Heads Up: A Mobility Aid for the Blind Using Laser Triangulation

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***Abstract* — This paper presents the design methodology to develop a mobility aid for the blind using laser triangulation technology. The conventional white cane commonly used by blind persons to detect and avoid obstacles as they navigate their environment has a limited detection range. This limitation inspired the project with the goal of developing a convenient and affordable mobility aid device to provide white cane users supplemental sensory feedback and to alert the user of an incoming object which is above waist level. The core of the project involved the integration of three critical subsystems: Optics, electronics and software, and mechanical design. Our hope is that this project inspires people to leverage engineering as a means to provide greater mobility for others.**

***Index terms* - CCD image sensors, Design for Manufacture, Laser Triangulation, Optomechanical Design, 3D Printing**

1. INTRODUCTION

Individuals who have total or near-total blindness face many challenges when trying to safely navigate their environment. In order to provide helpful sensory information, such individuals use a white cane. The conventional white cane provides tactile feedback, but fails to inform users of obstacles above the waist such as low hanging branches, beams, low doorways, signs, or other objects. The motivation behind the project was to develop a device which would enable the wearer to be alerted of such hazards in their path via haptic feedback [1].

The goal for the device was to detect obstacles between 0.5 meters and 1.5 meters in front of the user. There are various methods for rangefinding such as LiDAR, amplitude modulation of continuous light, frequency modulation of continuous wave, and interferometry, amongst others, but the implementation of such approaches is very challenging given time and resource constraints. [2,3] It was determined that laser triangulation would be the best method of range finding for this device. We desired a spatial resolution of 20 centimeters and a response time of less than 250 ms in order to give the user reliable distance information and the appropriate time to react to incoming obstacles. The operational lifetime for the device was set to be at least 24 hours for the user's convenience. The size constraint of the project was to keep it within a 9 centimeter by 15 centimeter area and the weight constraints was to keep it less than 2.5 kilograms, in order to feasibly head mount the device.

The working principles behind our project is laser triangulation. A visual representation can be seen below in Figure 1. Laser triangulation works by the emission and collection of light integrated with computation. Light emitted from a laser diode is collimated by two cylindrical lenses into a roughly oval shape. This beam travels a distance before striking a target and scattering in all directions, assuming non-specular reflections. The diffused light is collected and imaged onto a linear sensor [4]. The image location of the beam on the sensor is used to determine how far away an object is. The equation below describes this process simply:

$$\frac{D}{E} = \frac{F}{G}$$

Eq. 1: Imaging Triangulation Relations

Where, D represents the distance from the transmitter to the target, E represents the spacing between the transmitter and the collection optics, F represents the focal length of the imaging lens, and G represents the displacement from a reference point on the pixel array of the image sensor [5]. These distances are shown in Figure 1.

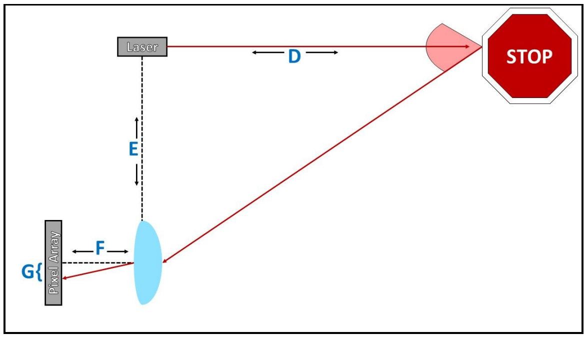

Fig. 1: Laser Triangulation Principle

II. SUBSYSTEMS

The subsystems which make up our device can be organized into three broad categories: *optics, electronics and software,* and *mechanical design*.

2.1 Optics

In this device, the optics were designed in two main areas: *lenses* and *laser*. Components from both categories were chosen to balance 'high output' for the collection optics and 'eye safety' for safe consumer use.

2.1.1 Lenses

The optics selected for the transmission side were two cylindrical lenses. The cylindrical lenses purchased were Thorlabs LJ1942L1-B with a focal length of 12.7 mm and LJ1402L1-B with a focal length of 40 mm. Fixing these two lenses at their respective focal length worked together to roughly collimate the emission of the laser diode. By slightly offsetting the position of the lenses we were able to generate a roughly collimated line that proved to be helpful for imaging the spot onto our image sensor. This beam shape can be seen in Figure 2.

Fig. 2: Scattered IR emission on camera

The imaging lens used for the project was a 1 inch plano-convex lens purchased from Thorlabs (LA1951-B-L) with a focal length of 25.4 millimeters. The field of view for this lens was 30 degrees. The imaging lens enables the collection of light that is diffusely reflected from the target a distance away to be imaged onto the sensor.

In addition, a bandpass filter was used to filter out the ambient light. We chose the Thorlabs FL905-10 which has a full width half max of 10 nm ± 2 nm, central wavelength of 905 nm, and an optical density of approximately 7 for all visible wavelengths and approximately 4 for most infrared light outside our range, effectively eliminating any ambient light noise. Decreasing the noise our system experiences increases its accuracy and effectiveness, while reducing the number of false positives [7].

2.1.2 Laser Diode

The laser diode selected for the project was the Thorlab L904P010. The wavelength of the laser diode is centered around 904 nm and has an output power of 10 mW.

The key reasoning behind this selection was attempting to adhere to laser safety standard ANSI Z136.1 and standard IEC 60825. ANSI Z136.1 outlines the different classes of laser as defined by wavelength and output power. The human eye is very sensitive to wavelengths in the visible light spectrum, thus a design decision was made to operate in the infrared regime. For much of the infrared spectrum, detectors can be very expensive, so we had to find a balance between cost effectiveness and system performance.

The maximum permissible exposure defines the amount of energy that can enter the human eye over a set exposure time with respect to the wavelength of light used. Fig. 3 below graphically represents the MPE for 250 ms exposures as reported in a table in the ANSI standard [6]. This shows that 1550 nm emitters would allow for the safest, highest powered device, but the cost of filters and especially image sensors are prohibitively expensive for the scope of our project. As silicon is readily available, cheap, and responsive in the very near infrared regime, 905 nm light was chosen as a suitable combination of cost and quality.

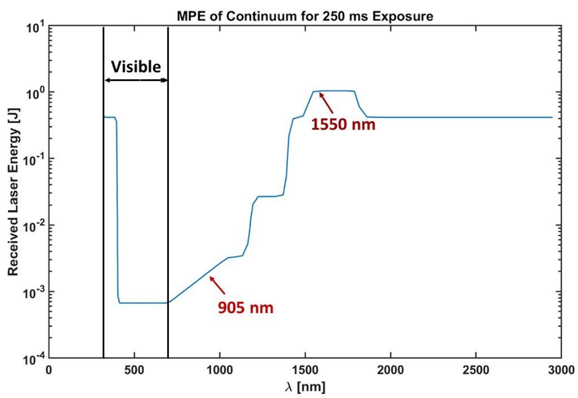

Fig. 3: Max Permissible Exposure

In order to power our laser diode, we configured a TI LM317 voltage regulator to put out a constant current of 60 mA. Using the LM317 precision current-limiter circuit with a 20 ohm feedback resistor between the output voltage and adjust nodes, as shown in Figure 4 below, provides the constant 60 mA current necessary to drive our laser

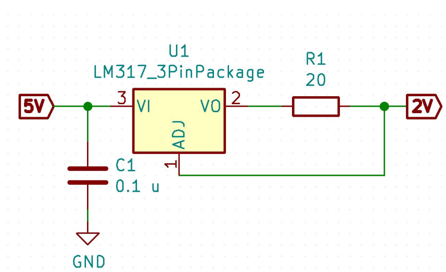

Fig. 4: Laser Diode Driver Circuit

2.2 Embedded Electronics

In order to drive the laser and collect the light that it emits, the embedded electronics were designed to be accurate, efficient, and low-power. In this section we will discuss the design choices made regarding the *image sensor*, *microcontroller*, and *printed circuit board*.

2.2.1 Image Sensor

The image sensor selected as a receiver for this project was the Toshiba TCD1304DG CCD Linear Image Sensor. The TCD1304DG was powered and controlled using the driver circuit seen in Fig. 5 below.

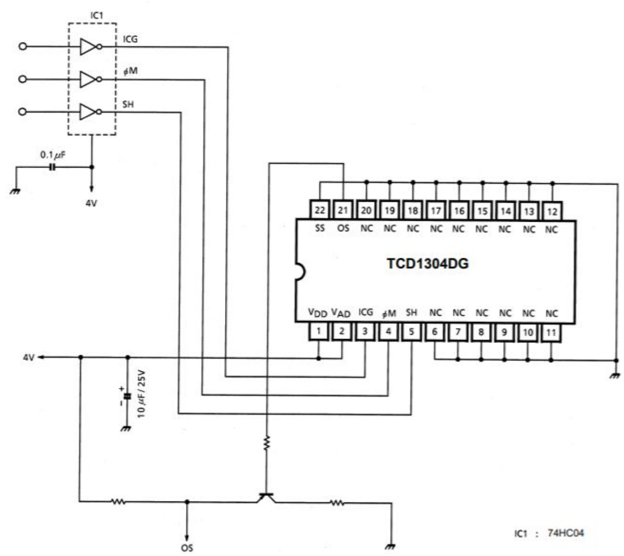

Fig. 5: Image Sensor Driver Circuit

While the image sensor itself must be mounted in a forward-facing orientation relative to the user in order to detect upcoming obstacles, the rest of the image sensor driver circuit is mounted on the main PCB, behind the user. To communicate between the main board and the image sensor, we routed control signals and power from the driver circuit on our rear-mounted main PCB to the forward-facing break-off board containing the image sensor. The image sensor driver circuit includes a series of inverters that invert the control signals from our microcontroller, as required by the image sensor, and a BJT circuit that feeds the output signal from the image sensor back into the microcontroller.

The CCD image sensor was controlled using three input timing signals to initiate the alternating electrostatic potentials necessary to transport charge. The timing signals required for the operation of the Toshiba 1304DG work by alternating high and low voltages according to proper timing patterns. In our implementation, we chose to design the signals to achieve an *electronic shutter* instead of a *global shutter*.

What attracted us to use the Toshiba 1304DG was the significant price difference to other CCD sensors offered in the market from companies such as Hamamatsu Photonics. Another factor was the ease of implementing the sensor, as some models on the market were difficult to interface with, or required expensive proprietary devices. Additionally the TCD1304 could be operated with only input power, a simple inverter circuit, and 3 signal inputs that most microcontrollers can easily generate, making it a component that we could design and integrate around.

2.2.2 Microcontroller

For all data processing, control, and interfacing, we chose to use one primary microcontroller that will manage all aspects of the electronics. The microcontroller selected for this project was the MSP430F6459 from Texas Instruments. The MSP430F6459 is a 16-bit RISC processing architecture in a 100-pin package. Some primary benefits of choosing this microcontroller over others include: (i) a large memory capacity for code and data (both flash and RAM), (ii) a speedy processor (in comparison with other ARM microcontrollers such as the Atmega and PIC), (iii) low cost (less than five dollars), and, perhaps the most significant benefit, (iv) previous experience with this platform.

2.2.2.1 Computational Logic

Our code on the MSP430 is written in C and compiled in Texas Instrument's custom Code Composer Studio Software. It is thus flashed to the microcontroller over a Spy-Bi-Wire JTAG interface. The code has two primary objectives: (i) read the image sensor and (ii) activate the haptic feedback buzzer, accordingly.

First, the image sensor is primed for *electronic shutter mode*. The control signals are then alternated to "open" and "close" the silicon pixels of the image sensor. The voltages read by the silicon pixels are received into a 12-bit *Analog-to-Digital Converter* channel on the MSP430. Based on the magnitude of these digitized values, the code is able to determine where on the image sensor the most reflected light is returned. Pixels that are lit up indicate that there is an object present at that location. Pixels which are not lit up indicated that there is, no object at that location. This process repeats indefinitely.

Given a reflection from an object, the highest returned digitized value is indicative of the spatial location of the physical pixel on the image sensor. Using the aforementioned triangulation relation, the distance from the object to the device is then known. This relation is summarized in Figure 6 below.

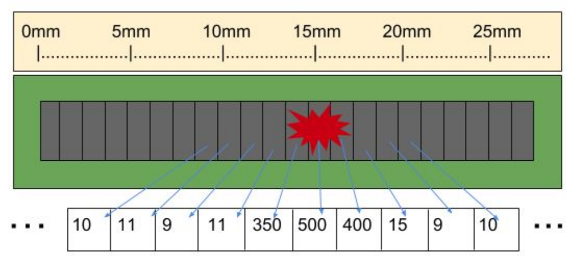

Fig. 6: Computational Logic

2.3 Printed Circuit Board

Our main printed circuit board is made up of several circuits. One controls the operation of the haptic feedback buzzer, another powers and programs the microcontroller, a third generates constant current for the laser, a fourth provides the necessary control signal processing for interfacing with the image sensor, and two voltage regulator circuits step down the 9V battery voltage to the 5V and 3.3V voltages used by the aforementioned circuits on the main PCB as well as the front-mounted laser diode and image sensor. A few of these circuits will be discussed in detail below.

The WeBench power designer tool from Texas Instruments was used to help design the voltage step down regulators, and the PCB design and layout were created using the KiCad open source electronic design automation (EDA) software. Copper pours were used to create one ground plane on the front copper layer and two power planes (both 5V and 3.3V) on the bottom copper layer. This was done in order to minimize the number of traces needed to achieve full electrical connectivity. Through-hole components and some simple surface mount components were hand-soldered by us throughout the three iterations of the PCB, and QMS provided invaluable assistance in populating more challenging surface mount components. The final revision of our PCB is seen in Figure 7.

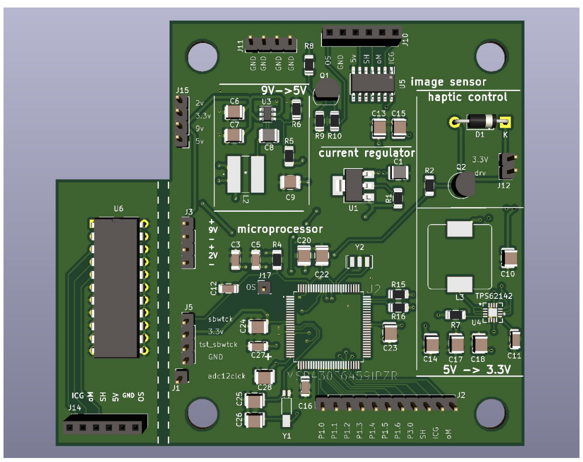

Fig. 7: 3D Design View of Revision 3 PCB

2.3.1 Haptic Feedback Circuit

When an an object is identified ahead, a buzzer is activated by a haptic feedback circuit. This circuit is driven by a control signal from the MSP430 microcontroller attached to the base of a BJT by way of a current-limiting resistor. When the control signal goes high, the BJT amplifies the control signal current and acts as a closed switch that powers the buzzer. When the control signal goes low, the BJT acts like an open switch, turning the buzzer off.

2.3.2 Step-down Circuits

Two step-down DC-DC switching regulators convert the input voltage from our 9V Li-ion batteries to 5V, for our image sensor and constant current circuits, and then to 3.3V, for our microcontroller and haptic feedback circuits, respectively. As stated previously, the initial designs for these voltage regulator circuits were generated in the WeBench power designer tool by specifying the needed input and output characteristics and filtering for efficiency, footprint, and component cost and availability.. Based on these criteria, we chose to use the TPS62142RGTR and TPS565201DDCR step down voltage regulators from Texas Instruments for our 3.3V and 5V voltage regulator circuits, respectively.

2.3.3 Image Sensor Circuit

Because the image sensor must be mounted in a forward-facing orientation, we placed it on a break-off board, which we detached from the main board, and used wires and connector terminal blocks to communicate between the two boards. The breakout section is denoted by the dotted lines in Fig. 7, previously shown.

III. PACKAGING

The housing of the final device was developed using CREO Parametric and the Prusa i3 3D printer. CREO Parametric is a computer aided design software. The concept behind the design of the housing was a modular approach. The modular approach of 3D printing enabled us to rapidly prototype.

3.1 Optics Housing

The various mounts holding the lenses could be printed in a manner in which the optical axis of our system is aligned after a few iterations. A rail system was also developed during this phase to optimize and align the spacing between optics used in the system.

The reason why we chose not to machine the housing is because 3D printing enabled us to do device testing and risk reduction on designs in real time. Machining can generate a lot of waste if a design fails because you are unable to reuse parts already made. Furthermore, the accuracy and precision of the 3D printers enabled us to fine-tune the alignment of our optics relatively quickly and inexpensively. The files from our project are shared online which can enable people from all over the world to 3D print their own version of the HeadsUP housing. Figure 8 shows the interior of the 3D printed optics housing with our lenses and filter mounted. Figure 9 shows the exterior of the 3D printed optics housing, with all optics components shielded and held in place. The 3D printed housing is mechanically stable and effectively maintains the required spacing between the transmitting and receiving optics.

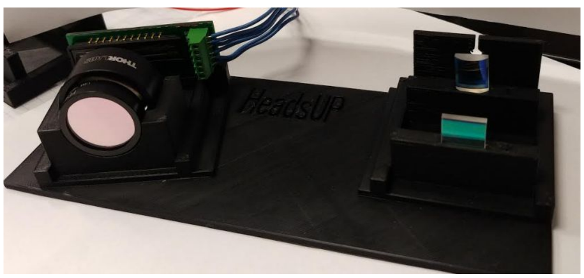

Fig. 8: Interior 3D Housing of HeadsUp

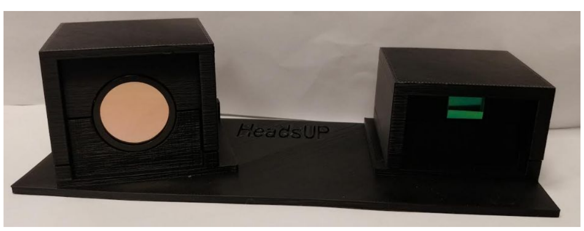

Fig. 9: Exterior Housing of HeadsUP

3.2 Printed Circuit Board Housing

Figure 10 shows an exploded view (left) and a cross-sectional view (right) of the housing which encases the main PCB and battery. The main PCB sits on the bottom of the housing. A platform sits above the main PCB on four pillars and supports the Li-ion battery that powers the system. There is sufficient space to allow for an additional two Li-ion batteries to be connected in parallel, supplying longer run-time. However, a single battery is sufficient to provide 12 hour run-time assuming constant operation, and much longer run-time assuming that the user will power off the system when not actively navigating their environment. Finally, a lid seals the housing and several small windows allow us to route wires for signals and power between the main PCB and optics.

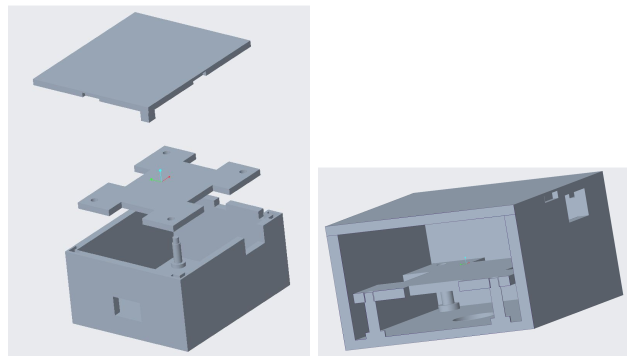

Fig. 10: PCB Housing Design

IV. TESTING

The testing phase of the project involved placing objects with various reflectivities in front of the system and verifying that our system was able to detect them. The first step in the test was to connect an oscilloscope probe to the output signal of the image sensor. A voltage drop indicates a detection of an object. The second phase of testing to determine the location of the object relative to the user was done by inspecting digitized values to see where the drop occurs in time. Oscilloscope readings were used to measure the various input signals and output signal of the device, as seen in Figure 11

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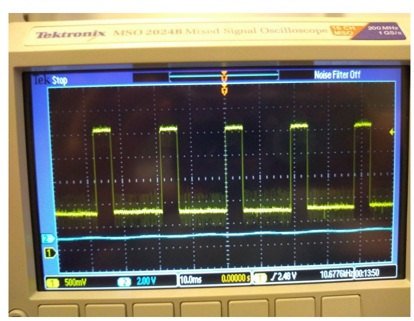

Fig. 11: Image Sensor Output Signal

V. RESULTS

The final device is able to detect objects between approximately 30 cm and 1 meter away and provide haptic feedback to the user which varies based upon the distance measured. The biggest limitation of the device as a prototype remains the detection of obstacles such as glass, mirrors, and extremely dark surfaces. The orientation of the laser triangulation system works best for diffuse reflection. The individual subsystems are all able to be mounted, but further work needs to be done to optimize the size and ruggedness of the integrated system to create a reliable head-mounted product. The lack of mechanical expertise on our team limited our progress in this regard. A challenge faced during our testing phase was the imaging side of the optical system. The image sensor pixels are 8 microns by 200 microns, making the alignment of the the image of our spot onto the array difficult.

VI. CONCLUSION

In conclusion, this project brought out the best in each team member's knowledge, skills and teamwork ethic. We learned so much through the entire process and are pleased with the device that we were able to create. Additional features we wish to add in the future include the ability for HeadsUP to communicate with smart devices such as smartphones and GPS capabilities that would help the user navigate unknown areas. From a design standpoint, given more time and resources we hope to continue to develop a smaller, sleeker packaging for the user to fit on the frames of their eyeglasses.

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BIOGRAPHIES

Austin Singh is a senior at the University of Central Florida and will receive his B.S. in Photonics Science & Engineering in May 2019. He has worked in a variety of research laboratories, studying optical tweezers and nanophotonics at the University of Arizona, fiber optics at the University of Central Florida, and plasma enhanced graphene at Clemson University. His primary interests lie in lasers and optical materials as they relate to communication.

Hunter Tanchin, an Orlando native, is a senior working towards his Bachelor's of Science in Computer Engineering from The University of Central Florida. Hunter attributes his love of technology to his father who nurtured his curiosity, to his UCF professors who bequeathed their knowledge, and to God who has gifted and faithfully guided him. His future plans include marrying his beautiful fiancé and moving to Virginia, where he will begin working in Embedded Systems.

Alex Radulescu is a senior at UCF working towards his Bachelor's of Science in Electrical Engineering. He has interned at NDI Recognition Systems, an Orlando area company specializing in automated license plate recognition technology, where he assisted with hardware assembly, testing, and training of computer vision systems. After graduation, Alex plans to pursue work in the Orlando area as a field applications engineer.

Duc-Quy Nguyen is a senior at the University of Central Florida and will receive his Bachelor's of Science in Photonic Sciences & Engineering in May of 2019. He has worked in the past as a research assistant developing beam shaping optical elements for Dr. Glebov and Dr. Diviliansky. Currently he is working as a manufacturing engineer in the UCF CWEP program at Lockheed Martin. His primary interests lie in the intersection of Optics & Photonics and healthcare.

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