Testing of a Collision Avoidance System for the Visually Impaired

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***Abstract*— The Collision Avoidance System assists the visually impaired while they walk by alerting them to obstacles in their path. It is capable of detecting obstacles at both head-level within 5 feet and ground-level within 7 feet and alerting the user with automatic audio alerts. The system consists of a peripheral device to detect head-level objects, another to detect obstacles on the ground, and an Android smartphone application to connect the system and generate the audio alerts. Two peripheral devices with integrated ultrasonic sensors and accelerometers are used to detect obstacles and prevent collisions while the user walks. A glasses-like headset ensures that the user is protected from collisions at head-level and an additional small attachment placed on the user's walking cane senses obstacles on the ground. Both of these devices communicate with the smartphone via Bluetooth wireless technology. Additionally, the phone uses built-in text-to-speech functionality to generate audio alerts that can be easily understood by the user. This document briefly describes the design process for the Collision Avoidance System, testing procedures, and test results.**

Keywords—collision avoidance; visually impaired; blind; assistive device; Bluetooth

I. Introduction

Vision is the ability to interpret the surrounding environment by processing information that is contained in visible light. The World Health Organization (WHO) estimates that around 39 million people worldwide are completely blind in addition to 285 million individuals who are visually impaired [1]. Cures, treatments, and medical devices to deal with blindness have been evolving through the years, resulting in Braille, retinal implants and transplants, and specialized walking canes. Yet, for the permanently blind, the range of options is very limited. Most employ the use of aids such as nurses and seeing-eye dogs in addition to white canes, but new research is striving toward integration between the brain and optical devices. For example, researchers James Weiland and Mark Humayun are working to develop artificial retinal technology, which consists of microelectrodes implanted within the eye that receive Laser or RF transmitted from a camera that then activates neural cells [2].

The Collision Avoidance System allows a visually impaired individual to navigate their environment with relative ease by alerting them to obstacles in their immediate path. The system assists the user a great deal by automatically alerting them to any obstacles that are at both head-level and ground-level, providing for a wide range of protection.

II. Theory of Operation

The main purpose of the system is to automatically measure the distances of objects within a predefined range, process this information through an Android™ cellular device, and then relay the information to the user in feet and inches. The device will consist of a headset containing sensors that will be able to detect objects at head-level of the user. Additionally, a walking cane attachment will be designed to detect ground-level obstacles. This attachment will contain sensors in combination with an accelerometer to gauge the distance of objects in front of the user. All information is communicated wirelessly using Bluetooth® between the external devices and the smartphone, which then relays this information as spoken audio alerts. Fig. 1 shows an example of a walking cane for the visually impaired as well as a basic illustration of the system.

Fig. 1. Basic system illustration.

Fig. 2. Finished headset with mounted ultrasonic sensor.

III. Testing Methods

In terms of the overall system, the Collision Avoidance System must meet multiple criteria before the team can be fully satisfied with the product. These tests for the overall system will correlate to the detection of obstacles at various distances, the effectiveness of ignoring non-relevant objects (i.e. ceiling), determining angle boundaries, and finally testing for 24-hour use time of the system.

A. Solid Obstacle Detection Tests

To test detection of obstacles at various distances, the system was placed over 10ft away from a wall, then incrementally moved closer to verify that the object were only detected when it was within the specified 7ft range at ground-level and 5ft range at head-level. This proved the system's viability for large, solid objects such as walls. Tape was used to mark off every foot up to seven feet away from a wall with a clear area in front of it. Both the headset and cane attachment were brought outside of the range of seven feet, then, gradually moved forward towards the wall. This test was repeated individually for the headset and cane attachment to ensure each was working to specification alone. Then, both devices were used simultaneously and the same test was performed.

B. Thin Obstacle Detection Tests

This test was performed to simulate the common obstacle that many visually impaired people have trouble with, low lying tree limbs. The sparse nature of the tree limbs makes for a different challenge than simply walking at a wall, which is much easier to detect.

For this test, a broom handle was used in place of a tree limb as it is also very thin. The headset was worn by one member of the group, while another group member lowered the broom handle into the field of view of the user at varying distances away. The test started at 1ft and progressed until it was over 5ft away from the user. This test also helped to determine the upper and lower angle boundaries for where the ultrasonic sensor could pick up an obstacle.

C. Horizontal Boundary Tests

This test was performed to characterize the horizontal bounds of detection for the ultrasonic sensors. It is important to know the width of the coverage of the ultrasonic sensor and the range within which objects will be detected. It is important that there is enough width in the beam detection range so that the sensor will detect obstacles roughly within the width of the user's body. It is also important that it does not pick up obstacles far off to either side that the user has no real danger of having a collision with. Fig. 3 shows the setup used to actually measure these angles quantitatively. The headset was setup on the edge of a lab bench, in front of which, seven one foot increments were taped off. A solid obstacle was placed on a rolling chair so that it could be smoothly and slowly rolled from either the far left or far right of the headset at a specific distance between one to five feet in one foot increments until an alert was given. At this point, the rolling object was stopped, and a line was drawn from the object, across the actual ultrasonic sensor to determine the angle at which the object was first detected. A protractor was then used to actually measure the angles of detection.

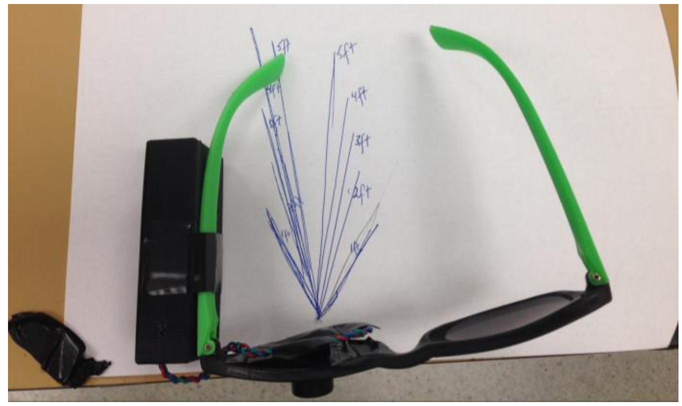

Fig. 3. Experimental setup to determine detection angles at various distances.

D. Vertical Boundary Tests

Similar to the previous horizontal boundary test, a vertical boundary test needed to be performed. One of the group members wore the headset shown in Fig. 2 and a piece of paper was taped to the wall next to the user. An object was both brought down and up into the user's field of view until the system issued an audio alert. Once an alert was sounded, a line was drawn from that point, across the sensor, and onto the paper. A protractor was then used to measure the angle.

E. Acclerometer Tilt Tests

Another necessary test is determining the angle boundaries of the sensors and the system's ability to ignore objects above the user's head. For this test, the headset will be placed next to a protractor to determine the angle at which notifications cut off. The device will be slowly tilted back and any solid object will be moved in and out of its field of view. The test will be successful if there are no notifications after being tilted 20° in either direction. A similar test can be performed for the cane attachment, only this time rotating it past 30° in either direction. A test will also be performed where a solid object is moved in from the sides of the user to determine the angle at which it is first detected as an obstacle. For success, this value should be roughly 10°.

F. Battery Testing

To test the battery life of each device to ensure that it meets the specification of 24 hours, both devices were fully charged, and then they were turned on at the same time. The circuits were monitored over the next day or so, waiting for either or both of them to eventually turn off. After the first device's battery died, the second device was monitored until it too ran out of battery. The times were recorded for each.

TABLE I. REQUIREMENTS AND SPECIFICATIONS

Requirement	Specification	Test Result
(1) The system should assist in avoiding collisions while a user walks	(1a) Horizontal object detection: ±20˚ (1b) Vertical object detection: ±10˚	(1a) Horizontal detection at 1ft: ±29.5˚ Horizontal detection at 5ft: ±5.5˚ (1b) Vertical detection at 1ft: ±30˚ Vertical detection at 5ft: ±6.5˚
(2) The system should detect obstacles at ground-level in the user's path	(2) Ground-level obstacle detection range: 0-7ft ± 0.5ft	(2) Met by specifications of Maxbotix LV-EZ3 ultrasonic sensor chosen[a] Range: 0-21ft; Accuracy: 1in
(3) The system should detect obstacles at head-level in the user's path	(3) Head-level obstacle detection range: 0-5ft ± 1in	(3) Met by specifications of Maxbotix LV-EZ3 ultrasonic sensor chosen Range: 0-21ft; Accuracy: 1in
(4) The phone application should run on a smartphone using the Android platform	(4) Smartphone Application Compatibility: Android 4.2	(4) Application tested on two separate phones using Android 2.3.4, Android 4.2 backwards compatible
(5) Both peripheral devices should be powered by separate rechargeable batteries	(5) Peripheral devices will be powered by independent, rechargeable batteries	(5) Battery mounted below PCB in each device and rechargeable via USB
(6) Batteries should last the user an entire day	(6a) 3.7V 1000mAh Li-Ion rechargeable battery (6b) Batteries will be recharged via standard micro-B USB connector (6c) Use time per full charge: > 24 hours	(6a) Specification met by chosen battery[b] (6b) Takes roughly 3 hours for a full recharge of the battery via included micro-B USB connector[c] (6c) Headset battery: 20.5 hours Cane attachment battery: 63 hours
(7) Both peripheral devices should be able to be turned on and off	(7) Will have physical switches on both peripheral devices to turn them on and off	(7) Accessible slide switch enables and disables power to the device
(8) Both peripheral devices should wirelessly communicate with the smartphone	(8) Peripheral devices will use Bluetooth 2.1	(8) Met by specifications of HC-05 Bluetooth transceiver that was chosen
(9) Both peripheral devices should be small and light enough so as not to impede normal motion	(9a) Headset Weight: < 10oz; Form factor: glasses with < $5in^3$ housing for circuitry (9b) Cane Attachment Weight: <10oz; Size: < $6in^3$	(9a) Total Headset Weight: 2.905oz (9b) Headset Volume: $3.11in^3$ (9c) Cane Attachment Weight: 2.305oz (9d) Cane Attachment Volume: $6.9in^3$
(10) The system should give the user spoken audio alerts and notifications	(10) The system will give the user audio alerts and notifications	(10) Android application produces audible alerts
(11) Should alert user to obstacles on the ground with distance to the object	(11) Will alert user to ground-level objects with "*Ground object X feet ahead*" audio output	(11) Audio messages successfully generated but shortened to be more efficient
(12) Should alert user to head-level obstacles with distance to the object	(12) Will alert user to head-level obstacles with "*Head obstacle X feet ahead*" audio output	(12) Audio messages successfully generated but shortened to be more efficient
(13) Should alert user once an obstacle is gone and their path is clear	(13) Will alert user with "*Ground Clear*" and "*Head Clear*" once the path is clear	(13) Audio messages successfully generated for each case
(14) Should alert user when the cane is improperly oriented	(14) Will alert user with "*Rotate cane clockwise* or *counter-clockwise*" audio output	(14) Audio messages successfully generated but shortened to be more efficient
(15) Should alert user when the battery in either peripheral device is low	(15) Will alert user "*Headset* or *Cane, battery low*" when battery is below 20%	(15) Battery alert audio messages successfully generated but shortened
(16) Obstacle alerts should be triggered in time for the user to react	(16) Response time: < 100ms	(16) Calculated response time: 66.5ms[d]
(17) Application should automatically and only connect to the headset and cane attachment	(17) Will connect as soon as the application starts	(17) Application automatically connects to headset and cane but can be buggy and may not work on the first try every time. Usually to ensure it works, Bluetooth should be restarted each time.
(18) Needs to receive serial data simultaneously over two Bluetooth links	(18) Will connect via Bluetooth SPP (Serial Port Profile) to both devices	(18) Application receives serial data from both devices simultaneously over dual link

a. See reference [3] for datasheet.
b. See reference [4] for datasheet.
c. See reference [5] for datasheet.
d. See Equation (1) for calculation.

IV. TEST RESULTS

The overall system met the majority of the given requirements and specifications that were previously decided upon. In most cases where the specification was not met, it was either impossible due to limitations of the sensors or it was decided through testing that the system would best operate with different specifications.

A. *Solid Obstacle Detection Tests*

This test provided conclusive results that proved that the ultrasonic sensor is capable of accurately measuring distance between 6-255 inches. The test was performed while reporting inches as well as the distance in half foot increments as required by the specifications. In both cases, the results were extremely accurate. Fig. 4 shows both the expected results in blue and the actual results reported in red. The sensor maintains linearity throughout its operation except for the 0-6 inch range where all readings are reported as 6 inches.

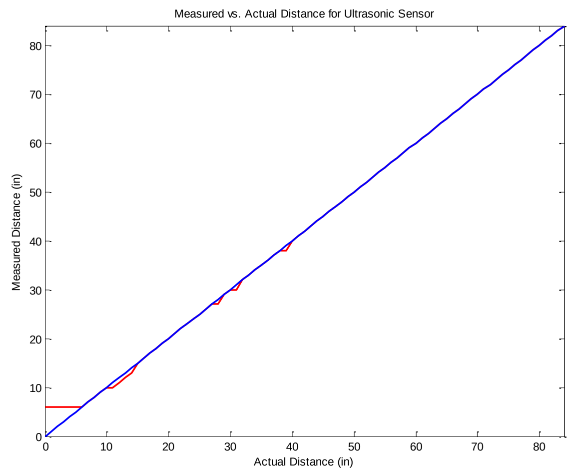

Fig. 4. Ultrasonic sensor characterization.

B. *Thin Obstacle Detection Tests*

In this test, the system was able to successfully detect a broom handle at different heights between 0-5 feet. This proves that the system will be functional even for much smaller objects that are harder to detect than large solid surfaces.

C. *Horizontal Boundary Tests*

This test returned results that accurately defined the lateral bounds within which the system will be able to detect obstacles. The results from the testing were plotted in MATLAB to more accurately replicate and explain the beam pattern for the system. Fig. 5 shows the report data that was collected over 10 specific data points. The data shows that the sensor has a detection width of approximately 2 feet between 1-5 feet away from the headset. While the angle at one foot away from the sensor is not within the specified bounds in the specifications, the width of the beam is a characteristic of the sensor itself and cannot be changed. After testing with the sensor and this beam width, it actually proves to provide the best results because it is capable of detecting obstacles within roughly a human's body width. When looking at Fig. 5, the origin at point (0, 0) is where the actual ultrasonic sensor was sitting and the points along the outside is where it detected the obstacle.

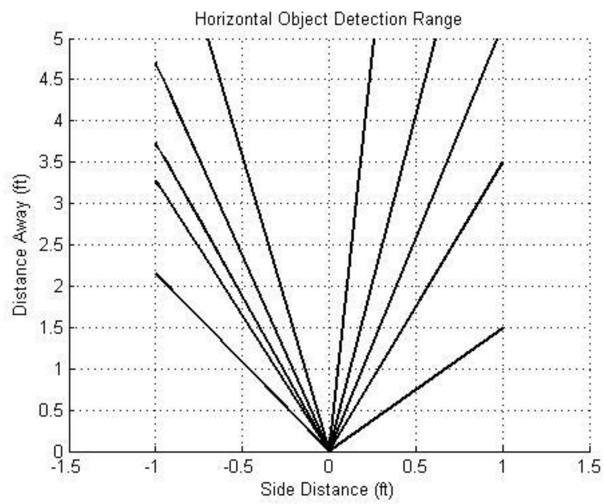

Fig. 5. Experimental beam pattern for horizontal object detection.

D. *Vertical Boundary Tests*

Similar to the previous horizontal boundary test, the vertical boundary test returned accurate results that showed the precise beam pattern of the ultrasonic sensor and its detection range. In Fig. 6, the origin at point (0, 0) represents where the headset was actually located during the testing and the points at the ends of the line show where the broom handle was first detected. The horizontal and vertical beam patterns match extremely well and prove that the beam from the sensor is conical and the same in any orientation. While the closer results do not meet the specified 10˚, readings from further away narrow the vertical detection range to within that value.

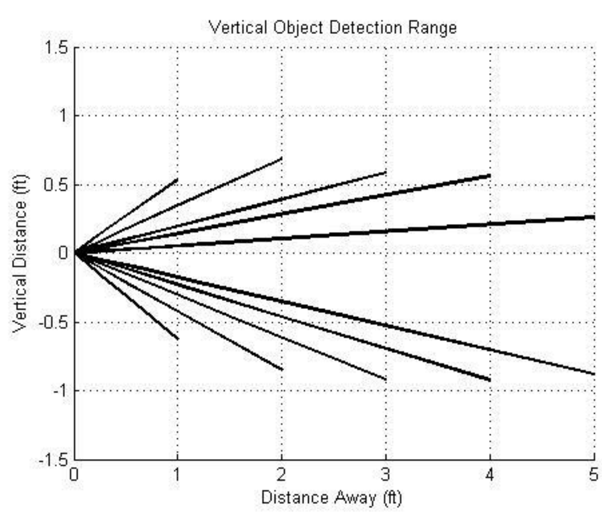

Fig. 6. Experimental setup to determine detection angles at various distances.

E. Acclerometer Tilt Tests

For this test, it was determined that 20˚ would probably be too small of a value to accurately determine whether the user's head was tilted up or if there was still relevant information to alert the user to. Using 20˚ as the cutoff, occasionally too many readings would be lost because the headset does not always sit level depending on who is wearing the device and how exactly it is mounted onto the glasses. To accommodate for many of these inconsistencies, which include some fairly shaky readings from the accelerometer itself, the degree value was increased to make a higher threshold for disabling alerts. It made the most sense to be conservative when disabling alerts so that no relevant data would be missed. With the higher threshold value of 50˚, the algorithm is able to successfully block alerts to objects in the user's field of view.

F. Battery Testing

The battery tests returned values of 20.5 hours of continuous runtime for the headset and 63 hours for the cane attachment. The main reason for the major difference in time is that the cane attachment uses a different Bluetooth transceiver, which was purchased in an attempt to get dual connections working. Another important aspect of the battery testing to make note of is that these numbers were collected while the circuits were running, but Bluetooth was not connected. On any Bluetooth chip, there is a higher current draw when it is searching for a connection as opposed to when the connection is made and data is being transmitted. Assuming that the headset would use roughly 10mA less while connected, it can be concluded that the average battery life would be closer to 29 hours. Similarly for the cane attachment, it may be assumed that it could run for upwards of 80 hours. This battery life far exceeds the specifications and would allow the system to run continuously for an extremely long period of time between charges.

G. Response Time Calculation

Instead of actually quantitatively testing the response time from obstacle detection to audio alert, the group decided to provide a calculation for the expected response time based on the knowledge of exactly what is happening between the time an obstacle is present and an alert is generated. The response time was calculated as the sum of the time it takes for the ultrasonic sensor to return a new reading (49ms), the time to transmit that reading's 5 byte message to the microcontroller at a 9600 baud rate (4.17ms), the time for the Bluetooth chip to transmit to the Android phone a maximum of 16 bytes also at 9600 baud (13.33ms), and the time for it to process through the algorithm and generate an alert on the phone (negligible). Equation 1 shows the

$$\begin{aligned} Response\ Time = \ & Sensor\ Cycle + Transmit\ to\ board \\ & + Transmit\ to\ Phone \\ & + Algorithm\ and\ Alert \end{aligned} \tag{1}$$

V. CONCLUSIONS

The results from the testing of a Collision Avoidance System for the Visually Impaired prove the viability and accuracy of the system. The vast majority of the specifications outlined in earlier documents were met and in certain cases, exceeded by a wide margin. The project has come together into a very polished product that could be used today.

Moving forward, there is a lot of room to continue future work on this product. The size of both the headset and cane attachment could be drastically reduced to be a more practical product for commercial use. The battery life of both devices could be sacrificed to reduce the size of the battery in the device, which would allow for the entire device footprint to decrease. In the headset especially, it would be important to reduce the size of the attachment so that it is not as bulky.

Another possible future improvement would be to 3D print the entire headset together as a single piece, glasses and housing. This would add increased stability and integration, eliminating the need to attach anything to the glasses after the fact. Recent products such as Google Glass show the amount of capability that can be packed into an extremely concise package. One idea for reducing the size of the overall housing would be to design a smaller PCB that includes integrating power management onto the board and having components on both sides of the board to maximize efficiency.

The design has a lot of potential to be commercialized in a fairly well integrated system consisting of the headset, cane attachment, and Android application. The three pieces combined make for a system that does not exist on the market today and far exceeds any capabilities that have been built into similar products previously.

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