A COST-EFFECTIVE INDOOR VIBROTACTILE NAVIGATION SYSTEM FOR THE BLIND

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Abstract: This paper describes the development of an indoor vibrotactile navigation system for the visually impaired people. We aimed at realizing a wearable, low-cost, and effective system able to help blind users in unknown indoor environments that they might visit occasionally, such as hospitals, airports, museums, etc. The designed system implements a Bluetooth (BT) localization service, and provides wayfinding cues to the user by means of a wearable device equipped with five motors. The last part of our work describes early results obtained by the use of electroencephalographic (EEG) analysis to evaluate the vibrotactile feedback.

1 INTRODUCTION

Navigation, in general, involves providing directional information to the user during a travel with respect to the intended route and the desired destination. People with visual deficits can be challenged by planning and performing navigation because of the reduced amount of information that they can perceive from the surrounding. Regarding navigation and wayfinding systems, the use of vibrotactile displays has several advantages over vocal messages. First of all they are less intrusive. Although tactile and vibrotactile displays can often offer a limited amount of information, they are less invasive and do not risk to distract the blind person from unexpected events, or more important tasks, such as orientation. Since there is no standard system for indoor localization (compared to the well known Global Positioning System used in outdoor environments), many technologies can be employed. Among the possible choices BT is a cost-effective, widespread and standard technology. In this context, this work presents an indoor navigation system based on vibro-tactile feedback and BT localization. Wayfinding cues are provided to the user by use of coded vibro-tactile messages, occurring in the case the user should change its direction of movement. Employing high sensitivity areas, such as shoulders and the stern, we can reach perfect stimulus detection while maintaining power consumption level low and adequate to the expected lifetime of the system. The last phase addressed in this work is an early validation of the system. We first performed traditional assessment by use of questionnaires on a group of subjects. However, we are also interested in determining the effectiveness both of the vibrotactile actuator and of the particular kind of feedback provided, without involving the subjective perception of the user. Therefore, we explored use of EEG to analyze and quantitatively assess effects of the vibrotactile stimulation. Even if we describe very early tests and methodology, the use of EEG analysis seems promising and can be further used to compare different kinds of vibrotactile actuators. The paper is organized as follows. An overview of the existing solutions for indoor and vibrotactile navigation is given in Section 2. In Section 3 the system architecture is explained. Section 4 describes briefly the localization system while Section 5 concerns the vibrotactile system. Experimental results are given in Section 6 whereas Section 7 deals with preliminary studies on EEG analysis. Conclusions can be found in Section 8.

2 RELATED WORK

Several navigation systems have been proposed over the last years, each of them employs one or more of the following modality to provide information to the user: video, audio or tactile. Targeting the development of an aid for visually impaired people the focus is narrowed to audio and tactile feedback. Wayfinding is aimed at helping the blind in reaching a destination within a building. The investigation of how to support this task has not yet standard

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solutions in indoor environments. Technologies for indoor navigation still require to be tuned to achieve satisfying results. We focused our effort in addressing the problem of supporting navigation in indoor spaces, having as target scenarios non-familiar public places where visually impaired people can require a stronger support (e.g. to be accompanied by someone). Navigation systems are moving from auditory (Crandall, 2001) to tactile interfaces for providing information to the user, this is due to multiple factors: first of all a tactile display is less intrusive. Secondly, progress in electronics is making it possible to realize wearable lightweight and low power systems, well suited for vibrotactile systems. Many devices have been proposed for outdoor navigation based on tactile interfaces: most of them are belts (Tsukada, 2004), others are instead wrist based interfaces (Bujnowski, 2008). Only a few systems address the problem of indoor navigation (Ross, 2004), (Ghiani, 2008) mainly by means of vocal messages and expensive architectures. As a matter of fact, one of the issues that arise in indoor environments is how to localize the user in a building. High accuracy is required to help a blind person in wayfinding tasks, thus the current state of the art employs RFID tags (Ghiani, 2008) or ultrasounds (Ross, 2004). Those methods require a big amount of tags or base stations in order to determine the user position, resulting in quite expensive systems. For this reason, they are often based on the proximity approach, providing information to the user only when he is close to a tag or a base station, implementing indeed obstacle avoidance instead of navigation. Radio frequency technology, such as BT, has not been adopted for navigation purposes because of the low resolution that usually characterize it. Employing a localization system based on BT would result in a cost-effective infrastructure, since many building are equipped with PCs with BT connectivity. Our novel approach in this direction showed promising results (0.5 meters of accuracy), as pointed out in (Altini, 2010).

Navigation systems are usually validated in three ways: questionnaires, time employed for completing a route, difference between the optimal path and the one taken by the user (Tsukada, 2004), (Heuten, 2008). Hence, other metrics to compare different kind of actuators or even to assess quantitatively the performance given by such systems are still needed. A small step in this direction was taken in (Bujnowski, 2008); the authors show the activation of the sensorimotor area of the brain during vibrotactile stimulation. They demonstrated that the tactile stimulation was actually influencing the user perception, even if it was not possible to quantify or characterize such influence.

3 SYSTEM OVERVIEW

The navigation process, often called wayfinding, is usually based on three steps. The first step is user localization, the position of the user in relation to some known landmarks in the building needs to be determined. The second step regards choosing the correct route. This phase usually requires some kind of mental elaboration by the user, which is aware of the current position and of the destination. The third step is keeping the user on the right track. This is the most challenging step. To overcome the challenge of keeping effectively the user on the route towards the destination selected, we developed the system supported by the architecture described in Fig. 1. The system is composed of four main components; the localization engine, a compass module, the haptic node (vibrotactile actuator), and the navigation engine. The navigation engine is the core of the system, receiving input from all other building blocks. It runs on a smart processing unit (in our preliminary setup, a netbook). The navigation engine coordinates input from the localization system and the compass module to control the vibrotactile actuation, in an effective close loop. For a blind person to be completely autonomous during a visit, we included a vocal component. The vocal component takes care of helping the user in deciding which destination to reach and notifies the user when he is arrived at the selected destination. Connecting the magnetometer module to a microcontroller we can easily provide the user orientation to the main application running on the netbook by means of a serial interface. The netbook is carried by the user and uses the information provided by the compass module, along with the RSSI values retrieved from the base station nodes, to determine the position of the user. Once the user has been localized the route planner has all the information that it needs for guiding him. Given the location and the orientation it can send the proper command to the vibrotactile actuator. The vibrotactile actuator is a small board composed of a microcontroller and five motors (see Fig. 2).
The whole system can supply the blind person with assistance while walking a route in a building using vibrations to point out what decision to make. Fig. 3 shows a map of the building in which the system has been tested. The circles in the picture represent the positions that the localization system can recognize

with high accuracy. Fig. 3 shows also the location of the base stations that are employed for the localization of the user. A total of five base stations are used by our architecture.

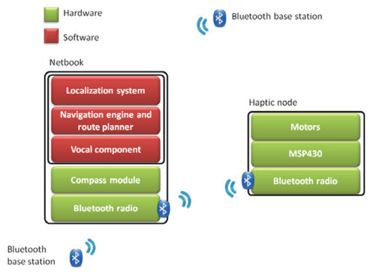

Figure 1: System architecture.

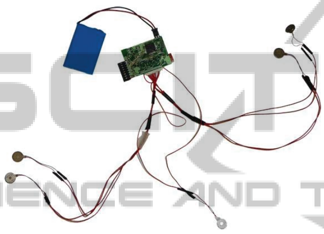

Figure 2: The Haptic Node, our vibrotactile actuator.

4 THE LOCALIZATION SYSTEM

One of the main building blocks of the navigation system is the localization engine. Many different methods have been proposed for indoor localization and navigation. Among others, localization algorithms based on BT technology have the advantage to work on top of the most widespread wireless communication standard. Many BT based localization and positioning systems are based on the use of RSSI (Received Signal Strength Indicator) to determine the user location. Unfortunately, the shortcomings that affect this parameter are manifold, mainly due to propagation effects. Thus, it is almost impossible to obtain accurate location services using standard techniques such as triangulation from three or more BT base stations. RSSI based localization systems are typically affected by low accuracy due to variability of the signal strength in presence of obstacles between the base stations and the user that is carrying the system. As a consequence, the differences in RSSI values often depend also on user orientation, which determines different degree of power absorption by user body. Thus, we introduced a multiple neural networks architecture that can handle changes in RSSI values due to user orientation. We demonstrated with experimental results that first training and then activating neural networks tailored on the user orientation (determined by the compass module), high definition accuracy is achievable, allowing indoor navigation with a cost-effective BT architecture. The system can provide position estimate with 0.5 meters of accuracy during a walk. Details on the system can be found in (Altini, 2010).

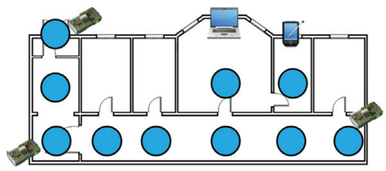

Figure 3: Map of the building where the system was tested.

5 VIBROTACTILE ACTUATION

The use of haptic interfaces to provide information non-visually has been widely investigated. The sensitivity of different parts of the body to vibrotactile stimulation has also been studied in depth. Vibrotactile displays are based on low-cost and low-power motors, such as page motors available in every mobile phone nowadays. Many studies on how to convey complex information with this kind of motors have been carried out, basically tuning parameters such as frequency, amplitude, rhythm and location on the body. One of the main goals of tactile displays must be providing directional information intuitively, in the easiest way possible. We realized a wearable system, composed of small sized parts, such as the 312-103 motors by Precision Microdrivers (see Fig. 2). The frequency of resonance of these motors is close to 200 Hz, which is the maximum sensitivity of the human skin. Our system is a wireless device composed of five motors, a microcontroller (MSP430) and a BT module. The MSP430 is a well known low power microcontroller, in our application it is constantly kept in Low Power Mode, since the actuator will be off for the most of the time (e.g. the user reached the destination and will go back to the entrance of the building after a few hours). In case the actuator has to provide vibrotactile feedback activating the motors the microcontroller is woken up by an interrupt followed by a code indicating the type of vibro-message to deliver. Four of the motors are placed on the shoulders, while the last one on the chest (see Fig. 4), those areas have been proved effective for this kind of application in other studies (Toney, 2003). According to van Erp (van Erp,

2005) the resolution on the torso is about 1 cm, nevertheless increasing the number of motors would bring easily to higher percentage of error during the recognition task. Thus we decided to employ only five motors and to activate them as follows:

- Go forward: motor on the chest is activated
- Turn left of 90°: both the motors on the left shoulder are activated simultaneously
- Turn right of 90°: both the motors on the right shoulder are activate simultaneously

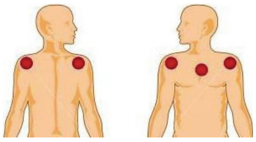

Figure 4: Position of the motors on the body.

Each command is provided by a double vibration of the motors involved (500 ms long). The indication of the direction to follow provided with motors vibrating in the corresponding location on the body is very intuitive and the user does not need any previous training to be able to use the device.

6 EXPERIMENTAL RESULTS

All the different parts of the system need to be tested. The system performance was measured in three different modalities on sighted users; time needed to complete a route, deviations between the correct path and the route employed by the user, and usability tests. By means of those tests we can determine how accurate the system is in a navigation task. Every route within the building in which we tested the system was composed of three basic paths. During the tests the system randomly chose five consecutive paths in order to build a more complicated route, necessary to effectively test the system. In this way every route was approximately 75 meters long (the main corridor that can be seen in Fig. 3 is 18 meters long). During the tests both the time and the route taken by the users were logged. Preliminary tests were run on three users, all men, between 25 and 27 years old. All participants had no mental or physical impairments. They had no previous knowledge about the routes. Each of them received a brief introduction on the system.

The main limitations shown by those tests are due to the localization system. In fact for navigation purposes the localization system needs to be reliable and thus the user has to walk at a slow pace, in our case 0.5 km/h. Although the speed is quite low it might be sufficient for blind users, especially in indoor environments. Finally, an adaptation of the USE questionnaire (Lund, 2008) was filled in by the users. The questionnaire is subdivided into three sections: ease of use, ease of learning, and satisfaction. It emerged that system is easy to use, user friendly and its use is effortless. It is easy both to learn and to remember how to use it. Moreover, the system is not really flexible due to its prototypal nature.

7 EEG ANALYSIS

Although many researchers developed different kinds of vibrotactile systems there is no common methodology for comparing them, making challenging to establish which one would fit best a given application. Typically, the evaluation of actuation systems is carried out by means of questionnaires and therefore based on user subjective perception. For those reasons we tried to explore a new approach to evaluate the efficacy of the vibro-tactile feedback by acquiring information on the user perception in a quantitative and measurable way. This is pursued by means of EEG analysis. The basic idea behind our experiment is based on the study of Event Related Potentials (ERPs), in particular the P300. An ERP (Neuper, 2006) is an electrical potential recorded from the nervous system following presentation of a stimulus and it can be directly associated with perception. ERPs do not depend only on the processing of the physical stimulus itself, but are believed to be caused by higher processes, that might involve memory, expectation or attention. The signal is typically measured in the parietal area, and it is evoked delivering a stimulus in one of the sensory modalities. The most common procedure is called *oddball paradigm*. A target stimulus is presented amongst more frequent standard background stimuli. In addition, a distracter stimulus is often used to make sure that the EEG response to the target stimulus is not only due to the change from the background pattern but it is a real cognitive function. One subject took part in this preliminary study. The experiment was structured as follows: the subject (26 years old, male, no impairments) was wearing the vibrotactile actuator (the haptic node). He was instructed to pay attention to one typology of stimulus, the target, counting the number of stimulations, and to ignore the other stimuli. Each one of the stimuli used for the experiment (both target and non-target) was one of the vibrotactile messages defined in section 5. A third stimulus was introduced as a distraction. Each experiment was carried out in different modalities, a total of six tests were run (oddball paradigm with two stimulations, target on the right (1) and left shoulder (2), with eyes pen (3-4) and closed (5-6). The inter-stimuli interval was between 2 and 3 seconds, for each trial the subject received more than 200 stimulations. 19 channels of earlinked referential EEG data were recorded positioning the electrodes according to the standard 10-20 system. Data was filtered and averaged. Independent Component Analysis was used for artifact removal (eye blinking). After this phase the data was ready for ERPs analysis. The P300 elicited by the haptic node showed low latency. The result of the experiment is shown in Fig. 5. The P300 is elicited by the rare non-target stimulus (marked as "center" in the picture), as well as by the rare target stimulus, but the P300 associated to the target stimulus, in this case on the left shoulder, is faster. This can be associated with the cognitive process that follows the recognition of the target stimulus.

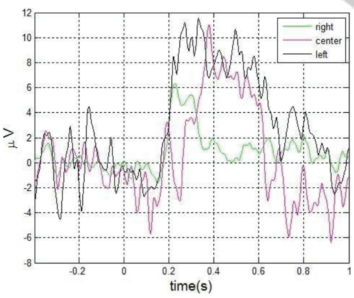

Figure 5: P300 elicited by the haptic node.

In our point of view those P300 evoked potential can possibly be used as the "fingerprint" of a given vibrotactile actuator, and along with other information such as the typology of motors adopted and the vibrotactile messages conveyed to the user can serve as a parameter for characterizing different kind of vibrotactile actuator systems, making it possible to compare them and to choose the most appropriate for a given application.

8 CONCLUSIONS

In this paper we presented an indoor navigation system for the visually impaired people that use vibrotactile messages to provide directional information to the users. The system is low cost and low power, employing off-the shelf motors, a few BT base stations, a compass module and common office devices we could obtain encouraging results during preliminary studies on non impaired users. Additional tests on blind users shall be carried out in the near future. Our system can enhance the autonomous mobility of individuals with visual losses within a building, providing directional information intuitively. The last section of the paper introduced a methodology to evaluate a vibrotactile system and to compare it against other solutions, by means of EEG analysis. In this context we analyzed the P300 evoked potential after vibrotactile stimulation in different conditions.

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