Wearable Range-Vibrotactile Field: Design and Evaluation

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Abstract. Touch is one of the most natural methods of navigation available to the blind. In this paper, we propose a method to enhance a person's use of touch by placing range sensors coupled with vibrators throughout their body. This would allow them to be able to feel objects and obstacles in close proximity to them, without having to physically touch them. In order to make effective use of this vibrotactile approach, it is necessary to discern the perceptual abilities of a person wearing small vibrators on different parts of their body. To do this, we designed a shirt with small vibrators placed on the wrists, elbows, and shoulders, and ran an efficient staircase PEST algorithm to determine their sensitivities on those parts of their body.

1 Introduction

Blindness is a disability that affects millions of people throughout the world. According to the World Health Organization, there are 285 million people who are visually impaired worldwide [1]. Performing normal navigational tasks in the modern world can be a burdensome task for them. In this paper, we introduce a wearable range-vibrotactile field approach that can be useful for aiding in blind navigation. In addition, we wish to further develop a theory of optimal use of range-field navigation to aid in the development of both alternative perception for the blind and non-visual sensors for robots, which have the promise of being cheaper, easier, and more efficient to develop than those that rely on some forms of computer vision.

The paper is organized as the following. Section 2 discusses related work and some background information. In Section 3, we present our approach in both design and evaluation. Section 4 provides some experimental results. Finally we conclude our work and discuss potential implications and applications in Section 5.

2 Background and the State of the Art

One of our collaborating consultants is equipped with an Argus II from Second Sight [2], a retinal prosthesis for patients blinded from outer retinal degenerations.

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The Argus II provides a novel opportunity to understand various kinds of alternative perception for the blind. The device consists of a tiny camera and transmitter that are mounted in eyeglasses, as well as an implanted receiver and an electrode-studded array (6x10) that is secured to the retina with a microtack that is the size of the width of a human hair. With assistance from Lighthouse International, our consultant reports that implanted perception is improving: she could see motion (cars driving by) when she is stationary, black and white patterns, but trees and poles appear the same. What she wants most are (1) depth, (2) information about when people are approaching, (3) higher contrast, and (4) color perception, all of which cannot be easily provided by the Argus II system.

A recently-blind student in our lab reports the necessity of two important characteristics from navigational aid devices: (1) easy, intuitive use and (2) minimal interference with the other senses. This student uses a white cane and a dog as primary navigational aids. He says that the main benefit of those aids is that they are very easy to understand and use. They have a minimal learning curve and provide easily understood cues to understanding the spatial environment. However, he says that the white cane and the dog also require a large commitment of mental and physical resources that decrease the attractiveness of their use. The white cane requires sweeping of the area in front of its user, while the dog requires nudges and commands to go to the right place.

The blind student has also tried the Brainport system [3], a tongue-based device that conveys information regarding the presence of light and dark areas in front of the user through an electrode array pressed against the tongue. A camera worn on the user’s forehead scans the area in front of him/her and translates the resulting light and dark pixels into voltages across electrodes on the user's tongue. The advantages of this device are: it conveys a large amount of information by virtue of the fact that its input is taken from a camera and translated into a matrix of corresponding "pixels", without any surgery as in [2]. It also doesn't occupy the user’s arms or hands, instead using their mouth, which isn't used for spatial navigation. However, this student has pointed out that there are a number of drawbacks to using the Brainport. For one, having the device in his mouth at all times is inconvenient, especially since he sometimes needs to talk to people and give commands to his dog. He has also found that images of light and dark shadows in the real world are difficult to correlate with tongue stimuli, thus producing a steep learning curve, and that the constant stimulus to the tongue can produce an acrid taste in the mouth.

Other devices have been developed, such as the one developed at AIC [4]. The AIC device uses a camera to create a depth map of the area in front of the user, which is then translated into a series of sounds that can be interpreted by the user to understand the world in front of them. Another device has been developed by EPFL [5]. This device uses an array of sonar sensors mounted on the chest to convey spatial information to an array of vibrators also mounted on the chest. A similar device was developed at the University of Toronto [12], which consisted of a Microsoft Kinect mounted on a helmet that relayed information about distances of objects in its field of view to vibrators surrounding the face.

All of these devices suffer from a number of problems, which we will try to address. Some problems include steep learning curves, overloading of the senses, interference with other functions, and the need for surgery. As mentioned, the Brainport interferes with the user's ability to speak and can leave an acrid taste in the mouth, making it difficult to use for long periods of time. It is also difficult for users to learn to use their tongue for spatial navigation. The AIC device suffers from similar setbacks: one can imagine that the constant barrage of new sounds can become annoying to the wearer and those around them, making it difficult to communicate and to hear other important sounds in the environment. Also, training the user to interpret sounds for spatial navigation could require significant mental effort. The EPFL and University of Toronto devices both possess a less intrusive method of conveying spatial information, but this information is limited and also not intuitive to interpret.

There is currently much interest in using haptic vibrational feedback as a means of helping people perform tasks that require spatial and temporal acuity. There have been many investigations of the prospect of using an array of vibrators to provide a novel means of increasing the bandwidth of information available to the wearer. This was investigated in [8], where a rugged vibrotactile suit was designed to aid soldiers performing combat-related tasks. In addition, arrays of vibrotactile stimulators have been paired with optical motion tracking systems [11] and inertial measurement units [10] to aid in teaching people new motor-learning tasks and facilitate their recovery in physical therapy. This combination has been shown to provide a noticeable improvement in the ease and speed of the wearer’s ability to learn a new task. In addition, the tactile detection abilities of people wearing many of the same kinds of vibrators we are using were investigated in [9].

While it is clear that the idea of using spatially oriented vibrotactile feedback is not new, none of these devices convey range information with respect to objects that are orthogonal to the skin of the wearer at the point of vibration. Furthermore a systematic approach to optimize the number of sensor- vibrator pairs and their locations is missing. The novel design and evaluation method of using full-body range-vibrotactile field is the contribution of this paper.

3 Our Approach: Design and Testing

With the design of our device, we hope to address most, if not all of these concerns. One of the most intuitive forms of navigation used by anyone who is blind is his/her sense of touch. We seek to enhance a blind wearer's use of touch by allowing them to "feel" with their skin the spatial environment around them. Our non-visual sensor network consists of very cheap (~$10 a pair) IR range-vibrotactile pairs and sonar-vibrotactile pairs that are worn on the whole body, using vibrotactile transducing for direct range sensing and obstacle detection. Range information around the whole-body will be created so that the user can use the vibration “display” on different body parts to directly feel the range perpendicular to the surface of that part to plan his/her route and avoid obstacles. We have successfully developed small prototypes, for example, hand sensor-display pairs for reaching, arm and leg sensor sets for obstacle avoidance, and a foot sensor set for stair detection. Figure 1 shows an early prototype of the arm sensor-vibrotactile sets tested in the lab and inside a building. An initial testing with a blind individual indicated that she liked the small device since it is light, direct and can be used without any need to learn.

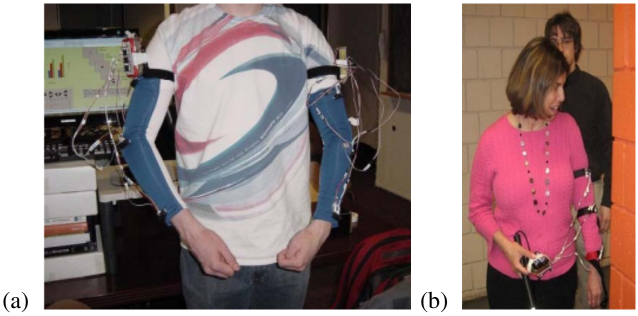


Fig. 1. Early prototype for the arm sensor-vibrotactile sets. (a) Two sets on two arms of one of the authors, each having three pairs of sensors. (b) One set of sensor-vibrotactile pairs tested by our consultant, a visually impaired person.

Our work has the following four major objectives:

1. Designing modular interchangeable sensor/vibrator pairs for use and wearability;
2. Designing comfortable and effective clothing for carrying sensor/vibrator pairs;
3. Designing circuitry for testing and controlling sensor/vibrator pairs; and
4. Designing software for testing vibratory sensitivity of different body parts.

The methodology is quick prototyping using Arduino and Java with a variety of sensors and vibrators placed in different configurations on the body. We imagine the sensation will be similar to having a "range field" around the wearer, causing sensation whenever a part of their body is near a wall or obstacle. By using parts of the body which are normally covered up by clothes, we also hope to minimize potential interference to senses that could be used for other tasks.

Our prototype for design and testing of a practical range-vibrotactile field will consist of an array of different kinds of vibrators and sensors, wires for interconnecting them, clothing for housing them on different parts of the body, and control electronics for controlling them. The evaluation experiments will run in three available modes.

In the first set of experiments, just the vibrators will be activated one at a time in order to find "thresholds" of perception for different vibrators on different parts of the body. In the second set of experiments, all or subsets of the vibrators are activated all at the same time in conjunction with input from virtual sensors as the wearer navigates a virtual environment. In the third set of experiments, the vibrators are connected to input from corresponding sensors as the wearer navigates a real environment. At the time of writing this paper, we have mainly performed the first set of experiments, which will be described in Section 4.

4 Experimental Results

We conducted the first experiment with vibrators individually activated to discern the sensitivities of various parts on the body where we thought placing range-based vibrotactile sensors would be most useful. In the first stage, we tested six locations. These were the elbows, shoulders, and wrists. Each of them is connected to a corresponding IR distance sensor, using pockets sewn into a specially designed shirt (Figure 2). This will allow the user to perceive a "force field" around their arms. In the next stage we will test other parts of the body, such as the legs, waist, chest, back, etc. The vibrators will be controlled through a transistor connected to the output from an Arduino microcontroller. The microcontroller will output a pulsed width modulation signal, which will take advantage of the inductive nature of the vibrators in order to average the pulses into a corresponding equivalent voltage as seen by the vibrator.

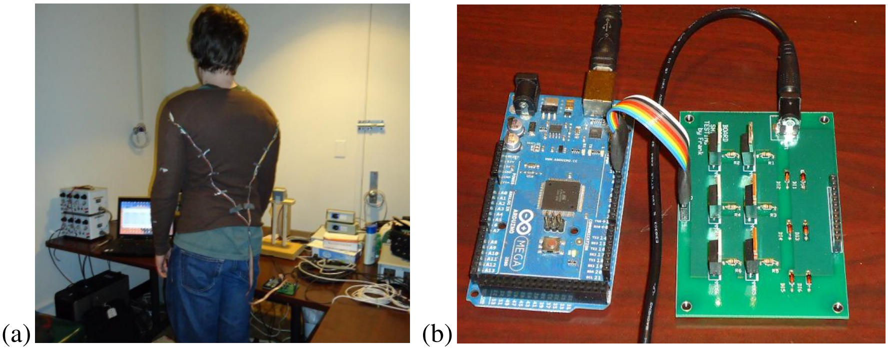
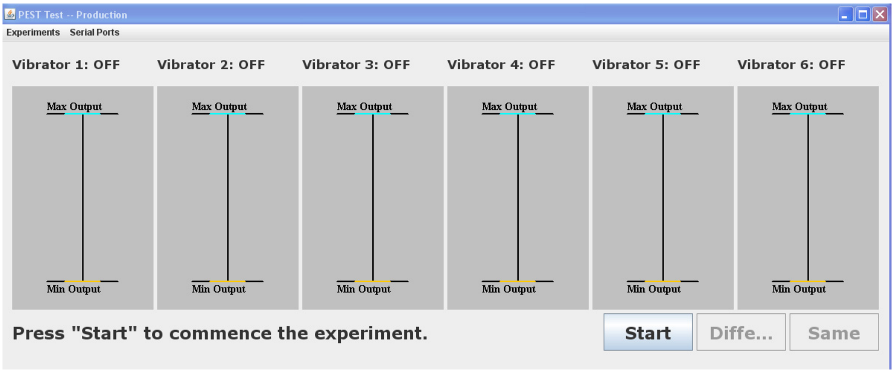


Fig. 2. Design and testing the wearable vibrotactile field. (a). A subject wearing the specially designed shirt. (b) The Arduino microcontroller.



Vibrator 1: OFF
Vibrator 2: OFF
Vibrator 3: OFF
Vibrator 4: OFF
Vibrator 5: OFF
Vibrator 6: OFF

Press "Start" to commence the experiment.

Fig. 3. A user interface for the PEST approach

At the moment, we have completed our design of the prototype shirt with six vibrators to be worn by the user, and an algorithm based on the PEST approach [6] for finding intensity discrimination thresholds on different parts of the body of a given user. Figure 3 shows a user interface for the PEST approach. The PEST algorithm presents the user with two vibrations of increasing similarity, until the user indicates that they feel the same. The PEST algorithm operates in a manner similar to binary search.

Approximately 45 minutes were required to discern the thresholds for all six locations that we were testing. Further work is in progress to improve the speed with which the algorithm converges to find a given discrimination threshold. We hope to cut the time down to a minute or two for each location so that we could perform full body vibration sensitivity evaluation in a reasonable amount of time, for example, within an hour for 100 locations.

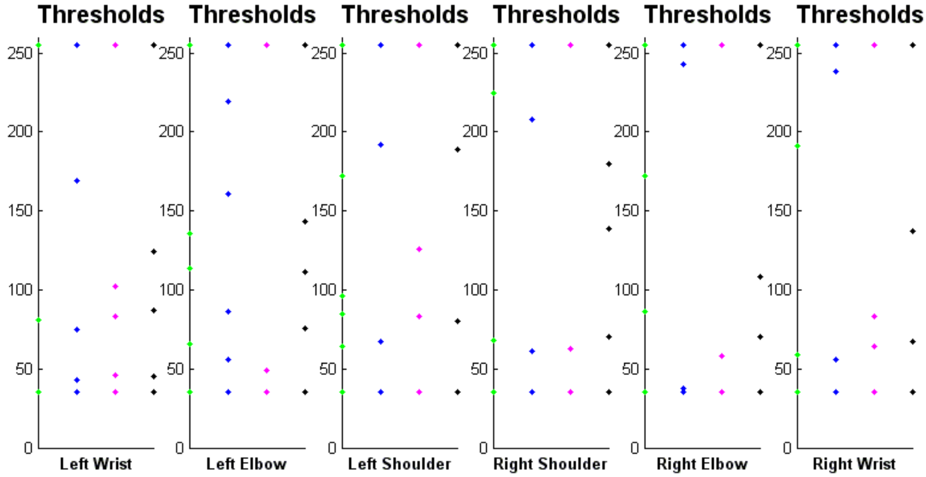


Fig. 4. Vibrotactile thresholds of six locations for four human subjects. Four different colors (green, blue, pink and black) correspond to four different human participants. The vertical axes are the voltages of vibration strengths, quantized from 0 to 255.

Table 1. Averages of vibrotactile thresholds on six arm locations (Length of intervals as quantized on a 0 -255 scale)

	Left Wrist	Left Elbow	Left Shoulder	Right Shoulder	Right Elbow	Right Wrist
Average Interval Length	62.86	58.67	62.86	73.33	80.0	73.33
Average Number of Thresholds	4.5	4.75	4.5	4	3.75	4

We have performed experiments with six human subjects. Figure 4 shows the experimental results of the discerning thresholds with four of the six human subjects, whose data were completely collected for our purpose. In the figure, for each location, each column of color dots represents the threshold locations for each person. The average interval distance and the average number of thresholds for each location along the arms are shown in Table 1. These results show:

1. Similarity and differences across locations. We found that on average, the sensitivity of various locations of human arms is very similar. In our experiment, human arms can discern about 3-4 levels of vibration whose voltage is from 0 to 5 Volts. However we found that the left arms are more sensitive to vibration than the right arms. This might be due to the sensor setup, the real discerning power of humans, or the combination of both. More experiments are needed to verify this difference, but if this laterality effect is real, it may be related to handedness as all of our subjects were right-handed and may therefore be less sensitive to somatosensory input on their more frequently used arm.
2. Similarity and differences among human subjects. We have found that the range of thresholds of the four participants varies from 3 to 6. However on average, the number is about 4.

Statistical tests of the experimental results will be conducted after more participants are test. However, these preliminary results indicate that three to four different distance ranges can be conveyed to users through vibration. Adding no vibration for a safe range, this would be sufficient to inform a user about ranges that are safe, far, medium, close, and very close, so that the user can respond accordingly.

Once we have systematically established an average threshold number and value for each body part, we will switch our attention to the second set of experiments in testing the design using a virtual reality based approach similar to [7], followed by connecting the sensors to the vibrators and testing the device in a real environment (the third set of experiments). All the while we will continue testing different kinds of vibrators and sensors to find the optimal combination of each.

5 Conclusion

Anyone who closes their eyes and tries to navigate their way around a room can attest to how quickly they begin to feel their way around, reaching out with their hands and arms, as their primary means of determining where they are. By allowing a person to feel their environment without touching it, we allow them to essentially “see” with their body. This paper describes the concept of a full-body wearable range-vibrotactile field approach for achieving this goal. As a first step, the experiments to determine the vibrotactile discrimination thresholds of perception on different parts of the body have moved us closer to creating this novel form of spatial navigation.

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