of sensors have been used in various combinations to acquire an accurate view of physical activity in different settings [17–21]. Location by itself is an imperfect proxy for physical activity because physical activity can occur without a change in location (e.g. exercising on a treadmill) and location can change without physical activity (e.g. traveling in a car). Thus, our system is a first step in developing a complete measure of physical activity in a community setting, but is incomplete without the addition of other measures (e.g. accelerometry).

Our long-term goal is to develop a complete measure of physical activity by adding additional types of sensor; however, in this study our goal was to investigate the accuracy, feasibility and acceptability of implementing an embedded assessment system in the homes of individuals aging with disabilities. We wanted to answer three research questions:

(1) How feasible is it to implement the system in the home and community settings of people aging with disabilities?
(2) How accurate are the location data collected by the system?
(3) How acceptable is it for participants to have the system installed in their home and how easy is it for them to use the system on a daily basis?

Methods

Participants

We implemented UbiTrack in the home and community environments of five participants with disabilities who were 45 years of age or older. The participants were recruited from a pool of individuals who had completed a large-scale survey project for the NIDRR-funded Rehabilitation Research and Training Center on Aging with Physical Disabilities. Application was made to the University of Washington Human Subjects Division in the Office of Research for approval to conduct this research. Approval was granted and subjects were consented using the IRB approved format. We did not apply exclusion criteria or screen participants based on their home setting or the nature or severity of their disability. Rather, we wanted to investigate feasibility within the context of the ''real-world'', naturally occurring challenges that might be found in a large-scale implementation.

Table 1 shows demographic data about participants. Participants ranged in age from 46 to 80 years and included two males and three females. Two participants had spinal cord injuries (SCIs), one had muscular dystrophy, one had multiple sclerosis (MS) and one had late effects of polio (LEP). Participants used a range of mobility devices including single canes, dual canes, and manual and powered wheelchairs. UbiTrack was installed in participants' homes which ranged in size from 520 to 1390 ft^2 and had 4–13 rooms.

Instrumentation

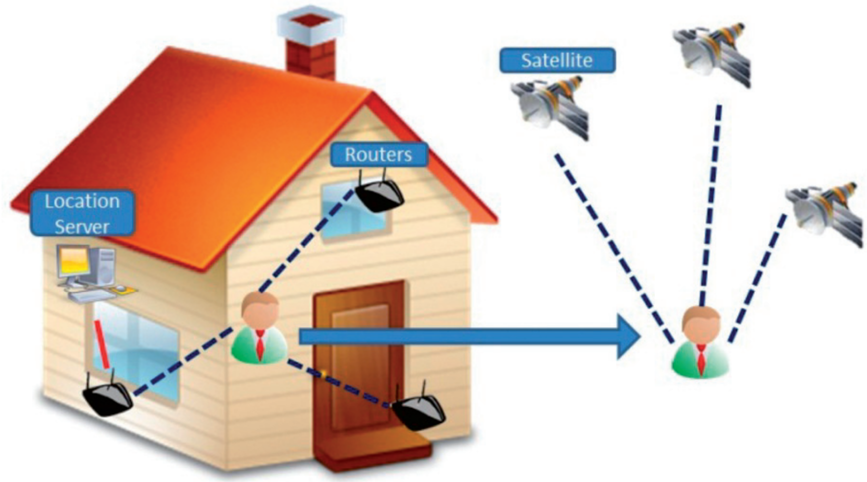
The location sensing system we developed, UbiTrack, consists of three components: a portable sensor ''tag'', the location sensing system and visualization software.

Sensing tag

The sensing tag includes two parts, a WiFi tag for indoor tracking and a GPS logger for outdoor tracking (see Figure 1). One side of the tag (black) is part of the Ekahau T301A WiFi tag (http://www.ekahau.com/products/wi-fi-tags.html) used in the indoor location tracking. The other side (white) is the GPS logger used in collecting the data of outdoor activities. In order to ease the burden on our participants, the tag needed to be as small, compact and easy-to-use as possible. We removed part of the T301A tag and designed a new cap to integrate the GPS logger with the tag. We choose iBlue 860E (http://gpsdatalogger.thebestpricegps.com/i-blue-860e-mini-gps-datalogger-receiver/) as our GPS data logger because of its compactness. It is the smallest GPS data logger we can find in the market. The integrated tag is only 70 g with compact dimensions (54 mm × 45 mm × 26 mm). The Ekahau part of the tag did not require charging during the 3–6 weeks of study; however, the GPS part of the tag has a battery life of ~11–14 h, which is enough only for one or days of activities. Therefore, participants were asked to turn on the GPS component of the tag when leaving the house and turn it off when returning, download the GPS data to the laptop, clean the memory and charge it.

Figure 1. The sensing tag with dimension of 54 mm × 45 mm × 26 mm. *Left-top*: GPS logger for the outdoor tracking. *Left-bottom*: WiFi tag for the indoor tracking. *Right*: different view of the tag.

Figure 2. System architecture of UbiTrack.



Location sensing system architecture

Figure 2 shows the system architecture of the location system, which includes two parts, indoor and outdoor location tracking. For the indoor positioning, we adopted network-based location system manufactured by Ekahau (http://www.ekahau.com). We installed wireless access points (WAPs) in the participants' house and used them as the signal sources for the tag. The tag searches nearby WAPs and sends the collected received signal strength indication as the fingerprinting to the location server for reasoning its position. For the outdoor location sensing, we adopted GPS to collect data of the subjects' outdoor activities due to its simplicity, usability, reliability and low cost.

Visualization software

*In addition to the hardware design, we also developed a platfor*m for participants to review their visualized and statistical location data including the participants' route in their house, total time spent in each room, total travel distance of an outdoor trip, thus allowing them to review their real-time and history activity status. Figure 3 (left) shows the visualization of the indoor tracking data. The software extracts the raw data (i.e. location positions) from the server database through Ekahau APIs and visualizes them as meaningful information. Users can specify the period of interest and explore the route of their indoor activities and the total time spent in different rooms during this period. For outdoor activities, as show in Figure 3 (right), the platform showed participants' routes based on their GPS data and the total travel time and distance of each route. We embedded Google Earth (http://www.google.com/earth/index.html) into our platform and provided an interactive map view that allowed users to easily view the route from different angles or to check where they were at any specific time. We chose Google Earth instead of Google Maps because many of our participants did not have Internet connections from home, which is necessary for Google Maps, but not for Google Earth.

Procedures

Each household was enrolled in the study for 3–6 weeks. In our first visit to a participant's house, we collected informed consent and measured the floor plan of the house. In our second visit, we deployed the system and provided training to our participants. In each home, we first installed the WAPs as the signal sources for the indoor location tracking and then performed the site survey of the whole house to build the signal model of the system.

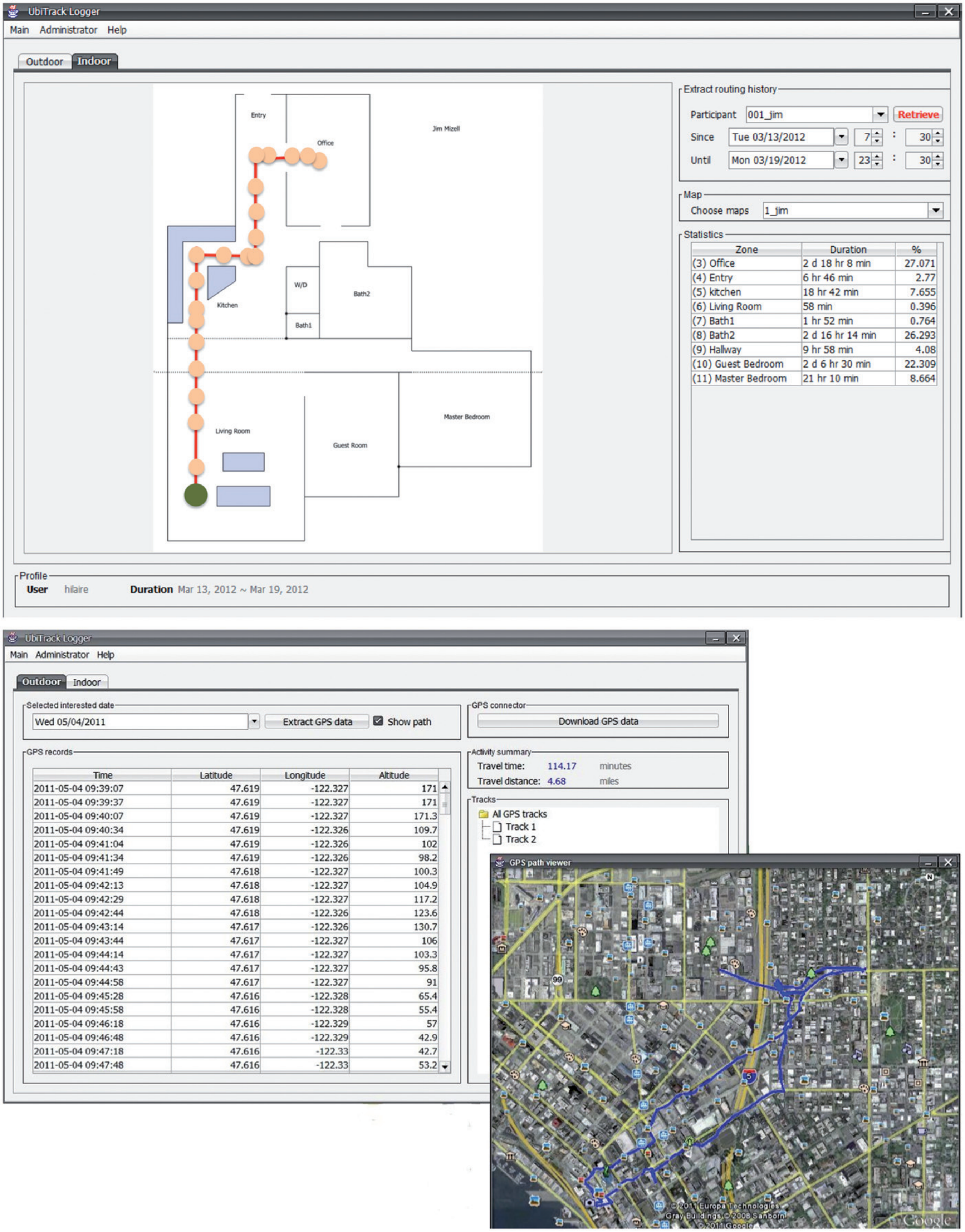


Figure 3. UbiTrack platform entry. *Top*: Indoor location tracking, showing the route, basic profile of the subject and the time spent in each room. *Bottom*: Outdoor location tracking, including an interactive map window, the trip route, way points and total travel time and distance of each route.

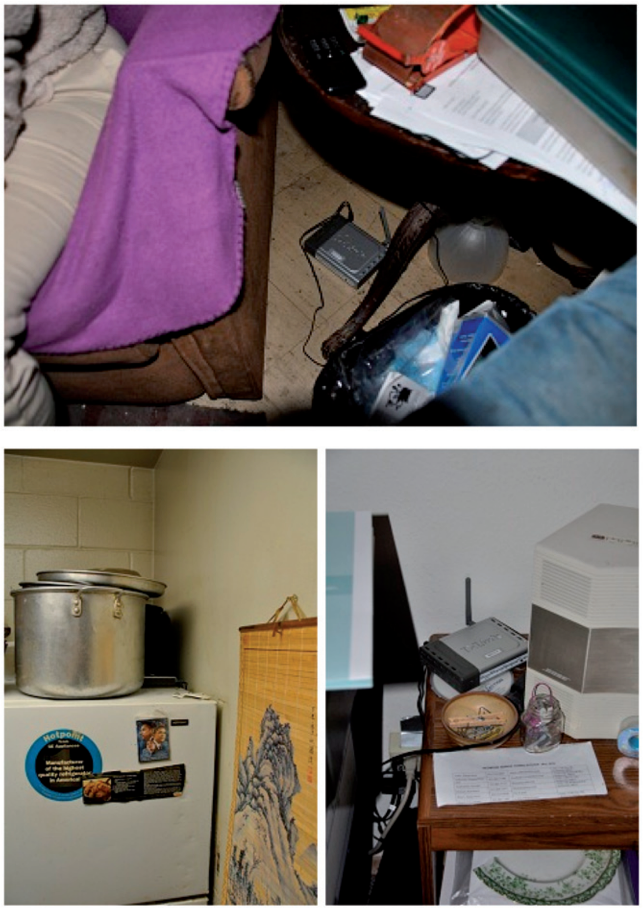


Figure 4. Examples of WAP installation.

Figure 4 shows some examples of the WAP installations. We tried to install the WAPs behind or below the furniture to minimize the intrusion caused by the deployment. We tested different topologies and number of WAPs in our participants' house to test the effect on accuracy of the indoor tracking system. We also set up a laptop that functioned as a server for collecting location data.

Participants were then trained in how to use the system, including how and when to carry the tag, how to download data, how to review data using the visualization software and how to charge the tag. Participants either carried the tag or attached it to their wheelchair. Sensor data was then collected throughout the rest of the implementation.

Participants were trained to use diaries to collect information about where they were and what they were doing every 30 min during the day. Diaries were collected on a different day each week. Researchers wrote qualitative field notes about interactions with participants during the implementation process.

At the beginning of each implementation, we conducted interviews regarding daily routines (e.g. What does a typical day look like? How far do you normally travel?); and perceptions about use of technology (e.g. What is your experience level with computers and technology?; How comfortable are you with new devices?). At the end of the implementation, we interviewed participants about the acceptability and ease of use of UbiTrack and asked them a series of open-ended questions in the following categories:

- Acceptability and challenges in use of the system.
    - Did you experience any difficulties when carrying the tag?
    - Any challenges with managing the tag (charging, turning on GPS)?
    - Did the installation of the Ubitrack system in your home cause any problems?
- Data use
    - Did you use the visualization software and if so, did you have any problems?
    - Now that you can see the information that was collected, for what purposes do you think it would be useful to collect this information?
    - Would you be comfortable sharing your data with others (e.g. family, caregivers, doctors)? Did you have concerns about loss of privacy?

Results

Participant completion

Of the five participants recruited for this study, four of them completed all components of the study successfully and their data are included in all analyses. One participant completed the study, but we were unable to gather sensor data in his home for reasons described below. His data were excluded from analyses of system performance and accuracy, but is included in discussions of feasibility and acceptability of the system.

Feasibility

We wanted to explore the feasibility of implementing UbiTrack in real-world community settings. Although UbiTrack was designed as a single, compact and easy-to-use tracking system from the participants' perspectives, we faced many challenges during system development and deployment.

Customization requirement

One challenge in moving to large-scale implementation of a system like UbiTrack is that deployment of the system is not ''plug and play''. Rather every implementation is a trial-and-error process that varies with different conditions such as the floor plan, house construction and available resources in the house. Trained installation personnel have to visit the participant's home, install the WAPs, test the accuracy of the model and possibly repeat the above steps until reaching an acceptable accuracy. While this might work for a small research study, it would not scale for a large clinical trial or for a clinical application.

Blind spots

The indoor tracking component of the UbiTrack system calculates the location of a tag based on the signals it receives from WAPs. To obtain acceptable location accuracy, the tag has to ''hear'' at least 3 WAPs for triangulation at any given time from any location in the home. When a room is surrounded by concrete walls (e.g. the bathroom) or full of a lot of metal items (e.g. the kitchen), the wireless signal will be attenuated by these objects and the tag may fail to receive stable signals from some WAPs. This kind of room then becomes a blind spot in the apartment, that is, the tag will only hear signals from two (or less than two) WAPs and therefore, the server cannot calculate the correct position of the tag. Concrete walls are usually hidden – even the tenants are not aware of them. The only way to find it out is through the trial-and-error process mentioned earlier.

Small room

The error tolerance of the system is 3–5 m. When the room size is too small, the tag may not be correctly located. For example, in Figure 5, the kitchen and the bathroom are both small areas (2–2.5 m^2) and close to each other. The tag in the kitchen (marked as the green circle) could be misidentified in the bathroom (marked as the red circle).

Rail planning

A *rail* is the possible path that a tag can move along in the map. Rails are set as part of the initial calibration of the system during installation. Choices made during rail planning may result in different levels of accuracy. In addition, when the small room problem occurs, the rail planning becomes even more significant since an inappropriate rail planning will deteriorate the location accuracy. For example, when the rails are set as the ones in Figure 6 (left), the tag supposed to be ''near-bed'' is misidentified in a ''far-from-bed'' position (the green circle represents the real location and the red circle is the position calculated by the system). However, if we knew the individual is never active in some specific place, we could change the rail planning accordingly so as to increase the accuracy. As shown in Figure 6 (right), the location of tag can be identified in a more reasonable spot after we truncate the unnecessary rail.

Limited resources

During the deployment process, it is important to have sufficient power outlets in the house so as to test as many topologies as possible to find out the best locations for the WAPs. In one of our cases (Home 3), the house lacked a stable power source and did not have sufficient outlets. Insufficient outlets limited the possible set-up locations of WAPs, which made the installation process more difficult. During the installation, the power in this home crashed, which forced us to terminate the installation process and return on the other day.

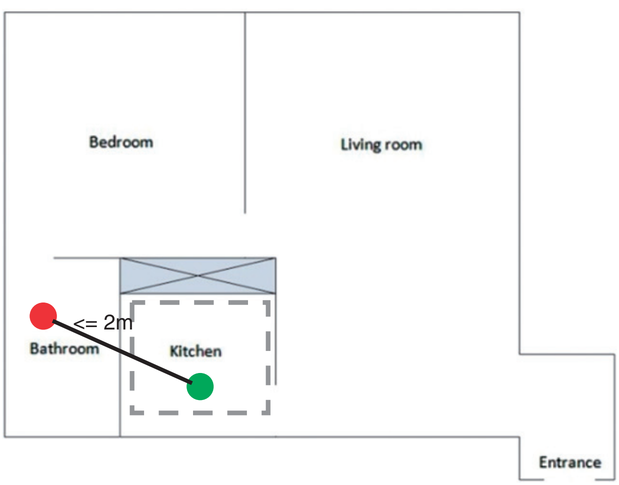


Figure 5. Small room problem. The kitchen is very close to the bathroom so the tag was identified as in the bathroom (green circle marked the current location and the red circle represents the location calculated by the server).

Challenges related to comorbid conditions

Implementation in Home 3 was also challenging for other reasons. In addition to his SCI, in hindsight it appears likely this participant had experienced a concurrent TBI which he did not report to us. This participant had a difficult time remembering to charge the tag or turn on the GPS when he left the house. His home was very busy with lots of people passing through the space and the server was sometimes turned off or moved. The home was cluttered with boxes along the walls and paths through the rooms. On several visits the participant and others were drinking beer early in the day. The addition of alcohol did not appear to improve his cognitive function. Comorbid conditions such as these increase the difficulty of implementing embedded assessment devices in community settings.

Accuracy

We calculated weekly averages of the time spent in each room indoors and of distance traveled outdoors (see Table 2). Participants' residences were quite different in size and configuration. Participants with fewer rooms spent more time in a single room; however participants spent the most time in their living rooms and offices, with about a quarter of their time in the bedroom sleeping. Participants differed in the amount of time they spent outside and the distance traveled. Participants who were outside more tended to have volunteer activities that kept them active. One participant (Home 4) worked from home and had relatively few hours outside.

Accuracy by home

We calculated accuracy of our sensor data by comparing participant completed diaries with the sensor data collected by UbiTrack. The diaries were considered the ''ground truth'' for location within and outside the house. In Table 3, we report the results of the indoor location tracking accuracy of UbiTrack. Room accuracy ranged from 61.59% up to 87.27%. Home 1 is one of the larger homes in our study and provided flexible options for our deployment. We therefore deployed more WAPs in this home. However, the accuracy result (61.59%) was not very encouraging and even a little bit lower than the results of Home 2. We noticed that in Home 1, three connected rooms (kitchen, office and dining area) were small and suffered from the ''small room problem'', which was the main cause of the low accuracy. Home 2 is a small 1-bedroom unit in an apartment style building, in which the kitchen and bedroom are both small and tightly connected to each other. Since the accuracy of the indoor location tracking system is 3–5 m, the ''small room problem'' degraded the room accuracy

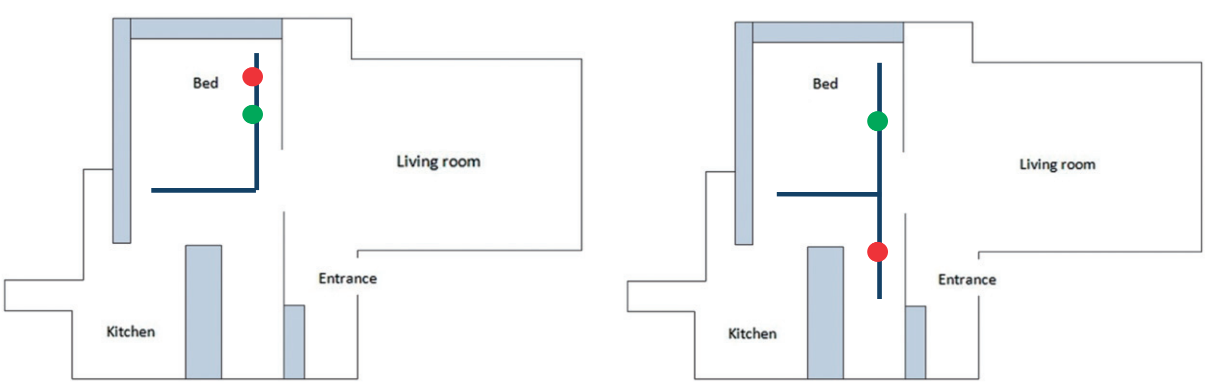


Figure 6. Rail planning.

Table 2. Statistics of location tracking data. Indoor tracking data shows the percentage of the participant's staying durations over the period of studies. Outdoor tracking data demonstrated weekly (average) travel distance and time.

Home	Indoor (weekly average)									Outdoor (weekly average)
1	Kitchen	Living room	Master bedroom	Master bathroom	Office	Dining room	Guest bedroom	2nd bedroom	Hallway	79.9 miles 34.2 h
	20.7%	26.3%	11.9%	0.9%	19.5%	0.6%	9.4%	9.3%	1.4%	
2	Kitchen	Living room	Master bedroom							64.7 miles 22.7 h
	12.3%	41.1%	46.6%							
3	–									–
4	Kitchen	Living room	Master bedroom	Master bathroom	Office	Dining room	Laundry	Activity room	Hallway	42.5 miles 14.3 h
	1.1%	6.0%	25.4%	2.0%	59.1%	0.0%	0.9%	4.0%	1.5%	
5	Kitchen	Living room	Master bedroom	Master bathroom	Office	Dining room	Guest bedroom	2nd bathroom		32.1 miles 16.4 h
	1.7%	47.0%	24.0%	3.6%	19.5%	0.6%	2.0%	1.6%		

Table 3. Accuracy results by homes.

Home	Home size (ft^2/m^2)	Number of WAPs	Room accuracy (%)
1	1350/120	3 ~ 5	61.59
2	520/50	4	63.37
3	700/68	4	–
4	1390/128	6	87.21
5	1185/110	7	79.27

in this case. Home 3 is a resource limited and environmentally dynamic house. During our study in Home 3, the location server was either unplugged or turned off by unstable electric power. Therefore, we are unable to present any results from Home 3. In Homes 4 and 5, we installed 6 and 7 WAPs, respectively, and performed more site surveys so as to get more accurate models. The accuracy increased tremendously to 87.21% (Home 4) and 79.27% (Home 5). Home 4 is a big house with spacious rooms, which relieves the 3–5 m system error tolerance. Home 5 has a small dining area tightly close to the kitchen and master bedroom, which degraded the location accuracy. However, we still can see the incremental accuracy (from 61.59% to 81.05%) when we use more WAPs (from 5 to 7).

Number of WAPs and performance

In order to find a good tradeoff between accuracy and the number of WAPs, we conducted accuracy tests using a varying number of WAPs. Table 3 showed the room accuracy using different number of WAPs in Home 1 (three to five WAPs), 4 (six WAPs) and 5 (seven WAPs). The accuracy increased from 24.76% to 58.99% when we increased the number of WAPs from three to four in Home 1. However, the accuracy (61.59%) did not improve a lot after we added one more WAP. We experimented with more WAPs in different homes (4 and 5) to observe the effect of using more WAPs. We also performed extra site surveys on Homes 4 and 5 so as to build a more accurate model. The results showed that the extra WAPs and site surveys greatly improved the accuracy (87.21% in Home 4 and 79.27% in Home 5). Overall, we believe a reasonable number of WAPs to get acceptable accuracy is six WAPs/1400 ft^2 (or five WAPs/1000 ft^2). In future studies, we expect the accuracy can be improved a further by coupling UbiTrack with other sensors such as ultrasound in confusion areas.

Acceptability and ease of use

Acceptability and challenges in use of the system

In general, participants reported that the system was easy to use, did not require significant effort on their part and did not interfere with their daily lives. They felt that the tag was light and easy to carry or attach to their wheelchair.

In particular, the indoor sensing system required very little effort on their part since it required no charging or downloading. Participants felt that the installation of WAPs in their home was not intrusive. Only one participant noted that when his children and grandchildren visited for a holiday it was difficult to find an available power outlet in part because of the WAPs.

Participants also reported that the outdoor sensing component of UbiTrack was also easy to use. As noted earlier, our system collected outdoor location using GPS. We designed a simple, automatic GPS reader program for extracting participants' data from the GPS logger to the laptop and asked them to charge the GPS sensor and download data on a daily basis. Participants noted that remembering to charge the device was a challenge. However, most participants remembered to charge the device consistently by building it into their daily night time routine. One participant (Home 3) had consistent difficulty remembering to charge the device, which resulted in missing data for several days. Participants were also asked to turn on the GPS unit when going outside and turn it off when returning indoors. All participants forgot to perform this task occasionally and reported that there were a few gaps in their outdoor data. Our participant in Home 3 consistently forgot to turn the GPS on and off when going outside. Several participants noted that it would be better if there were a way for the system to sense when they crossed the boundary between indoors and outdoors automatically. Finally, in order to make the tag as compact as possible and reduce participants' burden, we chose the smallest GPS logger in the market. Since the GPS device itself is small, the switch on the device was also tiny. We found that several participants had some problems using this tiny switch to turn the GPS on and off. Although most of them figured out a method for powering on the device (e.g. with a fingernail) within a few days, the size of the switch was an impediment.

Data use

We demonstrated the visualization software for participants and taught them how to use it, but did not require them to do so. In our interview, we asked participants whether they used the software and whether it was difficult to use. The majority of participants reviewed their data occasionally out of curiosity, but not frequently. None of the participants had difficulty using the software. When asked what they learned from looking at their data, several participants noted that it showed them that they are not as active as they thought and were not getting outside as much as they should. However, in contrast, our participant with LEP expressed surprise about how much he moved around in a half-hour period and noted that it made him consider ways to be more efficient because he was trying to preserve muscles in his polio-affected leg.

We also asked participants for what purposes the data could be used. In general, participants thought the system gave a general sense for physical effort or activity. They thought their physicians might find it useful to know how much activity they were engaged in. They did not believe that their caregivers, spouses or children would be interested in that level of detail about their movement.

We asked whether participants would be comfortable sharing their data with other individuals and whether they had any concerns about privacy. Surprisingly, most participants in our small sample had no concern about the privacy of their location data. Only one of our younger and computer-savvy participants expressed concern. She noted that she would not mind sharing her data, but would want control over it. In particular, she noted that she would want to provide data to someone else only after she had an opportunity to review. She would not want it to be reviewed in real time and noted that one major concern would be that if they system was hacked, it could allow someone to identify show patterns of travel and times when she was typically not home. If someone knew these patterns, they could burglarize her home or perhaps put her at risk of assault. She thought that summaries of data might make more sense when sharing with others.

Recommendations for improvements or additions to the system

Although we did not specifically ask participants for recommendations for improvements or additions to the system, they offered several. Recommendations fell into three categories: (a) goal setting, (b) prompting and (c) hardware. Participants felt that a system like UbiTrack that collected data automatically on a behavior would be very useful to them in managing health issues related to their disability, although in order to do so, the system would need to track more than just location. Exercise and physical activity was one common theme for which participants would like automated measurement. Participants identified several types of activities that ranged from doing sit-ups and spending time on a rebounder trampoline for our participant with LEP to weight bearing activities like standing in front of her pinball machine for a period of time for our participant with MD. Another area participants identified as important were health behaviors related to their disability such as reclining their wheelchair to raise their feet and reduce pressure, spending time on an incline table or transitions from sit to stand. Finally, participants were interested in more general health information such as blood pressure, lung capacity and frequency of bathroom use (related to bladder infections). Across all these types of health-related behaviors, participants were interested in measurement over time that could show incremental changes that might be hard to identify without data.

If more relevant variables could be measured by the system, then several participants noted that they would want it to be able to prompt them to engage in positive health behavior (e.g. exercise, sit/stand, pressure relief). One participant noted that such prompting would ideally be contextual so that she was prompted at the time and place when she should do something. Finally, a few of the participants noted that they would like it if the system were integrated into a smart phone so they would not have to carry multiple devices and/or connect to a computer to access data.

Discussion

In this article, we demonstrated the accuracy, feasibility and acceptability of an indoor–outdoor-combined location tracking system. Based on the evaluation of this system, we have confirmed that the tag is compact and easy-to-carry and the UbiTrack platform provided a friendly, easy-to-use interface and useful visualized information for our participants. However, we have also begun to identify the challenges faced in implementation of embedded assessment in real world contexts with diverse range of community-dwelling individuals. Future work should address issues related to the robustness of these types of systems and a better understanding of challenges to implementation that must be addressed as part of their design and planning. Also, in future work, the feasibility of using embedded sensors to measure other components of health behavior should be investigated and feedback with respect to goals set by individual participants displayed.

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Declaration of interest

The authors report no conflicts of interest.

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