Indoor Navigation with Mobile Augmented Reality and Beacon Technology for Wheelchair Users

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Abstract— **Physical disability is an obstacle to those who suffer with such, as it deprives the individual from participating in routine activities, without relying on the help of others. Although the difficulties faced are of a wide range, one in particular stands out: navigation in internal environments (indoors). In this context, the main motivation of this research is to investigate the use of Mobile Augmented Reality and Beacon technologies to support indoor navigation for wheelchair individuals. Such an initiative is very important since it emphasizes the use of new tools that can provide effective improvements in terms of social inclusion. To evaluate the proposed solution tests were conducted with regular users. One of the novel features implemented includes the ability to identify best routes free of potential hazards such as obstacles and ramps. Results shows that the proposed solution support safe indoor navigation for wheelchair users.**

I. Introduction

The difficulty of mobility is one of the most common problems experienced by people with disabilities and affects a wide range of the world population [1, 2]. In particular, wheelchair users still face a great number of challenges to navigate within indoor environments [2]. In this context, assistive navigation intends to help with mobility limitations by developing interfaces for wheelchair users associated with the implementation of obstacle avoidance [3, 4].

Finding the most appropriate route to navigate through large and complex areas, such as hospitals, bus terminals, supermarkets and shopping centers is not an easy task [4]. The best route may refer to the shortest, the easiest trajectory, such as a path without stairs, or one which offers appropriate dropped curbs for wheelchair access. On the other hand, the best route may also be the one that goes through points of interest or yet, a safer route for users to reach their destination. In a navigation system designed for wheelchair users, it is important that the selection of the navigation path considers only a subset of possible routes. It is suitable, for example, to have ramps or elevators instead of stairs. In addition, some particularly important destinations, such as toilets for the disabled, should be highlighted.

With the proliferation of wireless technology, a number of solutions for intelligent navigation has become common over recent years, as in the context of driving cars and other vehicles [4]. However, when such techniques are applied to wheelchair users, the systems fail in many aspects. For example, most applications are designed for outdoor navigation (GPS) and does not work properly indoors. Furthermore, the precision to indicate the best route is not provided. Limitations of this type prevent wheelchair users from safely moving around with agility. On many occasions, the task of steering the wheelchair may be too demanding for some users, while for others, reaching the elevator by pressing a button may not be possible at all. Despite the various efforts, current systems still lack proper features to fully overcome these limitations [1, 2, 4]. The scarcity of systems using mobile AR or beacon technology for navigating indoor environments along with techniques that identify best routes, by taking physical disabilities into account, is the main motivation of this research. It is believed that inclusion of this type will improve accessibility and facilitate navigation in various environments, such as shopping centers, hospitals and workplaces.

The authors have proposed an indoor navigation system dedicated to wheelchair users that is also capable of recording maps of buildings alongside accessibility issues. This overall strategy is also based on recording the location of special areas (such as rooms, bathrooms etc.). To support navigation, AR fiducial markers and beacons were positioned in points of interest. By means of voice or tapping commands on a smartphone interface, the user can request a specific location. In turn, the system provides an optimized route, considering possible user's physical limitations (a path without ramps and other obstacles, for instance). Also, when moving along the proposed route, the user will be able to spot fiducial markers. Positioning the smartphone's camera in front of those markers will allow for the visualization of directional arrows in an Augmented Reality environment, facilitating continuous navigation along the correct path and to the next marker, until the desired location is reached. In addition, an application of indoor navigation can be used through Beacon technology, which is a subclass of BLE (Bluetooth Low Energy) that transmit their location to electronic devices (laptops) in the vicinity [5]. These devices allow for the location of a user using mobile devices. The beacon transmits an identifier to the mobile device and allows it to calculate the distance between them, discovering the user's location.

II. Materials and Methods

We have developed two applications: the first using Augmented Reality with fiducial markers in the environment and another using the beacons technology spread around the environment. By integrating both, we propose an application where a wheelchair user should be able to visualize routes that provide better and safer indoor navigation, avoiding ramps, stairs and other kind of obstacles.

Besides, the system should allow for the registering of different environments/locations. The configuration of places of interests (such as bathrooms and emergency exits) and the

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repositioning of fiducial markers and beacons should also be allowed. It is also important to take into consideration the motor and cognitive abilities of possible users [5]. In other words, the navigation algorithm must consider the needs and capacities of each user. Those could influence a number of aspects associated with the design of the indoor navigation system, as well as the algorithms used for navigation and interface design. For example, the positioning of markers need to take into consideration the height of the user sat on the chair. Furthermore, the application should be designed to respond to both vocal and written (typed on a keyboard or selected from a form) instructions to define, for instance, the desired target for which the best route should be calculated and presented to the user's mobile display.

In this manner, we propose the following main functional requirements (FR):

- FR01: to allow indoor navigation for wheelchair users by means of Mobile Augmented Reality techniques;
- FR02: to register and configure a building CAD drawing in a smartphone display with fiducial markers, locating points of interest or obstacles to be avoided by the wheelchair;
- FR03: to find the best route for wheelchair indoor navigation, taking stairs and other obstacles into account;
- FR04: to allow for the visualization of virtual direction arrows in the smartphone display, according to AR fiducial markers and arrival point position. The placing of fiducial markers should consider wheelchair user limitations (such as eye height level) and mobile device specification (such as the reach of the digital camera focus);
- FR05: to incorporate voice commands to call for specific locations (such as bathrooms and emergency exits) in case the wheelchair user presents limitations to manipulate the smartphone.

To support indoor navigation, the beacon technology is used with an equivalent effect of a GPS (Global Positioning System). For operation, the wheelchair user can access the application and request a point of arrival by selecting it in the smartphone form, by touch or by voice. For example, considering Figure 2, suppose the user is at the building´s main entrance (starting point) and selects to go to a room referenced by marker '4'. The system processes the requisition and register marker '4' position as the point of arrival. At this point, a routing algorithm is activated and remains in a 'listening' mode, expecting a flag from the Indoor Navigation module, saying that a marker has been found and a directional arrow is requested. After the selection, the user starts navigating in the building corridors, looking for markers. When the user finds a marker, he/she must position the smartphone display, with its digital camera activated, in front of the marker to identify navigation directions.

Additionally, we used the same concept for applications using beacons (Figure 1), which works as follows.

Figure 1. Navigation Map and beacons technologies in the environment

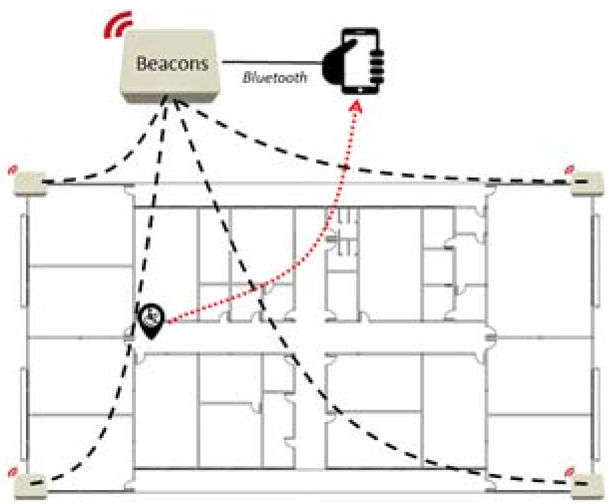
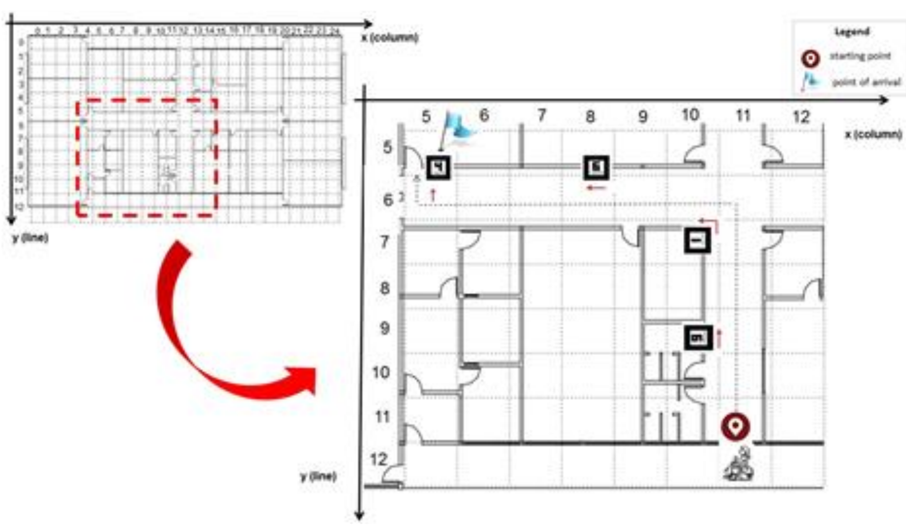


Figure 2. CAD drawing of the building used in the experiment. In the zoomed area, the start and arrival points are shown, along with the position of fiducial markers (small squares placed on the wall) and a possible path (dashed lines)



After selecting the point of navigation of interest, the user is connected to the beacon network. Next, the system calculates the distance between these and calculates the user's position so that information concerning the route can be displayed on user's smartphone screen.

This application was been developed using the following computer platform and tools:

- Android operational system, version 2.3 [6]. Android is a worldwide open-source platform, based on Java programming language, for the development of mobile applications;
- The building CAD drawings were stored in a local database – SQLite [7]. This database is integrated with the Android platform.
- AndAR (Android Augmented Reality) [8], which is a software library to create Augmented Reality applications. It contains a set of modules that are responsible for registering fiducial markers and associates virtual objects to these. When the smartphone digital camera captures a real image, AndAR provides all the necessary mathematical transformations to position the generated direction arrows onto the fiducial marker. AndAR is based on ARToolKit that is one of the very first platforms to develop desktop AR applications.
- Blender: an open-source 3D modeler that was used to create the directional arrows [9].
- OpenGL ES (Open Graphics Library for Embedded Systems): this library is necessary because AndAR only places the virtual objects onto the fiducial marker. However, a set of rotations and translations are necessary to position the arrows in the right navigational direction. OpenGL ES performs all these mathematical rigid transformations [10].

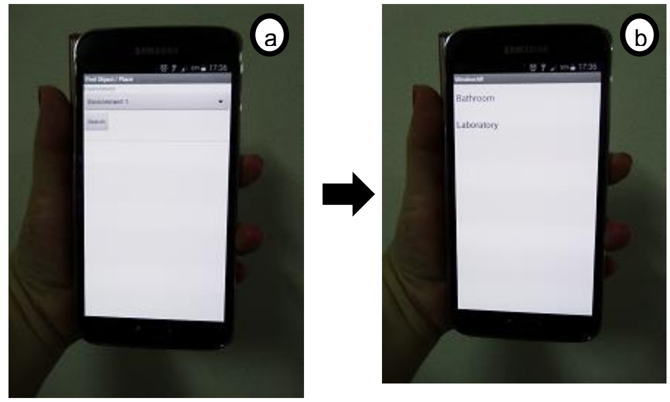
III. RESULTS AND DISCUSSIONS

As a proof of concept, the authors developed an application for smartphone to allow indoor navigation, based on the use of Augmented Reality fiducial markers and Beacon technology. Navigation tests were performed with two disabled volunteers. Figure 1 shows beacon positions and Figure 2 shows strategic placement for the fiducial markers. Beacons are placed on each of the extremities of the map so that it can connect via bluetooth to a mobile user who wants to browse this environment. However, these can be spread over an environment where they can perform triangulation in order to locate the user.

For both platforms (AR and Beacons), the system provides a navigation application to aid wheelchair users to find a bathroom or an elevator, for example. When using the system, the user expects to visualize routes of interest containing best access.

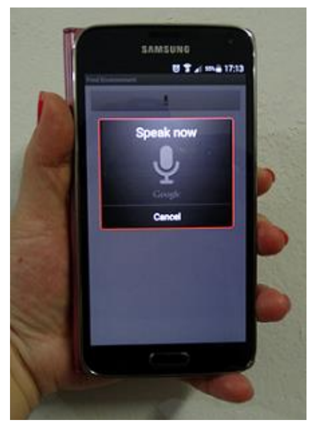
The starting point has been fixed at the entrance of the building. After starting the application, the user can select the desired environment and then the desired arrival point, as shown in Figure 3.

Figure 3: User accessing the application to (a) select the desired environment (left) and (b) the target location.



Navigation can also be controlled using a standard voice interface of the smartphone (Figure 4), just by vocalizing commands and names of specific locations, such as "environment one" followed by "bathroom".

Figure 4: Standard voice interface to indoor navigation.

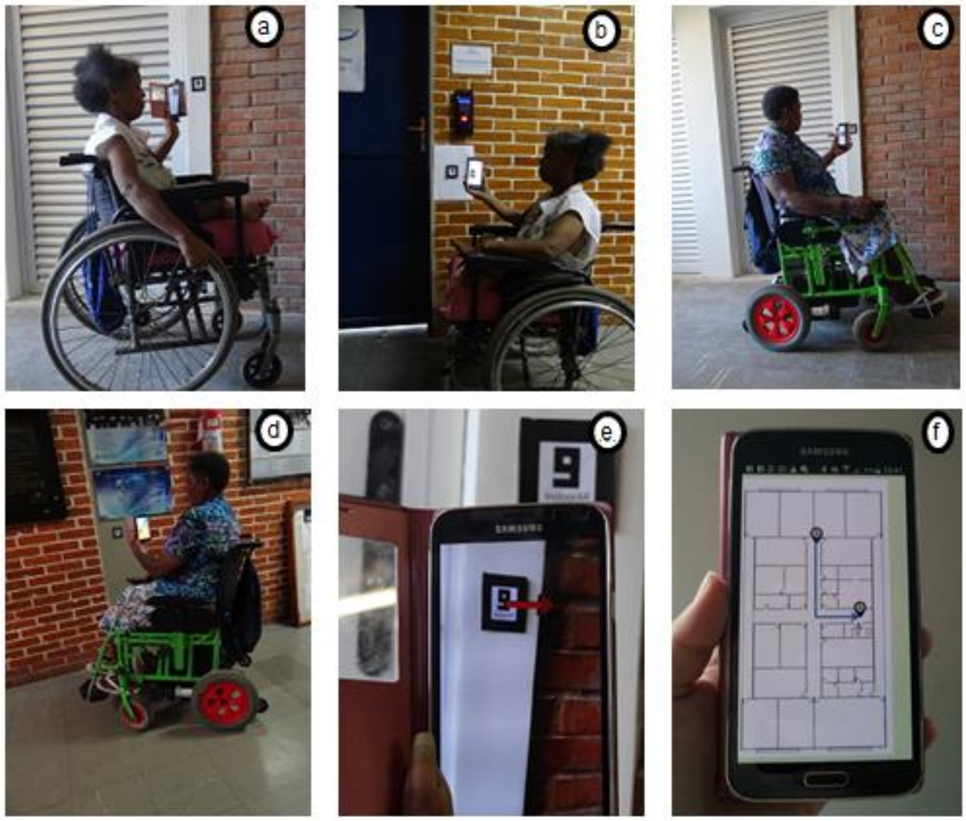


Once the final destination is selected, the interface presents the direction that the wheelchair user should follow to reach the destination via the best obstacle-free route. When passing by a marker or a beacon, the user could capture an image of that marker, using the camera of the mobile device, which would prompt the presentation of the direction to be followed for the best route from that point on. Note that, the use of fiducial markers or beacons allow for precise and swift navigation even in areas where traditional systems would not work at all, such as outdoor navigators. Figure 5 shows various stages of navigation using the application.

IV. CONCLUSION

In this work, we propose an indoor navigation system dedicated to wheelchair users. An algorithm that considers imminent physical difficulties (such as ramps, obstacles, etc.) has been provided to identify best routes and points of interest. In contrast to traditional approaches, the proposed technique also handles voice commands to provide support for different users.

Figure 5: Demonstration of the various steps associated with the use of the application to guide navigation of wheelchair users in indoor environments. (a) Volunteer 1 starting navigation; (b) User 1 at the arrival location; (c) Volunteer 2 starting navigation; (d) User 2 at the arrival location; (e) User in front of the first fiducial marker with the system presenting the direction for the best obstacle-free route; (f) Indoor navigation route interface with beacon for the user.



In order to perform tests, a case study was conducted with the collaboration of two volunteers, using a wheelchair in an indoor environment. At first, a block map was configured into the system. The user could select a point of interest by touch or voice. During the navigation process, the application indicates the direction that the user should follow until his/her final destination.

It is believed that the proposed system can be of great use to various individuals with physical deficiency, by helping them with orientation and mobility. This fact has the potential to facilitate the lives of these individuals, without the need for external help, since the system provides them with greater accessibility.

As future work, the authors intend to add new modules, as for example, the visualization of information relevant to individual wheelchair users; to incorporate new resources, such as personalized configurations for each user

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