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Quantitative and Qualitative Evaluation of PERCEPT Indoor Navigation System for Visually Impaired Users

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***Abstract*— In this paper we introduce qualitative and quantitative evaluation of PERCEPT system, an indoor navigation system for the blind and visually impaired. PERCEPT system trials with 24 blind and visually impaired users in a multi-story building show PERCEPT system effectiveness in providing appropriate navigation instructions to these users. The uniqueness of our system is that it is affordable and that its design follows Orientation and Mobility principles. These results encourage us to generalize the solution to large indoor spaces and test it with significantly larger visually impaired population in diverse settings. We hope that PERCEPT will become a standard deployed in all indoor public spaces.**

***Index Terms*— Indoor localization, Visually impaired users, RFID**

I. Introduction

The World Health Organization (2004) reported that there are at least 161 million people worldwide with visual impairments, of whom 37 million are considered legally blind [1]. In the US, about 12 million people have some degree of visual impairment that cannot be corrected by glasses (National Advisory Eye Council) [2]. Based on data from the 2004 National Health Interview Survey, 61 million Americans are considered to be at high risk of serious vision loss if they have diabetes, or had a vision problem, or are over the age of 65. According to the American Diabetes Association diabetes is the leading cause of blindness in persons ages 20-74 [3].

The blind and visually impaired encounter serious problems in leading an independent life due to their reduced perception of the environment. New environments pose a huge challenge for them to perceive their surroundings without seeking help from others. Current training programs for blind and visually-impaired people require them to memorize a large amount of information for numerous points of interest (i.e., university, shopping malls, bus terminals, etc) leading to an increase in personal frustration.

It is commonly accepted that the incapability of moving freely and independently can hinder the full integration of an individual into society [4]. Blindness, like other disabilities, affects one's mobility and quality of life [5], especially when the vision loss occurs at a later stage of adulthood after a lifetime with functional vision [6].

There has been research to provide navigation information to the blind and visually-impaired users both indoors and outdoors [7-18]. While most of these systems cover a wide range of functions, the end devices are inconvenient for daily use because they are heavy, complex and expensive [7,8,15,16] which is not a feasible option for a majority of the users. Only few of these systems were tested with at most three blind and visually impaired users. Moreover, none of these studies employed O&M principles at the core of the system design along with the use of an affordable platform.

PERCEPT system which was developed by the authors and first introduced in [19], 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 builds upon O&M principles.

In this paper we report quantitative and qualitative results of a multi-phase evaluation of PERCEPT system with 24 blind and visually impaired users.

The testing results showed 100% satisfaction from all users.

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In Phase II trials all users that received Orientation and Mobility instruction successfully used PERCEPT and reached independently all 10 destinations in the building.

The paper is organized as follows. PERCEPT system is introduced in the next section. Section III introduces PERCEPT trials and Section IV concludes the paper.

II. PERCEPT SYSTEM

PERCEPT system architecture was introduced in details in [19]. For paper completeness we summarize the architecture below.

When a user, equipped with PERCEPT glove and a Smartphone, enters a multi-story building equipped with PERCEPT system, he/she scans the destination at the kiosk located at the building entrance. The PERCEPT system directs the user to his/her chosen destination using landmarks (e.g., rooms, elevator, etc). The system consists of the following components [19]:

1. ***Environment:*** includes passive RFID tags (R-tags) that are deployed on each door at 4 ft height. On each R-tag we incorporate the room number in raised font and its Braille equivalent. R-tags that represent floor numbers and/or locations (Rooms, restrooms, emergency exits) in the building are also embedded in kiosks located at specific points of interest such as the entrances/exits to a building and at the elevators. 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).
2. ***User devices:*** the user wears PERCEPT glove and an Android based Smartphone which communicates with PERCEPT glove, PERCEPT server and the user. The glove, which we have designed and manufactured, 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 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. Our PERCEPT glove system includes an Arduino microcontroller, RFID reader, antenna, Bluetooth chip, buttons, rechargeable battery, and a power regulator.
3. ***PERCEPT Server:*** runs the software that stores the building layout in a spatial database and generates the navigation instructions. In designing the PERCEPT system navigation instructions, basic orientation and mobility principles were employed. Instructions were given in concise, two to three step units. **Directionality** was in spatial relationship to the user's body position to specific landmarks, i.e.: "turn right, and follow the wall on your left for two openings". **Physical landmarks** were included to assist the user in identifying a specified object to move toward, once reaching that landmark, the user is able to proceed with directions from a given point which has been confirmed accurate in completing the overall route. For example, "cross the hall to the opposite wall, turn left and proceed along the right hand wall until you reach the first opening on your right, You have reached Room 112". **Consistency** will help the user learn the system easily and know what to expect – similar to a car that reacts the same at all times given the user control (e.g. when the user presses the gas pedal with the same force, the car should react the same). If by chance the user becomes disoriented he or she is able to re-correct by locating any door tag at which point PERCEPT provides recalculated instructions from that point to the original destination.

III. PERCEPT TRIALS

We conducted two IRB approved phases of trials. In the first phase, 10 subjects provided feedback on ease of maneuvering around a building both with and without the use of the PERCEPT system. Subjects were randomized as to whether they performed the necessary tasks with or without the PERCEPT system on their first or second trial. Feedback from this first round of testing led to improvements in hardware (ruggedized and miniaturized), changes in the way the trials were conducted (we adopted one-on-one trials as opposed to group trials) and changes in the delivery of the navigation instructions. A second phase of trials was conducted with 20 subjects (6 of whom participated in Phase 1). These subjects only used the PERCEPT system.

Due to space constraints, we will provide results for Phase 2.

Population: We had a diverse subject population, in gender (8 male and 12 female), race (3 African Americans, 12 Caucasians and 5 Hispanics), age (2 under 20, 6 between 20 and 50, 11 between 50 and 70 and one over 80), education level (9 with GED/high school and/or some college, 9 had bachelors degree, and 2 with Master of Science degrees), level of blindness (9 blind from which 5 were blind from birth, and 11 with partial vision), and in navigational aids (10 cane users, 7 guide dog users and 3 with no mobility aid). 19 users out of 20 received O&M training.

Methods: Each trial followed three stages: Orientation, Test, and Evaluation. All stages were performed one-on-one with the subject and the test administrator.

<u>Stage 1 Orientation:</u> In this stage the subject is introduced to PERCEPT. First, we introduced PERCEPT hardware: PERCEPT glove, the Kiosks and the R-tags. PERCEPT system functionality was presented to the user by going through a system setup in a test area (i.e., a small portion of the building in which the trial took place). A mock mini-trial is done by asking the subject to navigate through a number of destinations in the test area using the PERCEPT system. At any point the subject can stop and ask for help from the test administrator. The orientation is completed when the subject feels comfortable with PERCEPT system. There is no time limit imposed. This stage took between 10 and 75 minutes.

Stage 2 Test: Each subject was asked to navigate to ten destinations within Knowles Engineering Building on UMASS Amherst campus (same sequence of destinations is presented to each subject).

The destinations (two different rooms, elevator, restroom, emergency exit, building exits) were located on the first and third floor of a typical classroom building. The test administrator told the user the destinations, one at a time, i.e., the next destination was given only after the current destination was successfully reached. During this stage the test administrator does not aid the subject with any navigational tasks. However, if the subject's safety was at all compromised, the trial administrator intervened on behalf of the well being of the subject. If the subject was not able to find a destination, they could ask anyone in the environment to help them, however this was recorded as a failure of the PERCEPT System.

Each trial was videotaped (with the subject consent). The videotape is used for evaluating the system performance quantitative measures as described below.

Stage 3.1 Quantitative Evaluation: We used the following quantitative metrics:

NEI - *Navigation Efficiency Index is defined as the ratio between* the length of the *PERCEPT Path* (presumed to be optimal) *and the length* of *Actual Path Traveled*.

ACU- *Accuracy is defined as the ratio between the number of destinations reached by the subject and the total number of destinations determined by the trial.*

The average NEI was 0.90 (in Phase I trials average NEI was 0.70). Investigators interpret this as an indication of the very high efficiency of the navigation instructions. 19 out of 20 users reached all the 10 destinations (ACU=1). All of these users had previously received O&M instruction. The one user that did not receive O&M instructions was not able to use PERCEPT to the full extent.

Figures 1a and 1b depict average NEI versus subpaths S (subpath is a portion of the path taken by the subject from source to destination) for partial vision and blind users, respectively. As expected, partial vision users performed better (i.e., have higher NEI) since they use visual cues. Notice that in S 1a for some subpaths NEI is higher than 1. This is due to the fact that PERCEPT navigation instructions follow the wall while users with partial vision can take shortcuts (do not always trail the wall).

Stage 3.2. Qualitative Evaluation: Each subject was asked a series of qualitative questions regarding their experience with the PERCEPT system. as follows:

- Did you think that navigation directions given by the system were difficult to memorize?
- During the course of the trial, did you feel that you were lost inside a building? (This will tell us user-friendliness of system)
- Did you ever find that you thought you have reached your destination when you actually hadn't? (accuracy)
- If so, how many times did this happen?
- What do you think about the pace of the audio directions? Should the pace be slower or faster or it is good enough?
- If you could design the system yourself, what is the first thing you would change to make the system more usable?

Satisfaction with PERCEPT system was reported by all the subjects. 90% mentioned that it is user-friendly, 85% said that it provides independence and that they would use it. We found that females had slightly more self-reported difficulty with the use of the system. Participants who had at least a college degree reported greater ease of use. 65% of the participants felt the pace of the instructions was good and 85% felt the pitch of the voice was within a good range. Text-to-Speech technology is deeply integrated into Screen Reader technology that helps the visually impaired use a computer. We found the participants that do not use this technology had difficulty with the pace and pitch of the voice.

The users suggested the following improvements: 1) Directions need to include proximity or given in feet/steps (75% of users), 2) Change instructions for those who have guide dogs (86% from dog users), 3) Provide options to adjust navigation instructions to user preferences- adjust voice pace – (60% of users), 4) Allow for abbreviated directions that should just mention left/right/…(15% of users), 5) Use of a Smartphone only (no additional hardware such as PERCEPT glove).

IV. CONCLUSION

PERCEPT system that we designed, implemented, deployed and successfully tested includes the following advantages: 1) the system design and the navigation instructions incorporate O&M principles and ADA guidelines, 2) the system is affordable to both the user and the building owners, and 3) the system is scalable to any size building.

Our future plans include further development of PERCEPT system to accommodate for large open spaces and test it with human subjects in different settings such as shopping malls, supermarkets, bus terminals, and hospitals/medical offices.

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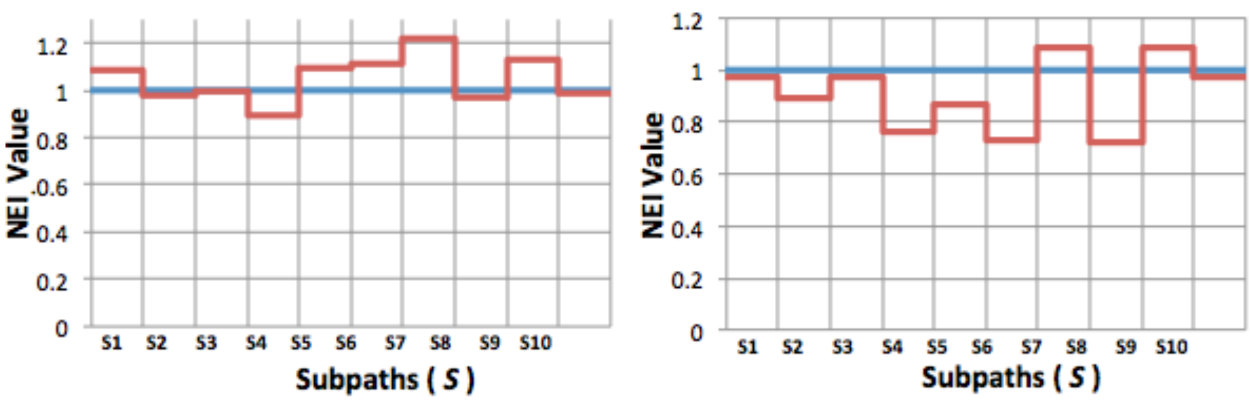

(a) Partial vision users (b) Blind users

Figure 1. Navigation Efficiency Index, NEI, vs Subpaths