# Vista Wearable: Seeing through Whole-Body Touch without Contact*

Edgardo Molina[1,2], Wai L. Khoo[2,4], Franklin Palmer[1], Lei Ai[1,2], Tony Ro[3,2], Zhigang Zhu[4,2]

[1]*Vista Wearable, Inc., USA;* [2]*The CUNY Graduate Center, New York, USA*
[3]*Dept of Psychology,* [4]*Dept of Computer Science, The CUNY City College, New York, USA*
molina@cs.ccny.cuny.edu, wkhoo@gradcenter.cuny.edu, fpalmer@vistawearable.com, lai@vistawearable.com, tro@ccny.cuny.edu, zzhu@ccny.cuny.edu

*Abstract*— **Using the sense of touch is one of the most natural methods of navigation available to the blind. In this work, we propose a method to enhance a person's use of touch for surroundings awareness by placing range sensors coupled with small vibrators on the surface of their body. Our device, Vista Wearable, seeks to enhance a person's sense of physical awareness with their surroundings by providing haptic feedback that directly corresponds with distance to nearby objects and obstacles. We constructed an array of connected range-sensors and vibrators that can be worn close to the skin for testing in controlled real and virtual environments. We then built small and unobtrusive devices that contain the range-sensor, vibrator, and a wireless Bluetooth interface, so that the user can configure and wear the units on their body where necessary without wires. Preliminary testing of the devices shows promise in real world applications including as a travel aid for the blind.**

***Keywords-wearable devices, assistive technology, visually impaired, vibrotactile display***

## I. INTRODUCTION

The global visually impaired population is over 285 million people according to the World Health Organization [1] and rapidly growing. In the United States alone, the visually impaired population is 6.6 million people [2] and expected to double by 2030 (from 2010 figures) [3] due to people living longer and thus prolonging chronic diseases, of which blindness or diminished sight are serious complications. Our research found that the only new navigational technology to be widely adopted by the community has been the talking GPS that provides verbal walking directions [4]. The majority of assistive devices have not been widely adopted and many have been abandoned. Through interviews with blind and visually impaired people, their mobility instructors, and caretakers, we identified the various reasons for a technology's failure. Chief among them are the user unfriendliness of devices/technologies, due to a lack of understanding of how visually impaired individuals cope in the real world without their vision. We also found that the white cane remains the most trusted technology among the community, but we found that above the waist, where hanging lamps, tree branches, or other overhanging objects may be, the blind person has no warning to impending danger to their chest, head, and face. And in scenarios where a cane is not wanted, such as crowded indoor environments or during athletic activities, there is no hands-free alternative to the cane.

*This work is supported by National Science Foundation (EFRI Award # 1137172, SBIR Award #1416396) and the City College Entrepreneurship Program.

In this work, we propose a wearable system VISTA (*Vibrotactile Intelligent System for Travelling Aid*) to enhance a person's awareness of their surroundings through the use of touch by placing range sensors coupled with small vibrators on their body. This allows a person to feel objects and obstacles in close proximity to them without having to physically touch them. Our device design seeks to enhance a person's sense of physical awareness with their surroundings by providing feedback that directly corresponds with distance to nearby obstacles. To this end, we have sought to construct an array of connected vibrators and range-sensors that are as small, modular, and reconfigurable as possible. We have also begun building small armband devices for the vibrators that can be worn as close to the skin as possible, which then connect wirelessly to range-sensing armbands that can be worn on top of any clothing the user might be wearing.

The organization of the paper is as follows. In Section II, we will provide a survey of some closely related work. In Section III, some key design considerations will be discussed to make the system small, modular and reconfigurable. Current implementations of a few prototypes and early tests are described in Section IV. Finally in Section V we conclude the paper.

## II. RELATED WORK

Depth (perception) is important for spatial navigation; many devices have been developed to utilize this information. Gonzalez-Mora et al. [5] used a camera to create a depth map, which was then translated into a series of sounds that conveyed the scene in front of the user. However such a technique has a high learning curve and it can easily overload a user's hearing. Also, with the advent of Microsoft Kinect, researchers and programmers alike have used it in a non-gaming fashion [6, 7, 8]. For outdoor navigation, the typical approach would be to use GPS. Meers and Ward [9] developed an obstacle avoidance and navigation system for outdoor environments using visual sensors, GPS, and electro-tactile stimulation.

Haptic vibrational feedback has become quite a popular technique to help people perform tasks that need spatial acuity. Lindeman et al. [10] developed a rugged vibrotactile suit to aid soldiers performing combat-related tasks. Furthermore, vibrators have been paired with optical tracking systems [11] and inertial measurement units [12] to help people in physical therapy and mobility rehabilitation. The Tactile Vision System (TVS) [13] is a wearable device powered by a portable computer carried in a backpack that converts visual information into tactile signals for navigation. It uses a stereo camera to compute 2D depth map and maps it to a tactile belt with 14 vibrator motors spaced laterally. Cardin et al. [14] created a wearable system that detects obstacles at shoulder height. The system consists of 4 stereoscopic sonars, a microcontroller, 8 vibrators, and a calibration console. Psychophysical evaluation and obtaining ground truth of human performance in real world navigation tasks can be very challenging. Torres-Gil et al. [15] developed a virtual reality simulator that tracks the user's head orientation and position in a room. Palmer et al. [16] first found the sensitivity thresholds on 3 different parts of the arm bilaterally and then Khoo et al. [17] used virtual environments testing the range-vibrotactile devices.

## III. Design Considerations

The skin as a receptor was chosen because our testing and interviews show that assistive technologies that require or heavily engage the use of the hands and hearing are highly likely to fail. Both the sense of touch and hearing are typically more sensitive in a non-sighted person compared to the average sighted person due to neural plasticity [18]. When we look at the sense of touch, particularly in the hands, we find that the person may already have one hand engaged by their white cane or guide dog, and need their other hand to feel objects, open doors, and for general use. When we investigated devices that provide verbal cues to the user, we found that users generally liked them, but our feedback from mobility instructors was that verbal cues must be used in a limited/minimal manner, much like the talking GPS products. Products that provide too much audio are eventually abandoned as they interfere with recognizing ambient sounds, an important navigation skill of the visually impaired. With this information we identified the skin (except on the hands) as an intuitive and underused receptor for feedback that does not interfere with the existing learned navigational skills of visually impaired people. We are specifically exploring the development of small units that are worn on the body to provide direct feedback to the wearer about obstacles in their immediate surroundings (Figure 1 shows this in a virtual environment). A person wearing our range sensors and vibrotactile stimulation device will experience a tactile sensation that can be described as having a "range force field" around the wearer, causing alerts whenever a part of their body is near a wall or obstacle. By using parts of the body, we also hope to minimize potential interference to senses that could be used for other tasks, such as hearing. With this goal, in the following we describe the design considerations of the VISTA system.

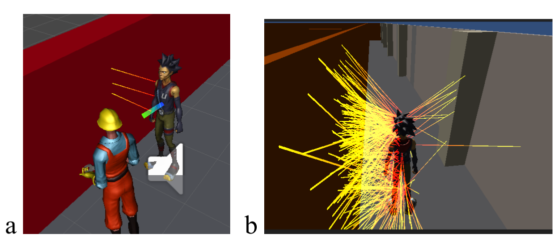


Figure 1. Sensor configuations on an avatar (the user without hat) in virtual environments. (a). Six IR range sensors and one sonar sensor. (b) 1000 IR range sensors. The rays show the distances to the closest objects.

### A. *Modular, mobile, and wearable*

Our initial test platform contained multiple range-sensors and vibrators wired, powered, and controlled, from a single Arduino board. This setup works well for testing in a virtual environment, but not for real world testing where a user is free to move about. For real world use, we took a modular approach to customize and test various sensor placements. We designed a small and unobtrusive device that contains a range-sensor, vibrator, battery, and a micro-controller. The electronics were placed inside a small enclosure that can be clipped onto armbands, shirt pockets, and clothing for wearability. In this way, each unit operates independently and can be placed where the wearer needs it. The device also contains a Bluetooth Low Energy wireless interface so that sensor data can be logged, and so that it can be controlled wirelessly from the virtual environment.

### B. *Wireless and reconfigurable*

Wireless capability was introduced for two purposes. The first is to allow a single device (like a smartphone) to control multiple units a person might be wearing, allowing us to leverage a device people already use and reducing the cost of another component and burden of carrying another electronic device. Researchers can also use a single Bluetooth enabled computer to log usage information and control stimulus during testing. The second reason for enabling wireless was to be able to separate the sensing and stimulation into two separate wearable "pods" that can communicate wirelessly. This would be useful in the winter, where a user can wear the stimulation pod on their arm under a winter coat, while the sensor can be clipped on the outside of the coat.

## IV. Implementations and Testing

Over the course of this project, we have designed a number of prototypes, and performed some tests in both virtual and real environments.

### A. *Prototyping*

We have developed various minimally functional prototypes (Figure 2). Prototypes I and II were built with off the shelf components to demonstrate the sensor-vibration unit. Prototype III is the first wireless enabled device. A controlling iOS app was developed to communicate with the unit; this unit serves as a rapid prototyping platform. Each prototype pairs an infrared (and/or sonar) range (distance) sensor with a vibrating motor. The range sensors can detect the distance of objects from 1 meter (5 meters for sonar) away with a sub-centimeter resolution. The intensity of the vibrating motor is controlled to increase from an idle state when objects are at a one meter distance, to a maximum intensity as the object sensed is within 0.15 meters (0.5 foot) from the sensor.

In prototype III, each device contains a microcontroller with Bluetooth Low Energy communication, which controls a Sharp IR sensor (with a 1 meter range) and an ERM vibration motor. Figure 3 shows a block diagram of one such device. The units are LiPo (Lithium-Polymer) battery powered and USB rechargeable. We map the distance reading to voltage powering the amplitude of the vibration intensity. With Prototype III, the functionality of the device is easily configured via software, allowing us to test various vibration modes and sensors faster than would be possible with complete hardware redesigns. This allows each unit to be tested as a sense only unit, a stimulation only unit, or with both sensing and stimulation enabled.

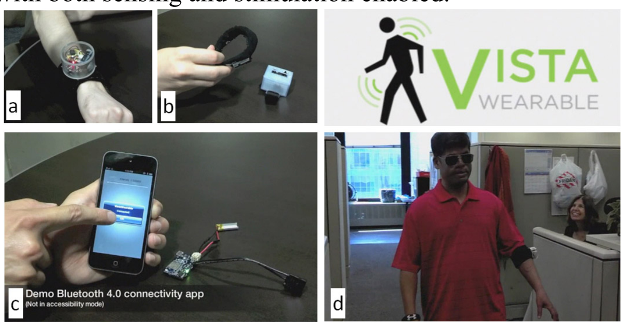


Figure 2. Wearable prototypes of the technology (a) Prototype I (b) Prototype II (c) components of Prototype III (d) A blind person using prototype I while another blind person "watches" (Demo video can be viewed in [19])

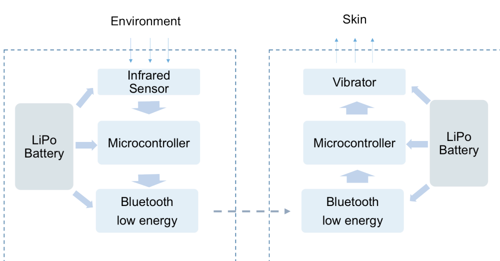


Figure 3. Block diagram of a range-vibrator pair in prototype III, where the sensor and the actuator are in two separated cases.

### B. Testing

We have performed some preliminary user tests collaborating with the NYS Commission for Blind. Figure 2(d) shows one of the test scenes, and a video clip can be viewed in [19]. In one of those tests, the blind user said one of the most difficult things as a blind person is the obstacles above the waist. Our devices provide constant feedback using vibrators on the skin in real time and would give a person the chance to detect obstacles in the upper-body space without swinging the white cane. In our test with the user, two devices paired with infrared sensor and vibrators were placed on the left and right arm. The two infrared sensors pointed left and right respectively that detected obstacles on the left and right side of space of the blind user. We allowed the blind user to walk freely in a real office space which was filled with desks and only had very narrow aisles. The blind user was able to walk successfully in the office without bumping into desks and other obstacles. In contrast, when he was walking without those devices, he tended to extend his hands to the right and left to feel obstacles and bumped several times into the desks. One important insight that he gave us was that the device gave him directional feedback directly about the space and it was very intuitive and easy to learn. In a more recent pilot study, 11 subjects (5 blind, 6 low vision), used a prototype device for 10-20 hours over 1-2 weeks under everyday scenarios. Comments from them include: Device use was intuitive; Device is discreet; Preference was to wear around wrist for active scanning; Clipped on belt was also useful; Useful in new indoor environments (such as museums, clinics); Low vision subjects found most value at night and in the dark.

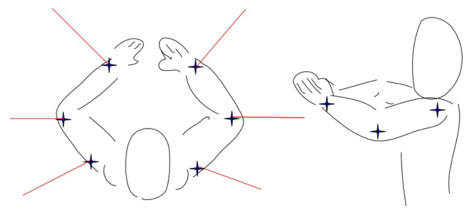

Figure 4. Placement of sensors in Unity3D for testing.

Before performing large-scale user tests in real environments, we have also performed some tests for navigation tasks in virtual environments. We have simulated a vibrotactile shirt in a configuration illustrated in Figure 4 to test the user's ability to complete a navigation course (designed as a game – Chicken Finder). Roughly, the sensors on each arm are placed on the subject's wrist, elbow, and upper arm (or shoulder, depending on the subject size). This is as if a person is walking with their arm raised in front of them, elbows bent. The game is set up as follows: (1) User has to find the source of the sound of a baby chick chirping without any visual information. (2) The computer screen is faced away from them. (3)They have to navigate the virtual environment and avoid obstacles based on the varying intensity of sounds and vibrations.

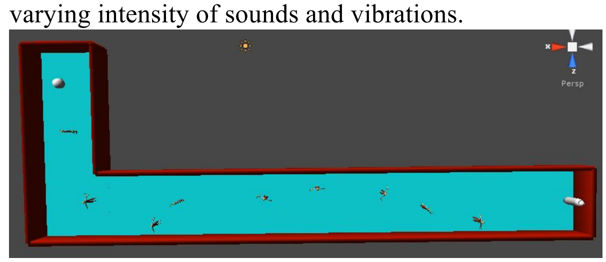

Figure 5. Aerial view of a halllway in the VE created in Unity3D.

Figure 5 shows a hallway of a virtual environment created in Unity3D (http://unity3D.com/), containing stationary people that should be avoided while trying to reach the white sphere at the end of the hallway. The game script that controls the avatar also records the player's position and orientation in the virtual world as well as a flag that marks if the user was bumping into an object (bumping into objects will also generate a sound in the virtual world). The game engine updates the sensors output at 60 – 70 Hz. In addition, we connected a modified mouse to Unity3D. We built a steering device by cutting a roller ball mouse in half to expose one of the rollers. We then attached a knob to the roller, which the subject could use to steer. This fix ensures that when subjects rotate the knob 90 degrees, the virtual avatar also rotates 90 degrees.

Eighteen subjects (range of 18-24 years) gave written informed consent and took part in the experiments for monetary compensation or for partial fulfillment of a course requirement. This study was approved by the Institutional Review Board of the City University of New York. More than half of the subjects were able to find the goal object in the hallway (Figure 5), but on an average of five minutes time span, compared to one minute of navigation while looking at the screen. The average time for the 10 subjects who were able to find the goal was 280.10 seconds and the average number of bumps was 17.3, whereas the average time of those who failed in goal finding was 288.65 seconds and the average number of bumps was 22.1.

Note that this is only a preliminary experiment and that we aim to test the concept of a full-body wearable range-vibrotactile field to aid visually impaired people in navigation. Towards that end, more sensors that cover other critical parts of a human body for navigation will be tested in subsequent experiments to determine the optimal number and locations of these sensor-actuator pairs.

## V. Conclusions and Discussions

The research and development of the VISTA system, we are currently undertaking with the pod prototypes and virtual testing environment will provide a clearer understanding of how people interpret vibration feedback along different parts of the skin and how to design devices that can best convey that information. Through our user interviews, we identified scenarios where a white cane is not desired (the use of the white cane fully occupies one of the hands, and the cane requires substantial space to be extended forward), particularly with children and adults that engage in sports or attend large social gatherings, events, or in workplaces. In these scenarios, we are testing pod arrangements that can be worn through out the body so that the wearer can independently move while freeing their hands to engage in the activity. With children, this allows them to engage in sports such as running track or playing basketball, and to feel when a wall or another player is within their space. For adults in the workplace, freeing up both hands while still being aware of their surroundings will increase the person's employability. Further, we are able to simulate different environmental situations that visually impaired people are interested in with the virtual environment allowing us to more readily test different sensor configurations and types. This knowledge will provide criteria that will help improve the use of vibration as a display technology throughout the body, particularly for assistive devices and applications.

**Acknowledgments:** We would like to thank Ms. Barbara Campbell and Mr. Masud Kalim at the NYS Commission for the Blind for assistance in testing our devices and providing valuable comments and feedback. We also thank students at the City College of NY in helping VE user tests.

## References

[1] World Health Organization, Visual impairment and blindness, http://www.who.int/mediacentre/factsheets/fs282/en/
[2] National Federation of the Blind. https://nfb.org/
[3] National Eye Insititute. Blindness, Statistics, and Data [NEI]. http://www.nei.nih.gov/eyedata/blind.asp
[4] HumanWare Trekker Breeze GPS. http://www.humanware.com/en-usa/products/blindness/talking_gps/trekker_breeze/_details/id_101/trekker_breeze_handheld_talking_gps.html
[5] Gonzalez-Mora, J.L., et al (2006). Seeing the world by hearing: Virtual Acoustic Space (VAS) a new space perception system for blind people, Info. Comm. Tech., Vol. 1, pp. 837-42.
[6] Diallo A., Molina, E., Goldberg, M., and Zhu Z. (2013), Using Kinect to empower visually impaired people to navigate unfamiliar environments, the 4th IEEE International Workshop on Hot Topics in 3D - Hot3D, July 15, San Jose, CA, USA.
[7] Mann, S., Huang, J., Janzen, R., Lo, R., Rampersad, V., Chen, A. and Doha, T. (2011). Blind navigation with a wearable range camera and vibrotactile helmet, Proceedings of the 19th ACM Int Conf Multimedia, pp. 1325-8.
[8] Khan, A., Moideen, F., Lopez, J., Khoo, W.L. and Zhu, Z. (2012). KinDectect: kinect detecting objects, In Computers Helping People with Special Needs (2), Springer, Linz, Heidelberg, pp. 588-95.
[9] Meers, S & Ward, K, A (2005). Substitute Vision System for Providing 3D Perception and GPS Navigation via Electro-Tactile Stimulation, Int Conf Sensing Technology.
[10] Lindeman, R.W., Yanagida, Y., Noma, H. and Hosaka, K. (2006). Wearable vibrotactile systems for virtual contact and information display, Special Issue on Haptic Interfaces and Applications, Virtual Reality, Vol. 9 No 2-3, pp. 203-13.
[11] Lieberman, J. and Breazeal, C. (2007). TIKL: development of a wearable vibrotactile feedback suit for improved human motor learning, IEEE Trans on Robotics, Vol. 23 No. 5, pp. 919-26.
[12] Lee, B.-C., Chen, S. and Sienko, K.H. (2011). A wearable device for real-time motion error detection and vibrotactile instructional cuing, IEEE Trans on Neural Systems and Rehabilitation Engineering, Vol. 19 No. 4, pp. 374-81.
[13] Johnson L. A. and Higgins C. M. (2006). A navigation aid for the blind using tactile-visual sensory substitution, in Proc 28th Annu. Intl. Con. IEEE Eng. Med. Biol. Soc. pp. 6298-6292.
[14] Cardin, S., Thalmann, D. and Vexo F. (2007). A wearable system for mobility improvement of visually impaired people, Vis. Comput. Vol 23 no. 2. pp. 109-118, January
[15] Torres-Gil, M. A. and Casanova-Gonzalez, O. and Gonzalez-Mora, J. L. (2010). Applications of virtual reality for visually impaired people, W. Trans. on Comp., Vol 9 Issue 2, February, pg. 184-193
[16] Palmer, F., Zhu, Z., Ro, T. (2012). Wearable Range-Vibrotactile Field: Design and Evaluation, the 13th International Conference on Computers Helping People with Special Needs (ICCHP), July 11-13.
[17] Khoo, W. L., Knapp, J., Palmer, F., Ro, T., Zhu, Z. (2013). Designing and testing wearable range-vibrotactile devices, Journal of Assistive Technologies, Vol. 7 Iss: 2, pp.102 – 117
[18] Cohen, L. G., et al. Functional relevance of cross-modal plasticity in blind humans. Nature, 389,September 1997, 180-183.
[19] VISTA technology, a pitch video may be found at http://ccvcl.org/~molina/vista/vista-aim-2014.m4v