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PERCEPT: Indoor Navigation for the Blind and Visually Impaired

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Abstract— **In order to enhance the perception of indoor and unfamiliar environments for the blind and visually-impaired, we introduce the PERCEPT system that supports a number of unique features such as: a) Low deployment and maintenance cost; b) Scalability, i.e. we can deploy the system in very large buildings; c) An on-demand system that does not overwhelm the user, as it offers small amounts of information on demand; and d) Portability and ease-of-use, i.e., the custom handheld device carried by the user is compact and instructions are received audibly.**

Index Terms— **Indoor localization, Bluetooth, RFID**

I. INTRODUCTION

"Vision loss is taking an enormous toll in the U.S. and around the world. 161 million people worldwide have vision impairment and without intervention the number will almost double by 2020. Of the 161 million people, 37 million are blind and 124 million have low vision. Vision loss affects people of all ages. Every five seconds someone in the world goes blind. A child goes blind every minute. It's very likely that you or someone you love may face vision loss due to age-related macular degeneration, cataracts, diabetes-related eye disease, glaucoma or other eye disorders." – These quotes by the Lighthouse International [1], a leading resource worldwide on vision impairment and vision rehabilitation, are enough to throw light on the importance of developing systems that aid the blind and visually-impaired.

Currently, there are various programs and devices for the blind and visually-impaired which make use of diverse technologies to help them in leading independent lives. For instance the VRCBVI (Virginia Rehabilitation Center for the Blind and Vision Impaired) [2] offers programs that include personal and home management skills, communication skills, pre-cane and cane skills, low vision services, and travel using a dog guide. Technology has been used screen magnifiers, and Braille keyboards and displays [2].

There has been research to provide navigation information to the blind and visually-impaired users both indoors and outdoors [3-6]. While most of these systems cover a wide range of functions, the end devices are inconvenient for daily use because they are heavy and complex [3,6] which is not a feasible option for a majority of the users.

In this paper we introduce PERCEPT system that provides enhanced perception of the indoor environment using passive RFIDs deployed in the environment, a custom-designed handheld unit which serves as the PERCEPT client device and a PERCEPT server that generates and stores the building information and the RFID tags deployment. PERCEPT is different from other systems in the following aspects: 1) the user carries a custom made handheld unit with small form factor and an Android based phone, and 2) the system deployment and maintenance cost is very low due to the use of passive RFID tags.

The paper is organized as follows. PERCEPT architecture is introduced in the next section. A sample scenario is described in Section III, Section IV introduces our testing and Section V concludes the paper.

II. SYSTEM ARCHITECTURE

PERCEPT system architecture consists of the following system components: the Environment, the PERCEPT glove and Android client and the PERCEPT server.

A. Environment

R-tags: The environment includes passive RFID tags (R-tags) that are deployed on each door at 4 ft height. R-tags are also embedded in kiosks located at specific points of interest such as the entrances/exits to a building, at the elevators and at emergency exits. Granularity was the main reason behind selecting this technology. Proximity of 2-3 cm is required to transfer data from the R-tag into the reader. Other reasons for selecting these R-tags were their cost and the fact that they do not need any power source. On each R-tag we incorporate the room number in raised font and its Braille equivalent.

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Kiosks: Kiosks are the junctions at which user's intention can be conveyed to the system. Kiosks are located at key points such as entrances/exits of the building, elevators and emergency exits on each floor. As shown in Figure 1 kiosks contain R-tags that represent floor numbers and/or locations (Rooms, restrooms denoted by M and W, emergency exits denoted by X) in the building. A Braille equivalent of the floor or room number is also provided on each R-tag. By activating a specific R-tag, the user implicitly requests the navigation instructions to reach this destination (either a specific floor or a specific room number).

B. PERCEPT Glove and Android Client

PERCEPT Glove: As shown in Figures 2 and 3 the glove allows the user free use of his hand as well as the ability to scan the R-tag. The user will first determine the requested R-tag (by using his fingers either through the raised numbers on the R-tag or the Braille) that represents the chosen destination. After the R-tag is determined the user places his palm on top of the R-tag. The glove communicates the chosen destination represented in the R-tag using Bluetooth technology to the Android based Smartphone.

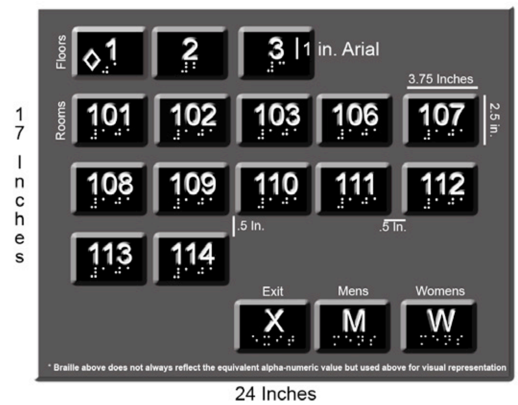

Figure 1. Kiosk Design

Figure 2. PERCEPT Glove (back view) Scanning an R-Tag

We have incorporated our PERCEPT client system into a weight training glove. Our PERCEPT glove system includes an Arduino Microcontroller, RFID Reader, Antenna, Bluetooth chip, a set of buttons, Rechargeable Battery, and a Power Regulator. The Arduino microcontroller is used to keep track of all the events occurring during the interaction between the user wearing the PERCEPT glove and the environment. On scanning the R-tag, the RFID reader sends the R-tag data to the Arduino microcontroller. The Bluetooth chip is used to exchange data between the microcontroller and the Android Smartphone. The buttons on the PERCEPT glove provide users different options to interact with the PERCEPT system. Each of the buttons has a unique texture and can be identified through touch. The buttons represent different functionality such as:

1. Help button (H): used for the return journey.

2. Replay / Rewind button (R): used to repeat previous instructions in case the user forgets them.

3. Instructions button (I): After the user follows a set of instructions, he will press the Instruction button to get the next set of instructions.

Figure 3. Front view of PERCEPT Glove

Android based Software: Components of PERCEPT software implemented in the Android Smartphone are:

1. Bluetooth Module: This module is responsible for exchanging data (e.g. R-tag scan and Button press) between the Android Smartphone and the PERCEPT glove.

2. Percept Application: This application differentiates among various events i.e. *R-tag Scan Event, Help Button Press Event, Replay Button Press Event and Instruction Button Press Event.* For R-tag Scan Event and Help Button Press Event, Unique Identifier of R-tag is sent to the Percept Server over Wi-Fi connection. Other events are processed locally and the output is converted into an audio form using the Text to Speech Engine.

3. Wi-Fi Module: Wi-Fi module is responsible for establishing Wi-Fi connection between the Android Smartphone and the PERCEPT Server. The navigation instructions are received over the Wi-Fi connection from the PERCEPT Server, which are then converted into an Audio form using Text to Speech Engine.

4. Text To Speech Engine: As PERCEPT system is designed to assist the blind or visually impaired, the system interacts with the user in audio format. The Android Smartphone provides a built in Text To Speech engine to convert the textual navigation information received from the server into audio format.

C. Percept Server

Floor layouts of the entire building are constructed using *Quantum GIS*. Floor layout is a node-link structure (shapefile) with each node representing a room. Once the node-link structure (shapefile) is ready, it is mapped to the *Postgres* database. Every route in the node-link structure is associated with an attribute table which is a tabular depiction of the entire set up. This attribute table is used to generate the *Postgres* database table of a particular floor. The Navigation Module formulates navigation instructions after receiving the shortest path route from the Postgres database. It accesses *node_info* database to acquire information about each and every node in the shortest path route. The navigation instruction given to the user is of the following form: E.g. "*Please turn left and proceed along your right side wall for 4 doors and then you will reach your destination*".

III. SAMPLE SCENARIO

We present a sample scenario to explain the flow of events.

John is a freshman and majoring in Computer Systems Engineering. He is trained by the Orientation and Mobility instructor on the use of the PERCEPT system. He stays in Knowlton Dormitory and wants to meet his advisor to discuss the courses he needs to take. His advisor's office is on 3rd floor (room number 312) in Knowles Engineering Building. He calls campus Disability Services Van for the ride to Knowles Engineering Building. John has a cane as well as a PERCEPT glove and an Android based phone. It is assumed that John knows the destination room number and destination floor number. Here is John's journey:

1. Designated Drop off Point: Every building on campus has a designated drop off point. Campus Disability Services van drops John at the Designated Entrance point (Exit 1 in Figure 4a). Once he reaches Exit 1, he moves towards the Kiosk located at Exit 1.

2. *Kiosk at the Entrance:* The Kiosk at Exit 1 (see Figure 1) includes R-tags for every room on the 1st floor and one R-tag for other floors. John finds the R-tag that represents the 3rd floor using his finger and then uses his palm to scan the R-tag. He gets the following directions to reach the Elevator on the 1st floor: 'Your Destination is on floor number 3, To reach your destination, Please turn right and proceed along your left side wall until you have reached one opening, Enter this opening. Once you reach there, please scan the card located on the Door'. Route: (Exit 1 > Room 102 > Room 107 > Elevator)

3. *Kiosk at the Elevator on 1st floor:* Once John reaches the elevator kiosk, he will scan the R-tag that belongs to the 3rd floor. Here he will get audio instructions informing him that he has reached the Elevator and he should proceed to 3rd floor (destination floor) using this elevator. John gets the following instructions: '*You have reached the Elevator of Floor number 1, Please use Elevator to proceed to Floor number 3. When you exit the elevator at Floor number 3, turn around and face elevator, the kiosk will be located to the left of the elevator door.*

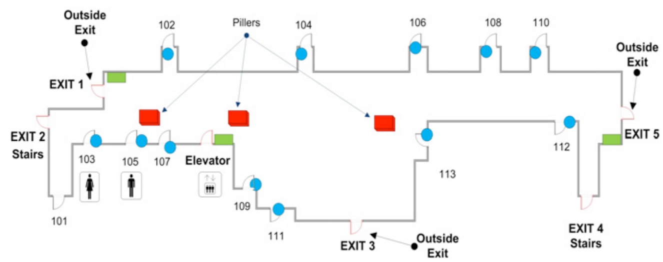

Figure 4a. 1st Floor Structure of Knowles Engineering Building

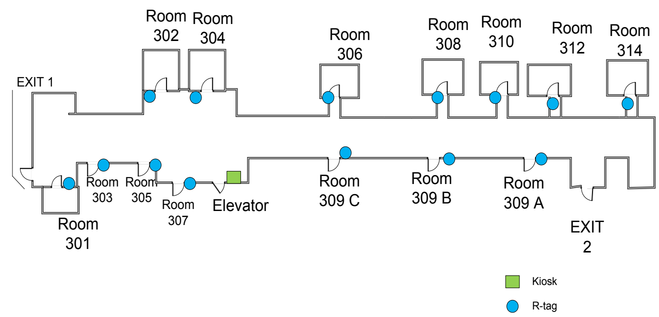

Figure 4b. 3rd Floor Structure of Knowles Engineering Building

4. Kiosk at the elevator on 3rd floor: After John reaches the 3rd floor using the elevator (see Figure 4b), he will exit elevator, turn around to face the elevator door, and locate another kiosk to the left of the elevator door.. Here, John will have to activate the R-tag that represents his destination room number i.e. 312. Once he scans the desired destination R-tag with the PERCEPT glove, John gets the following directions to reach his destination room number (312): *'Your destination is Room 312, To reach your destination, Please turn Left and proceed along your Right side wall for 3 doors, Once you reach there, Scan the card located at the door'.* Route: Elevator > Room 309 C > Room 309 B > Room 309 A > Room 312

5. *Any R-tag leads towards the destination*: In case John scans any R-tag on the floor he will be given directions to the chosen destination. For example, if John scans the R-tag at Room 306, he will get the following instructions: *Please Turn right and proceed along your left side wall until you have reached the 3rd opening, Enter this opening and you will reach Room 312".*

6. *Return journey:* After John finishes the meeting with his advisor he wants to obtain the return instructions. He presses the HELP button on the PERCEPT glove. This will give him the following directions to reach the elevator on the 3rd floor: *Your destination is Elevator. To reach your destination, Please put your back to the door and begin your return journey. Please proceed towards the opposite wall. After the user presses the instructions button the following instructions: Please turn Right and proceed along your left side wall until you reach at the Elevator. Once you reach at the elevator, Please scan the card belonging to your next destination'.*

7. *Kiosk at the elevator on 3rd floor:* Once he reaches the kiosk, he will scan the R-tag that corresponds to 1st floor.

John gets following Instructions: *'You have reached the Elevator of floor number 3, Please use elevator to proceed to Floor number 1. When you exit the elevator at Floor number 1, turn around and face elevator, the kiosk will be located to the left of the elevator door...*

8. Kiosk at the elevator on 1st floor: After reaching the elevator of floor number 1, John will scan the Emergency Exit card (denoted by X in Figure 2). As he scans this card, he will get the following instructions: '*Your destination is EXIT door, To reach your destination, Please turn around and proceed towards the opposite wall. After the user presses the instructions button he gets the following instructions: Please turn Left and proceed along your right side wall until you reach 1st opening. Once you reach there, Please continue walking along the wall for 1 door and then you will reach at the Exit door. Always scan the card located at the kiosk on the Right side of the Exit door before exiting the Floor number 1.*'

9. Kiosk at Exit 1: As John reaches the kiosk located at Exit 1, he scans the Exit card (denoted by X), to convey to the system that he wants to leave the building. He gets the following instructions: '*You have reached the Exit door on floor number 1, Please open the Exit door and walk straight to go out of the building.*'

IV. TESTING AND RESULTS

The testing that was performed in Knowles Engineering Building by the technical team as well as the Orientation and Mobility instructor tested the following features of the PERCEPT system:

1. *Testing the correctness and robustness of the navigation instructions,* on all the 3 floors of the building independently, and for inter-floor navigation. PERCEPT system navigation instruction accuracy was tested by choosing different source and destination locations on the same floor as well as on different floors of the building. Both intra and inter floor navigation instructions were consistent and correct.

2. *Testing the reliability, and availability of the system even when users use the system in unintended ways.* The user will be interacting with the glove throughout his entire journey and because of his visual impairment, buttons could be accidently pressed as well as R-tags accidently scanned. The system must handle these interactions to ensure the user's destination is not lost or altered. In order to test for these situations we prepared a list of possible interactions with expected results. In this list was a script of the possible steps a user could take at any point in time whether they were wrong or right. Each one of these situations was then tested in the Knowles building to ensure that the PERCEPT system provides reliable instructions.

3. *Testing system usability of the navigation instructions*, i.e., the instructions clarity (i.e., compliance with orientation and mobility instructions that are currently given to the blind and visually impaired) and pace (e.g. number of instructions given at a given time). The speed and the amount of information that needs to be given at a time are very important factors to guide visually impaired people. This phase was thoroughly tested by the Orientation and Mobility instructor for the blind and visually impaired.

4. *Flexibility and Control over the user journey*-PERCEPT system was tested to verify the kind of control it should have over the route taken by the user. Due to the use of spatial database, PERCEPT system was able to navigate the user via a route which is easy to follow. This was important because, sometimes the shortest route will have too many complexities (many corners and obstacles) for the blind or visually impaired user to undertake. In this scenario, the user can reach his destination quickly by following a bit longer but straight-forward route. This phase was thoroughly tested by the Orientation and Mobility instructor for the blind and visually impaired.

V. CONCLUSION

PERCEPT system that we designed, implemented, deployed and tested includes the following advantages:

* PERCEPT system was able to successfully provide directions to reach the required destination through the Knowles Engineering Building
* PERCEPT system relies on the "touch" capability of the blind by incorporating the PERCEPT glove. The glove has proven to be a solid and lightweight design that frees up the user's hand as well as augments the user's hand to enable him to scan the environment. This feature is especially important since the user already has his hands occupied with a walking cane or a guide dog.
* PERCEPT environment, i.e. the Kiosks and R-Tags follow the ADA signage regulations [7] and provide a tactile feel and color contrast for the visually impaired users.
* PERCEPT system is flexible enough to accommodate additions of new rooms or new structures in the building.

Our future plans include extensive testing with human subjects.

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