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Smart Cane Outdoor Navigation System for Visually Impaired Deaf-blind and Blind Persons

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Abstract

Purpose: The purpose of this study is to build an outdoor navigation system to assist Visually Impaired (VI) persons' navigation independently in urban areas, regardless of the person's hearing status. An augmented cane, magnetic point or continuous metallic trails, pulsing magnet apparatuses, and the transmission of serialized vibration braille encoded guidance are the features of the proposed navigation system. Trails of magnetic points or metal and pulsing magnet apparatuses will be installed on the sidewalks in the city centres. People with VI are able to sense the magnet points or the metallic trail through their augmented cane. This system will assist them to walk independently. Pulsing magnet apparatuses will be installed at Point of Interests (POI) on sidewalks, such as turns and other decision points, to inform persons through serialized vibrational messages.

Methods: The research follows design science research framework with characteristics of prototype construction validation in Living Lab environment.Qualitative research methods (interviews and questionnaire) are employed to for user centered development process and to evaluate afterwards how well the designed artifacts meet the requirements it was set to resolve. Quality Function Deployment (QFD) method will be applied to convert users' requirements into the features of the system.Usability experiments are defined to evaluate the usability of the proposed system in user tests. Pre-test qualitative interviews were performed in Pakistan with 15 blind or VI persons. All the subjects also participated into the system's usability testing.

Results: The feedback of the test persons on about the proposed system after participating in the practical experiment of the system was positive. Based on the results, this kind of system would aid their navigation. The study also collected usability suggestions for further development of the system.

Conclusion: The proposed navigation system receives positive feedback from the potential users and the stakeholders. 13 out of the 15 blind and VI test persons were able to follow the test track successfully with the prototype and they found the proposed infrastructure applicable as navigation aid for the VI as a whole.

Keywords: Deaf-blind; Visually impaired; Outdoor navigation; Vibration; Braille code; Sidewalks; White cane; Magnets; Trail; Points of interest, Quality Function Deployment (QFD), Usability Matrix

Introduction

Visually impaired persons including deaf-blind, blind and low vision people require assistance in their daily life. Navigating complex routes and finding objects of interest are challenging tasks for visually impaired persons and in today's world there is a lack of infrastructures to make it easier. One of the most problematic tasks for VI people is outdoor navigation. In the literature this element is typically termed as Macro-Navigation or Orientation [1]. It includes multiple processes such as being oriented, selecting an appropriate path, maintaining the path, and detecting when the destination has been reached [2]. These tasks are dedicated to processing the remote environment, beyond the immediate perceptible ones. In the case of visual impairment, the main cues (e.g. landmarks and paths) for sensing the environment are degraded. This results in difficulties relating to correct orientation or heading, piloting (i.e. guidance from place to place using land marks) and retaining the path etc [1]. A system that assists visually impaired persons' navigation and orientation in real time will be of great benefit to achieve this demanding task.

Despite over a decade of intensive research and development, the problem of delivering an effective navigation system to the vision impaired remains largely unsolved [3]. Navigation support for the VI persons involves the use of textured paving blocks, guide dogs, GPS based navigation systems, different sensors and wireless based systems among others [4]. Other technologies widely used are the Radio Frequency Identification (RFID), using radio waves emitted from a wireless LAN access points, Infrared (IR), Bluetooth, and Ultrasound Based Identification (USID) [5]. However, these technologies and navigation aids suffer from certain limitations for being an optimum solution for the navigation assistance system for the VI persons. Compared to the public places and transport facilities, no progress is being made in providing commercial facilities along textured paving blocks. Although guide dogs are effective for obstacle-free safe walkways, they cannot locate destination of a person [6]. As for the GPS, the perceived accuracy is not always sufficient for the blind navigation in urban areas. This is largely due to satellites visibility problem because of tall and congested buildings. The urbanization phenomenon also slows down GPS start up time. Most GPS systems use speech to convey directions to the user, but this approach is not valid for real-time tasks, thus more fundamental audio and haptic interfaces are required [7]. The RFID technology has many shortcomings including fluctuating signals accuracy, signals disruption, reader and/or tag collision, and slow read rates [8]. The wireless LAN access point method has encountered issues with fluctuating positional accuracy due to reflected signals from the wireless LAN, obstacles, or the surrounding environment [8]. The drawback of IR based systems is that natural and artificial light can interfere with IR [8]. In addition, IR based systems are costly to install due to the large number of tags that need to be installed and maintenance [9]. For Bluetooth beacons based systems, the user has to walk slower than with other techniques because of the device delay [10]. Bluetooth beacons also suffer from heavy installation cost, maintenance, and line of site as for RFID and IR technologies [11]. Ultrasound based systems have the problem that walls may reflect or block ultrasound signals [12], which result in less accurate localization. The other drawback of using ultrasound for localization is required line of sight between the receivers and beacons [13]. The studies into guidance systems using tactile maps, that are effective in creating mental maps, are also underway. However, it takes time to understand tactile maps by touch, and therefore, they are difficult to be used when on the move [14].

This study is organized as follows. Sections braille code introduces the braille writing system and describes the serialized braille code that is developed in this study to be used as a communication mechanism by proposed navigation system. Section system design explains proposed navigation system for overall system design, hardware components of the system, and serialized braille vibrational messages transformation method. Section test persons provide details of the test persons' recruitment for the qualitative interviews and testing of the system. Section qualitative interviews provides detail of the qualitative interviews session planned to get visually impaired persons' input for the proposed navigation system. A comprehensive semi structured interview questionnaire is designed to collect data about white cane usage patterns in different environments, premises, seasons, feedback about this system, and users' acceptability level of new navigation assistance solutions. This section also provides results of the interviews conducted in Pakistan. Section usability testing describes usability testing and usability matrix that will be used to test the efficacy and efficiency of proposed navigation system. This section also provides detail of the results of usability testing done in Pakistan. Section discussion and future plans concludes this research article with discussion on results achieved so far and future plans of the study.

Braille Code

Braille is a tactile writing and reading system for blind and partially sighted people [15]. Braille system employs group of dots embossed on a paper or some other flat surface to represent printed letters and numbers. The system's basic "braille cell" is illustrated in Figure 1. It consists of six dots-like the points of a domino-arranged in vertical columns of three dots each. For convenience, a standard numbering system has been established for the dots whereby the dots in the left column are numbered downward from one to three, and the dots in the right column are numbered downward from four to six [16].

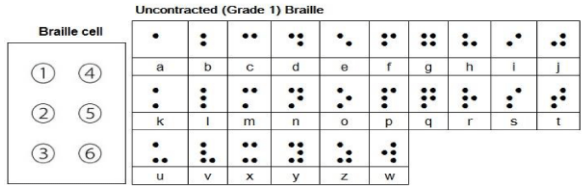

Figure 1: Braille cell and braille alphabet [16].

From the basic braille cell, 63 dot patterns and a blank can be formed for a total of 64 possible symbol variations. In conventional braille, these patterns, easily identifiable to the touch, represent letters of the alphabets, numbers, punctuation signs, and also certain common letter combinations (such as "ch" and "gh") along with a few common words ("and", "for", "of", "the", "with").

Serialized braille code

Braille was chosen as communication mechanism for the prototype to send guidance information to the blind and visually impaired users. Reading braille is more difficult than writing braille, thus making it difficult to use braille as a communication method in navigation systems for the VI persons. For that reason, a serialized braille version compliant of the traditional braille was developed for this study. Benefit of the serialized braille version is that a message encoded into it can be sent and read in the form of vibration.

Serialized braille transformation

The numbering system that is assigned to the braille cell dots is basic for conversion of conventional braille into serialized braille form. The braille code consists of three rows and two columns i.e. three by two matrix of cells. Position of each dot in a braille cell is assigned a specific number and combinations of those dots formulate different braille characters (Figure 1). A serialized braille could be devised by positioning two columns serially rather than parallel and get numeral value for each braille character, as shown in Figure 2. This modified braille code (i.e. a serialized braille) can be sent and received in auditory form and tactile form. In auditory mode, the cells of a column could be presented by different tonal frequencies and combinations (i.e. distinctive time gape with tones) and same way in tactile mode in the form of vibration. A serialized code could be easily learned by the blind persons who have already learned original braille code. Tactile mode would be especially advantageous for the deaf blind users.

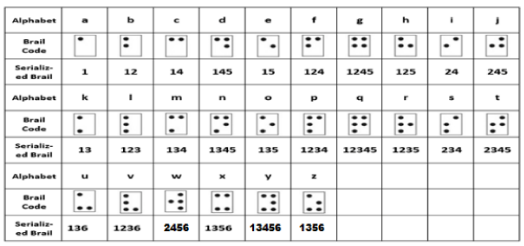

Figure 2: Serialized braille code.

System Design

The system comprises of four components:

- Augmented cane
- Stationary Magnet points' Trail
- Metallic trail
- Pulsing magnet apparatus

Augmented cane

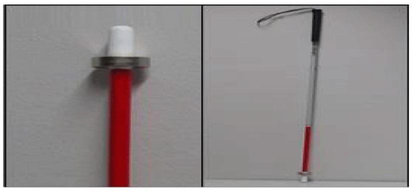

Figure 3: Augmented guidance cane.

Augmented cane is a walking stick that visually impaired persons will use to take assistance from the underlying navigation assistance infrastructure while walking on the sidewalks in the city centers. It is basically a regular white cane used by visually impaired persons augmented with a small powerful ring shaped Neodymium magnet [17] reader at its bottom (Figure 3).

Stationary magnet points' trail

The Stationary magnet points' trail will be made on the sidewalks for the VI persons in the city centres. This trail will contain powerful disc type Neodymium magnets [17] buried beneath the sidewalk forming a trail of magnetism on the sidewalk (Figure 4). The person walking on the sidewalk can sense and follow the trail of magnetism through her augmented cane magnetic reader. It will assist him walking independently being oriented on the sidewalk towards her destination.

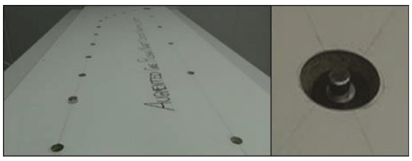

Figure 4: Magnet points trail test bed and pulsing magnet apparatus on it.

Metallic trail

The metallic trail is the second of the contending components to be made on the sidewalks in the city centres. It comprises of a tubular pure iron metallic pipe buried underneath the sidewalk (Figure 5). By using augmented cane with a magnet reader, the user can sense and follow the trail. It will assist them walking independently on the sidewalk being oriented towards their destination. Some part of the metallic pipe will be kept exposed to the surface. It will expedite sensing the metallic trail and aid in channelling the cane over it.

Figure 5: Metallic trail test bed and Pulsing magnet apparatus at trail splitting.

Pulsing magnet apparatus

The Pulsing magnet apparatus generates magnetized serialized vibrations to relay serialized braille encoded guidance message about a POI for the visually impaired persons' guidance (Figure 6A). The apparatus will be installed at the verge of the POIs on the sidewalks or at a point where a path is splitting into more trails (Figure 5). A person using an augmented cane can sense the serialized vibration emitted from the pulsing magnet apparatus through her augmented cane and becomes aware of the POI there. The serialized vibrations transmit serialized encoded guidance message that visually impaired person can get by decoding the serialized vibrations.

Architecture of pulsing magnet apparatus

Architecture of pulsing magnet apparatus comprises of following four components:

Micro Controller Unit (MCU): The MCU (Arduino UNO [18]) executes the serialized braille transformation logic. It encodes a guidance message into the serialized braille form. The encoded message is then sent to an electromagnetic coil in the form of serialized electric pulses.

Electromagnetic coil: An iron core electromagnetic coil is used to emit the serialized braille encoded message in the form of vibration through pulsing electromagnetism (Figure 6B). The Electromagnetic coil replicates the serialized electric pulses sent from MCU in the form of pulsing electromagnetism. The polarity of electromagnetism is reversed with each pulse. The reversing polarity causes white cane magnetic reader to be pushed and pulled by electromagnetic coil with each successive reversing pulse. This phenomena cause vibration effect to augmented cane. The electromagnet coil used is designed and developed indigenously for this project at University of Oulu because commercially available coils were not found appropriate after experimentation.

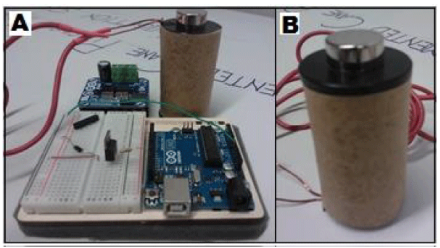

Figure 6: **(A)** Pulsing magnet apparatus and; **(B)** electromagnet coil.

The electromagnetic coil used for this prototype is developed in the lab at University of Oulu for this project because commercially available coils and electromagnets were found not suitable for this purpose after experimentation with them. Several coils are made with different specifications of core dimensions and wire diameter. The best suitable coil is chosen after experiments. Table 1 details the description of chosen electromagnetic coil.

H-Bridge: An H-Bridge is used to change polarity of the electrometric coil with each successive electric pulse. The H-bridge is an electronic circuit that enables a voltage to be applied across a load in either direction. These circuits are often used in robotics and other applications to allow DC motors to run forwards and backwards [19].

Reed-Switch: The reed switch is an electrical switch operated by an applied magnetic field. It consists of a pair of contacts on ferrous metal reeds in a hermetically sealed glass envelope. The contacts may be normally open, closing when a magnetic field is present. Once the magnet is pulled away from the switch, the reed switch will go back to its original position [20]. It is used in pulsing magnet apparatus to save power consumption. Pulsing magnet apparatus is not relaying serialized braille vibration all the time. It is activated when a VI person approaches to it with her augmented cane. The magnetism of magnetic reader of the cane connects the reed-switch that turns on the pulsing magnet apparatus and it starts relaying serialized braille vibrational guidance message. When visually impaired person once leaves the place and magnetism of the cane's magnet reader is absent again, the reed-switch is open again and pulsing magnet apparatus turns off.

Core			Wire			Current Frequency			
Material	**Diameter**	**Height**	**Material**	**Diameter**	**Turns**	**Current**	**Volts**	**Resistance**	**Reverse Pulse**
Pure iron	2.0 cm	8.0 cm	Enamelled copper	1.00 mm	600	8.5 Amp	12 V	1.4 Ohm	1~2 Hz

Table 1: Electromagnet coil description.

Test Persons

Total of 15 subjects (4 females and 11 males, aged 19-58 years) were recruited in three cities of Pakistan, i.e. Lahore, Islamabad, and Abbottabad. These cities were selected based on their different topography, landscape, and climate to get information of versatile environments when testing an outdoor navigation system. The interviews and tests took place in October-November 2014. The questions were asked in Urdu, the native language of the subjects.

The recruitment was done through two third sector organisations: the Prevention of Blindness Trust (POB) [21] and Movement for Independence of Disabled (MID) [22]. The person in charge in these organisations contacted potential visually impaired subjects by personal communication. Diverse age group and gender was enforced during selection of the test persons.

All subjects were given information on the study. They were informed that the participation was volunteer and they had right to abort their participation at any point without consequence. A signed consent was obtained. Permission of the interviewee was asked to perform the audio recording of the interview and video recording of system test for later analysis of more reliable data collection ensuring his/her privacy rights.

Qualitative Interviews

Content of the interview

A semi structured interview with open-ended question was designed to collect qualitative data (Appendix A) on blind and VI end users' white cane usage pattern in different environments (i.e. indoor, outdoor), premises (i.e. sidewalk with flat surface, trails like in some park, corridor, big halls etc.), seasons (i.e. winter, summer, rainy day, snows etc.), outdoor visits routine, role of alternative senses like hearing in navigation, and post-test feed-back about current prototype for the acceptability. The Post-test feedback session was conducted to get feedback of the users about prototype after pilot test. The interviews were guided by dramaturgical model [23]. All interviews were done in person.

Quality function deployment

Quality Function Deployment is a method for satisfying customers by translating their demands into design targets and quality assurance points. QFD is the converting of customer demands (WHATs) into Quality Characteristics (QCs) (HOWs) and developing a quality plan for the finished product by systematically deploying the relationships between customer demands and the QCs, starting with the quality elements in the product plan. Later, QFD deploys this WHATs and HOWs relationship with each identified quality element of the process plan and production plan. The overall quality of the product is formed through this network of relationships [24].

Results of the qualitative interviews

14 out of the 15 VI subjects use white cane frequently for everyday navigation. In outdoor use, all of the subjects use left right tapping of the cane technique on flat surface path. Reason of this is that they all use cane with a bare tip, not with a roller ball that can be swiped on surface. According to the subjects, rollers usage lifetime is usually short due to rapid rolling on possible rough surface. On a surface made of bricks, they use same left right technique but slow down their navigation speed so that cane may not stick into any gap between bricks.

Trails are especially challenging for them and grass makes it even worse. Their first reaction on encountering such a surface is to find a built path. In the case of walking on a trail, they use left right tapping technique and keep their cane at a safe height from surface so that it may not catch any bush or grass. For navigating a crossing bridge on a road, they use their cane in pencil style to find next stair and its width while going up. "Pencil style" means holding the cane loosely, vertically hanging way in their hand to let it touch the next stair to locate it. Crossing a bridge, they put left hand over its railing and use cane in left right technique with right hand. When they come to know ending of the crossing bridge by the turn of the railing, again they use cane in pencil style to come down through stairs. In a rainy season, the navigation technique remains same though noise of falling rain and noise made by nearby traffic in water disturbs their navigation. On a slippery surface, they may know through cane about it but it's their awareness that help them walk on such surface. For riding a taxi bus, or rickshaw, firstly they use their cane as an indicator for the driver to know they are blind. In the case of taxi car or rickshaw, there is no use of cane afterword. They fold it while riding. While in the case of bus riding, they use cane to locate height of foothold and stairs and then use while walking between the seats to sense bus's floor and any obstacle on the way.

Concerning indoor cane usage patterns, in a gallery they try to walk in its centre so that any open old style window, door, or split unit compressor may not hurt them. They may swipe the cane on the floor instead of left right technique if floor surface is fine enough. Big halls are especially challenging for navigation without personal or infrastructure assistance. On stairs, they use pencil style. They follow the railing of the stairs or wall with left hand. While coming down, they use cane to feel the depth and width of stairs by tapping and swiping. For escalator use, the bumped starting point let them know about the starting point. Then they feel starting stair by their cane. To step out of it on end, they either get info by sloping down reeling at the end or put cane on next stair so that they may know when it touches the floor. One subject said that he use to stand on heel when approaching towards end so he may safely end up on escalators. For lift usage, they use cane to know when lift arrived if it doesn't ring. Then they use cane to judge height of lift's floor from building floor, step in, and try to stand in the centre of the lift.

All users ranked the role of hearing for their navigation above 80%. One subject narrated that if his ear are caused to close, she will lose sense of orientation so much that may not be able to go out of his room without hurting herself. About going out, most of users may plan any time to visit any place meaning that they do not follow any strict routine. One subject said that she always plan in advance where to visit and by what time she should be back home. While about going out routines, other than going to job place or school, they mostly visit parks and friends twice a week in summer and once a week in winter, and once in two weeks for shopping.

About ideal navigation assistance, two subjects described textured paving blocks as ideal navigation assistance aid. Two male subjects said if they were informed about surroundings and roads through voice will be an ideal assistance for them. One female said a trail of magnet or metal line rails of train on sidewalk will be ideal navigation assistance. She also wanted braille signboards alongside the road. One female said if bumped textures of metal are made on sidewalk than may produce sound too when striking with can so they may not lose those will be ideal navigation assistance for her. One subject's ideal navigation system was metal textures of dots raised from the surface so she may follow those by striking her cane to those. The sound of striking as she recon would also help her in orientation. Few subjects were anxious to find assistance infrastructure for blind on public places like brail or voice in lifts, voice station calling in public buses, textured blocks inside buildings on stairs.

Usability Testing

The main objective of conducting usability experiment is to remove problematic issues from assisting users to walk independently on a predefined route and inform them about POI through serialized braille vibrational messages. Problematic issues mostly cause failure in achieving maximum desired system's usability. Analyzing tasks of usability test facilitates designing system's concept more accurately. There should be four to six participants in usability testing to rely on results; a final report should outline findings and provide developers with recommendations to redesign the system [25,26].

Usability experiment setting is defined as specific number of participants, a moderator, and a set of tasks to test the system. It identifies problems, which have been hidden through the development process from developer's point of view. In order to organize usability testing before conducting it, a set of assumptions should be predefined, and then assumption should be evaluated after the usability testing [27,28].

In order to measure usability in experiment, it is necessary to define following factors:

- Effectiveness means user's ability to accomplish tasks.
- Efficacy means user's ability to accomplish tasks quickly without difficulty and frustration.
- Satisfaction means how much user is enjoying doing tasks.
- Error frequency and severity means how often user makes errors and how serious are the errors.
- Learnability means how much user could learn to use the application after doing the first task.
- Memorability means how much user could remember from one task during next tasks.

Separate tasks could be designed to evaluate different usability factors [29,30].

Test scenarios

Test users in all experiments will be visually impaired persons deaf-blind, fully blind or near blind. The minimum number of participants in each test will be four. A video camera will be used to record test participants' activity in all tests. Pre-defined usability parameters will be used to record the results of all tests manually on a paper sheet. A separate data sheet will be printed and used for each user with his name. Later usability data will be saved on computer for further analysis by suitable tools. The results collected through usability metrics will help to investigate effectiveness, efficacy, satisfaction, and learnability of the system.

There are three phases of learnability for the system:

1st phase: User follows walking trail successfully.

2nd phase: User senses the serialized vibration successfully at a given POI through her cane.

3rd phase: User reads the serialized braille message successfully by decoding the serialized vibration.

In the 1st phase the users follow the magnetic trail. The test will be repeated for Stationary magnet point trail and Metallic continuous trail. A sub-test in the case of Stationary magnet point trail is to test do users prefer to follow it as a trail of magnetism or they want to search for next magnet point using their cane. In former case, distance between two successive magnet points is less and in latter case it's relatively more. Two test beds, one each for Magnetic point trail and Metallic trail are prepared. Two paths on each test bed are made, one straight line path and second a turning path. A post-test interview will ask test participants opinion about which walking trail out of Stationary magnet point trail and Metallic trail they prefer. This will help deciding which walking trail to be used as a component of system.

For 2nd phase testing, experiments will find if users are able to sense serialized vibrations successfully at a given POI through their augmented guidance cane. The experiment will be repeated both for Stationary magnet point trail and Metallic trail. This experiment will also investigate users ease level about pulsing frequency of vibration. It's thought that a suitable pulsing frequency of vibration will be supportive to read serialized braille message. Resonance frequency [30] of white cane will be used as a reference point to find near to ideal pulsing frequency of vibration.

For 3rd phase testing, experiments will find if users are able to read serialized braille encoded guidance message about a given POI successfully sensed in the form of serialized braille vibrations through their augmented guidance cane. Experiments will be conducted both for Stationary magnet point trail and Metallic trail.

Usability metrics

Specified usability metrics will be used to evaluate the results of all tests. The metrics will define all experiment settings for a given test e.g. detail of paths, description of white canes used in the experiment, POIs, and success/fail condition. The results will help to investigate effectiveness, efficacy, satisfaction, and learnability of the system. As stated by [30], while conducting usability tests, designers must use usability metrics to identify what it is they are going to measures. Designers test effectiveness, efficiency, and subjective satisfaction, by asking the user to complete various tasks. These categories are measured by the percent they complete the task, how long it takes to complete the tasks, ratios of success to failure to complete the tasks, time spent on errors, the number of errors, rating scale of satisfactions, number of times user seems frustrated, etc. Additional observations of the users give designers insight on navigation difficulties, controls, conceptual models, etc. The ultimate goal of analysing these metrics is to find/create a prototype design that users like and use to successfully perform given tasks [31].

Test setting for the 1st phase

In the 1st phase, as described in this article, the users followed a straight line trail (100 cm) followed by a 45 degree bending curve (50 cm). Ability to follow the straight line and the ability to turn were evaluated separately. Only the tests with stationary magnet points trail are performed and described at this point.

Each test person was first given an oral briefing before the test about how the system is supposed to work and how VI persons are supposed to use it. Then she was first made familiarize with the test-bed like one shown in Figure 4 by touching and walking over it. They were also handed over the augmented cane and they get a feel of its magnet reader on the tip by touching it. They were then asked to walk over the test-bed sensing the magnet points' trail by the magnet reader of the augmented cane. They required at least two three test walks over the test-bed to familiarize using it. After familiarization, the real test walk was observed. The performance was evaluated as successful if the person was able to complete the track from start to end point. The subjects were asked four feedback questions about the prototype after the test (Table 2). All tests were video recorded for later observation.

Usability test results

The results of the usability experiments are supportive to the proposed navigation system. 13 out of 15 VI and blind persons find this system helpful for their navigation. They also gave modification suggestions in current prototype (Table 2). After observation of the videos, it seems evident that test persons modification suggestions in current prototype are direct related to how they use white cane on surface while navigating. Persons who hold cane hard and walk fast have different feedback than people who either hold cane softly or walk slowly. The persons who have had formal education and training of the mobility and orientation needed a shorter learning curve for the proposed system as compared to persons who are self-learned. The users have varying opinions on appropriate magnetic force, distance between magnets, and additional features, suggesting the need for personalization in subsequent prototypes.

Serial	Gender and Age Group (Years)	Degree of Blindness	Is this system helpful for VI navigation?	Is magnetic force appropriate for navigation?	Is distance between magnets appropriate for navigation?	Any Suggestion?
1	Male (20-29)	100%	Yes	Should be less.	Appropriate for straight path but should be less near turns.	POI should be pointed vividly by increasing magnetic force or lesser inter-magnet distance.
2	Male (40-49)	~100%	No	Should be less so to not disturb flow of taking steps while detecting.	No, should be less.	If a magnetic rail made on sidewalk used with a roller tip augmented cane will be helpful.
3	Female (40-49)	100%	Yes	Should be little more so to be sensed by persons with weaker senses.	No, should be little more so to match the steps of walking blind persons.	Braille text on road direction and building signboards, adding voice guidance will benefit people unfamiliar with braille. This system will also need proper mobility & orientation training; self-

						learned walking skill persons may suffer.
4	Female (30-39)	100%	Yes	Should be more so that it may felt vividly.	Appropriate.	The magnets should be raised to surface so to be felt by cane or foot for usability.
5	Male (30-39)	~100%	Yes	It is appropriate like not stopping my cane and not missed, as I use pointing finger to put on cane so it helps move my finger in the direction the path is going.	Appropriate but should match footsteps distance of a walking blind person.	This system if installed will be very helpful for VI and blind person navigation.
6	Male (20-29)	100%	Yes	It is appropriate.	It is appropriate.	In current form, this system if installed will be helpful for VI navigation.
7	Male (50-59)	~100%	Yes	It is appropriate, not difficult to detect and follow.	It is appropriate but should match the footstep of walking blind man to ease smooth walking.	This system will ease blind and VI navigation.
8	Female (40-49)	~100%	Not sure as I do not use white cane, rely on personal assistance.	Not sure.	Not sure.	Voice guidance will be beneficial.
9	Male (40-49)	~100%	Yes	Should be bit more.	Appropriate.	Text to speech guidance for shops signboards and road signboards.
10	Male (30-39)	80%	Yes	It is appropriate.	Should be less distance so no time is wasted on detecting next magnet.	This system if installed will make navigation pleasant.
11	Male (20-29)	~100%	Yes	It is appropriate.	It is appropriate.	This system will help in navigation.
12	Male (20-29)	90%	Yes	Magnetic force should be more so to feel more on cane.	It is appropriate.	This system will be useful in navigation.
13	Male (20-29)	90%	Yes	It is appropriate but should be more on turns.	It is appropriate.	This setup is helpful for navigation.
14	Male (20-29)	80%	Yes	It is appropriate, easy to be felt without sticking cane.	It is appropriate.	Voice guidance on turns and other important points will be beneficial plus device should not be attached to cane but put into infrastructure. This system will work fine with a rolling tip cane.
15	Female (30-39)	75%	Yes	This much is appropriate.	Should be less.	A magnetic rail like of train on sidewalk will be more beneficial.

Table 2: Test persons feedback detail.

The degree of blindness of test persons as described in column number 3 was estimated by subject themselves. After introducing and getting familiar with the navigation system, 13 persons who gave answers in 'yes' to the question "Is this system helpful for VI navigation?" were able to follow the trail through with the augmented cane. The assistance was given to the subjects during introduction to the system in the form of telling them about presence of magnetic trail on the test-bed and orally telling how they need to use magnetic reader of the augmented cane to sense and walk following it. After this earlier assistance during introduction, the subjects did test the system and gave their feedback as described in Table 2. Two subjects were not able to walk successfully following the magnetic trail on the test-bid through augmented cane. One subject declines to continue testing when feeling failure and other subject was not able to sense and follow the trail.

Discussion and Future Plans

In this paper, the prototype of a navigation system to assist visually impaired deaf-blind and blind persons in outdoor navigation are

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presented. Scenarios of three testing phases of overall system for end users, and usability tests to evaluate usability factors of the system in each of its three testing phases are described. Results of first phase of usability testing done with stationary magnet points trail are presented. Based on the results the presented system has potential for navigational assistance, since 13 test persons out of 15 gave positive feedback about current prototype of proposed navigation system.

These results will help improve the design of the prototype based on feedback of end users. Usability tests done so far that are reported here have provided with actionable suggestions to increase usability of the proposed navigation system. We expect that participants could complete their tasks with the help of navigation system. Task accomplishment could fulfill expected efficacy and effectiveness of the system. Phases two and three of usability testing will be performed in the future. Quality Function Deployment (QFD) framework will be used to convert user demands into design quality.

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List of Questions for Interview		
Theoretical Construct	**Questions**	**Indicators**
Introduction Categorizing characteristics of interviewee-i Outdoor cane usage Indoor cane usage Alternative navigation aid & decision making Suggestion Categorizing characteristics of interviewee-ii Post demo feedback	1. Who we are and why we are doing this interview (general introduction)? 2. Do you use white cane for assistance? 3. How do you use cane on sidewalk that surface is flat? 4. How do you use cane on walking street that is built by bricks? 5. How do you use cane on a trail like in some of parks? 6. How do you manage to ride a bus, taxi, or private car? 7. How do you use cane when it's raining outside? 8. How do you use cane in soft snow outside? 9. How do you use cane in hard snow outside? 10. How do you use cane in hard slippery snow outside? 11. How do you use cane in corridor? 12. How do you use cane in a big hall 13. How do you use cane on stairs? 14. How do you use cane on an escalator? 15. How do you use cane in a lift? 16. How hearing help you in navigation outdoor and navigation indoor? 17. Do you plan your visit in advance or do you make decision where to visit while walking? 18. What are the places you visit in summer and in winter and how often? 19. Do you use any kind of assistance technology? 20. What is ideal guidance system for you? 21. How would you compare this system with other navigation systems? 21. What is your date of birth? 22. Do you lose sight late or blind by birth? 23. What is the cause of your visual impairment? 24. On a scale of 1-5 where 1 means nonexistent and 5 means perfect, how would you rate your vision in the following areas: a. Visual acuity b. Field of vision c. Night blindness d. Sensitivity to light e. Color blindness 27. What do you think of this system? 28. How do you compare this system with any navigation assistance your currently use for outdoor navigation like ordinary white cane or any navigator application? 29. What potential difficulties of yours when you navigate outdoor do you think this system could solve? 30. Would you like to use this system?	Acquaintance White cane acquaintance Urban environment cane usage pattern Transportation usage Seasonal cane usage pattern Indoor cane usage pattern How much info relayed about POIs View of ideal navigation aid Background info Degree & reason of blindness End users view and acceptance of proposed system

Appendix A: A semi-structured interview with open-ended question.

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