OptiCane Final Paper

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Abstract

The purpose of the OptiCane is to act as a supplement to the traditional white cane that a blind user would use. The cane uses four sensors to sense nearby objects and provides the user with haptic feedback in the form of varying vibration patterns and intensity based on the height of the object and distance of the object from the user. The results of the project show that the OptiCane is useful for detecting objects a distance of around 1.5 meters from the user.

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1. Introduction

1.1 Objective

In 2016, it was estimated that 7,675,600 people between the ages of 16 and up suffer from a visual disability[1] and globally 36 million people are estimated to be blind[2]. As a result, many resort to using sighted guides, seeing eye dogs, white canes, or, in some cases, their remaining vision.
In a 2011 study conducted at the University of Santa Cruz, more than 300 legally blind or blind individuals were surveyed on the frequency of head and fall injuries. Of the entire sample group, 266 reported having experienced some type of fall injury[3]. The study suggests that the main causes for fall accidents can be attributed to unexpected obstacles or misjudgement of distances and angles[3].
Our proposed solution will enhance the user's interaction with the environment by utilizing sensors and haptic feedback to detect both the distance and size of an object while maintaining the same operation of the traditional white cane. By enhancing the original design of a white cane, we intend to allow the user who may be familiar with how to use a white cane to have a better understanding of his or her surroundings without a much greater learning curve.

1.2 Background

Although reliable, seeing eye dogs are estimated to cost anywhere up to $50,000[3] and are not covered by health insurance. In addition to their high cost, such companions require several years of training and other overhead costs associated with them. Sighted guides are required to be trained by licensed specialists and are either typically family members or volunteer based. With the white cane, the user has independence while travelling and can still develop a meaningful sense for the environment around him or her. Additionally, white canes help others around the user identify that he or she is visually impaired through its globally recognized design.
Current issues with the standard white cane are that it limits the user's ability to identify key features of the environment through strictly tapping the cane against surfaces. Another issue is that the cane cannot identify the relative size of an object without other cues.

1.3 Functionality

The functionality of our project can be determined by three main high-level requirements:

A. Each of the cane's sensors must be able to detect an object within 0 and 1.2 meters from itself. Additionally, the cane must be able to detect objects between 0 and 0.7 meters in vertical height with respect to the cane.

B. The power source must allow the OptiCane to have an operating time of at least 3 hours.

C. The feedback mechanism must vibrate with intensity corresponding to the detected object distance and with a pattern corresponding to the uppermost sensor which detects the object.

2. Design

The final white cane assembly is comprised of sensors, a microcontroller, and haptic feedback to the user. The LIDAR sensors mounted along the shaft of the cane will be detecting for obstructions that enter their respective field of view and will relay that information to a central microcontroller. After receiving the sensor data, the microcontroller will then process an appropriate haptic feedback to relay to a vibration motor that is fixed to a wearable bracelet for the user. The vibration in the motor will have an associated intensity and pattern depending on the distance between the sensors and the height of which sensors are detecting an object. For example, if an object is 0.2 meters away horizontally from the lowest sensor on the cane and the second sensor spaced above it also detects an object, the vibrating motor will have 2 pulsed vibrations at a respective intensity.

The walking stick will require four separate modules in order to function: the power supply, control unit, feedback module, and sensor module. With the microcontroller connecting all modules together and acting as the "brain" of the project, the necessary information will be taken from the laser sensor array and used to create an intuitive feedback system. A removable battery will power all components, and a single pole single throw (SPST) switch will allow the stick to be powered on and off. This will allow for a versatile, lightweight walking stick and wearable bracelet combination for the user.

Below is a block diagram showing how each of these modules interact with each other:

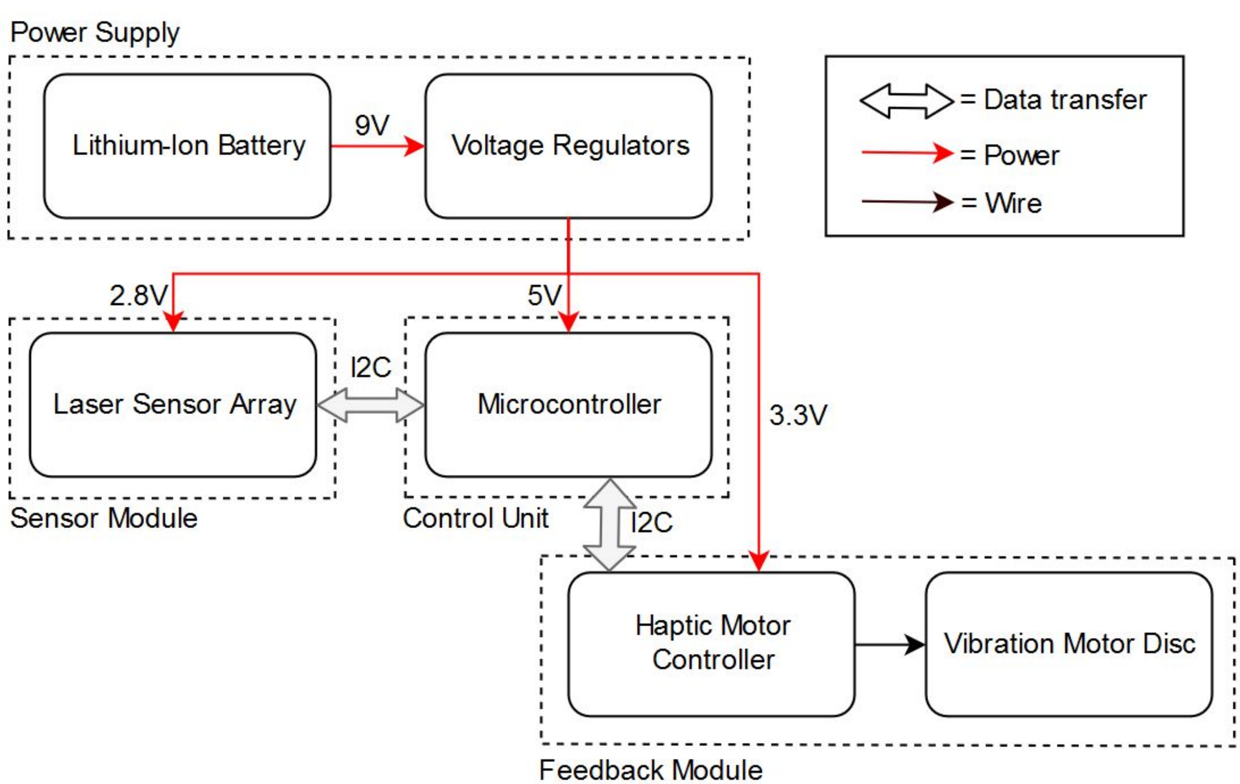

Figure 1. Block diagram for the OptiCane

Our physical design of the cane incorporates all of these major subsystems into a single compact package. As seen below in *Figure 2*, our final prototype has each sensor attached along the length of the cane fixed at 45 degree angles and are spaced approximately 13 inches apart from each other. The main black box mounted to the side of the cane contains both our 9V battery power supply and the main control unit circuit board. From the box, wires lead to a wearable bracelet in which the haptic motor controller and vibration motor disc sit.

Figure 2: Final prototype of the OptiCane

2.1 Power Supply

The purpose of the power unit is to supply the voltage required by each component of the design, such as the microcontroller, the sensors, and feedback module.

2.1.1 Lithium-Ion Battery

A 9V, 600 mAh Li-ion battery is used to power all hardware components that go into the walking stick and bracelet. A T-clasp wire connector is used to connect the battery, which allows the battery to be easily removable from the stick for either replacement or recharging. The use of a battery to power the walking stick will allow greater mobility for the user.

2.1.2 Voltage Regulator

To regulate the amount of voltage the devices in each module, we used several linear IC linear voltage regulators to provide a constant, fixed voltage to meet the power requirements for each device. In this way, we prevented unstable voltage inputs that could create inefficiency and/or damage in our project. Each of our sensors had 2.8V linear voltage regulators on their associated breakout boards while our motor driver had a 3.3V linear voltage regulator. For the microcontroller, we used a 5V linear voltage regulator in order to power it.

2.2 Control Unit

The control unit of the project consists of the microcontroller and all software components of the project. Data will be transferred to and from the microcontroller through I2C protocol for the sensor array as well as the motor driver.

2.2.1 Microcontroller

The control unit consists of the microcontroller which receives the necessary information from the sensors that in turn, sends the appropriate signals to the motor driver that controls the vibrating disc for haptic feedback. We implemented the ATmega328p microcontroller in our project because of its I2C communication capabilities. The ATmega328p has 2 kB of SRAM and 32 kB of flash memory. In order to operate the microcontroller, we used a 16 MHz crystal oscillator to provide a clock and 5V power supply that is stepped down from a 9V battery.

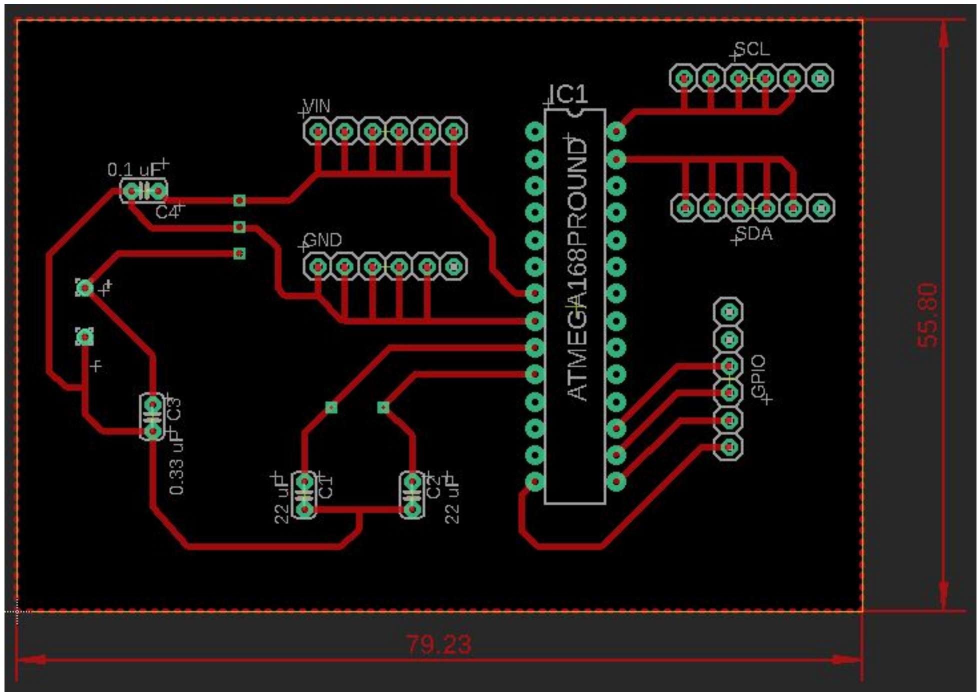

Figure 3: PCB schematic for microcontroller (dimensions in mm)

As seen in *Figure 3* above, our final revision PCB contains the ATmega328p microcontroller as well as the 16 MHz crystal oscillator and voltage regulator necessary to power the chip. From the chip, we utilized the I2C capabilities by creating buses for the SCL and SDA pins that would be directly soldered to the other external breakout boards. From the chip, traces were also made to GPIO pins 8-11 in order to use the addressability of each of the sensors that would allow us to use multiple sensors at once. The 5V and GND pins on the chip were also traced to in order to send power to all other breakout boards.

2.3 Feedback Module

The feedback to the user is given through a wearable bracelet. The bracelet contains a vibrating motor disc that provides feedback based on differing vibration intensities and vibration patterns. The vibration intensity indicates the distance of the object from the user in that the vibration intensity increases as the user moves closer to the object. Different vibration patterns indicate which sensor along the stick detects an object, allowing the user to get a rough estimate of the height of the object.

2.3.1 Haptic Motor Controller

The motor controller that we used is the DRV2605L. This motor controller communicates with the microcontroller via I2C protocol. The motor controller allows for finer control over the vibration disk’s vibration intensity as well as other vibrating effects that we implemented in the form of short pulse trains. The motor driver receives PWM values directly from the ATmega328p microcontroller that linearly relates the value to the measured distance data received from the LIDAR sensors. The PWM range at which we drive the motor driver is between 0 and 128. The most intense value of PWM=0 occurs when the closest measurable distance from a sensor is received.

Based on our code, we determined that we would map the vibration PWM values of 0 to 128 linearly to the sensor data receiving distance measurements of 0 to 1.5 m.

2.3.2 Vibration Motor Disk

The vibration motor disk is contained within an adjustable velcro bracelet to provide the user with the appropriate vibration pattern and intensity to indicate the object distance and height. Below in *Table 1* is a more detailed description of how the vibration pattern occurs.

Table 1. Sensor's corresponding vibration pattern for haptic feedback

Sensor Number (Starting from Bottom of Cane to Top)	**Vibration Pattern**
1st sensor (bottom)	A single vibration separated by a pause.
2nd sensor	Two vibrations in quick succession separated by a pause.
3rd sensor	Three vibrations in quick succession separated by a pause.
4th sensor (top)	Four vibrations in quick succession separated by a pause.

2.4 Sensor Module

The laser sensors we used for this project are VL53L0X Time-of-Flight sensors. They operate at 940 nm and measure the distance between a targeted object by emitting a laser and calculating the time it takes for the sensor to receive the beam back off of a reflected surface. The reason why we used these IR sensors as opposed to ultrasound for this project is due to the faster acquisition speed, narrow field of view, and level of precision in its measurements. The sensors are also able to be programmed to work in different operating modes which are default, long-range, and high frequency. For the purpose of this project, we set our sensors to operate in the long-range setting which is rated to sense a distance of up to 2.2 m. After initial tests, we determined that the absolute cut-off range that we would set each sensor to detect at to be 1.5 m, as we found it to be reasonable enough distance information for a user to have an understanding of the surrounding area.

2.5 Design Details

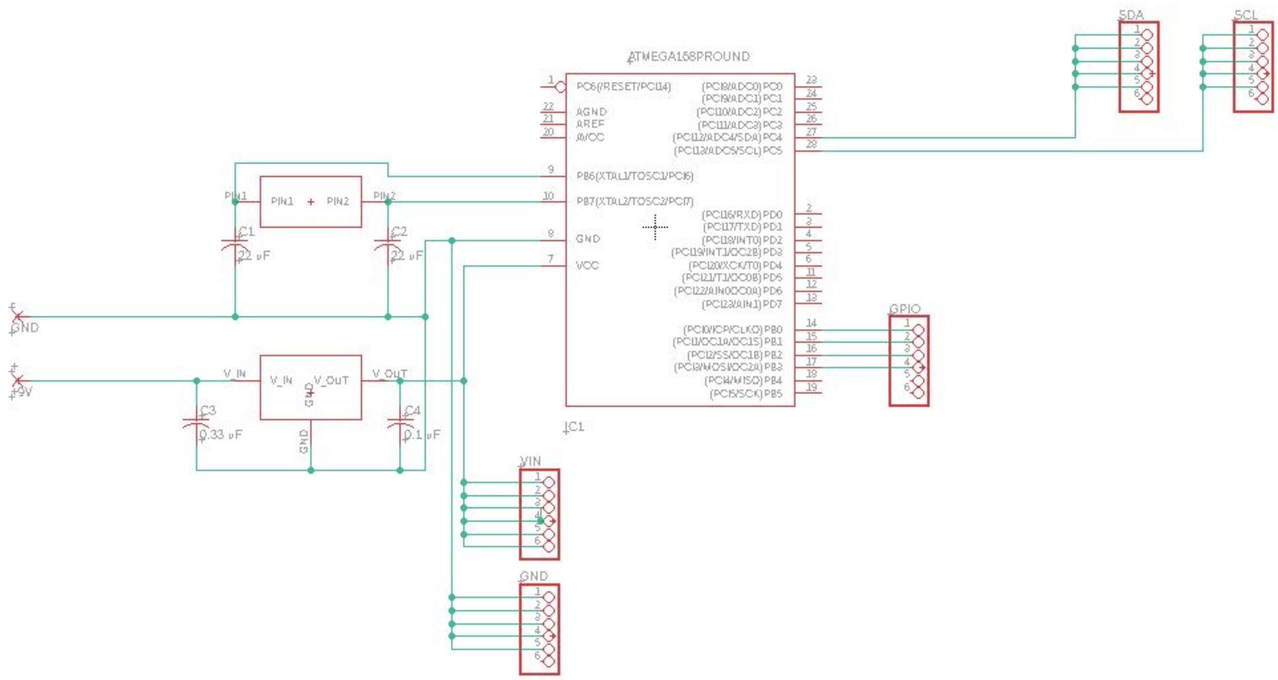

Figure 4. Main circuit schematic

Pictured in *Figure 4* is our main circuit schematic. The most prominent component that is shown is the ATmega328p microcontroller that we used to interface between the sensors and vibration motor driver. As discussed before, each of the GPIO pins that we used are connected to a general set of headers. Similarly, the SDA, SCL, and GND pins are also connected to respective headers. The VIN pins are all powered by the output voltage of the 5V linear voltage regulator. All of the pins are connected with wires to the associated headers located on our sensor and vibration motor driver breakout boards.

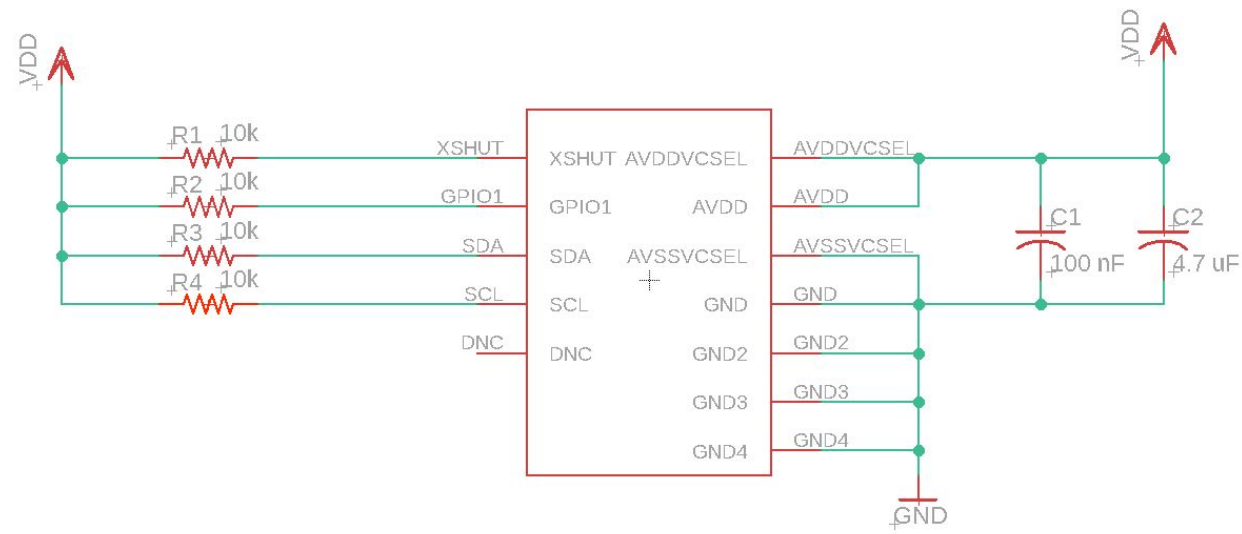

Figure 5. LIDAR sensor breakout board circuit schematic

Figure 5 shows the VL53L0X sensor with the appropriate pull-up resistor values necessary for it to operate as well as the capacitors needed for a stable connection. The XSHUT pin is connected to a GPIO pin on the main circuit board while the VIN, SDA, SCL, and GND pins are connected to their respective main circuit board pins accordingly.

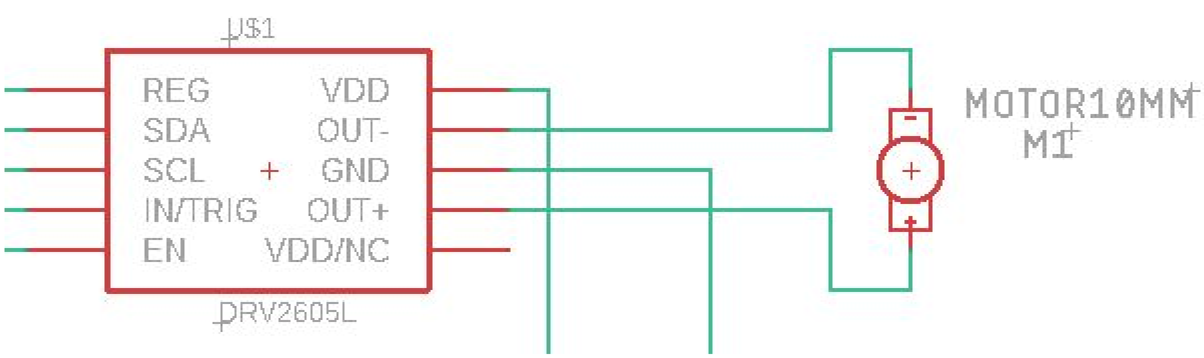

Figure 6. Haptic Motor Driver and Vibration Motor

Figure 6 similarly shows that each of the motor driver pins connects to an associated VIN, SDA, SCL, and GND pin that is placed on the main circuit board. The EN pin for our project was also tied high while the OUT- and OUT+ pins were directly soldered to our vibration motor leads.

2.6 Software

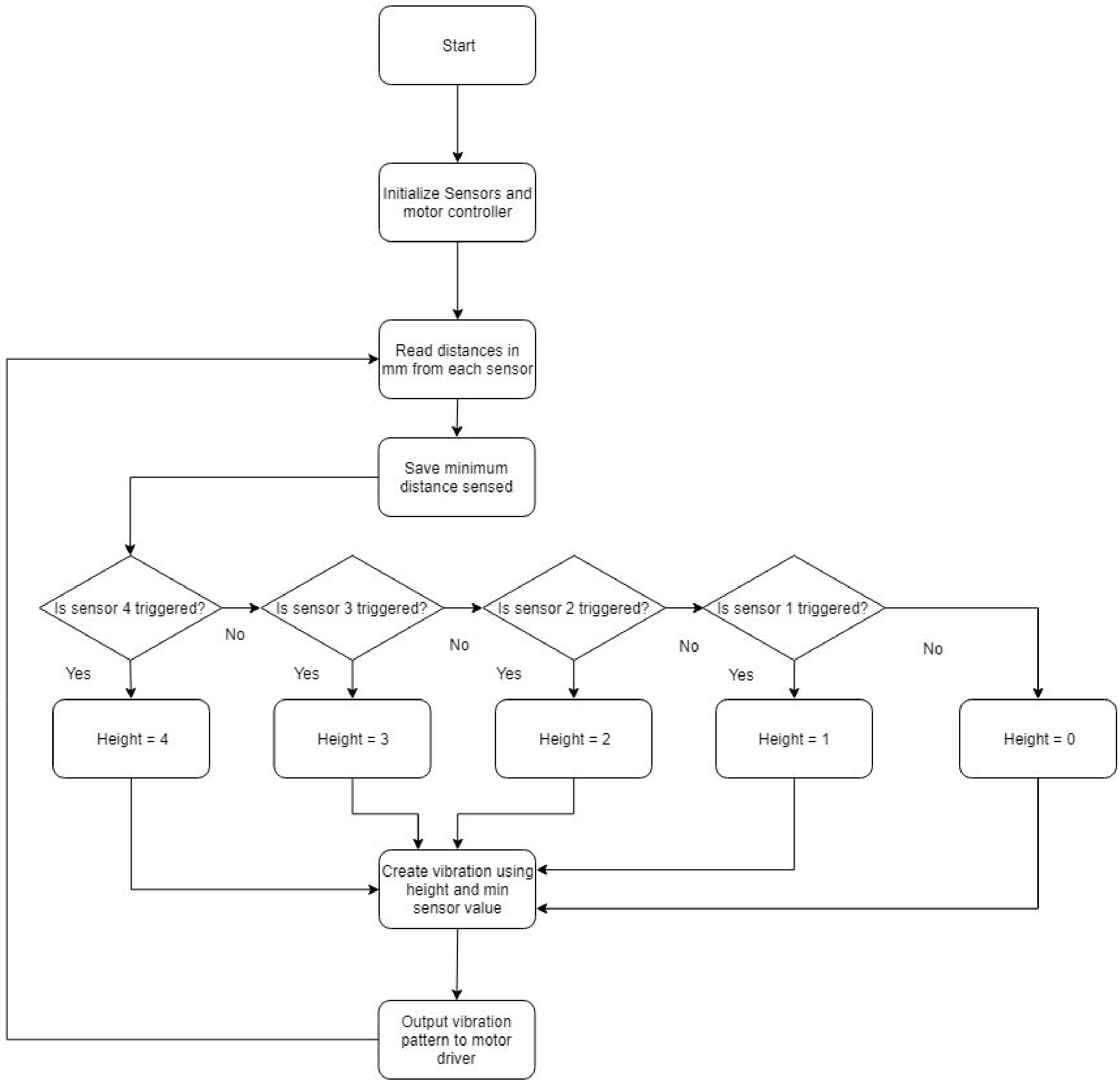

Figure 7. Software flowchart

Figure 7 shows our software flow chart. First, we initialize the sensors to operate in long range mode, which has a maximum sensing range of 2.2 meters. We also initialize the motor driver to operate in PWM mode. We then read the inputs from each of our sensors.

Since all the sensors are using the same SDA and SCL bus, we had to differentiate our sensors by giving them unique addresses. Each sensor has an active-low XSHUT pin that acts as a reset. In order to assign addresses to the sensors, we bring all sensors under reset and assign the addresses by bringing them out of reset one by one by setting their XSHUT pin high.

The sensors report measurements in millimeters and report a high constant value if they are out of range. We also set a max range of 1.5m, any measurements beyond that would be considered out of range. We take the minimum measured value out of all the sensors and saved that for later use. This value indicates the distance to the object sensed. The next set of conditionals in series is used to find the height of the object. If the top most sensor is triggered then the height will be set to 4. Else, if the third sensor is triggered, the height is set to 3. Similarly, the height would be set for the second and first sensors. If no sensors are tripped, the the height will be set to 0. Next, we produce the vibration pattern using the minimum distance reported by the sensors saved earlier and the height of the object. The vibration pattern will have number of pulses equal to the height and the intensity will correlate to the minimum sensed distance.

3. Design Verification

3.1 Power Supply

According to the datasheets of all required components in the OptiCane, we were able to find the maximum current draw of our project. This maximum current draw takes into account the current draw of all four sensors running in continuous sensing mode, as well as with the vibration disk vibrating at its maximum rated current. It also takes into account the current draw of the motor driver and the current draw of the ATmega328 microcontroller chip running at 5V, 16 MHz.

Table 2. Current drawn by each device in our project. Used to calculate total power consumption

Device	Quantity	Current
Laser sensor (active ranging mode)	4	76 mA
Haptic Motor Driver (average battery current during operation)	1	2.5 mA
Motor Disc (maximum rated current)	1	60 mA
Microcontroller (16 MHz at 5V)	1	10 mA
Total		148.5 mA

The 9V battery we used for our project is a 9V, 600mAh Li-Ion battery. By using the maximum current draw of the project, we were able to calculate that the cane would have a battery life of around 4 hours.

Battery Life = capacity of battery in mAh/load current = 600 mAh/148.5 mA = 4.04 hours

To meet the requirement for the 3 hour battery life of the OptiCane, we probed the voltage of a brand new 9V battery. The starting voltage of the battery was 9.69V. We then used this battery to run our OptiCane for 3 hours. The cane was set up to point towards an object so that the sensors would sense continuously and the vibration motor disk would constantly vibrate for the entirety of the 3 hours. At the end of the 3 hours, we probed the battery again and measured the final voltage to be at 8.57 V. The component with the highest voltage requirement is 5V for the microcontroller, and after probing the output of the voltage regulator for the microcontroller, we confirmed that we were still receiving 5V.

We were thus able to conclude that the OptiCane successfully lasted for the minimum 3 hours requirement of battery life and would last longer with further testing.

3.2 Control Unit

The microcontroller we implemented in our project was the ATmega328, which has I2C capability. For our project, we had the microcontroller act as the master device, with four sensors and the motor driver acting as slave devices (five slave devices in total). The four sensors and the motor driver needed to communicate with the microcontroller via I2C protocol to meet the requirement.

In order to verify that the components could communicate via I2C, we wired up the slave devices to the microcontroller using the setup shown in *Figure* 8 . We then set unique addresses for each slave device so that they could communicate using the same data (SDA) and clock (SCL) buses. Because the clock speed of the I2C bus is set by the master, we set our microcontroller to run at the standard speed for I2C protocol, which is 100 kbit/s. We successfully verified that our four sensors and motor driver could communicate at this speed by receiving data from the sensors and using that data to correspond with a unique vibration pattern given out by the motor driver to the vibration disk.

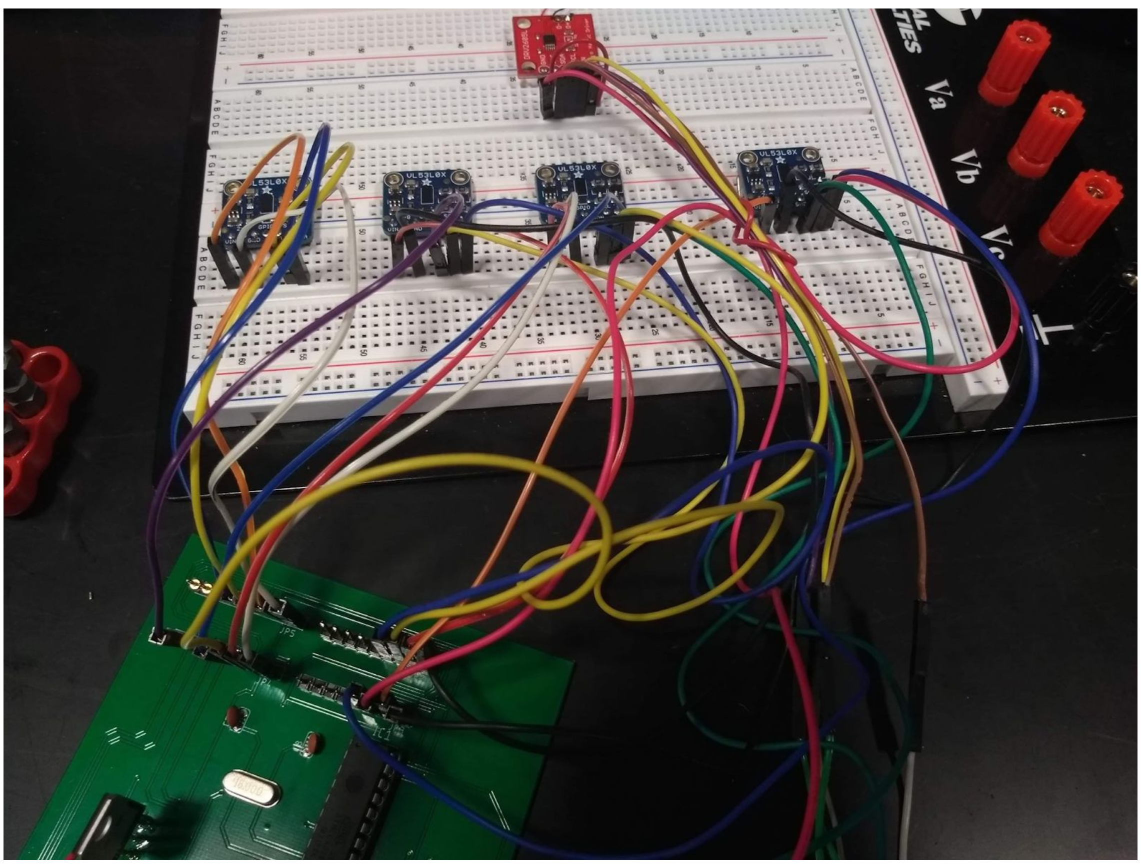

Figure 8 . Image showing wiring of all slave devices (four sensors and motor driver) to the master controller on the PCB for testing and verification

3.3 Feedback Module

We were able to successfully communicate with the motor driver via I2C at 100 kbits/s (see *Section 3.2*).

To verify that our vibration motor was vibrating at an intensity correlated to the distance of the object detected, we had to measure the PWM value output from the microcontroller to the motor driver. The PWM value ranges from 0-128, with 0 being the most intense and 128 corresponding to the least intense. From *Figure 9*, we can see that there is a linear relationship between the intensity of the vibration and the distance of the object detected. The farther the object, the less intense the vibration, and the closer the object, the more intense the vibration. In this way, we were able to verify the relationship between vibration intensity and distance of the object.

We were also able to verify that the feedback module correctly gives the user predetermined vibration patterns based on the sensor that was triggered. Using the setup shown in *Figure 8*, we assigned unique vibration patterns to each sensor, where the first sensor was assigned 1 pulse, the second sensor was assigned 2 pulses, and so on. By triggering a sensor, we were able to receive the correct number of pulses that corresponded with the sensor.

Table 3. PWM value measured at various distances

Distance(mm)	PWM Value
0	1
200	11
400	22
600	33
800	47
1000	56
1200	68
1400	76
1600	90
1800	100
2000	111
2200	122

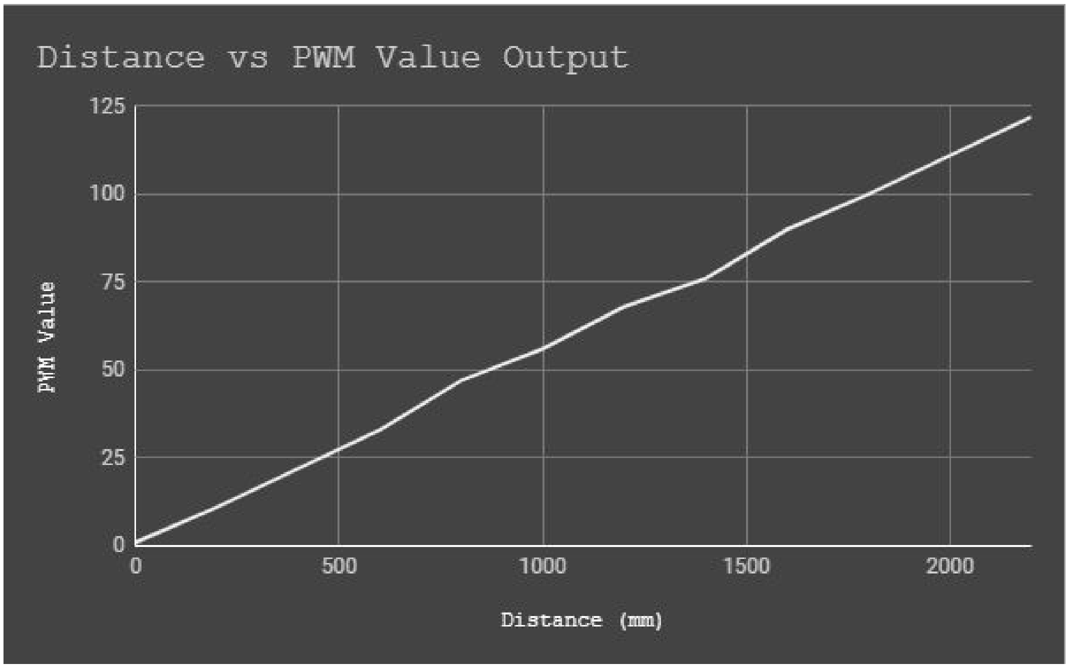

Figure 9. Plot of distance vs. measured PWM value

3.4 Sensor Module

To test the FOV of the sensors, we took a protractor to measure out 25 degrees and marked out that range using tape. We then took the sensor array and aligned the FOV of the sensors to the marked 25 degree measurement and moved an object in and out of the FOV. We found that the sensors accurately detected the object once it entered the 25 degree FOV. We were thus able to verify that the sensors were able to detect objects from within a 0 to 25 degree FOV.

We were also able to successfully determine the relative height of an object through the use of the sensor array. To test this requirement, we used the sensors on the cane as well as the vibration patterns that correspond to each sensor (see *Table 1*). We then used objects of varying heights to test that the correct sensor would detect that object by verifying with the vibration pattern. We used a small, 4-inch tall box to verify that the bottommost sensor would detect the object, which we verified with getting a single pulse vibration pattern. By using similar tests, we were able to verify that the sensor array could detect the relative height of various objects and that each sensor was able to contribute to height detection, which we verified with the vibration patterns.

To test the accuracy of sensing the location and distance of an object, we created a test in which we measured distances between 0 and 2.2 meters in 200 mm increments using the sensors. By placing an object at these set distances, we compared the output of the sensor measurements with the actual measurements. We then took the percent difference and From the plot in Figure 10 , we found that as the distance increased, the sensors became more accurate with the lowest percent error being about 0.25%. The large spike in the percent error at the shorter distance can be attributed to the absolute minimum distance that the sensor can actually detect, which was recorded to be about 23 mm. We were able to calculate the average percent error to be 2.017%, which means the cane is able to detect the distance of objects with around a 98% accuracy, which meets our requirement.

Table 4. Measured distance of object from sensor output and actual measured distance

Measured(mm)	Actual(mm)
23	0
219	200
407	400
617	600
807	800
1012	1000
1213	1200
1412	1400
1610	1600
1815	1800
2005	2000
2208	2200

Figure 10 . Plot of calculated percent error at each measured distance

4. Cost

4.1 Parts

Table 5. Parts cost table

Part Description	Quantity	Unit Cost	Cost
Haptic Motor Driver (DRV2605L, Texas Instruments)	2	$7.95	$15.90
Vibrating Motor (SparkFun)	4	$2.15	$8.60
Laser Sensor (VL53L0X, STMicroelectronics)	6	$14.95	$89.70
9V, 600mAh Li-Ion Battery - 2 pack (Energizer)	1	$2.00	$2.00
Microcontroller (ATMega328P, Microchip Technology)	1	$2.08	$2.08
Assorted resistors, capacitors, ICs, crystal (Digikey)	---	---	$10.00
PCB (PCBway)	1	$10.00	$10.00
Total Parts Cost			$138.28

4.2 Labor

The labor cost will be estimated using the average hourly wage of an entry level electrical engineer, which is about $33/hour. The group consists of three people, and each member of the group will spend 12 hours/week on the project. We will consider the design and development phase to be 12 weeks.

Total Labor Cost = 3 people * $33/hour * 12 hours/week * 12 weeks = $14,256.00

The total cost of the project including labor cost and parts cost will be **$14,394.28**.

5. Conclusion

5.1 Accomplishments

In conclusion, we were able to verify that our sensor array module was able to accurately detect the distances to obstacles and also measure the relative heights of objects according to our requirements. Additionally, the sensor array and haptic motor driver were able to effectively communicate with our microcontroller through I2C. Also, our haptic feedback module was able to correctly produce the desired vibration patterns and intensities. Since all of our subsystems met our requirements, we were able to clearly convey the information from our sensors to the user. As a whole, our project was very successful.

5.2 Uncertainties

Our biggest uncertainties lies in our PCB integration. We had difficulties properly fitting the microcontroller and battery onto our PCB which resulted in incorrect behavior. In the end however, since all of our requirements were verifiably met and in many cases exceeded, we did not have any uncertainties in our final product.

5.3 Ethical Considerations

Our project has several safely and ethical concerns to protect the user and the ones around them. The Opticane will guide users around obstacles through a safe path and not purposefully guide them through dangerous environments. The Opticane will not fabricate false information about the environment. The Opticane shall only be used as a navigation tool and not a weapon. Violating any these will infringe upon the IEEE Code of Ethics [7].

5.4 Future Work

5.4.1 Hardware Improvements

Further hardware and software improvements can be made to the Opticane. On the hardware side, Incorporating a battery gauge allows the user to know how much battery is left and can warn the user when the battery is close to depletion. Adding rechargeability to the battery will increase the ease of use of the Opticane allowing users to simply plug the cane in to charge instead of opening the casing and replacing the battery. The addition of gyroscopes or accelerometers will keep the sensors aligned with the ground. Incorporating a molded handle will keep the cane straight avoiding unintended twisting of the cane.

5.4.2 Software Improvements

On the software side, unique vibration patterns can be added to convey the information from the battery gauge. Unique stair detection can be implemented so the user can differentiate between walls and stairs. Finally, a way to easily vary detection range will be beneficial to users who are not comfortable with our 1.5m preset range.

References

[1] National Federation of the Blind, ‘Blindness Statistics’, 2019. [Online]. Available: https://nfb.org/resources/blindness-statistics. [Accessed: 3-February-2019].

[2] World Health Organization, ‘Blindness and vision impairment’, 2018. [Online]. Available: https://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment. [Accessed: 3-February-2019].

[3] Roberto Manducci and Sri Kurniawan, ‘Mobility-Related Accidents Experienced by People With Visual Impairment’, 2011. [Online]. Available: https://pdfs.semanticscholar.org/609b/3d62282eaa5c2e4a89c803c0b401a789e27d.pdf. [Accessed: 4-February-2019].

[4] Mikolajczak C., Kahn M., White K., Long R.T., ‘Lithium-ion batteries hazard and use assessment’, 2011. [Online]. Available: http://www.prba.org/wp-content/uploads/Exponent_Report_for_NFPA_-_20111.pdf. [Accessed: 4-February-2019].

[5] United States Department of Labor, OSHA Technical Manual Section III, Chapter 6, Laser Safety [Online]. Available: https://www.osha.gov/dts/osta/otm/otm_iii/otm_iii_6.html [Accessed: 20-February-2019].

[6] Bluedot, ‘How many Devices can you Connect to the I2C Bus?’. [Online]. Available: https://www.bluedot.space/tutorials/how-many-devices-can-you-connect-on-i2c-bus/ [Accessed: 20-February-2019].

[7] Institute of Electrical and Electronics Engineers, Inc, “IEEE Code of Ethics”, 2006, Available: https://www.ieee.org/about/corporate/governance/p7-8.html

Appendix A: Requirements and Verification Table

Note: All requirements were met and verified.

Power Supply

Table . Power supply RV table.

Requirements	Verification	Verification Status
Li-ion Battery : The battery should be able to provide the specified voltage for at least 3 hours while powering the Opticane.	Note: This requirement can only be verified after completing all other parts of the Opticane. 1. Attach the battery to the finished Opticane. Leave the Opticane on for 3 hours. 2. Probe the output of the 5V voltage regulator with a voltmeter. 3. This requirement is met if the voltmeter reads 5V (±5%).	Yes

Control Unit

Table . Control unit RV table.

Requirements	Verification	Verification Status
Microcontroller Interface: The microcontroller should be able to transfer I2C data from both the sensor array module and from the haptic motor driver at least 100 kbits/s according to I2C specifications.	1. Connect the sensors via the interface PCB to a pin on the ATmega328 chip. 2. Connect the vibration motors to the motor controller. 3. Connect the motor controller to a pin on the ATmega328 chip and power the motor controller with 3.3V (+/-0.3V). 4. Power the ATmega328 chip	Yes

	with 5V (+/-0.3V) power. 5. Write and load a test code that reads from the sensor pins and write different level outputs onto the ATmega328 chip. 6. Run the code. 7. The requirement is verified when the console prints the sensors' outputs and the motors are vibrating at an increasing intensity.	

Feedback Module

Table . Feedback module RV table.

Requirements	**Verification**	**Verification Status**
<u>Haptic motor and controller system:</u> A: The haptic motor controller should be able to receive I2C data to the microcontroller at least 100kbits/s according to I2C specifications. The vibration motor should operate within a 2V-3.6V range, which will correspond to the intensity of the vibration we need for the user feedback. B: The feedback module must also be able to vibrate at predetermined patterns.	A: 1. Connect the motor controller to an output pin on the ATmega328 chip and power the motor controller with 3.3V. 2. Power the ATmega328 chip with a 5V (+/-0.3V) power supply. 3. Write and load test code that writes different levels to the motor points onto the ATmega328 chip. 4. Run the code 5. The requirements are verified if the motors are vibrating at an varying intensity depending on the test code. B:	A: Yes B: Yes

	1. Change the code so that it supplies voltages at various patterns to the motor controller. Examples of patterns include 2 or 3 vibrations in quick succession followed by a long pause. 2. This requirement is met when the vibration motors correctly vibrate in the pattern specified by the code.	

Sensor Module

Table . Sensor module RV table.

Requirements	**Verification**	**Verification Status**
Optical sensor array: A: The sensor array composed of 4 optical sensors should be able to detect objects within a FOV between 0 to 25 degrees. The sensor array should also be able to detect an object from 0 to 1.5m from each sensor and determine the distance of the object to each sensor. B: The sensor array must determine the relative height of the object based on how many sensors detect it with a tolerance of 1 more sensor up or down. C: The sensor array must correctly sense the location and	All requirements: 1. Connect each sensor via the interface PCB and connect the PCB output to the microcontroller. 2. Connect each sensor to 2.8V±%5. 3. Load a test code which analog reads the outputs of the sensors and prints the values of each sensor to the console with 33ms intervals A: 1. Using a protractor or a compass to measure 25 degrees and mark two lines with masking tape from the sensor to 1 m(+-5cm) out in a V-shape with the sensor facing the center of the angle. Use a tape	A: Yes B: Yes C: Yes

range of an object with at least 90% accuracy	measure to precisely measure the distance. 2. The requirements are verified if the console reads different distances when the test object enters and leaves the effective range. The range must be verified to be 1.5m(+-5cm). Also, the outputs must correlate to the distance of the object from each sensor. B: 1. Move an object up and down in the effective range of the sensor array. 2. This requirement is met if each sensor outputs different values relative to the height of the object. It is within tolerance if the sensor above or below also reads the object. C: Set up the sensor so that the measurements can be read from the serial monitor. Place the sensor array at the end of a measuring tape. Place and object starting at 0 cm away from the sensor and record the value measured through the serial monitor. Move the object away from the sensor at 20 cm increments until 120 cm. Record the measured distance and compare with the actual distance and calculate the percent error. This requirement is met if the error is less than 10%.	

Appendix B: Datasheets

Laser Sensor Datasheet:

http://www.st.com/content/ccc/resource/technical/document/datasheet/group3/b2/1e/33/77/c6/92/47/6b/DM00279086/files/DM00279086.pdf/jcr:content/translations/en.DM00279086.pdf

Haptic Motor Driver Datasheet:

https://cdn.sparkfun.com/datasheets/Robotics/drv2605l.pdf

Vibrating Motor Disc:

https://cdn.sparkfun.com/datasheets/Robotics/B1034.FL45-00-015.pdf

ATMega328P Datasheet:

https://cdn.sparkfun.com/assets/c/a/8/e/4/Atmel-42735-8-bit-AVR-Microcontroller-ATmega328-328P_Datasheet.pdf?fbclid=IwAR1_w2gqvp3GUWK-siz1_DRUs5xwcgb-ZO9kI6PWYCZ6jBiT47qgcbTex4Q