Blind Guardian: A Sonar-Based Solution for Avoiding Collisions with the Real World

Conference Paper · May 2015

DOI: 10.1109/SVR.2015.41

Marina F. Rey
Universidade Federal do Rio Grande do Sul

Nicolas Kagami
Universidade Federal do Rio Grande do Sul

Luciana Nedel
Universidade Federal do Rio Grande do Sul

Blind Guardian:
A Sonar-Based Solution for Avoiding Collisions with the Real World

Marina Rey, Inatan Hertzog, Nicolas Kagami, Luciana Nedel
Instituto de Informática
Universidade Federal do Rio Grande do Sul (UFRGS)
Porto Alegre, Brazil
Emails: {mfrey,ilhertzog,nskagami,nedel}@inf.ufrgs.br

***Abstract*—Sightless navigation is an ever-present issue that affects a great part of the population. The affected include permanent or temporarily blind individuals, persons walking in the dark, and users of immersive virtual environments using real walking for navigation. This paper presents an alternative solution to this problem, which relies on a simple wearable device based on ultrasonic waves to detect obstacles and on vibrotactile feedback to warn the user of nearby obstacles. In the following pages, we describe the design and implementation of this apparatus, called the Blind Guardian. We conducted user tests with 29 subjects in a controlled environment. Results demonstrated the potential of Blind Guardian for future use in real life situations, as well as for immersive virtual reality applications based on the use of head-mounted displays.**

***Keywords*-blind navigation, real walking, collision detection, ultrasonic signs, tactile feedback, arduino**

I. Introduction

Human locomotion is based on the knowledge one has of the environment as well as on the information acquired during the movement. It relies mainly on vision but is reinforced by audition and, eventually, touch. Therefore, the task becomes much more difficult for persons deprived of vision. Individuals in this situation tend to walk slowly using their hands to detect nearby obstacles, possibly requiring the aid of others. A sophisticated and more difficult feat is the use of echolocation [1]. This technique uses background noise or self-made clicks to sense obstacles, but only a select number of persons develop this skill.

Blind people have to learn the environment before moving through it, which is usually done with the help of a human guide or a dog. In familiar places, they often move with the assistance of a cane to scan the near area, creating a kind of near vision field. However, while the cane is helpful to detect obstacles and ways on the floor, it cannot foresee collision with obstacles such as tree branches and other obstructions.

We propose a solution to help people walk without the aid of vision using a very simple apparatus based on sonar. The device is attached to the user's head using a cap as a support (see Figure 1). It detects obstacles in the user's field of vision and notifies him using a vibrotactile feedback. The device can be constructed out of readily available and economically feasible parts, and can be mounted with simple instructions.

The motivation for this work was twofold. According to the World Health Organization (WHO), 285 million people are estimated to be visually impaired worldwide (39 million are blind) [2]. Visually impaired persons usually rely on very simple locomotion methods, i.e., using a cane or a guide dog. Both methods require the use of hands, preventing their use for other functions. Blind Guardian is a hands-free device and can be used alone or

Figure 1. Blindfolded user walking freely with the help of Blind Guardian. The sensor for obstacles detection is mounted in the cap, while the vibrator for tactile feedback is in the user right hand.

combined with the cane, enhancing the capacity to detect obstacles.

Our second motivation is the navigation in immersive virtual environments based on head-mounted displays (HMD). The use of HMDs is becoming more and more popular after the recent release of Oculus Rift, as well as the HMDs based on smartphones [3][4]. Real walking seems to be the best solution to allow navigation in these environments [5]. However, there is still some challenges involving this technique, such as indoor position tracking [6] and collision avoidance. Due to its simplicity and size, we believe that Blind Guardian can be attached to an HMD and used for collision avoidance.

The remainder of this paper is organized as follows. Section II presents some related works involving the use of technology to help blind persons. Section III introduces the Blind Guardian design and explains its implementation. In Section IV we present the protocol used for the user tests. Finally, Section V presents the results achieved and Section VI our conclusions and future work.

II. Related Work

In the last few years, many computer science researchers have been working on new ways to help blind persons on mobility. Thanks to the new off-the-shelf, non-expensive and easy-to-use interaction devices, the exploration of this technology as a support for disabilities is becoming popular.

Brock and Kristensson [7] used Microsoft Kinect technology to train blind people to move in any environment calculating the depth of the surrounding scene and relaying the information to the user using headphones. The different depths presented before the user are translated to contrasting sounds. Comparing with the device proposed in this paper, the information of the environment is more accurate, but the size and usability of the prototype would probably be an issue for long-term and everyday use. Additionally, the system proposed in their work is considerably more expensive since it is based on Kinect and the use of a computer.

The Kinect-based solution attempts to sonify the landscape captured by the camera by modulating the frequency and intensity of the sounds played as feedback. That is, sounds change according to the variations in the depth perception of the environment in front of the user. Comparing with Blind Guardian, this is a much more sophisticated solution. Blind Guardian intends to be an affordable way of avoiding obstacles, being built out of readily available, cost-effective parts. Also, it serves as an intuitive manner of warning for nearby obstructions, as opposed to a more complex goal of describing the field of view. For that reason, the Blind Guardian tries to approach a different demographic, those who want to avoid the environment instead of those who wish to interact actively with it. This goal allows the Blind Guardian to be smaller, cheaper and more portable.

The Enactive Torch [8] is a very interesting device that translates the distance of the most nearby object in its trajectory to tactile feedback. As it is held as a flashlight, it can be operated very instinctively and with high reach. The Enactive Torch's circuit diagram and Arduino source code have been made available. In comparison, the Blind Guardian schematics and source code are simpler, thus being easier to build.

D'Atri et al. [9] explored the possibility of using the emerging and cost-effective RFID technology to tag and map areas with more precision than that obtained from GPS available for civilian use. The civilian GPS could still be efficiently used to locate the user in a more general area. They suggested integrating the RFID reader to a cane, which would then relay the information through Bluetooth to a PDA (Personal Digital Assistant) to properly instruct the user. Both the cane and PDA are equipments the blind population embraces some time, possibly easing the apparatus' assimilation by the community.

Duarte et al. [10] propose a system capable of directing the user through public buildings or shopping centers to find available services and stores. The envisioned system requires deployment of Bluetooth emitters and sensors responsible for its location and a database to store the places and their respective information. It aims to communicate with the user entirely through voice commands and speech-synthesized feedback. Even though this project intends to use commonplace technologies like Bluetooth and smartphone, it would still require a lot of dedication to deploy a comprehensive network. It should be even harder to adequately instruct the user about movement and different services through voice alone.

Fusco et al. [11] developed the work called "Determining a Blind Pedestrian's Location and Orientation at Traffic Intersections". This endeavor seeks to help visually impaired pedestrians to cross the street through the use of a mobile phone with GPS and camera. The system uses image processing to recognize the lanes along with the GPS. Despite its initial similarities, this application differs a great deal from ours. The Blind Guardian should not be used to cross the street, it does not have the range required to detect an incoming car or any way of detecting the pedestrian crossing signal.

All that is required to use our apparatus is to wear a lightweight cap, to which a mobile phone vibrator is connected through a cord. This vibrotactile actuator can be placed in several areas around your head in order to maximize compatibility with different kinds of head-worn equipment (see Figure 1). Resting atop of the ear lobe, for example, has proven to be an excellent place for the vibrator. The user does not have to listen in and decode sounds to move around and does not need to hold anything. One only needs to be warned intuitively of the existence and distance of an obstacle ahead. For that reason, hearing-impaired people can fully reap the benefits of the Blind Guardian.

III. Blind Guardian

A. Design

Blind Guardian is a system designed to help visually impaired people to avoid hitting walls and large objects without having to hold anything such as a walking stick (usually known as a cane). For this purpose, we created an entirely independent headpiece, which holds all the hardware required. The user only needs to wear this cap (see Figure 3) and hold or cling to a small cell phone vibrator. This vibrator will indicate when the person is close to any object in his way. This hands-free design allows users to walk without restraining their movements or having to decode a sound.

B. Implementation

The system is composed of an Arduino UNO (see Figure 3) and the Ultrasonic Ranging Module HC-SR04 (see Figure 2), a sensor capable of measuring distances by means of ultrasonic waves. The ultrasonic device works by sending a high-frequency wave to the environment. When this wave hits an object, it generates an echo back to the device. Then, by measuring the time it takes to come back, it calculates how far away the object must be. It is important to note that this detection happens in a relatively narrow cone with a range of 2cm to 400cm and an angle of 30 degrees. Therefore, objects located on the sides (out of this cone region) will not be detected. For this reason, users must always move their heads sideways when walking, mimicking the movement of a cane. This ultrasonic sensor will measure the distance from objects and, when closer than 90 centimeters, will warn the user with a small vibration. When under 50 centimeters range, the vibrator will vibrate more vigorously, so the user can feel the approach. This warning is made by activating a small vibrator that can be found in any ordinary cell phone. The vibrator works by spinning a little off-center weight using a tiny motor.

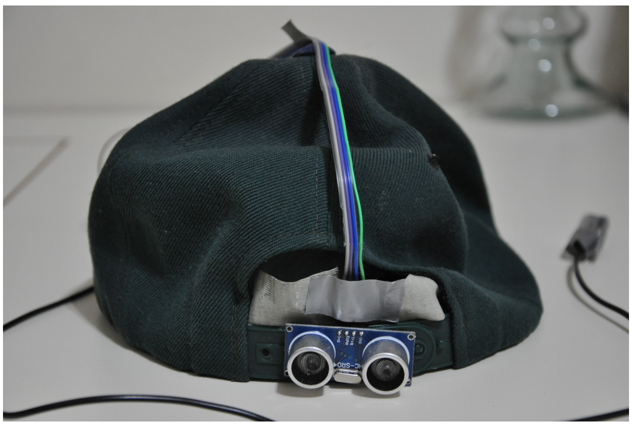

Figure 2. Blind Guardian Module HC-SR04 that use a trigger then the echo to know the distance of the object. The vibrotactile actuator is at the right in the picture.

Figure 4 presents the schematic of the circuit that implements Blind Guardian. For testing purposes, two

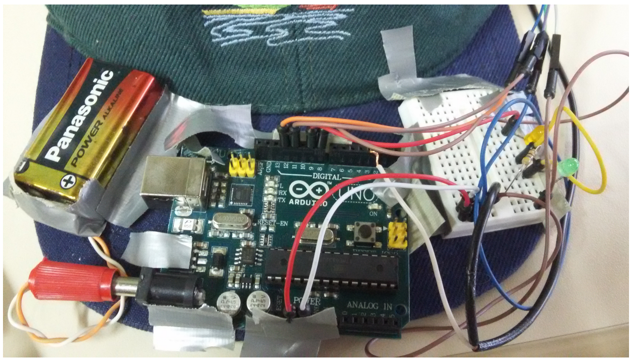

Figure 3. Blind Guardian Arduino circuit and battery.

LEDs were integrated to indicate the current state of the system. The LEDs helped a lot throughout the tests, detecting faulty connections and signaling the level of vibration experienced by the user. The yellow LED indicates whenever an object is detected by the ultrasonic module. The green LED indicates that the apparatus is on, but not detecting anything.

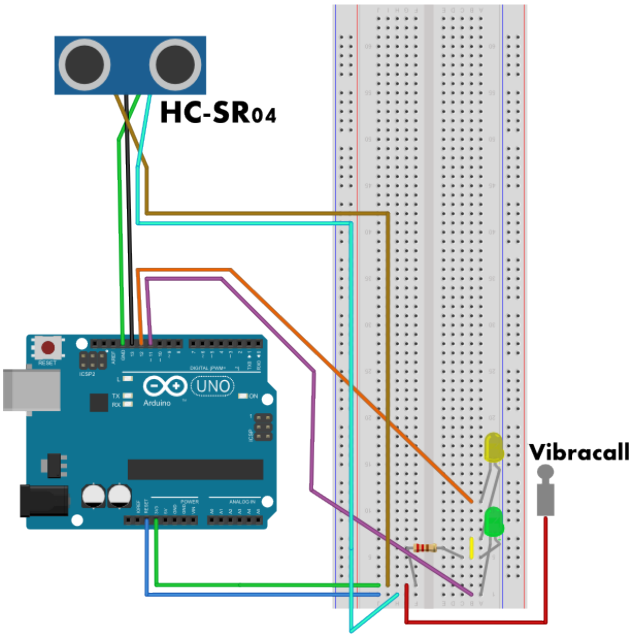

Figure 4. Schematic of the circuit used for the construction of the Blind Guardian device.

In our prototype, the Blind Guardian and all its parts are placed on an easily adjustable cap worn reversed, and held together by duct tape. This approach was taken for practical reasons since it can be easily obtained anywhere in the world and has a natural base for holding all hardware components. The cap flap holds the Arduino, cables, and a 9V battery, as can be seen in Figure 3. Only the vibrator and the ultrasonic device are not located at the cap flap. The vibrator hangs by a cord so that it can be placed wherever the user wants, as long as its vibrations can be felt. The ultrasonic device is located at the cap straps, directed to the front of the user (see Figure 2).

```
#define trigPin 12 // Module trigger
#define echoPin 11 // Module Echo
#define led 9      // Yellow distance led
#define led2 8     // Green out of distance led
#define motorPin 3 // Vibracall
int lastDist =0; // Variable used to update the last distance

void setup()
{
  Serial.begin (9600);
  pinMode(motorPin, OUTPUT);
  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);
  pinMode(led, OUTPUT);
  pinMode(led2, OUTPUT);
}

void loop()
{
  long duration, distance;
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);
  duration = pulseIn(echoPin, HIGH); // time of vibration
  distance = (duration/2) / 29.1; // distance detected
  if (distance < 90) // first level of distance
  {
    if( distance < 50) // second level of distance
     analogWrite(motorPin, 255-(distance)); // start the vibration more intense
    else
    {
     analogWrite(motorPin, 255); // start the vibration
     delay(10);
     digitalWrite(motorPin, LOW);
     delay(10);
    }
    digitalWrite(led,HIGH); // turn on the distance led
    digitalWrite(led2,LOW); // turn off the out of distance led
  }
  else
  {
    digitalWrite(led,LOW); // turn off the distance led
    digitalWrite(motorPin, LOW); // turn off the vibracall
    digitalWrite(led2,HIGH); // turn on the out of distance led
  }

  lastDist = distance; // update the new distance
}
```

Listing 1. BlindGuardian Arduino Code

The source code for the Arduino controller can be seen below. The sonar sends the pulse and acquires the echo, registering the time it takes to come back. The time measured is used to determine the distance to the obstacle. If the estimated distance is less than 50 centimeters, it will turn the motor pin with a high intensity that decreases with the distance. Else, if still within 90 centimeters, it will turn the motor pin in the maximum intensity for 10 milliseconds followed by 10 milliseconds of turning it off. This brings about a lower vibration between 50 and 90 centimeters than that below 50 centimeters. We arrived at this solution empirically after extensive tests, trying to avoid a vicious cycle that was present in the 50 – 90 centimeter ranges. Apparently the vibrations caused perturbations in the sonar, creating a feedback loop that would leave the vibrator on after moving away from an obstacle further than 90 centimeters.

IV. User Tests

We conducted a straightforward user test to verify the efficiency of Blind Guardian, as well as its acceptability by ordinary users. The primary goal of the test was to check if it is possible to avoid collisions with obstacles using Blind Guardian in a simple environment. The test consisted of having a blindfolded subject walk freely in a small 1.83m x 7.94m corridor (Figure 5 shows some pictures taken during the experiment). The corridor was closed in order to block the incoming light, which could give hints to the users, such as the indication of the exit. It is important to mention that we used nothing but walls as obstacles, since we were focused on testing frontal vision. We tried to avoid the necessity of looking down during the test. Since Blind Guardian sensor is mounted on the user's head, users with different heights could perceive smaller obstacles with differing degrees of precision. So, the only obstacles present in the environment were the walls that enclosed the experiment area.

This test was designed in order to verify if a person can understand the sensorial output of the device and use it to avoid hitting objects even when temporarily blindfolded and not entirely familiar with the environment.

The protocol used for the tests followed the steps presented here. Initially, the test subject filled out a characterization form with basic personal info. Soon after, the instructors explained the objective of the test and introduced the subject to the new device, explaining how it works. Then, the subject was invited to test the device with open eyes – for as long as he/she wished – to become familiarized with the obstacles detection technique and the vibrotactile feedback. He/she was then blindfolded in the middle of the corridor and asked to spin until he/she has no spatial notion of his surroundings anymore.

The subjects performing the experiment needed to adhere to the following instructions:

- Use the blindfold during the test
- Spin until to lose the spatial notion
- Do not use the arms or legs to probe the environment
- Walk upright and do not incline the body
- Move the head sideways to cover the environment better and detect the walls
- Walk around until instructed to stop

The subject has no verbal communication with the instructors (and nobody else) during the test. The examiners counted 40 steps and then concluded the test, noting the time spent for it. A simple drawing of the path was made, with a red 'x' representing any occurrence of collisions (see Figure 6). Once the test finished, the subject was

Figure 5. Some users during the experiments.

requested to fill a post-test opinion form, inquiring about their experience.

Subjects were asked to rate every aspect from 1 to 5 using a Likert scale (where 1 represents the worst experience and 5, the best one), avoiding a straight “yes” or “no” answer.

The post-test form contains simple questions, listed below:

- How comfortable was it to use the device?
- How useful was it to prevent collisions?
- How much spatial notion could you acquire by wearing it?
- How useful was it moving the head horizontally while walking?
- Did you remembered to move your head during the experiment?
- Could you perceive the two levels of vibration?
- Any additional comments or suggestions for improvements?

V. Results

The population was composed of 29 subjects (2 females and 27 males) with an average age of 23.93 years old. They were all undergraduate students in computer science. Most of the subjects reported no mobility problems and little experience in walking in the dark. None of them were visually disabled.

As can be seen in Figure 6, users took very different paths during the experiment. Some of them would only step forward after carefully surveying the surroundings, which was the suggested method. Others tried to walk around in a very organic approach, and these moved quickly and sometimes forgot to look sideways before the next step. The latter were more prone to colliding sideways, as can be seen in path D in Figure 6. The red ”x” marks a lateral bump with the wall.

We considered the results were very satisfactory in terms of avoiding the environment since no more than two hits on objects per test were made by any of the 29 subjects tested. Results showed that 68.9% of the subjects did not hit any obstacles, only 17.2% hit it only once, and 13.7% percent hit the wall twice during the tests (see

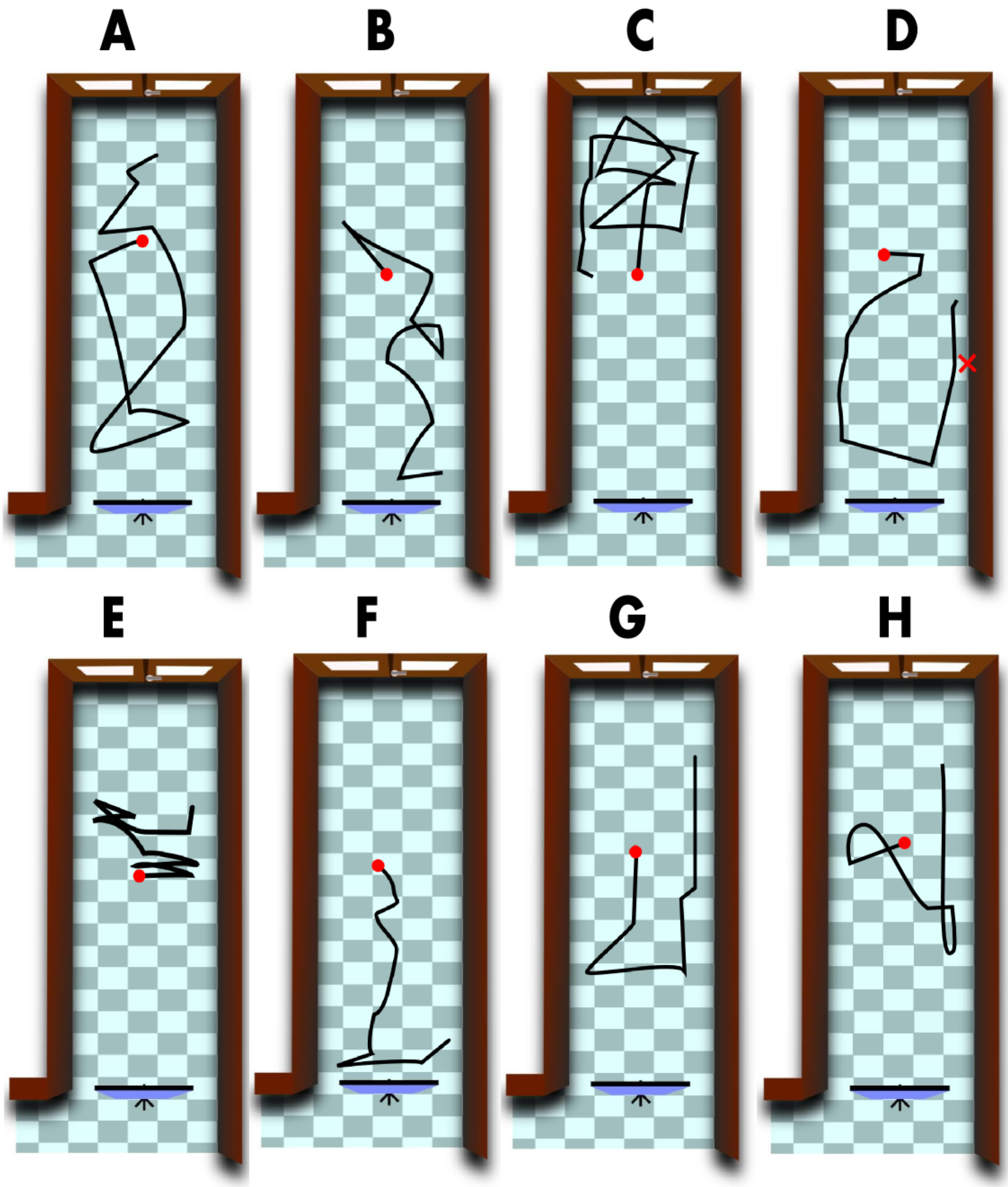

Figure 6. Eight paths followed by users during the test. Black lines represent the executed path, red circles are the starter point, and red x is collision points. Different paths have been chosen to illustrate the results.

Figure 7).

These numbers indicate that Blind Guardian was very useful in avoiding the type of obstacles available in the test, considering that the test was performed in a confined corridor. The voluntary comments of the subjects were overwhelmingly positive, and all subjects agreed that the device worked as intended. Some of the comments suggested doubling the number of sonar sensors and vibrators, so as to have one for each side, increasing the coverage area.

No correlation was found between the rate of success and the user's previous experience for walking in the dark or history of mobility problems. Most of the test subjects paid close attention to the objective of the test and instructions given. Those who followed the instructions more accurately were remarkably successful in avoiding obstacles.

We were also concerned with the possible relation between the height of the user – also representing the distance from the sensor to the floor – and his ability to detect obstacles better. In Figure 8 we can observe that the number of hits is well distributed and that the user's height did not influence the results of the test. We had this in mind while developing the experiment. The absence of obstacles of differing sizes allowed users with distinctive heights to overcome the same hurdles.

VI. Conclusions and Future Work

In this work, we presented Blind Guardian, a new device to help persons to walk in the dark. The device is lightweight, non-expensive and can be easily assembled with the information provided in this paper. The parts used to build the device are convenient to find and purchase.

Blind Guardian was a positive experience for most of our test subjects. The results demonstrated that it is efficient and can help individuals to find their way in the dark avoiding collisions with obstacles such as walls. Users demonstrated to be capable of using this tool after a very quick instruction session. The equipment can be helpful for sightless, hands-free and non-auditory locomotion in indoor environments.

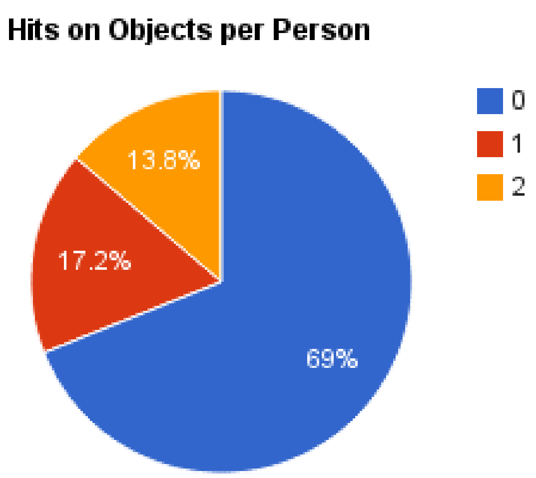

Figure 7. Number of hits on obstacles per subject. The blue area represents no hits; the red area one hit; and the orange one, two hits. No one hit more than twice.

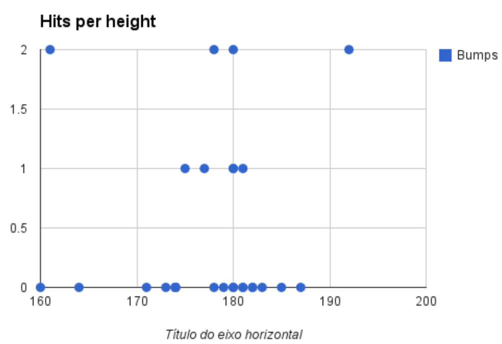

Figure 8. Hits per height

We believe Blind Guardian can be used to help blind users while walking in dense environments, in this case, being used as a complementary tool to the cane. We also believe it can be easily adapted to a head-mounted display to be used in immersive virtual experiences. During a navigation task based on real walking, the user cannot see the real environment, but it is still there, and collisions should be avoided to guarantee safety.

Thanks to the feedback given by the users during the tests, we identified several adjustments to implement in the future. The current arrangement is quite fragile, especially concerning its connections. Thus, a better structure should be designed.

Changes can be made to improve the precision and efficiency of the device, including adding an ultrasonic sensor on each side of the cap in order to eliminate the necessity of sideways motion. The sensors can also be fixed in other places instead of the head so as to detect obstacles with differing heights and shapes. On the other hand, all of these modifications would certainly increase the complexity of handling the equipment.

As an alternative to the Arduino UNO, the project could be implemented with a microcontroller, allowing an even cheaper alternative. However, the code and integration with the sonar would not be as simple.

We also hope to be able to test it under different circumstances. The Blind Guardian has proven to be well suited to avoid sizable surfaces. However, it would be interesting to apply it to other kinds of obstacles, with different shapes and variable heights. We did not manage to find a substantial visually disabled population to test the device in time. We hope to be able to perform such an experiment in the future and more accurately assess the applicability of the device for the disabled.

Acknowledgment

The authors would like to thank all the users that took part as volunteers in the experiments, as well as CAPES and CNPq-Brazil project 485820/2012-9 for partially funding this work.

References

[1] T. A. Stroffregen and J. B. Pittenger, "Human echolocation as a basic form of perception and action," *Ecological Psychology*, vol. 7, no. 3, pp. 181–216, 1995.

[2] W. H. O. V. impairment and blindness Fact Sheet n.282. (2014). [Online]. Available: http://www.who.int/mediacentre/factsheets/fs282/en/

[3] O. VR. (2015). [Online]. Available: https://www.oculus.com/

[4] T. Mota, M. Mello, L. P. Nedel, A. Maciel, and F. Faria, "Mobile simulator for risk analysis," in *16th Symposium on Virtual and Augmented Reality, SVR 2014, Piata Salvador, Bahia, Brazil, May 12-15, 2014*, 2014, pp. 163–170. [Online]. Available: http://dx.doi.org/10.1109/SVR.2014.52

[5] G. Bruder, V. Interrante, L. Phillips, and F. Steinicke, “Redirecting walking and driving for natural navigation in immersive virtual environments,” *Visualization and Computer Graphics, IEEE Transactions on*, vol. 18, no. 4, pp. 538 –545, april 2012.

[6] G. Welch and E. Foxlin, “Motion tracking: no silver bullet, but a respectable arsenal,” *Computer Graphics and Applications, IEEE*, vol. 22, no. 6, pp. 24–38, Nov 2002.

[7] M. Brock and P. O. Kristensson, “Supporting blind navigation using depth sensing and sonification,” in *Proceedings of the 2013 ACM Conference on Pervasive and Ubiquitous Computing Adjunct Publication*, ser. UbiComp ’13 Adjunct. New York, NY, USA: ACM, 2013, pp. 255–258. [Online]. Available: http://doi.acm.org/10.1145/2494091.2494173

[8] T. Froese, M. McGann, W. Bigge, A. Spiers, and A. Seth, “The enactive torch: A new tool for the science of perception,” *Haptics, IEEE Transactions on*, vol. 5, no. 4, pp. 365–375, Fourth 2012.

[9] E. D’Atri, C. Medaglia, A. Serbanati, and U. Ceipidor, “A system to aid blind people in the mobility: A usability test and its results,” in *Systems, 2007. ICONS ’07. Second International Conference on*, April 2007, pp. 35–35.

[10] J. S. S. P. F. Karen Duarte, Jose Cecilio, “Information and assisted navigation system for blind people,” in *Proceedings of the 8th International Conference on Sensing Technology, Sep. 2-4, 2014, Liverpool, UK*, September 2014, pp. 470 – 473.

[11] G. Fusco, H. Shen, V. N. Murali, and J. M. Coughlan, “Determining a blind pedestrian’s location and orientation at traffic intersections,” in *Computers Helping People with Special Needs - 14th International Conference, ICCHP 2014, Paris, France, July 9-11, 2014, Proceedings, Part I*, 2014, pp. 427–432.

[12] L. Berretta, F. Soares, D. J. Ferreira, H. A. D. Nascimento, A. Cardoso, and E. Lamounier, “Virtual environment manipulated by recognition of poses using kinect: A study to help blind locomotion in unfamiliar surroundings,” in *Proceedings of the 2013 XV Symposium on Virtual and Augmented Reality*, ser. SVR ’13. Washington, DC, USA: IEEE Computer Society, 2013, pp. 10–16. [Online]. Available: http://dx.doi.org/10.1109/SVR.2013.55