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Vibrotactile Sensory Substitution on Personal Navigation

Remotely Controlled Vibrotactile Feedback Wearable System to Aid Visually Impaired

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***Abstract*—Tactile sensory substitution is a field of science and engineering that studies the intersection of neuroscience, haptics, human sensory physiology, and the function of perception. Tactile feedback (e.g., vibrations and pressure) provides one solution to aid visually impaired. This paper presents the development and assessment of a simple pilot wearable system with vibrotactile feedback. We followed an iterative approach in which the proposed system went through user evaluations and technical refinements. The final prototype includes vibrotactile feedback for orientation with two unobtrusive actuators in contact with each arm of the user. Sixteen blindfolded sighted were invited to conduct travel experiments in a mutable labyrinth. Their evaluation was registered in video record. A post-experiment interview regarding the usefulness of the proposed system for the participants was performed. Our study indicates our pilot system is useful to provide unobtrusive indications of the level of proximity of an obstacle and the personal orientation in a controlled environment. The goal is to use the vibrotactile feedback on navigation of visually impaired people and inform the research community and society about the capabilities of these navigation systems. It is the first study involving vibrotactile feedback and we will consider the results for future works. We consider this work important because the projects involving vibrotactile in literature cover mainly the GPS technologies, in outdoor environments. We intend to prove that vibrotactile feedback is a good option in indoor and small environment, as house and office, in local application, using low cost enhancements in known objects at indoor environments. The study provided great empirical data and meaningful insight and information for the design of projects involving technologies of vibration for future application.**

Keywords*—*Vibrotactile feedback; Personal navigation; Visually impaired; Tactile sensory substitution; Wearable system

I. Introduction

According to American Foundation for the Blind (AFB) [1], 20.6 million American adults age 18 and older reported experiencing vision loss. According to European Blind Union [2], there are estimated to be over 30 million blind and partially sighted persons in geographical Europe. An average of 1 in 30 Europeans experience sight loss. According to World Health Organization (WHO) [3], 285 million people are estimated to be visually impaired worldwide: 39 million are blind and 246 million have low vision. About 90% of the visually impaired live in low-income settings. Therefore, the need to for assistive devices and technologies are constant, mainly the low cost devices.

Mobility is the ability to identify the relation between the position of a person or object in the environment and then move in an independent, safe and efficient way [4]. There is a wide range of navigation tools available for visually impaired, as the white cane, the most popular tool for impaired people. [5]. The white (or walking) cane is a simple device dedicated to detect static obstacles on the ground, surfaces, holes and steps using the tactile-force feedback. However, the white cane does not provide all the necessary information as speed, volume and distance of the surrounding objects [6]. For complex situations, as cross walks, the guide dogs are a good option. However, guides dogs are unaffordable because their price and limited working time [7].

Accessibility is a term used to indicate that some product, device or service is accessible to as many people as possible, including those with some disability, and technological support is increasingly used to provide services, products and new opportunities to allow this group of people to access or perform activities difficult to do [8]. There are some projects involving sonars, laser scanners, or cameras and the user can be alerted through the auditory and/or tactile sense.

A compact size, low-cost and simple wearable system with vibrotactile stimulators was developed and assessed in this study. The prototype of this system was evaluated using blindfolded sighted participants. They were invited to walk in a mutable labyrinth. This study hypothesized that vibrotactile stimulators can navigate a person in a controlled and small environment, as his house or office. One of the main contribution of this system is the use of vibrotactile feedback to give spatial information about the path front of the user. The rest of the article is organized as follow: next section presents assistive technologies of navigation systems and the advances done in this area for visually impaired. After, we present information about tactile sensory substitution. Then, we present the test methodology and its analysis. The paper concludes with general discussion and our plans for future work.

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II. NAVIGATION SYSTEMS FOR VISUALLY IMPAIRED PEOPLE

Since 1960s, a variety of portable or wearable navigation systems have been developed to aid visually impaired people during navigation in various environments, as indoor and outdoor environments [5].

A. Categories of Navigation Systems

Typically, there are three main categories of navigation systems [5]: Electronic Travel Aids (ETAs), Electronic Orientation Aids (EOAs) and Position Locator Devices (PLDs).

In our study, we focused about Electronic Travel Aids. The ETAs for the visually impaired have been developed for navigation, orientation and obstacle detection/avoidance. The National Academies of Science, Engineering and Medicine [9] present conditions for ETAs as follow: distant object and cardinal direction information for projection of a straight line; information enabling self-familiarization and mental mapping of an environment; operation with minimal interference with natural sensory channels; reliable; low power; easily repairable, etc.

III. TACTILE SENSORY SUBSTITUTION

The function of any sensory aids is to detect and locate objects and provide information that allows user to determine (within acceptable tolerances) range, direction, dimension and height of objects [6].

Human distinguish their surrounding environments based on the basic five senses of sight, hearing, touch, smell and taste. Skin is the largest sensory organ, which has a surface area of almost 1.6 m^2 and includes a variety of receptors. Mechanoreceptors located beneath the skin detect units as vibration and temperature. These receptors change when the skin is subjected to mechanical stimulation. This allow the human to experience tactile sensation in general [10].

Tactile Sensory Substitution is an area of science and engineering that is at the intersection of research domains as neuroscience, haptics, and sensory prosthetics. It studies the translation of sensory information that is normally available through one sense to another. [11].

The most successful and traditional sensory substitution system is Braille. Information usually acquired visually is acquired through the fingertips. In addition, as studied, the white cane transmit the information usually acquired by the eyes through tactile force.

A. Resolution of tactile sensation

Haptic perception refers to a combination of cutaneous and kinesthetic sensations relying on active exploration to perceive distal objects and events [11]. Haptic perception relate the connections between touch and movement, depending on skeletal and muscle developments, and on orienting and spatial processes, which relate to vision in normal development [12].

Table 1 outlines four mechanoreceptors and their respective sensory modalities. It analyze the different levels of appropriateness for the construction of a tactile display [13].

TABLE I. CHARACTERISTICS OF MECHANORECEPTORS IN HUMAN SKIN [13]

Receptor	Parameters		
	Sense Modality	***Field Diameter***	***Frequency Range***
Meissner Corpuscle	Skin Stretch	3-4 mm	10 – 60Hz
Merkel Disks	Local Skin Curvature	3-4 mm	30 Hz
Pacinian Corpuscle	Unlocalized Vibration	> 20 mm	50 – 1000 Hz
Ruffini Endings	Direction Skin Stretch	> 10 mm	15 Hz

B. Tactile and Vibration Feedback

The sensory substitution systems also can be defined by the way the information about the environment is given to the user. The user can be informed through sounds or synthetic voice; and through electrotactile or vibrotactile stimulators [5].

Vibrotactile feedback provides contact information to the user with minimal cost and complexity. Vibrations are an important way to understand tactile information, as when a finger is stroked over a surface to determine roughness. Humans have highly specialized nerve endings for the perception of vibrations, which can detect vibrations to over 1 kHz in frequency and less than 1 micrometer in amplitude [14].

The presentation of information by vibration is directly to skin, been discreet and it does not disturb other people. Besides, the vibrotactile feedback does not prohibit the use of the auditory sense, which is the most important perceptual input source for a visually impaired user [5] and the feeling of vibrotactile signals can still in noisy environments, when the user might not hear a voice or an audio message [15].

Research has presented the use of vibrotactile feedback, as works of Russo et al., [16] (the use of vibration in musical timbre discrimination), and Raj et al., [17] (the use of vibrotactile feedback in hovering a helicopter). The application of vibrotactile feedback as a primary information modality is beneficial for people with visual disabilities [18]. Yano et al. [19] developed a suit-type vibrotactile display with 12 vibrotactile actuators attached to some parts of a human body as the forehead, the palms, elbows, knees, thighs, abdomen, and back (one on the left side and one on the right). Their study showed that tactile cues was effective to communicate probable collision.

Many researches study the use of tactile feedback to enhance sensory substitution, mainly when sight is reduced, absent or overloaded, giving spatial orientation information to the user through vibrating feedback. Brewster and others researchers [20] deals with Tactons, structured vibrotactile messages that carry complex information to the user. They studied the use of haptic feedback to encode parameters as roughness and spatial location. In addition, Bach-y-Rita and his collaborators [21] created the Tactile Vision Sensory Substitution (TVSS) system. This system converted the image from a video camera into a tactile image. After the conversion, it transmit the information to the tactile receptors on the back of the blind volunteer.

IV. System Architecture

In this section, we present the system architecture and its components.

A. General Structure and Components

The system are attached in two armbands. The armbands provide easy way of carrying (see Fig. 1). Cables connected all the components and they are fixed by solder. Furthermore, there is a laptop with a shield for XBee antenna module. It sends information to the XBee in armband.

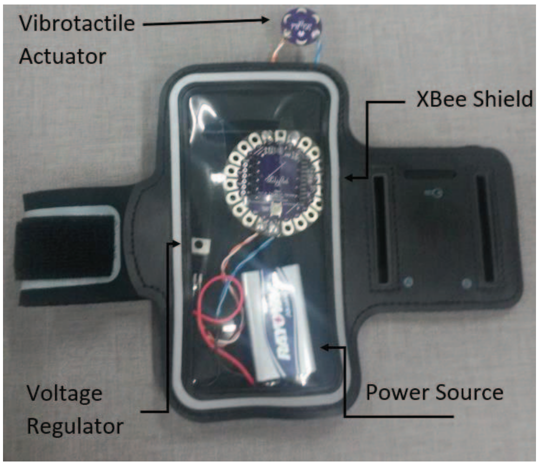

Fig. 1. The embedded system in an armband

B. XBee and its operation

According to Digi, "XBee modules are embedded solutions providing wireless end-point connectivity to devices. These modules use the IEEE 802.15.4 networking protocol for fast point-to-multipoint or typically peer-to-peer networking" [22].

We used two XBee PRO S2B antenna module and the software XCTU for programming both XBee modules. This software is a free multi-platform application designed to enable developers to interact with XBee Radio Frequency Modules through a graphical interface, including tools to set-up and test XBee Modules [23].

Fig. 2. XBee PRO S2B

The operation of the system occurs wirelessly because the XBee module is in an XBee LilyPad Shield. The power source and the vibrotactile actuator of the system are connected in the LilyPad Shield as well. The XBee in the system receives specific commands from a remote computer.

V. Materials and Test Methodology

A. Materials

For tests, we used materials as follow:

a) A laptop PC with a mbed compiler;

b) A mbed Application Board;

c) A mbed NXP LPC 1768;

d) Two armband;

e) Three XBee PRO S2B modules;

f) Two LilyPad XBee Shields;

g) Five 9V Batteries;

h) Two Voltage Regulators;

i) Two LilyPad Vibe Boards;

j) 13 stanchions to make a mutable labyrinth;

B. Test Methodology

Using the mbed OS, we provided an interaction between our remote laptop PC with the system embedded in armband. We use a C++ application to run our programming language. When we designed the GUI of our test application, we decided that widgets we will correspond to the possible movements of user, as right/left, forward and stop using "buttons" called layout containers. We built this application considering the operation of vibrating actuators. Thus, we created a C++ language code to turn on or turn off the actuator. The software firmware is shown in Fig. 3.

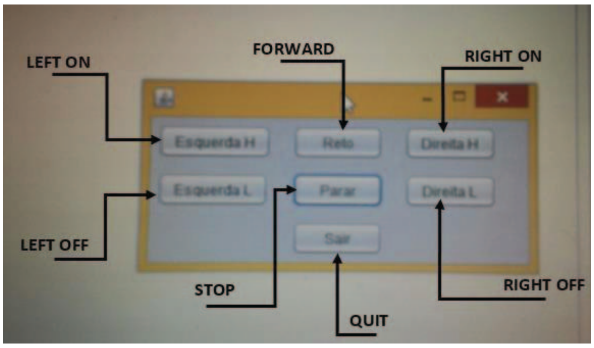

Fig. 3. The software firmware

We utilized a Java interface to send the commands to the system. These commands are sent via serial to ARM LPC 1768 microcontroller connected to the laptop by a specific COM port. The XBee transmitter was connected to this microcontroller. The LPC identifies the command and create an XBee protocol package and the XBee connected in the application board sends this package in broadcast mode. The programming of XBee transmitter was done using the mbed online compiler. Depending the command, the left and/or right actuator will vibrate or stop vibrating.

The language code was embedded as follow: if only the right/left actuator vibrated, the volunteer should turn 90º to the right/left, respectively. If both actuators vibrated, the volunteer should go forward. If both actuators stopped vibrating, the volunteer should stop.

As a primary prototype, we considered as measurements the feeling of the vibration. The LilyPad Vibe Board has a frequency of 12.000 rpm and we designed the system to send information directly to skin. The main measures taken and analyzed during the tests were the efficiency and frequency (in Hz) of the actuators in the arms of volunteers. We sent the commands from the remote computer. Depending of command, the specific actuator vibrated or stopped vibrating.

To evaluate the system we developed a prototype. We wore the volunteer with an armband in each arm. First, we test the vibration of the actuators with the volunteer, and we explained the process.

We blindfolded the person to simulate the deficiency of vision sense. Then, we disoriented him/her by several rotations around him to avoid the memorization of the path through the environment. Furthermore, we used 13 stanchions to build the labyrinth and its layout was changed many times to avoid the memorization as well.

From our feedback, the mbed NXP LPC 1768 was giving the information based on XBee present in the embedded system on armband. If the actuator vibrated, the microcontroller displayed this information. The measure of this information is the package confirmed (if the vibration actuator vibrated, the XBee module in the system sent us the information of the execution of package). As security of the XBee's feedback, if the actuator vibrates, the volunteer should raise his arm.

An outside person measured the user's time to pass through the labyrinth using a chronometer. To avoid any incident and to do orientation refinements, a person escorted the volunteer though the labyrinth, as shown Fig. 4.

Fig. 4. Our guide escorting the volunteer though the labyrinth

VI. RESULTS

One test have failed because there was a technical issue in the wireless connection on communication between remote computer and the system embedded in armband.

We measured the time of each user on their walking through the labyrinth and the average time. Each time was registered in Table II.

Volunteer	**Parameters**	
	Time of Conclusion	***Average Time***
1	03:01	02:02
2	03:00	
3	01:32	
4	--------	
5	02:00	
6	02:34	
7	01:58	
8	01:59	
9	01:39	
10	01:40	
11	01:30	
12	02:30	
13	02:45	
14	01:50	
15	01:30	
16	03:10	

The time to conclude the pass of labyrinth is different considering that we change many time the layout of the labyrinth. Nevertheless, we registered the average time of conclusion as a type of measurement to analyze the efficiency of system. The average time to conclude the mutable labyrinths was 2 minutes and 14 seconds.

VII. RESULTS

The user equipped with the system is able to walk through the labyrinth in a reasonable time by the simple vibrotactile actuator used. The collisions are avoided many times by vibrotactile and the user could feel the vibration in both arms. After a bit of training, the user was able to walk in the defined way. The combined motion of the user and the vibrotactile system provide an accurate perception of its trajectory.

Those results demonstrate that our system is intuitive and easy to use, considering that user was using the system for the first time and blindfolded. The fast explanation about the system before the tests was enough to understand it. The user managed to navigate indoor easily and the system provided accurate information about the way of labyrinth.

We emphasized characteristics as *free-ears* (the user's ability to listen surrounding environment was not interfered), the system is wearable, offering flexibility to the user and utilizes the advantages of wearable technologies. Furthermore, the system is easy to use and without the need of extensive training.

One aspect to correct is the failure in communication between the remote control XBee (plugged at computer) and the armband, which happened once. The delay on the sending of commands happened because the XBee module was in "sleep" mode. Except this fact, we were very pleased with the behavior of the system in those preliminary tests.

The system demonstrated itself low cost, intuitive and accurate.

VIII. Conclusion and Future Work

A compact, low cost and easy to use system for the visually impaired people was developed and evaluated in this study. The system was used to communicate commands such "left/right", "go forward" and "stop" with the goal to guide a person by vibration. We carried out some user tests regarding the vibrotactile feedback for walk through a labyrinth. Statistical analysis on the result demonstrate that most of blindfolded sighted could finish the path in an acceptable time, considering that the labyrinth was mutable.

The goal is to use the vibrotactile feedback on navigation of visually impaired people and inform the research community and society about the capabilities of these navigation systems. The expected result of these tests is the conclusion of the labyrinth using vibrotactile feedback only.

We highlight that one of goals of this study is to prove that vibrotactile feedback is a good option in indoor environment, as house and office, using low cost enhancements in known objects at indoor environments, as the projects involving vibrotactile in literature cover mainly the expensive or uncomfortable technologies, in outdoor environments. As a primary study, we used a computer to help a blindfolded person in his navigation. Our future work includes an autonomous network to help a blind person.

It is the first study involving vibrotactile feedback. The results provided great empirical data and meaningful insight and they will be used for the design of a wearable vibrotactile system to help blind athletics to run in sport events by the vibrotactile feedback, GPS technologies and an autonomous networking.

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