Comparing Modalities in Autonomous Indoor Wayfinding for People with Cognitive Impairments

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ABSTRACT

A wayfinding system is presented with an aim to increase workplace and life independence for cognitive-impaired individuals such as people with traumatic brain injury, cerebral palsy, intellectual and developmental disabilities, and schizophrenia. PDA prompting with navigation media at the right time and place can assist cognitively-impaired persons. 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.

Categories and Subject Descriptors

H.5.2 [Information Interfaces and Presentation]: User Interfaces–Evaluation/methodology, *User-centered design, Prototyping, Screen design*; K.4.2 [Computers and Society]: Social Issues–*Assistive technologies for persons with disabilities*

General Terms

Design, Human Factors.

Keywords

Cognitive disability, ubiquitous computing, user interface, Bluetooth

1. INTRODUCTION

The majority of otherwise-employable persons with mental impairments remain unemployed, rarely access appropriate community services, and are socially isolated [1] [2] [3]. Wayfinding systems are an assistive technology targeting cognitive-impaired individuals who are mobile and need to travel through both indoor and outdoor environments, thus increasing workplace and life independence. An adult with mental disorder 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 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 of people with mental disabilities.

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 of navigation prompting take context and situations into account [15, 16, 17, 18, 22, 23, 34]. 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, eliminate manual passkey challenges, and reduce privacy and security concern as the use 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.

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, prototype design is presented. Implementations and results are shown followed by some concluding remarks.

2. LITERATURE SURVEY

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 [7-11] that can improve quality of life. 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 [4]. 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 [5]. Later a feasibility study [6] of user interface was carried by the same team, who found photos are a preferred medium type for giving directions to cognitively impaired persons in comparison with speech and text.

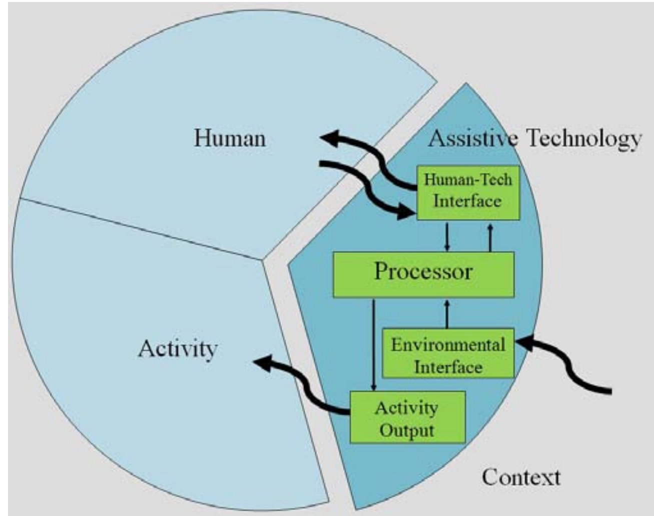
Personal computers, including laptops, tablet PCs and special purpose communicators [27, 28], have been integrated with various assistive technology to provide prompting. The proliferation of mobile compact computing devices such as palm size PDAs enables a new platform for personal prompting and cognitive aides [19, 21, 23, 25, 29]. PDA-based prompting is especially useful for mobile users. Previous work on prompting using PDAs replies on “Wizard of Oz” approaches [19, 30], on user self-conscience [21], or on a preset timer [20, 28, 29] in order to send the prompts. The Clever project [5] 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.

Our previous work [16] 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 [15]. 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) [31] for evaluating assistive devices.

3. PROTOTYPE DESIGN

As informed by the human activity assistive technology (HAAT) model [33], 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 Figure 1. Each component will be described in the following.

The Bluetooth beacons 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 seconds 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, usability studies of interfaces by people with cognitive impairments, and the requirements based on interviews with nurses and job coaches at rehabilitation hospitals and institutes.



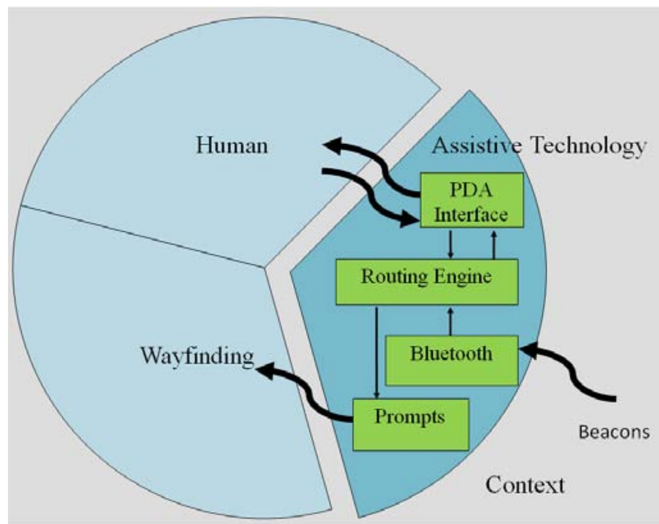


Figure 1: (upper) The HAAT model. (lower) Model of wayfinding devices.

Bluetooth signals are designed to cover small areas of diameter 10 meters. In order to provide sufficient resolution of locations and reduce device cross-talk, we deliberately attenuate by 20 dB the transmitting power so that the radiating radius is between 1.5 to 2.0 meters. The Bluetooth module is shown in Figure 2. 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.

Figure 2: Beacon source powered by a 9-volt battery

Figure 3: A just-in-time picture. Taking a right turn when exiting.

Figure 4: Just-in-time video clips shown on the wayfinding PDA. (left) Taking a right turn at the end of a hallway. (right) Pushing a button in an elevator to get to the 5th floor.

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 (Figure 3) or videos (Figure 4), triggered by Bluetooth 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 5 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.

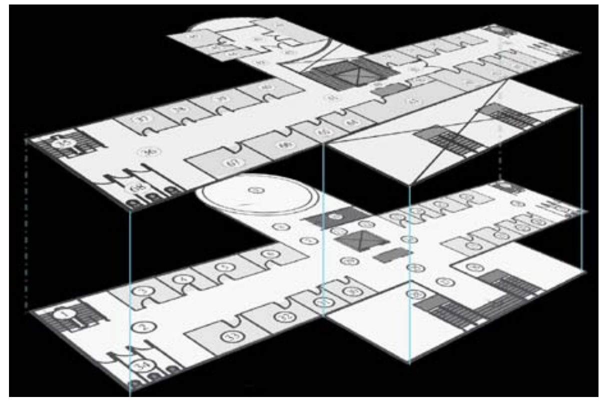


Figure 5: Building floor plan with all the decision points labeled.

The graph in Figure 5 is then used in the determination of optimal routes. The routing scheme in our implementation is deployed in the handheld device, namely a PDA. 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 wheel chair users so that stairs will not be selected for navigation. In the prototype, the Dijkstra algorithm, a time-honored graph theoretic method [32], is applied. A computed route is depicted in Figure 6.

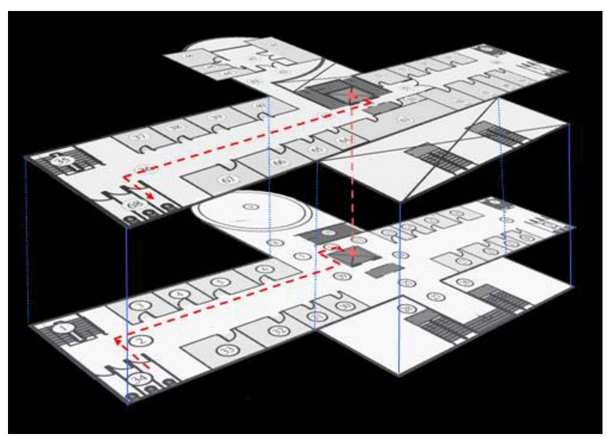


Figure 6: Route planned by the Dijkstra algorithm

4. EXPERIMENTS

4.1 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 1. 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 (Figure 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.

Table 1: Route profiles and complexities

Destination / Route ID		Difficulties	Vertical movements	Turns	#beacons deployed
Library, Tech Building	R1	average	1F~6F	3	7
Warehouse, Central Building	R2	difficult	1F~B1	6	6

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. After the user submits the destination on the PDA, the wayfinding activity starts.

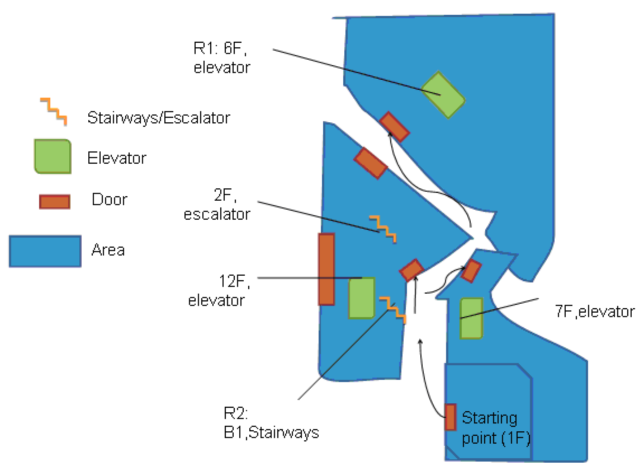


Figure 7: The two routes used in the experiments

4.2 Procedures

We recruited 20 subjects for 3 days of experiments. The individuals were impaired with various cognitive disabilities such as schizophrenia, mental retardation, brain syndromes, epilepsy, organic depression, Pakinson'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 to 20 minutes. Afterwards, 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.

Picture-based prompting was compared with the performance of vide-based prompting. Subjects 1~10 used video prompting to navigate route 1 while using picture-based prompting to navigate route 2. On the contrary, subjects 11~20 used picture-based prompting for route 1 while using video prompting for route 2.

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.

4.3 Results

In Table 2, 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 between 80%~100% for video prompting and between 70%~90% for picture-based prompting. The results are depicted in Figure 8. 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 suffer from 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 photo 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.

Table 2: Experiments of 20 cognitively-impaired participants taking the two routes, once for each route

Parti-cipant	Route1 Video	Route 1 Picture	Route 2 Video	Route 2 Picture	Route 2 Oral
1 SC	1	-	-	0	0
2 SC	1	-	-	1	0
3 SC	1	-	-	0	0
4 MR	1	-	-	1	1
5 MR	1	-	-	1	0
6 MR	1	-	-	0	0
7 MR	1	-	-	1	0
8 BS	1	-	-	1	1
9 BS	1	-	-	1	0
10 BS	1	-	-	1	0
11 BS	-	1	1	-	1
12 BS	-	0	1	-	0
13 EP	-	1	1	-	0
14 EP	-	0	0	-	0
15 EP	-	1	1	-	0
16 OD	-	1	1	-	1
17 OD	-	1	1	-	0
18 DE	-	1	1	-	0
19 DE	-	1	1	-	1
20 DE	-	1	1	-	1

1: success 0: failure -: N/A

SC: Schizophrenia MR: Mental Retardation BS: Brain Syndrome

EP= Epilepsy, OD=Organic Depression, DE=Dementia

In Figure 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 [31]. 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 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 Figure 10.

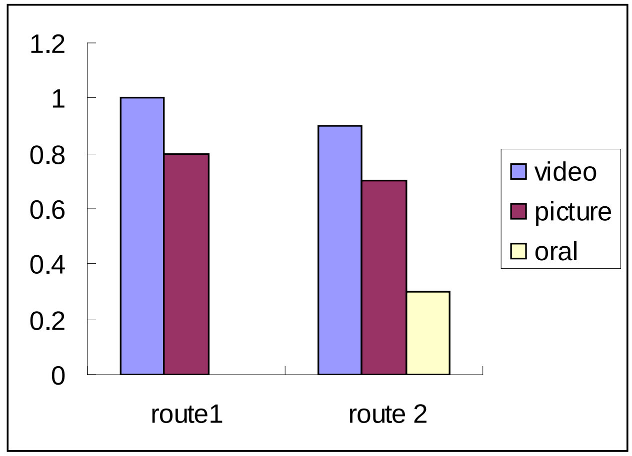


Figure 8: Trip success ratios using two prompt modalities and oral instructions

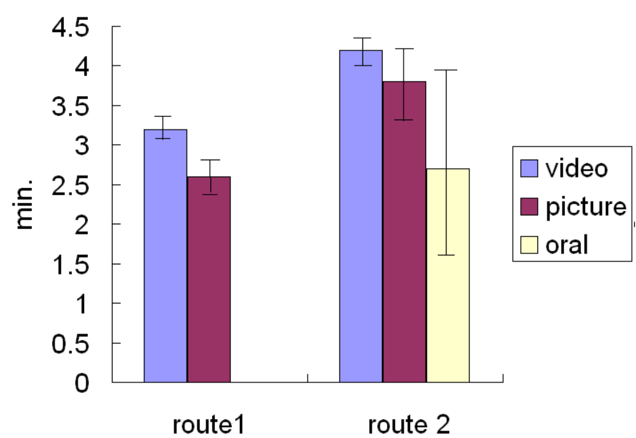


Figure 9: Travel time on the two routes. Error bars represent confidence intervals.

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 seconds, 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.

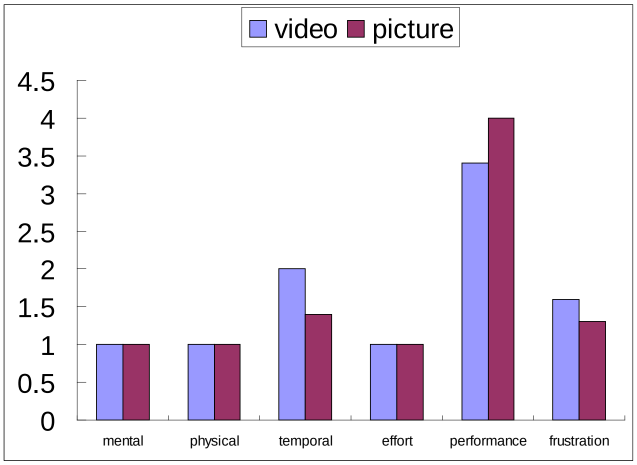


Figure 10: Task load index (TLX) results.

5. 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 TLX results show the prototype is user friendly with high reliability. The success ratio can depend on the extent to which participants suffer from mental disabilities, the complexity of routes, the degree of received training and self-practices, and the distractions the participants may encounter.

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