Retrofit Framework for Indoor Mobility in Unstructured Spaces

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Globally, it has been estimated that approximately 1.3 billion people live with some form of vision impairment. Out of these, around 91 million people are in South-East Asia [13]. Most people with vision impairment (PVI) are over the age of 50 years, and in fast-growing economies like India and China, a certain demographic shift would mean a significant fraction of the population would be above the age of 50 years in the coming decades. Despite improving health facilities, PVI continues to feel dependent, less confident, and more isolated due to the inaccessibility of information and built environments. The rising adoption of mobile technologies, particularly in countries like India and China has contributed to improvement in independent outdoor navigation for PVIs through applications such as Google Maps, despite the poor structure and accessibility of the space itself. But indoor spaces continue to be difficult to access and navigate, particularly for PVIs in low-resource settings. The major contribution of this paper is to address the problem of indoor mapping and wayfinding for PVIs, taking into consideration the realities prevailing in low-resource settings. The project involved the development of a custom mapping application and a pilot implementation of an interactive ("Person – Building - Space") indoor navigation system. The system has been deployed in a public hospital and a building of an academic institution covering an area of more than 15000 square meters[1]. A controlled trial of the system is in progress.

Keywords: *Mapping, Accessibility, Wayfinding, Visual Impairment, Mobility, Location-based services*

1. INTRODUCTION

Wayfinding and accessibility are necessary but challenging requirements for visitors to indoor facilities. These challenges occur primarily due to a lack of information and its accessibility or an appropriate medium of communication for this information. This challenge can increase in unknown and unstructured spaces, particularly for people with sensory limitations, such as persons with visual impairment (PVI). Over the past decade, there has been a major technological shift in outdoor navigation assistance and access to relevant information. But the same cannot be said for indoor environments where people in urban areas tend to spend most of their time. To understand the challenges related to indoor wayfinding and accessibility, we surveyed users of a tertiary hospital, an academic institution and a national center for visual disability. Our survey revealed that wayfinding and accessibility are common challenges in these spaces, primarily due to the limited

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availability and accessibility of information. The survey indicated that the limited access to information could be due to the transient nature of the service protocol and incrementally-developed indoor spaces.

To improve access to building information, technology can be used to capture, highlight or redefine navigation-related information, and provide it to users in a more comprehensible form through digital applications. An effective person-space communication will require this application to provide navigation information with time and space. In this paper, we propose a novel information annotation and delivery framework to capture indoor navigation information and create, update and build applications around this information. To make these applications relevant to low-resource settings, we developed a system and a service requiring low capital expenditure with a maximum accuracy of navigation information.

2. EARLIER WORK

The problems of access to indoor spaces have been well documented in academic literature [7,15, 16]. These problems are further aggravated in low-resource settings due to a lack of signages, information cues, and unreliable building information [3–6]. While studies have suggested solutions to support indoor wayfinding, including mapping, localization, path planning, identification of decision points, strategic inclusion of signages and cognitive map modeling of indoor facilities, very few interventions have been implemented and tested in real-world settings (References?). Many case studies validate the increasing use and efficacy of mobile technology for assisting wayfinding in outdoor and indoor environments. MyWay [8], is a mobile app to access hospital maps and locate the user within the facility through GPS and Wi-fi positioning using smartphones, with turn-by-turn navigation. Similar indoor positioning technologies are becoming increasingly reported, such as the Wifarer system, WifiSLAM, HERE, and Micello Inc. [7, 14]. Wright et al. [9] used a touch screen monitor to enable users to find 16 pre-selected destinations based on the frequency of use. Results of 22 users indicated a high rate of success (86%) in finding the selected destination.

There has also been some progress in enabling persons with visual disabilities (PVDs) to navigate independently in unfamiliar indoor environments [10–12]. Guerreiro et al. [10] presented an interactive virtual navigation app in which users can learn unfamiliar routes before physically visiting the environment. Sato et al. [11] presented an enhancement to their indoor navigation work as NavCog3 - a specially designed application for PVDs which provides turn-by-turn instructions. We find that most of the documented indoor wayfinding and accessibility research and pilot projects have been performed in developed and more structured settings whereas very limited field research & intervention has been evidenced for low-resource contexts [2].

3. SOLUTION REQUIREMENT

Based on earlier surveys and open-ended discussions with PVIs and other stakeholders, we identified four main requirements of a prospective solution for indoor navigation in low-resource settings as provided below. The first two are functional requirements which were validated with a focus group of 7 PVIs (M= 41.3 years). The remaining two are not critical to indoor navigation but important for the adoption of the solution and generating value addition for stakeholders.

1. *Usability:* To make a system acceptable to a large number of users, the navigation system must consider the needs and sensory abilities of a wide range of users. In this project, we specifically focus on navigation requirements across the spectrum of visual impairment.
2. *Accuracy of localization:* The solution should ensure that the correct information is provided to the user at the appropriate place and time. The system should be designed to analyze the requirement of the user and suggest the level of accuracy of localization required.
3. *Generalization:* The solution should be easy to replicate in diverse indoor settings, with the flexibility of accommodating various levels of building information detail and accuracy.
4. *Functionality:* The system should be designed to complement and support the existing services offered by an indoor facility, improving access rather than hindering it. For instance, in hospitals, the system should benefit hospital staff to monitor the patients whereas patients to access the facility.

4. Our Method

We propose a technology framework to make existing indoor spaces digitally accessible to all, with a particular focus on PVIs. To achieve this, we have built two software modules; module 1 is a custom map annotation tool to capture navigation and accessibility cues from the indoor environment and create digital maps with additional semantic information. This information is then provided to users of the indoor space through module 2, which is a custom-built wayfinding application. Wayfinding application is integrated with the indoor space using bluetooth beacons for localizing users inside a building. The beacons are placed strategically so that the application can pick up the signals from beacons and locate the user. The Wayfinding application uses the smartphone's electronic compass sensor to help the user in orienting themselves in the appropriate direction. Using accurate location and orientation, this application provides users with turn-by-turn directions to the desired destination. The following sections detail the software modules and their functionality.

4.1 Map Annotation Tool

In our survey on challenges to wayfinding in indoor spaces, we found that organizations managing existing and new indoor spaces typically have architectural floor plans for reference. But these floorplans are often obsolete and do not contain accurate information and sufficient cues for wayfinding and accessibility. The floorplans available are often closed format documents such as images or PDFs, and thus the organizations cannot incorporate changes or update the building elements to the floorplans. To create an accessible digital map with rich information cues, the annotation tool uses these floorplans as underlays to augment navigation information. The building information is categorized by locality (a campus or set of buildings within the same area), and further divided into individual buildings, and their individual floors. The annotation tool can be used to mark the identified non-walkable areas, entrances, rooms, amenities, accessibility services and connections between floors (staircases, elevators, etc.).

The process of annotating a building has been divided into two stages. The first stage, called pre-processing, involves sourcing and validating the information required for the annotation. This process involves site visits to understand the building model and its complexity, discussion with the building owner/administrator to understand their needs & expectations and processing the floorplans of the building. The second stage involves the annotation and testing of the digital map for navigation. The annotation process involves the use of custom editing tools in the application to augment navigation and accessibility information on the floorplan. The information includes fixed and temporary structures, access to rooms, amenities and floor connections, and a delineation of all inaccessible areas. Based on the annotation of landmarks and accessible areas, a heat map can be generated to identify areas requiring high accuracy of localization, which translates to the positioning of Bluetooth beacons in the indoor space. The annotated floorplan can be validated using the same application by simulating navigation from point A to B, within the same floor, same building or between buildings in the same locality. The annotated map can then be made available for use through the navigation application.

4.2 Wayfinding Application

Based on the heatmaps generated of the digital maps, Bluetooth beacons can be physically installed in the indoor spaces and integrated with the maps. Apart from the beacons, we also propose the deployment of open-source April tags. These tags are like QR codes but easily recognized through mobile cameras. The April tags can be used to localize and augment certain visual/audio information for a particular location or a service *(such as display objects in a museum)*. April tags are shown in the figure below.

Figure 1: April tags are used as a robust location signature

Having prepared and integrated the indoor space with the digital maps, the navigation information is available for users to access through the wayfinding application. In this application, the user can identify a starting point and an ending point and the application will generate the route requiring the least effort to navigate in real-time. During the navigation process, the application provides information cues related to nearby landmarks, places of interest, accessibility cues such as floor-level changes and other directional information required on the route. Users can choose to receive detailed information for new locations, and brief information for previously visited locations. The application has been designed to suit the requirement of a wide spectrum of visual ability. High contrast interfaces make legibility easy for people with blurred vision or color blindness. Users can specify if they are sighted, with low-vision or blind, and the application is designed to use in-built accessibility features of smartphones to generate a seamless experience through audio cues. The application also factors the security and privacy requirements of an organization managing their indoor spaces by using two-factor authentication systems and capturing the minimum data required. The wayfinding application interface has been designed to meet the W3C Accessibility Guidelines for user interfaces and provides turn-by-turn navigation through both visual and audio feeds to users.

5. SYSTEM EVALUATION AND DISCUSSION:

Initial versions of the software modules have been tested in a large public hospital [1] and the feedback was incorporated in the upgraded version. The testing and validation of the upgraded software modules are in progress at a multi-story public building which is frequently used by PVIs, selected in consultation with the World Health Organization, in New Delhi. The proposed testing is aimed at evaluating the usability of the two modules, and the ease of navigation for three sets of users; sighted users, users with low-vision and blind users. A self-assessment method will be used in the first phase of trials, where users will be provided with a set of tasks to complete using the wayfinding and annotation applications. The users will then evaluate their experiences, and provide feedback on the interface, the user experience, and opportunities for improvement in the modules. This study aims to understand how indoor wayfinding and accessibility can be addressed for diverse visual abilities through digital solutions in low-resource settings.

From this research, some key points are open for discussion related to mapping and wayfinding development. Currently, there are no standards available for indoor information for wayfinding and accessibility purposes. The annotation tool developed in the project has been designed to accommodate a variety of information cues for accessibility and navigation, keeping in mind the unstructured contexts in which it will be used. Thus, it becomes important to explore how the annotation tool can be developed to acquire building information more comprehensively, and the standards required for these contexts.

The creation of digital indoor maps also has other challenges that we have encountered in the creation of this solution. Users of the annotation tool may come from a variety of backgrounds, with varied digital literacy and spatial understanding of indoor spaces, thus appropriate interfaces and automation features must be developed to simplify the process. Indoor spaces are often private spaces, and cannot be developed easily through crowd-sourcing of information, as has occurred for outdoor maps over the last couple of decades. There are also data privacy and information security concerns for public spaces that generate significant traffic but contain sensitive and secure spaces. Our survey indicated that indoor wayfinding is one of the key challenges in the day-to-day journey of PVIs but they face other challenges related to navigation as well that must be factored in similar solutions. For example, the transition from an indoor space to an outdoor space and the associated accessibility cues are often not in synchronization. Furthermore, an organization may own multiple buildings in a locality, but the floorplans may not indicate the outdoor spaces between these buildings.

Finally, in a world where many of our services are now mediated through smartphone applications, how can an indoor navigation application provide additional value to customers to improve the navigation experience?

6. Conclusion and Future Work:

This project addresses a crucial gap in knowledge for accessibility and wayfinding needs in low-resource settings. The project builds on previous work in the creation of digital mobile solutions for indoor navigation for PVIs and focuses on identifying the challenges and potential solutions for developing nations such as India. Due to the high density of population, unstructured indoor environments, the high number of PVIs, and a rapidly increasing uptake of mobile technology, we propose the development of cost-effective mobile solutions. The solution consists of a tool for generating digital maps and a wayfinding application to provide users with a self-reliant solution for navigating through indoor spaces. The mapping tool uses site surveys and architectural floor plans to generate a digital map with augmented accessibility and wayfinding cues. The digital maps are then localized at the venue using bluetooth beacons and April tags. The wayfinding application is designed to use bluetooth to localize users in the space and provide real-time navigable routes to various destinations within the indoor space. The focus on the modules has been to keep the process simple, easy to use, low cost, and make the system accessible to people across the spectrum of vision abilities. The proposed solution can be scaled and evolve as a standard framework for providing access to large public indoor facilities. The development of the two modules has helped identify various challenges in creating indoor wayfinding solutions for low-resource settings, particularly in generating and updating digital maps of unstructured spaces, and the data security needs for organizations and individual users. The on-going testing of the system at a few public facilities in New Delhi, India will shed more light on the specific challenges of accessibility and wayfinding in low-resource settings such as those in India.

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