Pers Ubiquit Comput (2010) 14:737–747
DOI 10.1007/s00779-010-0285-9

ORIGINAL ARTICLE

Comparing picture and video prompting in autonomous indoor wayfinding for individuals with cognitive impairments

Yao-Jen Chang · Tsen-Yung Wang

Received: 30 May 2009 / Accepted: 22 October 2009 / Published online: 3 March 2010

Abstract A challenge to individuals with cognitive impairments in wayfinding is how to remain oriented, recall routines, and travel in unfamiliar areas in a way relying on limited cognitive capacity. According to psychological model of spatial navigation and the requirements of rehabilitation professionals, a novel wayfinding system is presented with an aim to increase workplace and life independence for people with traumatic brain injury, cerebral palsy, intellectual and developmental disabilities, schizophrenia, Down syndromes, and Alzheimer's disease. An architecture is proposed based on Bluetooth tags and scanning PDAs. A prototype is built and tested in field experiments with real patients. Two modalities, video and picture prompts, were compared by 20 subjects with cognitive impairments. The experimental results show the computer–human interface is friendly and the capabilities of wayfinding are reliable. Video prompts performed better by 25–28% than picture prompts at the price of users feeling slightly more rushed.

Keywords Cognitive impairments · Ubiquitous computing · User interface · Bluetooth

Y.-J. Chang (✉)
Department of Electronic Engineering,
Chung Yuan Christian University,
Chung-Li 320, Taiwan, ROC
e-mail: yjchang@cycu.edu.tw

T.-Y. Wang
Institute of Health and Welfare Policy,
National Yang Ming University,
Taipei 112, Taiwan, ROC
e-mail: tywang@ym.edu.tw

1 Introduction

The majority of otherwise-employable persons with mental impairments remain unemployed, rarely access appropriate community services and are socially isolated [1–3]. Difficulties in wayfinding hamper the quality of life of many individuals with cognitive impairments who are otherwise physically mobile. For example, an adult with cognitive impairments may want to lead a more independent life and be capable of getting trained and keeping employed but may experience difficulty in using public transportation to and from the workplace. Remaining oriented in indoor spaces may also pose a challenge, for example, in an office building, a shopping mall, or a hospital where GPS devices fail to work due to scarce coverage of satellite signals. In addition, the state of art displaying positions on the navigational interfaces has not taken into consideration the needs and abilities of people with mental disabilities. People without disabilities often use maps or written directions as navigation tools or for remaining oriented. However, this cognitively impaired population is very sensitive to issues of abstraction (e.g., icons on maps or signage) and presents the designer with a challenge to tailor navigation information specific to each user and context. Some patients with dementia may show spatial disorientation at unfamiliar places or forget intended destinations [4]; people with traumatic brain injury or mental retardation may not be able to recall clues of the routes they once firmly trained to acquire [5, 6]. Wayfinding systems are an assistive technology targeting patients with cognitive impairment who are mobile and need to travel through both indoor and outdoor environments for work, shopping, socializing, therapy, and other purposes, thus increasing workplace and life independence. Most of the real-world wayfinding scenarios, such as going back home from a complex indoor workplace, seeing a doctor in hospitals, or shopping at malls, consist of indoor and outdoor navigations. Therefore, an ideal wayfinding device should address both. In this paper, the main theme of the proposed system is indoor wayfinding.

One of the key research issues in providing navigation aids for people with mental disabilities is the timing of the prompts. Put it in more precise terms, researchers are faced with challenges of when, where, and how the prompts are delivered to the users. Very few studies on navigation prompting take context and situations into account [7–13]. By bringing context awareness to handheld prompting devices and reducing cognitive load on users, eliminating the need of shadow teams as "wizards", people with cognitive impairments can have the prompting experiences in easier and more comfortable ways.

In this paper, Bluetooth is used for personal wayfinding purposes where Bluetooth beacons and ID scanning are used, but no device inquiry, time-consuming pairing, or information exchange does happen. Bluetooth operated in this discovery mode saves power, eliminates manual passkey challenges, and reduces privacy and security concern as the user does not expose her ID. Based on the Bluetooth beacon received, the position where the user is can be identified and enable the wayfinding sequences. The Bluetooth sensors can automatically be read from several meters away and does not have to be in the line of sight of the reader.

We propose a personal guidance system based on Bluetooth for individuals with cognitive impairments. Such a personal guidance system will help them safely and effectively with personal wayfinding and, thus improving the quality of life without the great cost and inconvenience of special assistive services. An individual who is able to comprehend picture-based or video-based directions on a handheld is instructed when she reaches a position on a planned trip. Every such media is triggered by a Bluetooth ID beacon emitted at important positions, such as intersections, exits, elevator doorways, and entrances to stairways. By sensing the Bluetooth beacon with his reader-ready handheld, the individual is able to receive guidance embedded within the media just in time.

Our previous work [9] has successfully employed Bluetooth beacons for wayfinding. In this study, we also used the same type of beacons to trigger prompts. On top of picture-based prompts, we added video-based prompting as a new modality and compared it with our previous work in [8]. The unique strength of the system is the ability to provide unique-to-the-user prompts that are triggered by context. As this population is very sensitive to issues of abstraction (e.g., icons) and presents the designer with the need to tailor prompts to a "universe-of-one", the use of media specific to each user and context is implemented. The key to the approach is to spread the context awareness across the system, with the context being flagged by the tags and the appropriate response being evoked by displaying the appropriate path guidance media indexed by the intersection of specific end-user and context ID embedded in tags. By separating the context trigger from the media rendering response, responses can be updated independently of the rest of the installed system, and a single tag can trigger multiple responses in the PDA depending on the end user and their specific path. The second contribution of this paper was selective routing which was implemented on the wayfinding PDA to autonomously determine the paths for individuals with cognitive impairments. The third contribution of this paper was the adaptation of NASA TLX (Task Load Index) [14] for evaluating assistive devices.

The paper is organized as follows. In the next section, we survey the state of the art in the wayfinding research for individuals with cognitive impairments. Then, the prototype design is presented. Implementations and results are shown followed by some concluding remarks.

2 Literature survey

People's spatial abilities depend mainly on the following four interactive resources: perceptual capabilities, fundamental information-processing capabilities, previously acquired knowledge, and motor capabilities [15]. These abilities are a necessary prerequisite for people to find a way from an origin to a destination. However, for people with severe cognitive impairments, the first three resources are generally limited. Therefore, the proposed system provides multimedia cues for them to use as environmental information, and a PDA for them to process representations of spatial knowledge in order to move through the environment. In addition, Passini [16] studied the communication aspect of wayfinding design. In terms of wayfinding communication, designers have to respond to three major questions: what information should be presented, where and in what form. Passini further pointed out that a key rule of environmental perception is that information is not seen because it is there but because it is needed. During wayfinding, people will select that information that is relevant to their task. An analysis of decisions made by subjects who tried to find a destination showed that they tended to perceive information when it was directly relevant to the behaviors associated with an immediate task and did not perceive information irrelevant to the immediate task even if it might be useful later on. Therefore, spatial abilities are sensitive to perceptual information, and in particular the time and place to receive it.

Previous work with dementia [16] has shown individuals with dementia show marked cognitive wayfinding deficiencies. They tend to have significantly reduced cognitive mapping abilities. They are not able to make way-finding decisions requiring memory or inferences, while they may still be able to make decisions based on explicit architectural information and directional signs. They can no longer develop decision plans and can only operate from one decision point to the next, so that they can be mobile and as autonomous as possible.

The growing recognition that assistive technology can be developed for cognitive as well as physical impairments has led several research groups to prototype smart systems [17–21] that can improve quality of life. In [22, 23] a resource-adaptive mobile navigation system was studied for both indoor and outdoor environments, although it was not specially designed for people with disabilities. Cognitive models were built-in [24] to study human wayfinding behaviors in unfamiliar buildings, and salient features of route directions were identified for outdoor pedestrians [25] without considering the special needs resulting from cognitive deficits. Kray [26] used situational context for navigational assistance at a pioneering work in 2002. Baus et al. [27] developed auditory perceptible landmarks for visually impaired people and the elderly people in pedestrian navigation and conducted a field experiment on a university campus. Goodman et al. [28] showed that an electronic pedestrian photograph-based navigation aid based around landmarks was more effective for older people than an analogous paper version. Researchers at the University of Colorado have designed a system for delivering just-in-time transit directions to a PDA carried by bus users, using GPS and wireless technology installed on the buses [7]. The Assisted Cognition Project at the University of Washington has developed artificial intelligence models that learn a user behavior to assist the user who needs help [29]. Later, a feasibility study [30] of user interface was carried out by the same team, who found photographs are a preferred medium type for giving directions to cognitively impaired persons in comparison with speech and text.

Personal computers, including laptops, tablet PCs, and special purpose communicators [31, 32], have been integrated with various assistive technology to provide prompting. The proliferation of mobile compact computing devices such as palm size PDAs enables a new platform for personal prompting and cognitive aides [4, 5, 7, 33, 34]. PDA-based prompting is especially useful for mobile users. Previous work on prompting using PDAs relies on “Wizard of Oz” approaches [5, 35], on user self-conscience [4], or on a preset timer [32, 34, 36] in order to send the prompts. The Clever project [29] uses on-bus GPS devices to send prompts to PDAs carried by cognitively impaired people to remind them to get off buses at right stops. Design approaches used in implementations of prompts can be fundamentally different.

For indoor navigation, GPS-based devices are not usable. In [37], an indoor navigation system called “Cyber Crumb” was developed for blind users. As the individual traverses the course toward a destination, his device detects each strategically located cyber crumb and provides instructions accordingly. The cyber crumbs are located at key locations such as elevators, hallway intersections, exits, and entrances. Modalities of prompting media may depend on individual variances in cognitive disabilities or experiment environments such as indoors/outdoors. For example, the results from a University of Washington research team suggested that photographs appear to be a preferred media for indoor wayfinding [30]. However, the results from a University of Oregon research team [5] in a community-based study with 21 outdoor participants indicated that voice guidance was welcomed by most of their users, especially those with visual impairments in addition to cognitive impairments.

Finally, we use Opportunity Knocks [29] to compare the contributions of our research. Opportunity Knocks provides text-based routing directions for users with GPS-enabled cellular phones. It can issue user errors if there is deviation being detected. Not only our proposed system differs in user interface modality and approaches to context awareness, but also the experiments differ in settings. The Opportunity Knocks experiment was based on one single outdoor user. In contrast, our experiment attempts to include a user group of various syndromes in cognitive disabilities to reduce bias in experimental results. As users with cognitive impairments could be sensitive to modalities in user interfaces, we used different media to convey the routing directions in light of other previous work in literature. Furthermore, Opportunity Knocks used a hierarchical Dynamic Bayesian Network model in the inference engine to continuously extract important positions from GPS data streams in outdoor navigation. By contrast, our approach bases context awareness on ambient beacons to trigger navigation instructions which is more appropriate for indoor environments.

3 Prototype design

As informed by the human activity assistive technology (HAAT) model [38], an assistive solution has four components: the human, the activity, the assistive technology, and the context in which the first three integrated factors exist. In light of the HAAT model, our prototype is designed to assist with navigation for individuals with cognitive disabilities. It consists of PDA user interfaces, beacons, and a routing engine. See Fig. 1. Each component will be described in the following.

Methods of indoor positioning [39, 40] include received signal strength (RSS), location fingerprinting, and

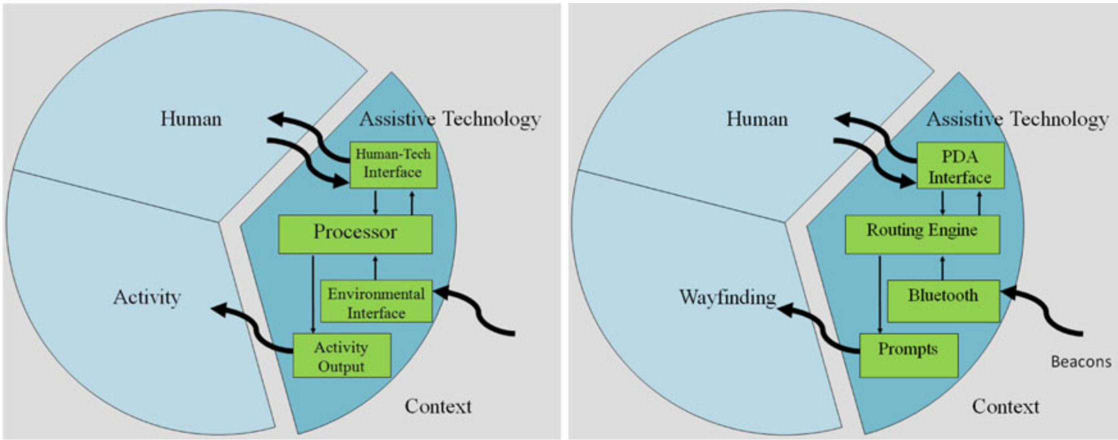


Fig. 1 (*left*) The HAAT model. (*right*) Model of wayfinding devices

triangulation based on varieties of hardware such as ultrasound [41], infrared, Wi-Fi access points (AP), wireless sensor networks (WSN), and active RFID [42]. For example, positioning accuracy of the state of the art WSN-based triangulation approaches 3 m. However, considering WSN and Wi-Fi AP for indoor wayfinding, it is probable to locate oneself only after the decision point is passed. To provide navigation aids, wayfinding instructions have to render before decision points rather than after. To overcome this problem, we deploy Bluetooth beacons at important positions such as hallway intersections, exits, and elevators to ensure the handheld pick up beacons before making navigation decisions.

In a real-world scenario, a user of the proposed wayfinding system initiates interaction by selecting the icon that represents a destination. In this way, the specific human tells the system where to go. Beacon signals received by handhelds trigger downloading of media with directional instructions, thus eliminating the need of a shadow support team behind the user. When triggered prompts arrived, the device vibrated for 3 s to alert its user. Route personalization is accomplished by the system identifying the user and the destination set ahead of time. Therefore, even sensing the same beacon on the same spot, different users may receive different directional instructions. It works indoors where GPS signals cannot reach. The design draws upon the psychological models of spatial navigation [43], usability studies of interfaces by people with cognitive impairments [5, 26, 30, 44], responsiveness to device prompting documented across a wide spectrum of type and severity of impairments for a range of functional tasks [45–47], and the requirements based on interviews with nurses and job coaches at rehabilitation hospitals and institutes [8–11].

In light of Passini's findings [16], the proposed wayfinding system uses the PDA to provide the signage on the screen in the format of pictures or videos when individuals with cognitive impairments approach decision points. Therefore, a PDA is carried by the individual who has difficulty in indoor wayfinding. The PDA shows the just-in-time directions and instructions by displaying pictures (Fig. 2a) or videos (Fig. 2b) triggered by Bluetooth

(a) (b)

Fig. 2 **a** A just-in-time picture. Taking a right turn when exiting. **b** Just-in-time video clips shown on the wayfinding PDA. (*left*) Taking a right turn at the doorway. (*right*) Pushing a button in an elevator to get to the 5th floor

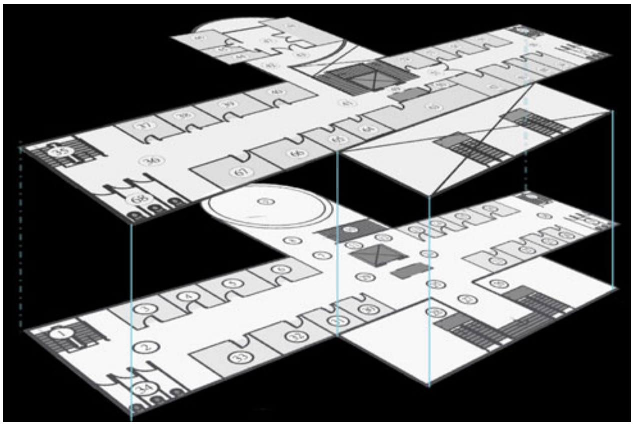


Fig. 3 Building floor plan with all the decision points labeled

beacons sensed by the PDA's built-in reader. The media have to be prepared ahead of time. However, that is a kind of one-shot effort. Note that the persons who carry the wayfinding PDAs may at times need assistance when they find themselves lost somewhere.

A beacon is placed on the floor plan at each decision point, that is, any physical space where the individual is presented with a navigational choice. Figure 3 exemplifies a graph generated from two levels of a building floor plan. Decision points may be doorways, corners, the interior of a room, or the intersections of hallways.

The graph in Fig. 3 is then used in the determination of optimal routes. The routing scheme in our implementation is deployed in the handheld device, namely a PDA. In the prototype, the Dijkstra algorithm, a time-honored graph theoretic method [48], is applied. A computed route is depicted in Fig. 4.

A typical user scenario involves a user who wants to travel from node *A* to node *B* in a building. Weights represent time to travel between adjacent nodes, which may depend on disability types. For example, weights of stairways are set to very large values for wheelchair users, so that stairs will not be selected for navigation. Nodes that represent physically connected spaces are joined with an edge. A numerical weight is then assigned to each link. Considering physical barriers such as barriers of mobility, the weight of an edge between node *A* and node *B* is computed as follows:

$$\begin{aligned} \mathrm{w}_{\mathrm{AB}} = {} & (\text{physical distance weight}) + \text{PhysicalDisabilityFlag} \\ & * \text{BarrierPanaltyWeight} + \Sigma_i \, \text{MiscFlag}_{\mathrm{i}} \\ & * \text{MiscPanaltyWeight}_{\mathrm{i}} \end{aligned}$$

PhysicalDisabilityFlag is of values 0 or 1 that present different challenges to different users according to personal ability profiles such as physical disabilities, low visions, and blindness. BarrierPanaltyWeight indicates a barrier, such as stairs to wheelchair users. The information of stairs is obtained from floor blueprint. Generally, when a link contains an environmental barrier, the corresponding weight should be large enough to rule out the possibility of this link being included in the recommended route for the routing algorithm used. For other disabilities that may impact pedestrian behaviors, the equation for w_{AB} can be easily modified to account for such impacts in the routing decisions.

Preferences are important for individuals using assistive technologies [49]. To address the preferences for people with disabilities, the users can define their choices in the profiles. For example, users who are blind or with low vision may choose to avoid taking stairways, although they may be capable of doing so. Some individuals with schizophrenia are advised for medical reasons not to take routes with low illumination, although their vision may not be impaired at all. There are some cases that female users may prefer routes with sufficient levels of illumination for safety reasons. The user preferences are represented by MiscFlag and MiscPanaltyWeight.

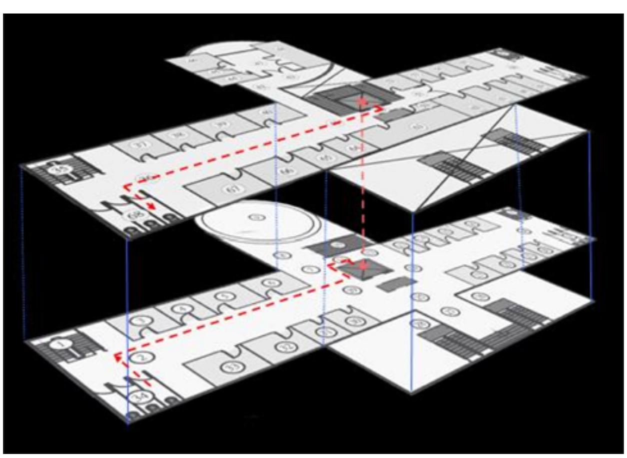


Fig. 4 Route planned by the Dijkstra algorithm

4 Experiments

4.1 Configuring beacon sources

Bluetooth signals are designed to cover small areas of radius around 10–15 m. In order to provide sufficient resolution of locations and reduce device cross talk, we deliberately attenuate the transmitting power, so that the radiating radius is less than 5.0 m for typical buildings with corridor length greater than 15.0 m.

In light of Passini's findings [16], the timing for displaying cues is important. We use a parameter to model the acceptable prompt delay to render the signage somewhere before decision points such as hallway intersections. The

Table 1 Parameters of technology, environments, and humans

Typical Bluetooth coverage	10–15 m
Assumed distance of adjacent beacon sources	>15 m
Tuned Bluetooth radiating radius	<5 m
Guard length between beacon sources	>4 m
Human walking pace	76 step/s (Andante)
Length of a human step	0.5 m
Distance from waypoints for making decisions based on received prompts	>2 m
Desired beacon discovery latency	<5 s

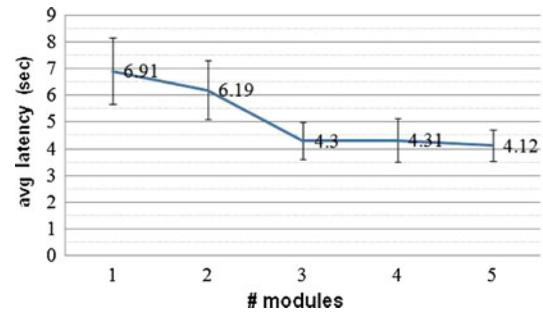


Fig. 6 Determining the number of modules needed in a beacon source. *Error bars* stand for confidence intervals

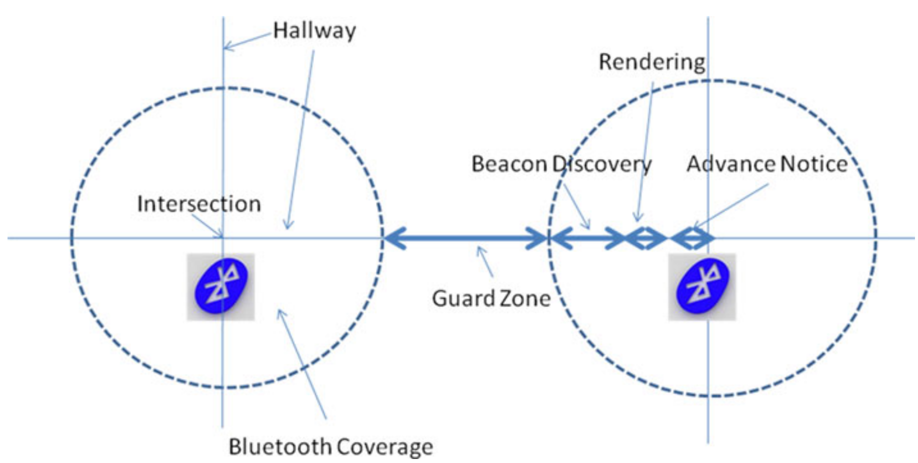
proposed model for acceptable prompt delay translates to the minimum required distance for the user to perceive the signage. See Table 1 for the parameters we assume for the experiments. Note that we reserve at least 4.0 m as a guard length for adjacent beacon sources to avoid erroneous reading. In order to render navigation media somewhere before decision points such as hallway intersections, for example 2 m in front of intersections, average beacon discovery latency should be smaller than the time needed to travel for 3.0 m, roughly 6 steps for adults or 5 s in an andante pace.

The experiment scenario is shown in Fig. 5. When an individual enters Bluetooth coverage, the PDA spends a few seconds to discover beacon ID. According to the identified ID, the PDA starts to render navigation media. Photographs of size <100 KB used in navigation take less than 0.1 s when rendering on the PDA screen, and therefore the rendering time is negligible. Video clips of size <1,000 KB as navigation prompts may take up to 3 s for loading, depending on the context. During rendering time, users of the wayfinding PDA are advised to stop walking for safety reasons. Time for advance notice is required for the individual to understand navigation instructions and make decisions before proceeding to decision points. Note that the positioning delay is an important performance metric. Positioning delay, i.e., time to determine the location, as large as 10–30 s in some commercially available geolocation systems [39, 40] may not be acceptable in wayfinding applications.

We use off-the-shelf Bluetooth 2.0 from the Broadcom chipmaker which sets the inquiry scan interval equal to 1.28 s, the inquiry scan window equal to 18 RX slots and does not implement random back-off. Readers can find the parameter details of Bluetooth in the published specification [50]. Since parameters of the inquiry scan interval, the inquiry scan window, and random back-off are already fixed, the goal of empirical experiments is to optimize the number of beacon modules used in a beacon source pack. To do so, we took a series of field measurements to determine beacon discovery latency versus numbers of modules in a beacon source pack. We measured the discovery latency as elapsed time until the PDA successfully identified the first beacon code from the beacon source pack. The results are shown in Fig. 6 where each measurement was based on 100 runs with a total of 500 runs.

As the inquiry scan proceeds, randomly encountered modules are likely to discover each other. Since Bluetooth uses the TDMA scheme, it scans the beacon in a multiplex manner. As long as one beacon code is successfully identified, the scan is completed. This explains why the latency

Fig. 5 Bluetooth as beacon sources deployed at intersections of hallways



decreases as the number of beacon modules in a pack increases. For people walking in an andante pace and buildings deployed with beacons whose distance of adjacent beacon sources is at least 15 m, in order to achieve less than 5 s in beacon discovery latency, the optimal number of beacon modules in a beacon source should be three Bluetooth modules in a pack which empirically results in an average discovery latency of 4.3 s and a confidence interval of 0.6 s. In this case, a single-module or two-module beacon source does not allow pedestrians enough time to respond to prompts before hitting decision points. However, a pack of more than three beacon modules will be an overkill. Theoretically, too many beacons close to each other will result in severe collisions and therefore large latency. IDs received from any of the three modules will be treated as from the same beacon.

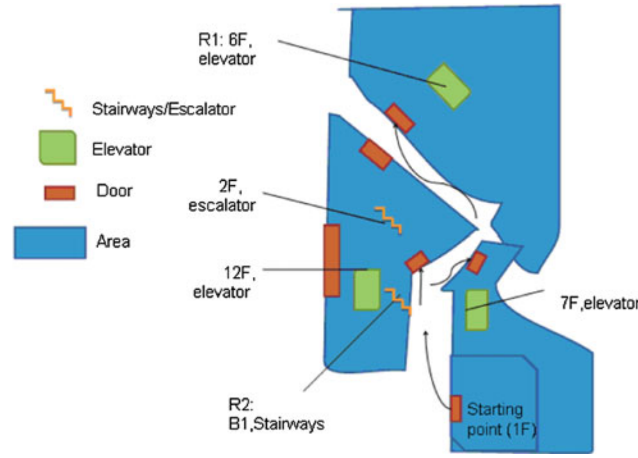


Fig. 7 The two routes used in the experiments

4.2 Settings

Experiments are designed to test the implemented prototype. Two routes in different combinations of stairways, elevators, and turns have been planned in the study. The routes are designed to exhibit various complexities, which are summarized in Table 2. Route 1 (R1) starts from the Rehabilitation Center, which is located on the ground floor, to the Employee Library, which is at the 6-th floor of the Tech Building (Fig. 7) and involves using an elevator in the middle. Route 2 involves taking the stairs down one flight after entering a small exit door to a basement. It is considered a difficult route to new comers.

In order to accomplish the trip, selected positions on the route have to be passed successfully. The positions are posted with beacons, which are embedded with location information.

4.3 Procedures

Participants with cognitive disabilities and ages in various ranges were recommended by the participating rehabilitation institutes and screened according to degrees of cognitive impairments, the ability to remain oriented, and severity of loss in short-term memory. Priorities were given to medium and low functioning patients as opposed to high functioning and very low functioning ones. Moreover, assessment on patient capabilities also took into account the ability to operate the PDA and understand its feedback. We recruited 20 subjects for 3 days of experiments. The individuals were impaired with various cognitive disabilities such as schizophrenia, intellectual and developmental disabilities, organic brain syndromes, epilepsy, organic depression, Parkinson's disease, and dementia. Their ages were between 19 and 35 with an average of 24. They all received community-based occupational training under supported employment programs. Efforts were made to try not to exhaust or bore subjects in experiments. Therefore, subjects 1–10 were assigned to day 1, and subjects 11–20 were assigned to day 2. In day 3, all the subjects participated in a baseline experiment using only oral instructions they received at the start place, namely no PDAs.

Participants were shown the device and trained before the experiments. They practiced how to touch the buttons on the screen and when to pay attention to the media on the screen. They also asked questions that they came up with, and we tried to answer and explain until they felt comfortable to start taking the test routes. The pre-test session normally took 10–20 min. Afterward, they were led to the starting location of each route and given the task of following the device's directions to a set destination. The routes were completely unknown to the individuals before the experiments. Participants were told their destinations before starting their trips. When people decided to drop out in the middle of the training or route taking, we still thanked them and their families for the participation.

Picture-based prompting was compared with the performance of video-based prompting. Subjects 1–10 used video prompting to navigate route 1 while using picture-based prompting to navigate route 2. On the contrary,

Table 2 Route profiles and complexities

Destination/route ID		Vertical movements	Turns	#beacons deployed
Library, tech building	R1	1F–6F	3	7
Warehouse, central building	R2	1F–B1	6	6

subjects 11–20 used picture-based prompting for route 1 while using video prompting for route 2.

The evaluation contains two parts: the outcome and the process. The outcome is measured by objective measurements, such as the success of arriving at the destiny and the time to complete the trip. The evaluation of the process is to ensure that the interface of the device is user friendly, and the task load is acceptable, so the subjective perception of the participants' experiences as a user is conducted.

No matter whether they reached the destination, we applauded them for their participation when sessions ended. Subjects occasionally asked for confirmation about the prompts they received, because they had hard time interpreting them. In such cases, we first encouraged them to make their own judgments. If they insisted in getting our confirmation, we gave them orally, but the trip was considered unsuccessful.

4.4 Results

We summarize the experimental outcomes based on the observations of the prototype design team. In the 40 trips made by 20 participants taking the 2 routes, once on each route, respectively, the ratio of participants with PDAs successfully following the navigation prompts is 95% for video prompting and between 75% for picture-based prompting. The results are depicted in Fig. 8. To test whether the difference in performance is statistically significant or not, we conduct a Pearson's chi-square test with respect to the three treatments, namely, video-based prompts, picture-based prompts, and oral instructions. The Pearson's chi-square test yields statistically significant results when we compare video-based as opposed to picture-based prompts ($\chi^2 = 3.1373$, $p = 0.0765 < 0.1$, $df = 19$) and picture-based prompts as opposed to oral instructions ($\chi^2 = 8.1203$, $p = 0.0044 < 0.01$, $df = 19$).

Indeed, route 2 is more difficult to navigate than route 1. In the baseline experiment on route 2 where no PDA is used, the success ratio is 0.3 only. The PDA is helpful as a cognitive aid for individuals with cognitive impairments. We anticipate that the ratio can also depend on the extent to which participants are affected by mental disabilities, the complexity of routes, the degree of received training and self-practices, and the distractions the participants may encounter.

For Individual 6 on route 2, he bypassed a beacon without scanning it, which caused him to deviate from the correct path. Individual 12 failed to complete route 1 involving an elevator where he seemed to have difficulty understanding the photograph that told him to press a button. The problem was overcome in the video mode. Similarly, Individual 14 did not understand the "push the button" picture on route 1. On route 2, she repeatedly asked for confirmation from us when she received video prompts on her PDA. Therefore, her trip on route 2 was also considered unsuccessful, although she made it to the destination. Many cognitive deficits are highly variable (even within an individual), challenging the notion of a typical or representative user.

In Fig. 9, we studied statistics of travel time as observed in the field trials. Only trips made through the end were counted. Travel time on video mode was statistically greater than that on picture model. Video clips just took more time to play. That was the trade-off between wayfinding correctness and elapsed time. Travel without wayfinding technology was fast at the price of higher probabilities of getting lost.

Besides technical evaluation, subjective workload measurement is also important to the success of the system and adoption of the device. To evaluate the task load subjects may have experienced during device use, we adopt Hart and Staveland's NASA Task Load Index (TLX) method [14]. NASA TLX includes six indices: mental demand, physical demand, temporal demand, performance, effort, and frustration. Considering the reading and verbal limitations with our subjects, TLX-based assessment was

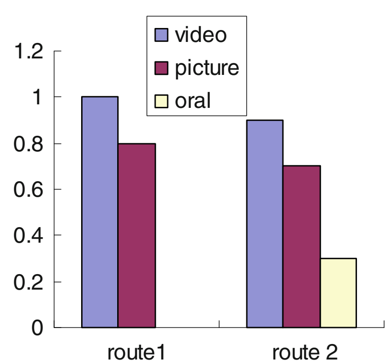


Fig. 8 Trip success ratios using two prompt modalities and oral instructions

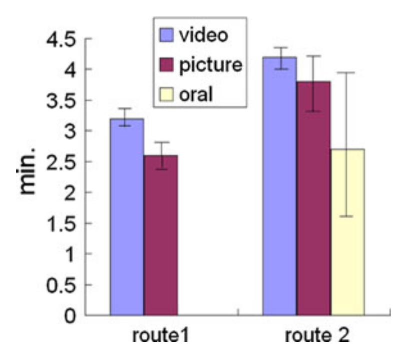


Fig. 9 Travel time on the two routes. *Error bars* represent confidence intervals

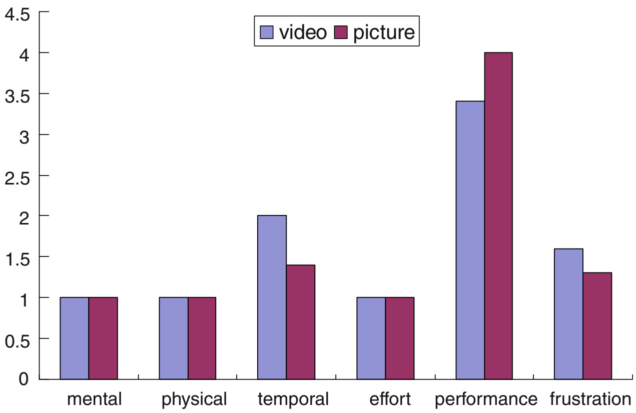


Fig. 10 Task load index (TLX) results

conducted in the form of oral interview. In the meantime, 21 gradations have been simplified and reduced to only 5, i.e., 1 to 5, representing very low, low, neutral, high, and very high. The survey results are summarized in Fig. 10.

In this study, the subjects unanimously found mental and physical demands, and efforts to operate the device very low. The pace of the task in the video mode was slightly more hurried than the picture mode; their average temporal demand is 2.0 versus 1.4. The main reason was that the video mode took more time, usually 3–5 s, than pictures. In addition, the subjects often stopped walking in order to concentrate on the video clips. Once the participants comprehended the video content, they might feel rushed to start walking to catch up time. The performance of the proposed system in both modes was considered high (video = 3.5, picture = 4.0). Again the picture mode was felt better than the video mode which was obviously against the results we found in the trip success ratios. Pictures rendered smoother and started faster on PDAs than video clips, although video messages were easier to comprehend. Therefore, subjectively they found video clips better. When prompted by video to push a button in an elevator, the participants could see the button light up when pressed, while the effects of picture prompts were not as good. During the interviews, all the participants felt comfortable recommending the system to their friends. No significant frustration was experienced by the participating users, although some had difficulty interpreting pictures or videos and felt confused.

Social stigma was once considered as a potential issue before the experiment was started. Having to interact with a handheld device at decision points was supposed to single out some potential users of the system and reveals the condition of the user to all bystanders. However, our field experiments in a crowded building complex revealed that it was not a real issue. Bystanders were rarely attracted to watch our subjects using their wayfinding PDAs, except that only two seemed curious about the beacons deployed on the routes and mere one of them bothered to ask what it was. PDAs have been around for several years, and people tend to see them as cellular phones. Therefore, using PDAs as wayfinding devices is not likely to become a target of social stigma. For the same reason, there were low initial reservations and resistance users exhibited about the device and the technology.

5 Limitations and future work

The proposed solution depends on the beacon system to provide location-aware prompts. One limitation of this work is that buildings without such beacons installed will not support the proposed wayfinding system. The freedom of mobility can be enhanced for people with cognitive disabilities if spaces become “smarter” by adding location awareness. For modules that ship as low as 7 USD per beacon chip, a placement of 100 beacons as in our case each with 3 modules economically costs only 2,100 USD or so. Our previous prototype has relied on visual tags and passive RFID tags, respectively. However, cognitively impaired subjects report difficulties in using PDA cameras to capture visual codes and paying attention to looking for RFID tags in order to receive prompts.

The experimental results, in particular travel time, were dependant on ages, physical strength, and behavioral patterns in addition to cognitive impairments. Determining how the choice of categories of cognitive impairments influences the experimental results, in particular travel time, is challenging.

The latency in presenting the video prompts as opposed to the photographs might be an issue worth further exploring. Future work includes the development of an adaptive algorithm which adjusts the framerate of the video depending on maximum delay acceptable for a given individual, such that for a fast runner, only one frame would be shown (corresponding to the single photograph case) and for a slow walker, a high-framerate video would be used. For anyone in between, the video adapts its framerate in real time to the pace of the wayfinding individual.

6 Conclusions

In this paper, we present a wayfinding prototype system-based Bluetooth sensors for individuals with cognitive impairments. Two modalities were implemented and their performance was compared. Video prompts were found 25–28% better than picture prompts in terms of success ratio. The success ratio can depend on the extent to which participants are cognitively impaired, the complexity of routes, the degree of received training and self-practices, and the distractions the participants may encounter. Furthermore, the TLX results show the task load of the prototype on the users was acceptable.

Acknowledgments The work presented in this paper has been funded by the National Science Council under grant numbers NSC 95-2627-E-008-002-, NSC 96-2627-E-008-001-, and NSC 97-2627-E-008-001-. Thanks for all the participating job coaches who have served the mentally impaired heartily and truthfully. Thanks for all the participating individuals with cognitive impairments, who have shown us deeper values of life. We thank the anonymous reviewers for their comments and suggestions which greatly improve the presentation of the paper. We also would like to extend our special thanks to a reviewer who suggests the idea of adaptive video framerate in the future work.

References

1. Bond GR, Liberman RP (1992) Vocational rehabilitation. Handbook of psychiatric rehabilitation. Macmillan, New York
2. Bond GR, Drake RE (1996) Supported employment for people with severe mental illness: a review. Psychiatric Services
3. Goodwin S (1997) Comparative mental health policy: from institutional to community care. Sage, Thousand Oaks
4. Wu M, Baecker R, Richards B (2005) Participatory design of an orientation aid for amnesics. In: Proceedings of the SIGCHI conference on human factors in computing systems, pp 511–520
5. Sohlberg MM, Fickas S, Hung PF, Fortier A (2007) A Comparison of four prompt modes for route finding for community travelers with severe cognitive impairments. Brain Injury, January, pp 531–538
6. Dutton GN (2003) Cognitive vision, its disorders and differential diagnosis in adults and children: knowing where and what things are. Eye 17:289–304
7. Carmien S, Dawe M, Fischer G, Gorman A, Kintsch A, Sullivan JF (2005) Socio-technical environments supporting people with cognitive disabilities using public transportation. ACM Trans Comput Hum Interact 12(2):233–262
8. Chang YJ, Tsai SK, Wang TY (2008) A context aware handheld wayfinding system for individuals with cognitive impairments. In: Proceedings of the ACM ASSETS 2008, Halifax, Canada. Oct. 13–15, pp 27–34
9. Chang YJ, Chu YY, Chen CN, Wang TY (2008) Mobile computing for indoor wayfinding based on Bluetooth sensors for individuals with cognitive impairments, In: Proceedings of the international symposium of wireless and pervasive computing (ISWPC 2008), Greece, May 7–9. pp 623–627
10. Chang YJ, Chen CN, Chou LD, Wang TY (2008) A novel wayfinding systems based on passive RFID for individuals with cognitive impairment. In: Proceedings of the pervasive health 2008, Tempere, Jan. 31–Feb. 2, pp 108–111
11. Chang YJ, Tsai SK, Chang YS, Wang TY (2007) A novel wayfinding system based on geo-coded QR codes for individuals with cognitive impairments. In: Proceedings of 9th international ACM SIGACCESS conference on computers and accessibility, Tempe, Arizona, Oct 15–17, pp 231–232
12. Bohonos S, Lee A, Malik A, Thai C, Manduchi R (2007) Universal real-time navigational assistance (URNA): An urban Bluetooth beacon for the blind, In: Proceedings of the 1st ACM SIGMOBILE international workshop on Systems and networking support for healthcare and assisted living environments, pp 83–88
13. Chang YJ, Liu HH, Wang TY (2009) Mobile social networks as quality of life technology for people with severe mental illness. IEEE Wirel Commun 16(3):34–41
14. [Online]. Available: http://humansystems.arc.nasa.gov/groups/TLX/downloads/TLXScale.pdf
15. Allen G (1999) Spatial abilities, cognitive maps, and wayfinding: bases for individual differences in spatial cognition and behavior. In: Golledge R (ed) Wayfinding behavior: cognitive mapping and other spatial processes. Johns Hopkins University Press, Baltimore, pp 46–80
16. Passini R (1996) Wayfinding design: logic, application and some thoughts on universality. Des Stud 17(3):319–331
17. Giroux S, Pigot H (2005) From smart homes to smart care, assistive technology research series. Proceeding of the 3rd International Conference on Smart homes and health Telematics. In: Proceedings of ICOST'05, Sherbrooke, Canada
18. Bauchet J, Mayers A (2005) Modelisation of ADL in its environment for cognitive assistance. In: Proceedings of the 3rd international conference on smart homes and health telematic, ICOST'05, Sherbrooke, Canada, pp 3–10
19. Boger J, Poupart P, Hoey J, Boutilier C, Fernie G, Mihailidis A (2005) A decision-theoretic approach to task assistance for persons with dementia. In: Proceedings of the international joint conference on artificial intelligence (IJCAI'05), Edinburgh, Scotland, pp 1293–1299
20. Fatiha L, Lefebvre B (2005) A cognitive system for a smart home dedicated to people in loss of autonomy. In: Proceedings of the 3rd international conference on smart homes and health telematic, ICOST'05, Sherbrooke, Canada, pp 245–254
21. Pigot H, Mayers A, Giroux S (2003) The intelligent habitat and everyday life activity support. In: Proceedings of the 5th international conference on simulations in biomedicine, April 2–4, Slovenia, pp 507–516
22. Wahlster W, Baus J, Kray C, Krüger A (2001) A resource-adaptive mobile navigation system. In: Proceedings of the international workshop on information presentation and natural multimodal dialogue (IPNMD-2001). Verona, Italy, pp 5–9
23. Baus J, Kray C, Krüger A (2001) Visualization of route descriptions in a resource-adaptive navigation aid. Cogn Process 2(2/3):323–345
24. Raubal M (2001) Human wayfinding in unfamiliar buildings: a simulation with a cognizing agent. Cogn Process 2(2/3):363–388
25. Nothegger C, Winter S, Raubal M (2004) Selection of salient features for route directions. Spat Cogn Comput 4(2):113–136
26. Kray C (2002) Situational context and navigational assistance. In: Proceedings spatial cognition 2002, Tutzing, Starnberger, Germany
27. Baus J et al (2007) Auditory perceptible landmarks in mobile navigation. In: Proceedings of the 12th international conference on intelligent user interfaces. Honolulu, Hawaii, USA, pp 302–304
28. Goodman J, Brewster SA, Gray P (2005) How can we best use landmarks to support older people in navigation? Behav Inf Technol 24(1):3–20
29. Liao L, Fox D, Kautz H (2007) Learning and inferring transportation routines. Artif Intell 171(5–6):311–331
30. Liu L, Hile H, Kautz H, Borriello G, Brown PA, Harniss M, Johnson K (2006) Indoor wayfinding: developing a functional interface for individuals with cognitive impairments, In: Proceedings of computers & accessibility, ASSETS 2006, October, pp 95–102
31. Van Laarhoven T, Van Laarhoven-Myers T (2006) Comparison of three video-based instructional procedures for teaching daily living skills to persons with developmental disabilities. Educ Train Dev Disabil 41(4):365–381

32. Cannella-Malone H, Sigafoos J, O'Reilly M, de la Cruz B, Lancioni GE (2006) Comparing video prompting to video modeling for teaching daily living skills to six adults with developmental disabilities. Educ Train Dev Disabil 41(4):344–356
33. Cihaka DF, Kesslerb KB, Alberto PA (2007) Generalized use of a handheld prompting system. Res Dev Disabil 28(4):397–408
34. Cihak DF, Kelby K, Alberto PA (2008) Use of a handheld prompting system to transition independently through vocational tasks for student with moderate and severe intellectual disabilities. Educ Train Dev Disabil 43(1):102–110
35. Liu A, Hile H, Kautz H, Borriello G, Brown PA, Harniss M, Johnson K (2007) Indoor wayfinding: developing a functional interface for individuals with cognitive impairments. Disability and Rehabilitation: Assistive Technology 3(1):69–81
36. Gentry T, Wallace J, Kvarfordt C, Lynch KB (2007) Personal digital assistants as cognitive aids for individuals with severe traumatic brain injury: a community-based trial. Brain Injury, December, pp 19–24
37. Ross DA, Henderson VL (2005) Cyber crumbs: an indoor orientation and wayfinding infrastructure. In: Proceedings of the 28th RESNA conference, June
38. Cook AM, Polgar JM, Hussey SM (2008) Assistive technology principles and practice, 3rd edn. Mosby, Elsevier
39. Liu H, Darabi H, Banerjee P, Liu J (2007) Survey of wireless indoor positioning techniques and systems. IEEE Trans Syst Man Cybern C 37(6):1067–1080
40. Gu Y, Lo A, Niemegeers I (2009) A survey of indoor positioning systems for wireless personal networks. IEEE Commun Surv Tutor 11(1):13–32
41. Hazas M, Hopper A (2006) Broadband ultrasonic location systems for improved indoor positioning. IEEE Trans Mobile Comput 5(5):536–547
42. Ni LM, Liu Y, Lau YC, Patil AP (2004) LANDMARC: indoor location sensing using active RFID. Wirel Netw 10(6):701–710
43. Golledge R (1999) Wayfinding behavior: cognitive mapping and other spatial processes. John Hopkins University Press, Cambridge, MA
44. Sutcliffe A, Fickas S, Sohlberg M, Ehlhardt L (2003) Investigating the usability of assistive user interfaces. Interact Comput 15(4):577–602
45. LoPresti EF, Mihailidis A, Kirsch N (2004) Assistive technology for cognitive rehabilitation: state of the art. Neuropsychol Rehabil 14(1/2):5–39
46. O'Connell MI, Mateer CA, Kerns KA (2003) Prosthetic systems for addressing problems with initiation: guidelines for selection, training & measuring efficacy. NeuroRehabilitation 18(1):9–20
47. Sohlberg MM, Ehlhardt LA, Fickas S, Sutcliffe A (2003) A pilot study exploring electronic mail in users with acquired cognitive-linguistic impairments. Brain Inj 17(7):609–629
48. Dijkstra E (1959) A note on two problems in connexion with graphs. Numer Math 1:269–271
49. Cannella H, O'Reilly M, Lancioni G (2005) Choice and preference assessment research with people with severe to profound developmental disabilities: a review of the literature. Res Dev Disabil 26(1):1–15
50. Bluetooth SIG. Bluetooth specification v2.0, 2004