DESIGN AND USER TESTING OF AN AFFORDABLE CELL-PHONE BASED INDOOR NAVIGATION SYSTEM FOR VISUALLY IMPAIRED

Jain Dhruv[1], **Agrawal Prabhav**[1], **Maheshwari** Kartik[1], **Mittal Aman**[1], **Gupta** Akshay[1], **Ollagnier** Amaury[1], **Goyal** Arpit[1], **Paul** Rohan[1], Ranjan **Ashish**[1], **Gupta** Anuraag[1], **Paldhe** Manas[1], **Das** Supriya[2], **Sanyal** Saurabh[2], **Taneja** Yogesh[2], **Manocha** Dipendra[2], **Balakrishnan** M[1], **Rao** P.V.M.[1]

[1]Assistive Technologies Group
Department of Computer Science and Engineering,
Indian Institute of Technology (IIT), Delhi,
Block II-A, Hauz Khas,
New Delhi - 110016
India
Phone - (+91)-(11)-(2659-1704)
Email: mbala@cse.iitd.ac.in

[2]Saksham Trust,
Dakshineshwar Building, Hailey Road,
New Delhi - 110001
India
Phone - (+91)-(11)-(4241-1015)
Email: dipendra.manocha@gmail.com

SUMMARY

Navigating in an indoor building and finding path to common locations is one of the primary challenges for visually challenged people. Current systems do not function in GPS-denied indoor environments and only do identification of particular landmarks encountered by user. As an attempt to address this problem and facilitate independent movement for visually impaired, in this work, we present the design of a cell-phone based indoor navigation system which is easy to use, low-cost and can be attached to the user's waist or cane. Further, the system was installed in a building and user studies were done to test its performance and usability for the visually impaired. We also determined the current limitations of the system and the future work to be done.

Approach

- Use of infrared sensor network and accelerometer to assist the person to navigate inside a building by acoustically providing the user directions to his destination through the mobile phone application. System is designed for ease of use at an affordable cost at the user's end.
- Installation of the system on multiple floors of a campus building and conducting user-trials in a simulated life-like scenario to evaluate the efficacy and utility of the system.

System Design

The system consists of a waist-worn user module, a user interface in form of a mobile application and a network of wall-mounted infra-red sensors. The waist-worn user’s module which is an assembly of infra-red receiver and an accelerometer is used to trace the position of the person in the sensor-network. As the user moves in the building, his current position is updated and the navigation information is made available to the user acoustically over text-to-speech engine of phone application. The system can be easily retrofitted to existing buildings with minimal augmentation to building infrastructure. Projected cost of the device is about 20 USD.

Experimentation

Firstly, a questionnaire based survey was conducted to understand the current scenario regarding independent navigation of visually challenged people in an unfamiliar indoor environment.
In order to evaluate the efficacy of the system, controlled trials were conducted wherein 6 users were trained for the usage of the device and then asked to navigate on two different paths – first without the device and then with the device. The performance of the device was studied with respect to the following metrics: (1) Travel time and (2) Reduction in deviation from direct path.

Conclusions
We have conducted the user study to determine the current problems faced by blind persons in navigating in indoor buildings. The user group confirmed that independent wayfinding is a considerable challenge and causes high anxiety and creates dependence on sighted assistance.
Indoor Navigation System was demonstrated as a potential solution to the above-mentioned problems. The system was developed using a user centric and iterative design approach. The system reduces the dependence of visually challenged people on sighted assistance and ameliorates their anxiety while navigating inside an unfamiliar building. Formal trials with 6 users demonstrate (a) reduction in travel time and (b) reduction in deviation from direct path. The developed system has been tested and has received positive and encouraging user feedback.
Future work will include optimisations in the design of the device and user study covering larger varied proportions of visually impaired persons so as to increase the usability of system as a product.

Key Words: Indoor Navigation System; Visually Impaired; Infra-red; Cell-phone; Audio output

1. PURPOSE OF THE STUDY

Independent mobility and navigation in an unfamiliar environment is one of the greatest difficulties faced by persons with visual disabilities. Majority of the visually impaired population reside in the developing nations whereby building accessibility through signage is seldom available [1]. Many of the existing systems are GPS based and thus are not suitable for indoor navigation. Most Visually impaired persons tend to do their productive work in the indoor spaces like offices, schools etc. and do not wish to be socially awkward.

In the past, there has been several attempts from notable research communicates to develop devices aimed at solving the problem of indoor navigation. Talking signs [2], a Remote infrared audible signage (RIAS) technology, uses network of infrared transmitters installed on the walls (or poles) at strategic locations. Each transmitter sends different “tagged” IR signal. There is a hand held IR receiver held by the user which picks up and decodes the signal and delivers it acoustically to the user. The user walks in the direction of the desired IR signal to reach the destination. Since, an IR beam is highly directional, the user must point the handheld receiver towards the transmitter which may not lead to accurate path identification. Also, the cost of the installation is also a barrier for deployment since a large number of transmitter units have to be installed before making it useful for the user.

Another approach which is currently under development is the Building Navigator [3]. It includes a handheld device which emits the infrared beam. The building is fitted with retro-reflective bar-coded signs. The emitted infrared beam is reflected from the sign and the image is recognized by computer software which provides auditory output to the user via synthetic speech. The information includes nearby points and the routing information to the destination. Although a good method, the user has to carry a bag-pack for the computer which is heavy and thus inconvenient to use.

PERCEPT [4] is based on RFID technology. The system uses RFID tags corresponding to the various locations available in the building. These tags are embedded in kiosks located at specific points like entrances, exits, elevators etc. The user identifies the destination using Braille fitted onto those RFID tags. The user wears a glove which when bought in close contact with the tags scans the destination and sends the information to the smart phone via the Bluetooth module fitted on the glove. The smart phone then contacts the percept server for instructions pertaining to the location of the next kiosk or the destination. The major limitation is that it doesn't convey the position of the user in between sparsely placed kiosks and the user may get lost.

Moreover, any technology which uses proximity messages (those which are spoken when the user is closed to them) like audio signs which uses some form of switch located near the installed sign to convey the positional information, inductive loop or radio-frequency transmission; suffers from a potential problem. Since the messages are omni-directional, they will be heard by navigator from all directions which would lead to wrong navigation if the person was not facing the expected direction [5].

Researchers have shown that distance information can be provided to the navigator using estimated number of steps [6]. Few systems provide the remaining number of steps information (Bentzen and Mitchell, 1995). Although a good measure, this information is inappropriate since step length varies from person to person. As suggested by Mason, Legge and Kallie [7] using computer-readable pedometer may give the distance information more accurately.

Devices have also been developed using gyroscopic compasses and sensors which can tell the direction of travel [8]. These devices are less accurate, affected by changes in environmental temperature and magnetic fields and are not within the affordable range of an average person.

All systems currently available possess one or more of the following limitations: (i) unaffordable cost (ii) non availability of sales, marketing or servicing in developing countries (iii) highly inaccurate and thus unsuitable for public use; and/or (iv) cumbersome to carry or difficult to operate.

Barlow, Bentzen and Franck in the Foundations of Orientation and Mobility [9] articulate the unmet needs for an indoor navigation system as follows:

*"From the user's perspective, the ideal **audible signs might be audible when needed** but silent when unnecessary; **audible to the user only**, not to all passerby; **capable of being picked up from a distance** and **simple to use**, **not requiring comprehension of and memory** for detailed verbal directions. If receivers are used, they should also **precisely provide the information** desired by the individual user; be **free, miniscule, and light**; and **not require use of the hands**. Above all, audible message need to provide information that clearly directs users to where they want to go. **No existing or proposed technology meets all these criteria**, but advances continue to be made in the functionality and size of the devices."*

Hence, working with the target group user, we developed a cost effective navigation system that can function effectively in indoor environments. It is user friendly and provides audio based guidance allowing a visually challenged person to navigate independently in an unknown building without any external sighted assistance. Further, we conducted a before and after (A-B type) user study to (i) understand the current problems faced by the visually impaired individuals in indoor wayfinding and (ii) evaluating the prototype system deployed in a real university building.

2. MATERIALS AND METHODS

We have developed a novel low-cost cell-phone based indoor navigation system for visually impaired that gives active path guidance in addition to position identification. The system was developed through an iterative user-centric approach wherein a sustained interaction with representative users has led to the incorporation of the feedback at every stage of development. Next, we present a brief functional description of the system:

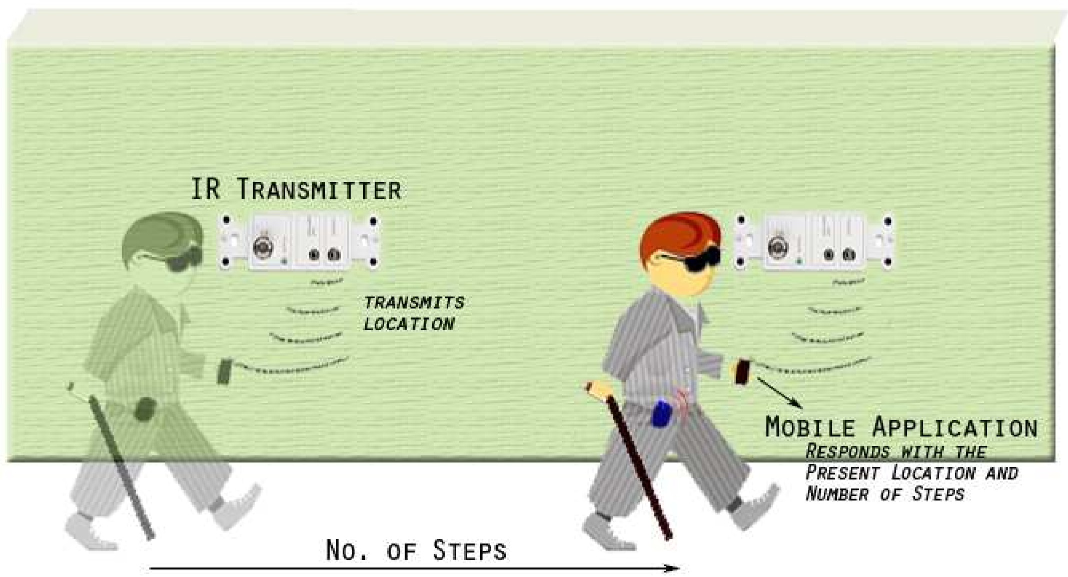


Figure 1: Users get information about the details of their location through mobile application which in turn updates the position of user in the map with the help of IR module (transmits location) and accelerometer (counts the number of steps)

2.1. System Description

The system has three components: (i) *User Module*: A waist-worn device carried by the user, (ii) *Wall-Mounted Module*: A module mounted on the walls of the building at regular intervals in a corridor and at key destinations, and (iii) *Mobile Phone application*: A cell phone navigation application that interacts with the user by taking inputs on target destinations and providing audio based guidance while traversing.

Upon entering an unknown building the user enters the destination of interest in the mobile phone application and navigates in the building as shown in the Figure 1. Then, the application finds the shortest path from current location of user to the destination entered and provides him directions to reach his destination acoustically. In order to track the user and provide periodic guidance, infrared-red sensor and accelerometer technology is used. For pointing the user exactly towards his destination, buzzers are installed on the entry points of possible destinations. Whenever the user approaches close to the destination, the application prompts the user to trigger the buzzer for the exact location. A special key is assigned for this purpose on the keypad.

One key feature of device is that the user does not have to carry a backpack or wear cameras. Only a waist-worn module attached via a belt and a cell phone will serve the purpose. It is easy to operate and only requires the map of the building stored in a file to be downloaded on the mobile application. Further, the infrared units can be easily integrated onto any existing building. Next, we present a technical overview of the system components and functionality.

2.1.1. Hardware Components

The system uses the commercially available infrared sensor-suite mounted on the walls of the building for locating the user. As the user moves inside the building, infra-red receiver in the waist worn module receives the identification tag from the sensor in user's vicinity. From that tag, position of the user in the building can be determined.

The system localizes the user in the building when he is present between two wall-mounted units by multiplying the number of steps obtained from accelerometer with the average step-length of the user. The average step length of the user is initially taken to be equal to a statistical estimate based on the past users and then dynamically updated as the current user moves inside the building using the distance between sensors and the number of steps returned by the accelerometer.

2.1.2. Stored Map

The map of the building is installed in the mobile phone application. The building information is stored in the form of an undirected graph: (i) a node either represents an access point or the meeting point of two corridors and (ii) there exists an edge between two nodes if and only if there is a direct path (no node in between) between the two nodes. The graph is maintained as an adjacency list of nodes, represented by their coordinates and edge weights and stored as a file.

(a) (b) (c)

Figure 2: (a) User with the waist worn module (red arrow) and the mobile. Wall-mounted Infrared Unit in background (black arrow) (b) Close-up view of the belt mounted user module (c) a Wall-mounted Infrared Unit

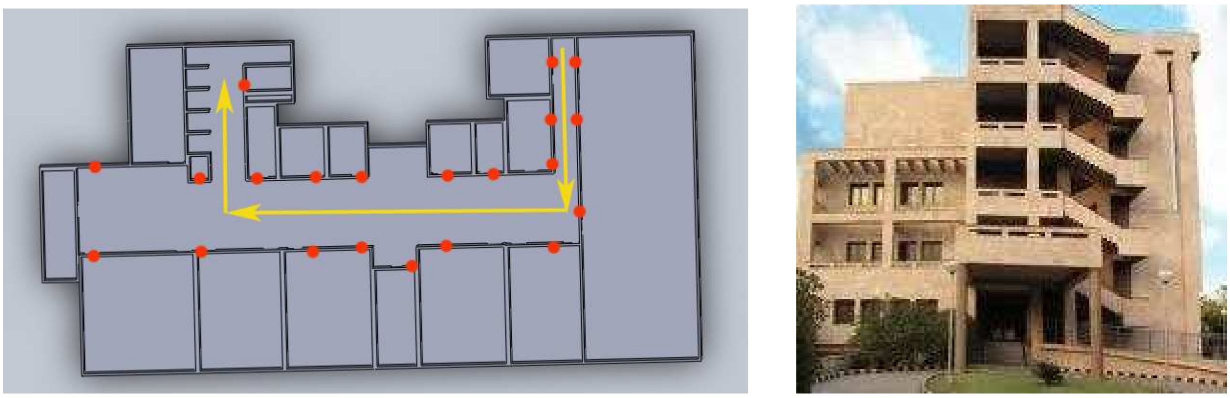
The edge weights model user preference for certain paths (due to convenience) over other paths to the the destination. For example, a user may prefer to use the elevator instead of stairs even though the latter may give a shorter path. The system uses the *Dijkstra's* shortest path algorithm to find the best possible path from the user's current location to the destination that the user has queried for.

2.1.3. User Interface

As the user enters an unknown building, his destination in the building is entered via the QWERTY keypad on the cell phone. The application has an auto-completion feature to automatically predict the queried text in case there exist only one destination with the given initial characters. If the user feels to change the destination that he/she entered earlier, he can do it using "Change *the Travel"* option. The path would be re-calculated and the user would be re-directed accordingly. At any point in the building, the user can make a query about his location using the *"More information about the Travel"* option. All the information is acoustically conveyed to the user over the text-to-speech-engine. The application has quick audio feedback like screen reading software to allow a visually challenged person to use effectively. It also allows speed control in voice output i.e. the pace at which voice output is delivered can be altered.

2.2. Controlled Trials

In order to evaluate the developed system under real-life conditions, field trials were conducted with 6 visually challenged users in an academic building in IIT Delhi campus. Special care was taken to maintain the diversity of users based on age, gender and familiarity with the campus building. In the trials, users were made to navigate inside the building on a selected track, firstly without the device and then with the device. The experiment design is discussed in the subsequent sub-sections.



(a) (b)

Figure 3: (a) Track used for user trials. Red dots represent position of infrared units, yellow arrows shows the traversed path. (b) University building where the system was installed.

2.2.1. Experiment-site

Experiments were conducted in a corridor in an academic building with the wall mounted module at every 5-7 meters on the walls and on the doors of all possible destinations, Figure 3. To eliminate the effect of spatial map learning, different paths were created for training and experimental trials. The navigation path was regularly tiled. This facilitated quantitative estimation of deviation from direct path as well as the speed of the user.

2.2.2. User Enrolment

To have a diverse representation of our focus group, we selected six persons with total visual impairment who navigate independently in buildings. They mostly use cane and ask for directions from sighted individuals. While two of the users are daily visitors of the experiment site, others had no familiarity with the building beforehand. The users were contacted via two NGOs and schools serving the visually challenged in New Delhi. There were 5 male and 1 female volunteers representing an age-group spanning from 16-32 years. While one female user had late onset of blindness at the age of 10, the rest were congenitally blind. Due to the apprehension of the organizations to allow female volunteers for trials, probably due to the need to travel to the site or other cultural reasons, we could not maintain a 1:1 gender ratio as desired. A female researcher conducted the interview of the female user. All interviews were conducted on a one-one basis in Hindi.

2.2.3. Standardized Protocol for Training

User training was conducted in two parts for two consecutive days. On the first day, they were introduced with the basic three modules (i) Wall mounted unit (ii) Waist-worn device and the (iii) Mobile application. Functioning of each individual part as well as its interaction with other parts was explained briefly. The training sessions were conducted on consecutive days to ensure retention and accurate learning.

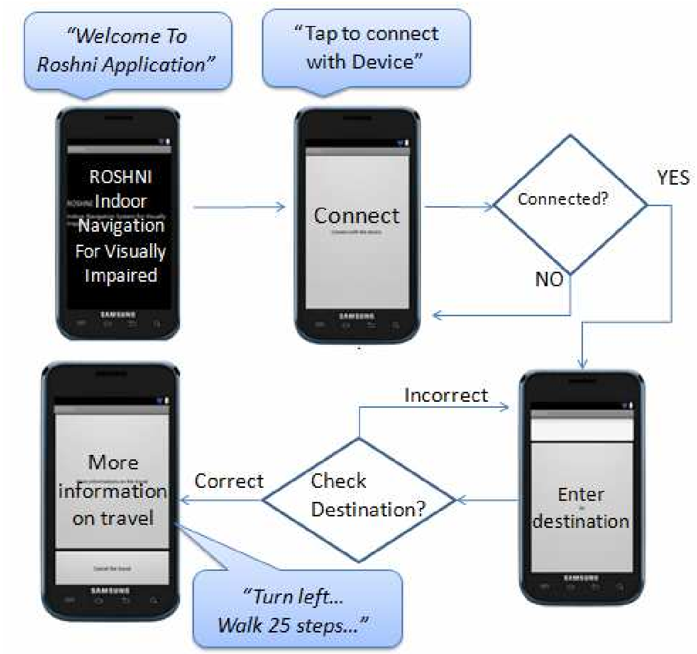


Figure 4: Flow diagram illustrating the audio-based user interface.

On the second day, the users were given a detailed description of the operation of mobile application which includes starting the application, connecting with the waist worn module, entering the destination, and getting instructions about their travel. Subsequently, reinforcement sessions of the user were conducted on the training track (a simpler version of experimental track) till the user became comfortable in using the device. In this phase, volunteers were walking with the user to assist him in getting acquainted with the device. Training track and testing track were completely different from one another to avoid the effect of map learning by the user.

2.2.4. Trial Phase

The trial phase involved three main components:

- Baseline questionnaire: The training started with a brief introduction of the users followed by their views on visiting unknown buildings and the need for a technology for indoor navigation.
- Field Testing: Independent navigation of user on the testing track with the Indoor Navigation System. The users were positioned at a starting location and were asked to move towards their entered destination following the instructions provided by the mobile application. Users were handed a white cane to assist them in moving straight and avoiding the obstacles present in the path. The user's movement was videotaped and analyzed later.
- Post-Trial Questionnaire: The training concluded with an interaction session in which the users were asked about their views on the utility, merits, demerits, ease of learning and further improvements for the device.

2.2.5. Key Performance Indicators

To compare the performance using Indoor Navigation System over the baseline performance without any such device, following performance indicators were studied:

- Deviation from Direct Path: Total deviation in path length (in meters) between the paths taken by the user compared to the direct shortest path. This metric attempts to capture the fact that without guidance a visually challenged person has to stochastically explore the surroundings causing deviation from the direct prescribed path. We hypothesized that through periodic acoustic guidance; the deviation would be reduced allowing the user to follow a path close to the ideal path.
- Time of travel: Total time taken by user to reach his destination. A system that reduces deviation would allow the users to navigate faster to their destination and/ or increase their travel speed. However, travel time can increase if there is intermittent system failure or when the user is slow to operate the device.

3. RESULTS

3.1. Questionnaire based Survey

The first part of the trials involved a questionnaire based survey aimed at understanding the current scenario regarding independent navigation for visually challenged people in an unfamiliar indoor environment. Users mentioned that most buildings they navigate in rarely have accessible signage and wayfinding in an unknown building is a significant challenge. On being asked about the methods they adopt to identify locations and navigate inside unfamiliar buildings, they reported that they usually try to find signs, ask for help, or resort to a hit and trial approach. This random exploration of an unfamiliar site makes them vulnerable to many hazards.

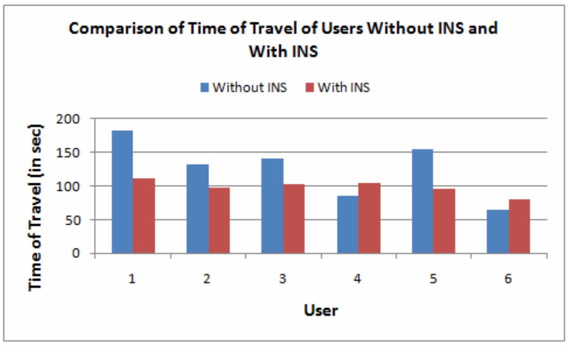
All users said that they always try to find a sighted person to accompany the first time they visit a new building and explicitly avoid coming alone making them dependent on availability of external help. The results emphasized their high degree of anxiety in accessing unfamiliar locations independently, their hesitation to ask for help and their requirement for sighted assistance in general thereby making them reluctant to go alone anywhere. 5 of 6 users reported taking sighted assistance while accessing a location for the first time.

Some users also reported frequently getting lost and injured in case when the signs they used to locate a place got removed or due to confusion among similar appearing buildings. All users emphasized the need and utility of an affordable navigation guide.

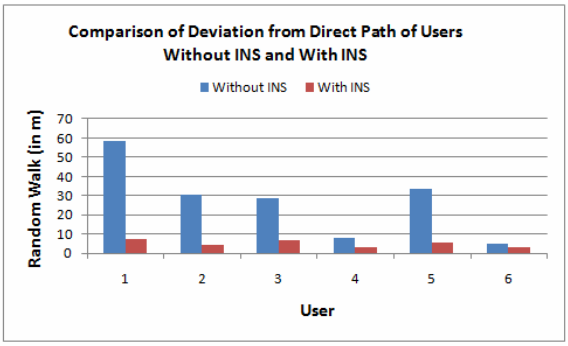
3.2. System effectiveness

The system was used effectively and successfully by users to reach their destination. All users were able to learn the operation and were able to use the system as an effective navigation guide. There were no notable differences in response of different categories of users. The results of the quantitative studies on the navigation pattern of the individuals during the trials complement the qualitative feedback obtained through the questionnaires. As is evident from the bar graphs in Figure 5, there was a significant reduction in the amount of deviation from direct path observed when visually challenged users walked with the device during the trials. The navigation device reduced the amount of deviation for all the users.

The other effect of the navigation aid was in terms of the reduction in travel time. Please note that while the device showed a significant improvement in time for people without prior familiarity of the building, travel time actually increased for frequent visitors. The reason for the same, as figured out from the feedback by the users was that they had to stop to listen to the voice messages when they carried the device.



(a)



(b)

Figure 5: Histograms illustrate the effectiveness of Indoor Navigation System (INS) in reducing (a)Time of Travel (b) Deviation from Direct Path (Without System (blue) and With System (Red))

Figure 6: User navigating without any external sighted assistance.
User module (red arrow) and wall-mounted module (black-arrow)

3.3. Post-experiment User Feedback

After completing trials, users were interviewed about the overall utility and usability of the device. All 6 users believed that the device is useful for day-to-day living. On an average, users rated the benefits of the device as 3.5 on a scale of 1 to 5. All users said that they would be willing to use the device if it is available in future as a real product.

All the users mentioned that they were able to reach their destination comfortably. Users both male and female also suggested significant improvements to be made in the design and user-friendliness of the device such as multi-language support, clearer accent, reduction in size and the provision to mount the device on the walking cane. One of the users also supported the fact that the device is not very useful for familiar buildings since they have to stop to listen to the message which takes more time.

4. CONCLUSIONS

We have conducted the user study to determine the current problems faced by blind persons in navigating in indoor buildings. The user group confirmed that independent wayfinding is a considerable challenge and causes high anxiety and creates dependence on sighted assistance.

Indoor Navigation System was demonstrated as a potential solution to the above-mentioned problems. The system was developed using a user centric and iterative design approach. The system reduces the dependence of visually challenged people on sighted assistance and ameliorates their anxiety while accessing unfamiliar indoor environments. Formal trials with 6 users demonstrate (a) reduction in travel time and (b) reduction in deviation from direct path. The developed system has been tested and has received positive and encouraging user feedback.

Future work will include optimisations in the design of the device and user study covering larger varied proportions of visually impaired persons so as to increase the usability of system as a product.

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