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An Accessible BLE Beacon-based Indoor Wayfinding System

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Abstract

Navigating large indoor environments can be challenging, especially for those with disabilities. To address this issue, a Bluetooth Low Energy (BLE) beacon-based indoor wayfinding system has been developed, considering the unique needs of individuals with and without disabilities. The system was designed using the same methodology as the GuideBeacon indoor wayfinding system and features mobile applications for both Android and iOS devices. Based on usability testing conducted with 16 subjects across 4 user categories (including individuals with visual impairments, mobility impairments, hard of hearing, and those without disabilities), the indoor wayfinding system was found to be effective for individuals with diverse abilities.

Keywords

BLE beacon, localization, indoor navigation, people with disabilities.

Introduction

People with disabilities face several mobility challenges that prevent them from being engaged citizens. These include navigating independently in and to buildings that provide important services (educational services, medical care, etc.), and exploring unfamiliar environments safely and independently. Current navigation services fall short of addressing the wayfinding and navigation needs and preferences of people with disabilities.

For outdoor environments, a satellite-based system such as GPS provides a quick and easy means of wayfinding that is mostly accurate. However, in most indoor environments, GPS is neither reliable nor accurate. Reading indoor maps of buildings and following static signage is still the most reliable option but this indoor wayfinding strategy fails to consider the unique needs of people with disabilities. Even individuals without disabilities can struggle to navigate large, unfamiliar indoor environments. This could be due to the lack of well-marked signs and maps, not being familiar with the conventions or language used on the signage, or just the fact that the layout of the space is disorienting. Thus, there is a need for a low-cost, easy-to-use, and reliable wayfinding system that can aid both individuals with and without disabilities.

The early systems for enabling auxiliary location-based services (ALBSs) for independent wayfinding in GPS-limited areas were based on radio-frequency identification (RFID) tags (Wang and Katabi; Mooi et al.; Willis and Helal; Chang et al.; Kulyukin et al.) or infrared technology (Aitenbichler and Mühlhäuser). These were not very flexible for changing embedded information and required special hardware to be carried around by users. Such constraints had hampered the widespread use and adoption of ALBSs. Some recent efforts for wayfinding for the blind and visually impaired (BVI) using Bluetooth Low Energy (BLE) beacons that interact wirelessly with smartphones include StaNavi (Kim et al.), GuideBeacon

(Cheraghi et al.), ASSIST (Nair et al.), PERCEPT (Ganz et al.), and NavCog (Ahmetovic et al.). All report significant improvement in the ability of BVI individuals to navigate indoor spaces independently. Such beacon-based navigation systems may be a viable solution for indoor wayfinding for the BVI if the underlying challenges to their deployment can be overcome.

The biggest limitation of existing work is that it has targeted solving challenges for just one type of disability (such as vision loss), resulting in a very small potential user base. This work aims to be inclusive in addressing the unmet auxiliary wayfinding needs of people with and without disabilities using a common technology infrastructure.

Discussion

This work presents a wayfinding system that builds upon the methods developed for GuideBeacon, a BLE beacon-based indoor wayfinding system (Cheraghi et al.). Figure 1 shows the components of the BLE beacon-based wayfinding system. Every point of interest in an indoor setting that the user may wish to navigate to is associated with a BLE beacon. Each beacon is linked to at most 4 points of interest that lie close to each other. These beacons and the paths that connect them can be depicted in a connected graph $G(V, E)$, where V is the set of vertices representing the beacons and E representing the paths that exist between the beacons. Each path that a user can take between any two beacons u and v has a certain weight w, which could be a function of the distance between the beacons and/or the ease at which one can move between these beacons. Figure 2 shows a connected graph where the beacons serve as vertices and the paths between beacons serve as edges (the walking paths). The round markers represent the beacon locations, and the square markers represent the points of interest. Each of the edges has a weight (in this case, the actual distance between the markers) that determines if a path needs to be part of the end-to-end route computed during navigation. A shortest path algorithm (such as Dijkstra's algorithm) helps find the shortest path between the source node (the beacon that the user is close to) and the destination node (the point of interest that the user intends to navigate to). All this graphical information that contributes to wayfinding is stored in a database and later retrieved using a mobile application.

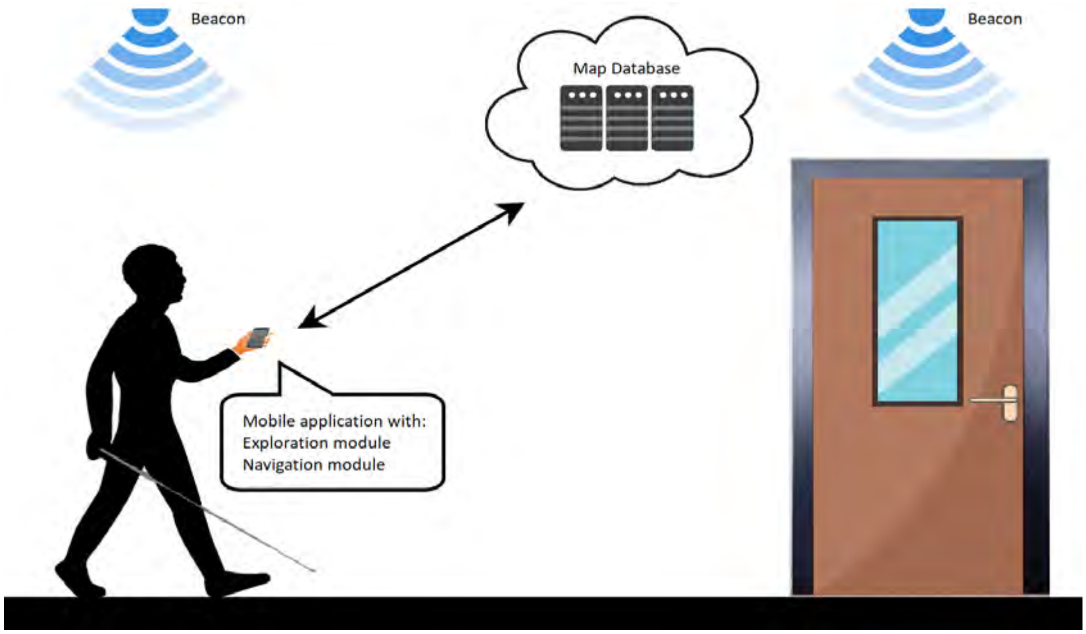

Fig. 1. BLE beacon-based wayfinding system.

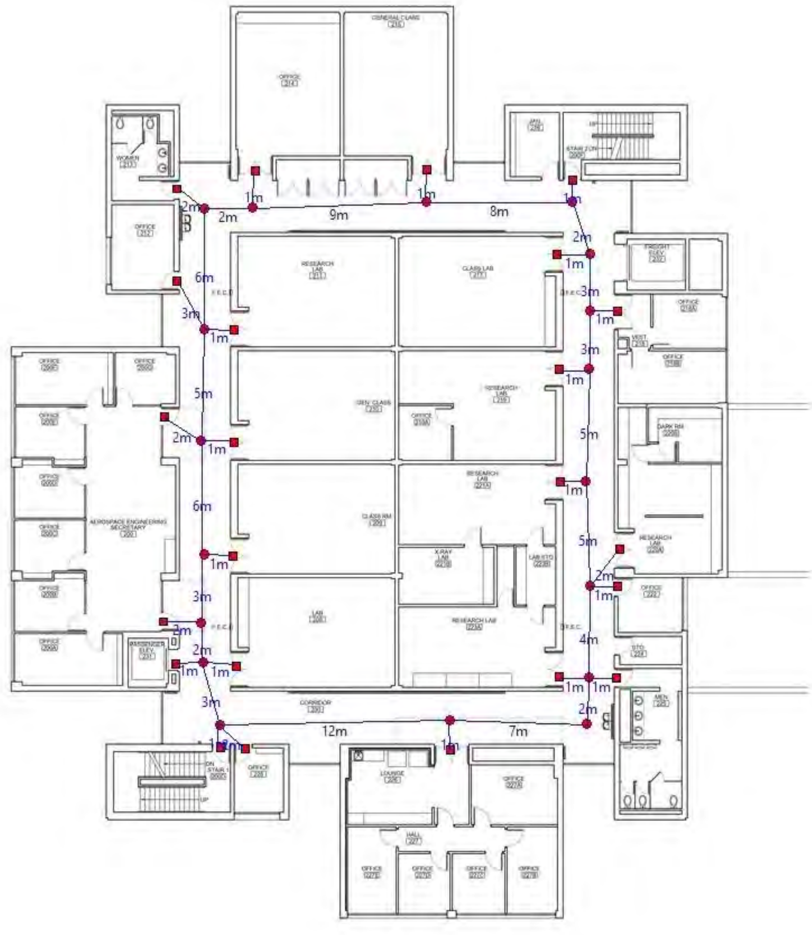

Fig. 2. Connected graph.

To estimate the position of a user in an indoor space, the wayfinding system utilizes a beacon-based proximity detection mechanism. It relies on received signal strength indicator (RSSI) readings to determine if a user is near a beacon; the closer the user is to a beacon, the higher the RSSI will be.

The mobile application developed for indoor wayfinding features two modules that can help with both localization and navigation. The exploration module activates when the user is near a BLE beacon that is part of the indoor beacon network. This module provides information about the nearby points of interest associated with a beacon. As the user moves through the indoor space and encounters new beacons, they will be able to discover new points of interest.

This is useful for users who simply wish to learn about their new surroundings without a specific destination in mind. While standing close to a beacon, users can perform a voice search or type in a search box to look up their desired destination in a database of indoor points of interest. Once the user chooses their destination, the navigation module activates. This module computes the end-to-end route and generates guidance instructions that help users navigate to their desired destination. If a user deviates from the computed path, a rerouting mechanism kicks in and computes a new route from the user's current location to the intended destination and guides the user along this new route.

Beacon Deployment

The three-story college campus building that houses the authors' research laboratory was chosen as the beacon deployment site. Its 2-meter wide, double-loaded corridors served as a testing ground for the BLE beacon-based indoor wayfinding system presented in this paper. Due to its low cost and long battery life, the Gimbal Series 21 beacon was the beacon of choice for this work. The Gimbal Series 21 beacon uses four standard AA alkaline batteries and has a battery life of around 18 months.

Beacons were installed on all three floors of the campus building. Beacon placement locations included entrances to rooms, corner spaces of angled corridors, and entryways to vertical circulation spaces such as elevators and stairwells. Beacons placed near elevators and stairwell doors served as floor transition beacons that allowed for navigation between floors.

Mobile Applications

Two mobile applications were developed for operating the wayfinding system presented in this paper: one for Android and another for iOS devices. Both these applications can seamlessly switch between the exploration module (which allows users to learn about their immediate surroundings) and the navigation module (which provides navigational guidance to users as they move toward their destination).

The mobile applications were equipped with a feature set that is largely the same. The route preview feature gives users a preview of the entire route (which includes information about the turns and the distances to these turns) from the user's current position to their destination. Both applications were equipped with built-in accessibility features of their respective platforms. Users can customize settings, which include changing the audio narration speed, turning the route preview on or off, changing the unit for distance to the next point on the route (meters, feet, or steps), and changing how relative directions are given (left-right-forward or clock position). Within the application, users can look up a destination in the database of indoor points of interest either by typing text in a search box or by using voice search (user input captured through voice is converted to text using a text-to-speech application). For both these types of input, users can search through partial or other known information associated with a destination. For example, the room number associated with a location could be used in place of the location name to search the database.

The differences between the iOS and Android applications lie in the presentation of the system responses and navigational instructions. In addition to voice directions, users are provided turn-by-turn directions in a list format on the screen in the Android application (Figure 3a). This list always displays the upcoming turn instruction as the first item and shortens as the user approaches their destination. In the iOS application, the user has to rely on voice directions for navigation, but the user's position will be denoted as a dot on the floor plan that updates frequently as the user moves towards their destination (Figure 3b). This feature helps the user track their location in the indoor space at any given time. Users also have the option to double-tap anywhere on the screen to repeat the last spoken turn-by-turn direction (while in navigation mode) or to replay the audio description of their surroundings (while in exploration mode).

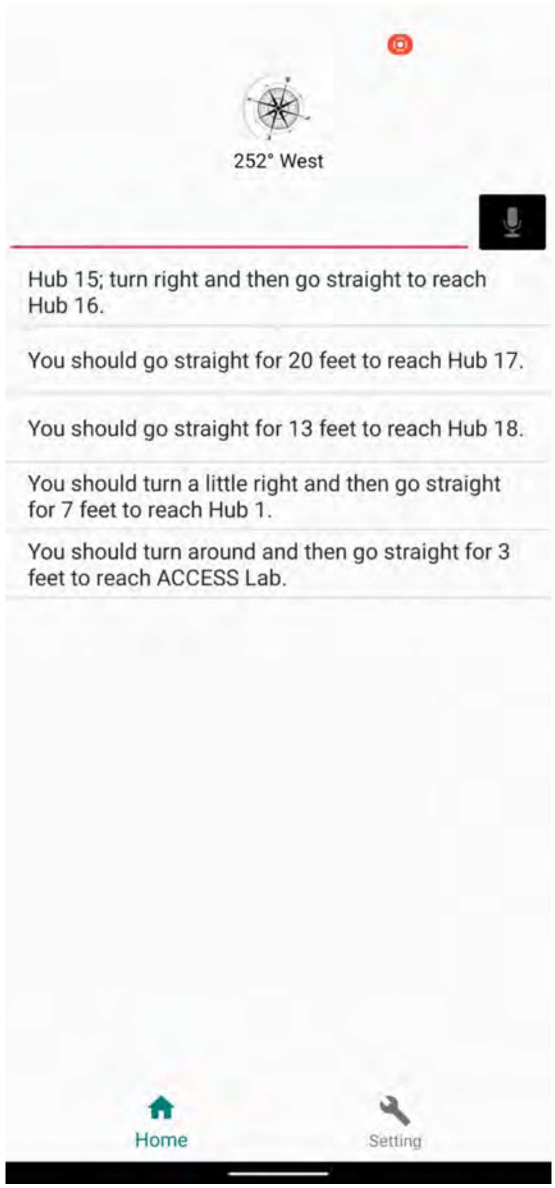

Fig. 3a. Android application. Guidance provided by the mobile applications when the navigation module is active.

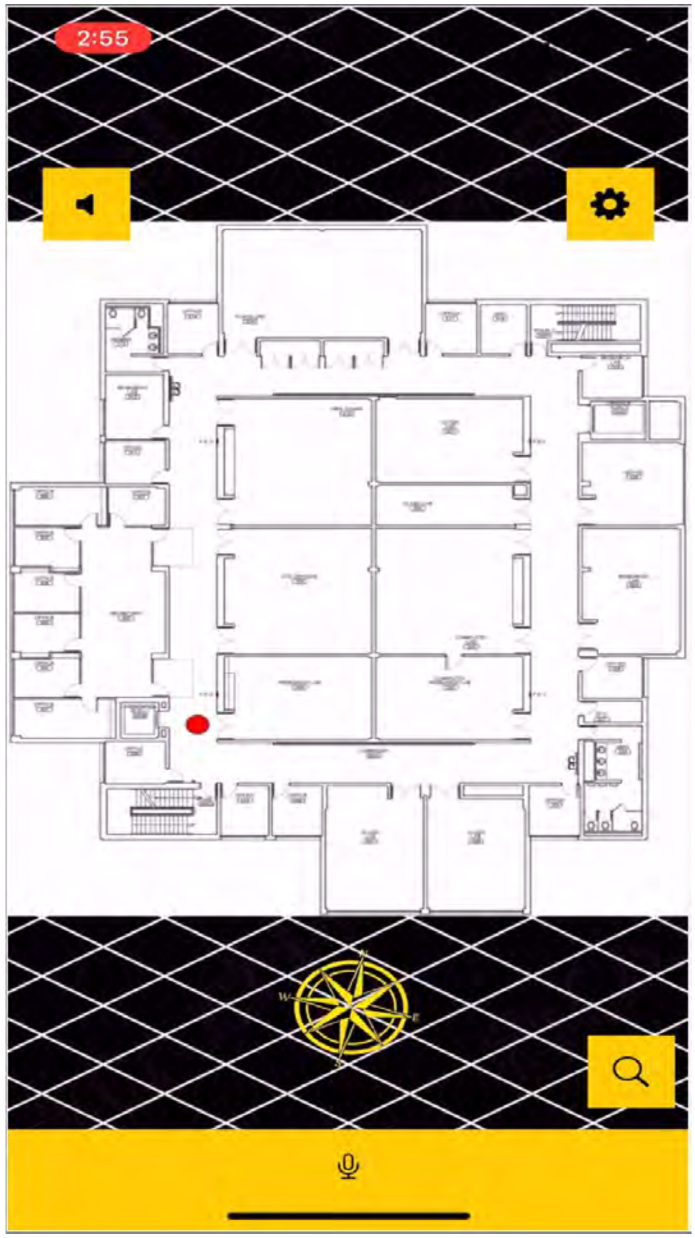

Fig. 3b. iOS application. Guidance provided by the mobile applications when the navigation module is active.

Usability Testing

A total of 16 subjects who were unfamiliar with the building layout of the test site were recruited for testing the wayfinding system: 4 with visual impairments (cane users), 4 with mobility impairments (electric wheelchair users), 4 who are hard of hearing, and 4 with no disabilities. From each of the four user categories, two were asked to navigate without any assistance aside from their mobility aid (the control group), and the other two were asked to navigate using both the wayfinding app and their mobility aid (the experimental group). Each test subject was first positioned near the accessible entrance on the ground floor and then asked to make their way to the authors' research lab on the third floor. This test route is illustrated in Figure 4. All test subjects were asked to take the elevator to get to the third floor. To evaluate the effectiveness of the navigation module of the wayfinding app, the navigation time and navigation distance for each test subject were recorded. To evaluate the performance of the exploration module of the wayfinding app, the test subjects were asked to walk around and explore the third floor of the building.

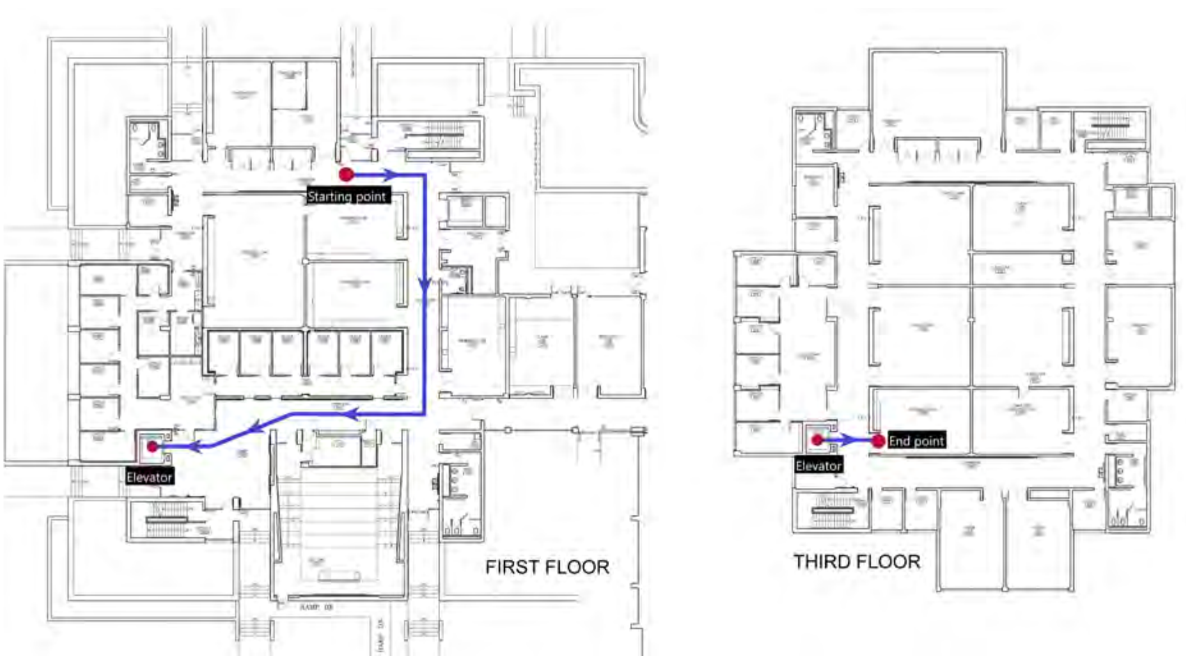

Fig. 4. Test route.

The quantitative results obtained from this testing are shown in Figures 5 and 6. During testing, the time spent waiting for and riding the elevator was not considered when calculating the navigation time. Within each user category, the test subjects who used the wayfinding app took less time to reach their destination and traversed less distance overall when compared to the test subjects who navigated the test route without the app. For all user categories excluding the BVI, the difference in results between the control group and the experimental group does not seem significant. This is because the test route used only had one main intersection where the subjects had to decide what path to take. None of the test subjects who used the wayfinding app took a wrong turn. Among the test subjects who did not use the app, the ones who took a wrong turn had to backtrack which resulted in an increase in their navigation distance and navigation time. Test subjects with visual impairments faced different challenges compared to their sighted counterparts. While the latter could visually verify if they had made a wrong turn and check for the elevator's presence, those with visual impairments had to rely on manual search and identification of each point of interest along their path (such as reading braille door signs) to ensure they did not miss the elevator. This significantly increased the navigation time and distance for individuals with visual impairments.

Qualitative data was collected using a combination of observational usability testing and post-test interviews. When exploring unknown indoor spaces, the test subjects with visual impairments who used the app were satisfied with the exploration module since they were able to discover all points of interest as they moved along the corridor path. The ones with visual impairments who did not use the app took considerable time and effort in finding and identifying the points of interest along the path since they had to resort to touching the walls and interpreting the braille signage. Those with no visual impairments did not find listening to information about their immediate surroundings (the names of the points of interest nearby) to be particularly useful since each of the points of interest had a sign near its entrance that clearly showed the room name. However, having a map of the indoor space in the form of a digital floor plan on the wayfinding app gave them a bird's eye view of all points of interest and helped them learn about the indoor environment more effectively. Additionally, the dot on the floor plan indicating their current position in relation to other points of interest was beneficial. All test subjects found the double-tap feature that allowed them to listen to the same information more than once to be helpful.

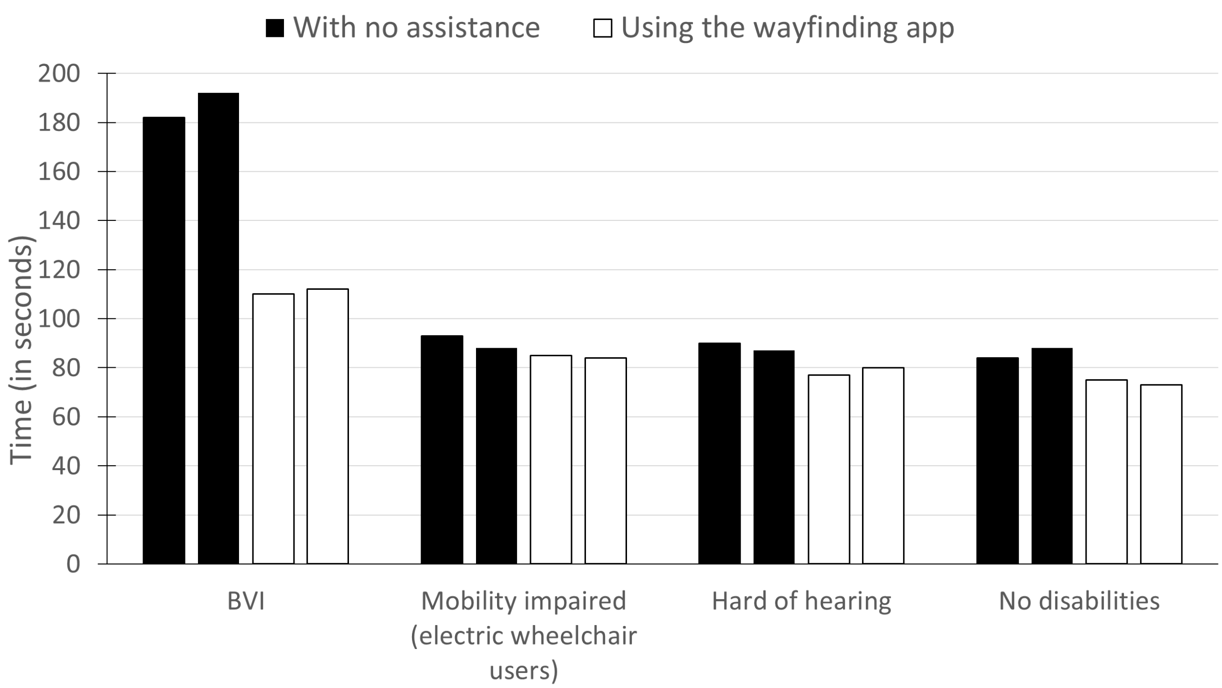

Fig. 5. Time taken by test subjects to navigate the test route.

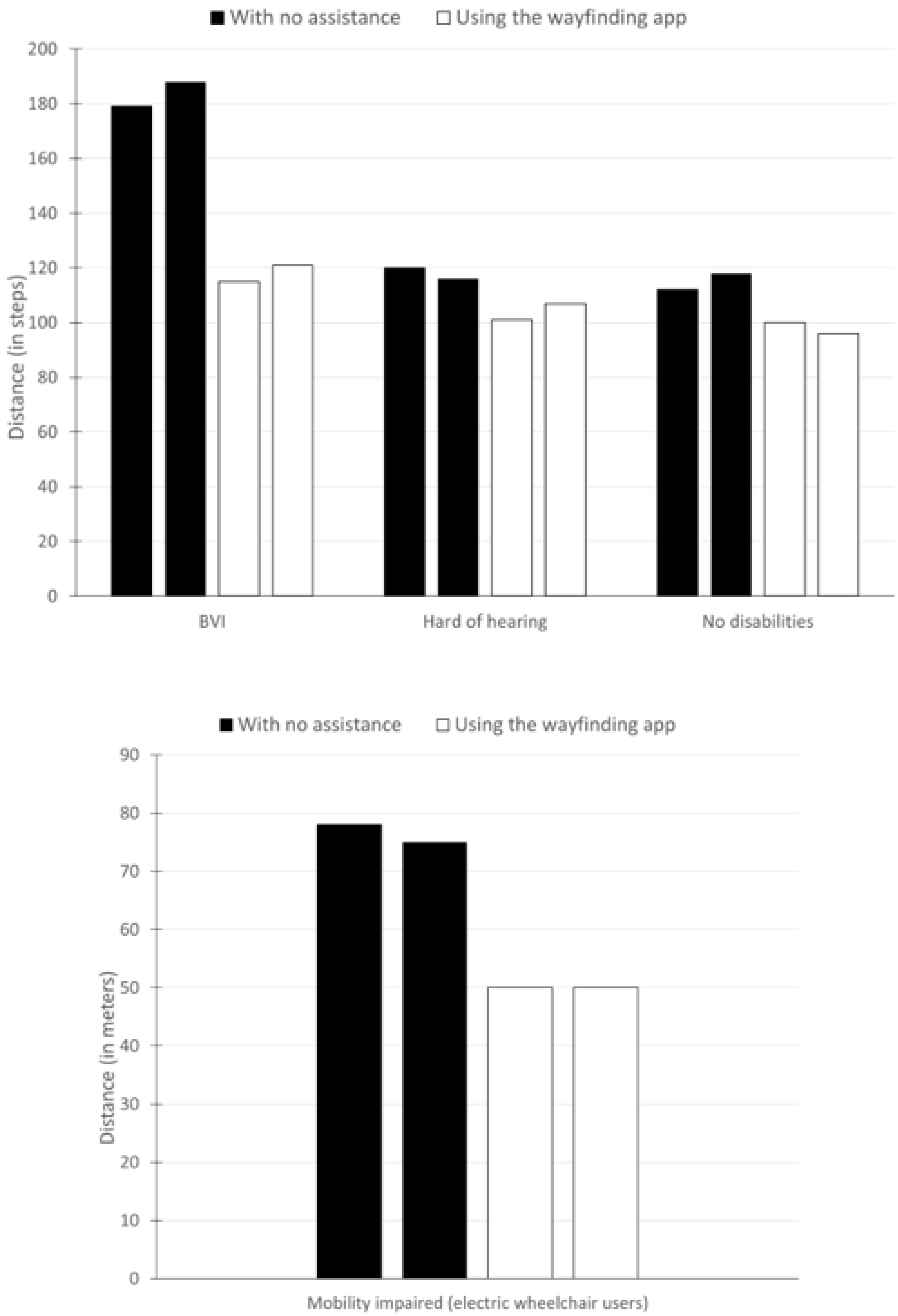

Fig. 6. Distance traversed by test subjects from the starting point to the endpoint of the test route.

When using the mobile application, almost all BVI users wanted information relayed to them at a very fast rate and would therefore set the application's narration speed to a high value. This confirmed that most BVI individuals can easily understand speech at a fast rate.

The wayfinding app successfully met the unique navigation requirements of all four user categories tested. While the subjects who are hard of hearing wanted turn-by-turn navigation instructions to be displayed as text on the screen, others wanted voice navigation. When looking up possible indoor destinations to navigate to, most BVI subjects preferred using voice search instead of manually entering text in the search box. Since they had a smartphone in one hand and a mobility aid such as a white cane in the other, they wanted hands-free control of the application. Most wheelchair users favored this hands-free operation as well. All subjects, irrespective of the user category they belonged to, found the navigation module of the mobile application to be the most useful.

Conclusions

The BLE beacon-based indoor wayfinding system presented in this work considers the unique information needs of people both with and without disabilities. The usability testing results suggest that people with diverse abilities can use the indoor wayfinding system effectively.

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