ProxiPole

An Electronic Walking Stick for the Visually Impaired

Team 29

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1. Introduction

1.1 Objective

One of the main objectives of creating an enhanced walking stick capable of sensing surrounding objects is to create an electronic system that is portable, reliable, and durable enough to be mounted on the lightweight walking sticks currently in use. Many of the attempts at enhanced walking sticks have only included single-dimensional information, like the object range, and typically only include one proximity sensor.[1] These solutions really only give the user rudimentary range and direction information. The inclusion of an array of sensors can give the user an even better understanding of exactly where, and how far, the detected obstacle is. This can provide a significant improvement over current solutions.

The goal of ProxiPole is to allow its users to have an enhanced understanding of their surroundings by using electronic sensors. ProxiPole will make use of a small array of laser proximity sensors, haptic motors, and audio devices to detect incoming obstacles and alert the user to their approximate range and direction. This information will allow the user to have a heightened awareness of their environment, and by extension afford them the opportunity to make better informed decisions.

1.2 Background

Currently, there are approximately 253 million people in the world who suffer from some form of vision loss, with 36 million of those people being completely blind.[2] Although many blind people are able to adapt very well to a life without sight, there are still many issues they have to deal with that normally-visioned people do not even think twice about. Auxiliary issues associated with blindness include non-24-hour sleep-wake disorder,[3] depression,[4] anxiety,[5] and many more. One of the main obstacles that blind people face is navigating their surroundings, especially in unfamiliar environments. A lack of situational awareness can pose serious threats to the safety of blind people, and many tools have been created to aid them in increasing that awareness. One of the main tools that the visually impaired use is a walking stick. They sweep the stick out in front of them to physically probe for objects, allowing them to avoid obstacles and to navigate other changes in their environment. Because of the issues that blind people face, it’s a moral imperative to help them as much as possible to make their lives easier.

1.3 High-Level Requirements

1. The electronic walking stick should be equipped to detect and alert the user of any obstacle and its direction, that lies within a sector range of 100° ahead of it and a straight distance of 2 meters.
2. The user will be alerted of the horizontal distance from the obstacle via the vibration motors' intensities. The intensity will increase in magnitude when the user starts closing in to the obstacle. Additionally, the installed speaker would also sound an audible beep when the obstacle is extremely close to the user.
3. An SOS Panic button will be installed in the stick. When pressed, this will output a catchy noise and a voice message, asking for assistance, from the speaker to alert surrounding by-standers for aid.

2 Design

2.1 Block Diagram

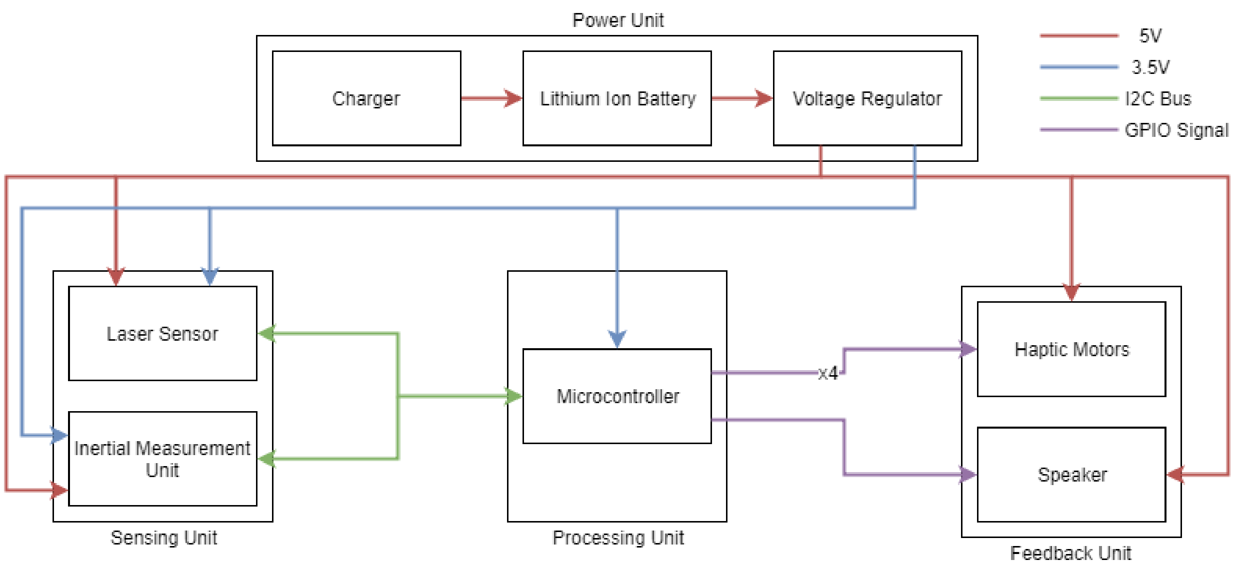

Figure 1: Block Diagram of ProxiPole

This design provides our system with the four main components that are needed: a power system to power the components, a sensing system that will provide spatial and locality information, a microcontroller to process the input, and the feedback system that will report to the user information about their surroundings.

2.2 Circuit Schematic

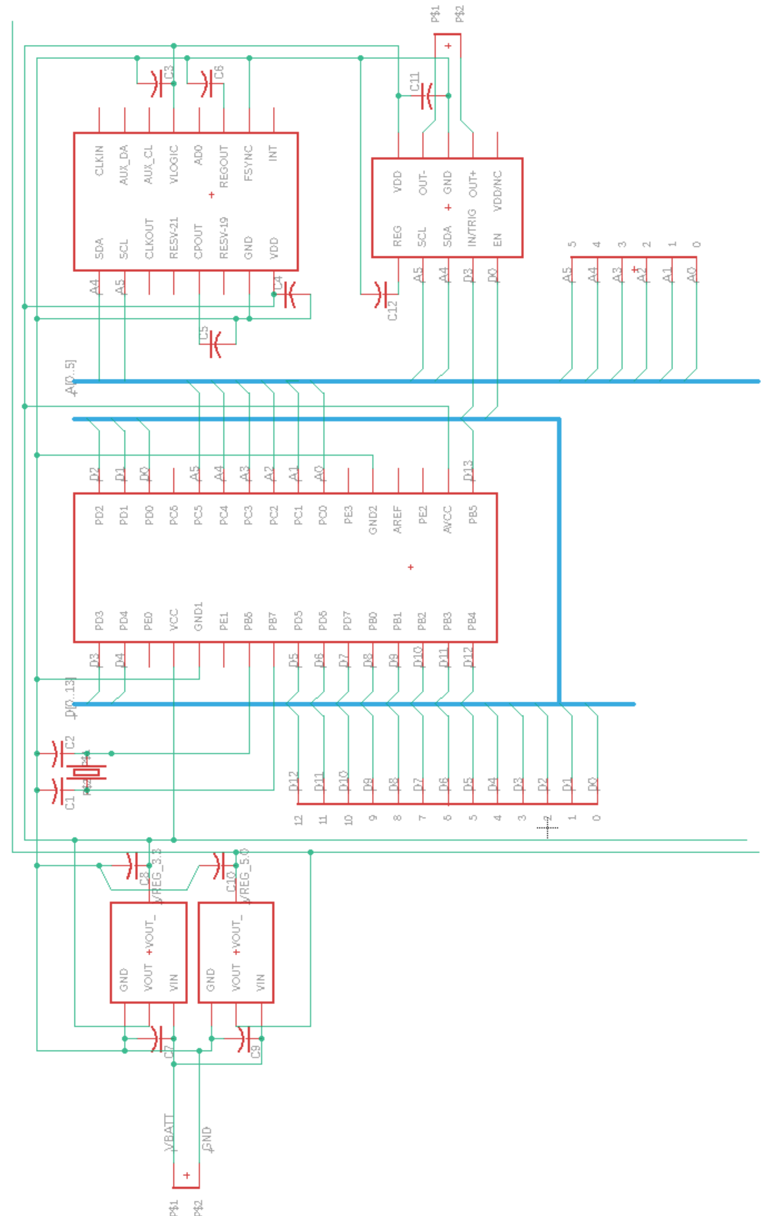

Figure 2: Schematic of Main Circuit

This is the Main circuit board schematic which contains the voltage regulator, microcontroller, IMU, and motor driver. Terminals will be used for connecting the external laser sensors.

2.3 Physical Design

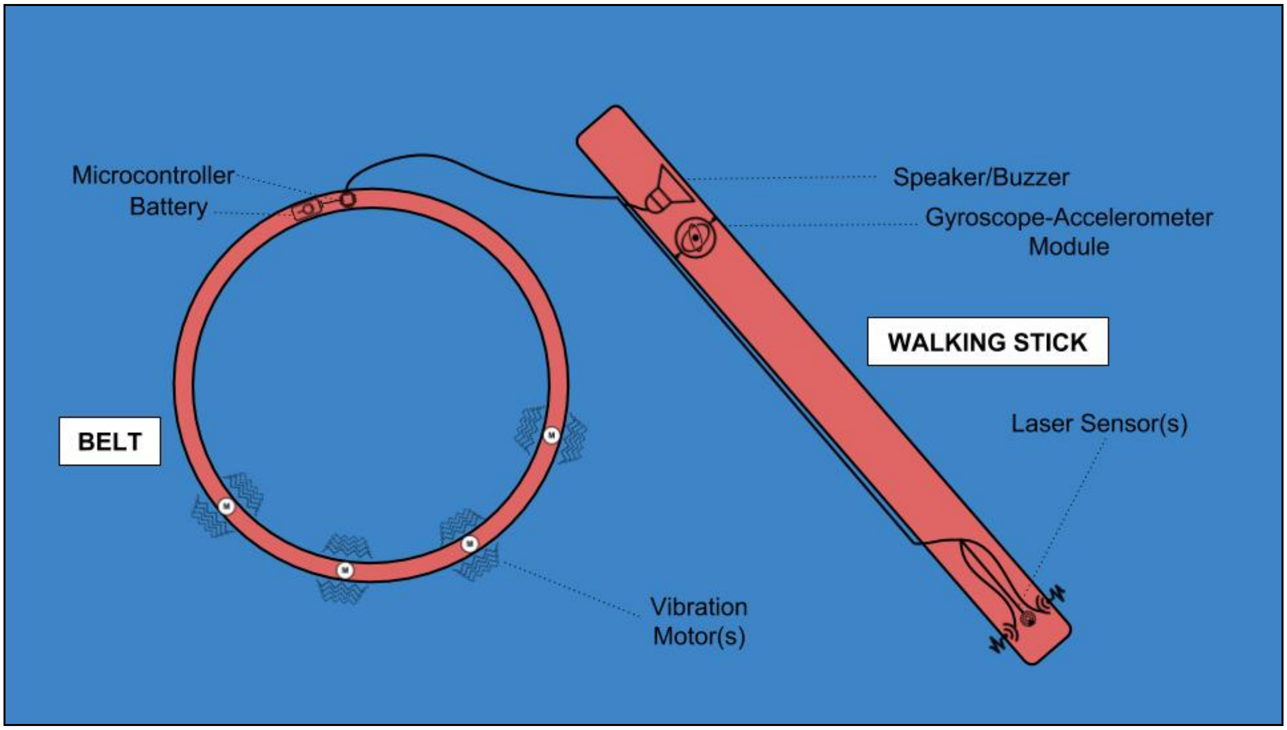

Figure 3: Physical Design of ProxiPole

We aim to to have 2 physical modules comprising our final device. These would be a belt unit, that will be worn around the user's waist, and the actual electronic walking stick, which will be handheld. In order to minimize the weight of the walking stick, the main circuit component and power source will be fitted onto the belt itself, as depicted in Figure 2. Lastly, our walking stick will also have a grip that would make it easier to hold on to.

2.4 Functional Overview

The block diagram is separated out into 4 main components, the power system, the sensing system, the microcontroller, and the feedback system.

2.4.1 Power System

The power system will provide the power necessary to drive both the digital circuitry (including the sensors and the microcontroller) and the haptic motors. The power will be supplied with a bank of rechargeable Lithium Ion batteries that are recharged through a proprietary lithium ion charger. We do not intend to implement our own charging system because of the dangers associated with accidentally overcharging Li-ion batteries. The power system will also need to be regulated through a power regulator. The regulator will ensure that each of the components in the entire system are receiving the voltage necessary for safe operation, as well as providing electrical shorting safety mechanisms (implemented with simple fuses).

2.4.2 Sensing System

The sensing system will provide our product with sensing capabilities of the outside world. There will be two main types of information provided: object locality/object distance through the use of infrared laser sensors, and system orientation through the use of electric gyroscopes and accelerometers, in a circuit called Inertial Measurement Unit (IMU). The IMU will be used primarily to determine the true direction of detected objects relative to the user as the user sweeps the stick back and forth. The reason why this is needed is because we require the system to activate the haptic motor that points to the actual location of the detected object, irrespective of the orientation of the walking stick at any point in time.

The IMU will be a 3-axis system that uses a combination of accelerometers and gyroscopes to determine spatial orientation and location. The board will feature an on-board digital processor that uses the MotionFusion algorithm to interpret raw sensor data into spatial location that will be sent to the microcontroller via I2C. The algorithm is factory-implemented on the chip, so our product will not have to directly interact with the algorithm.

2.4.3 Microcontroller

The microcontroller will be the central component that translates incoming sensor data into user feedback. This chip will receive incoming input data from the IMU and the proximity sensors, and implement a basic algorithm to determine the position of the detected object relative to the user and activate the corresponding haptic motor. If the chip detects an object is within a predetermined threshold, it will sound an audible alarm. The program that is executed on the microcontroller will be written in C and compiled to the native architecture of the chip. Additionally, some minor circuitry will be needed to implement a clock for the microcontroller.

2.4.4 Feedback System

The feedback system will be what provides the user with information on object range and locality. It will be a fairly simple system that comprises of 4 haptic feedback motors, and one audible speaker mounted on a wearable belt. These devices will be connected to and controlled by the microcontroller. Each of the haptic motors is driven by a driver circuit, which itself is toggled on and off by the microcontroller. This driver circuit is necessary because the microcontroller is not capable of sinking enough current to the motors.

2.5 Software Flowchart

The ATmega328 Microcontroller will handle all the software computation of the project. It's primary function would be determine which motor to activate and with what intensity. This control logic will have the following inputs and outputs:

- Inputs: IMU Angle Measurements (A_x , A_y , A_z), Laser Sensor # (L), Measured Distance (D)
- Outputs: Motor # to activate (M), Intensity (I)

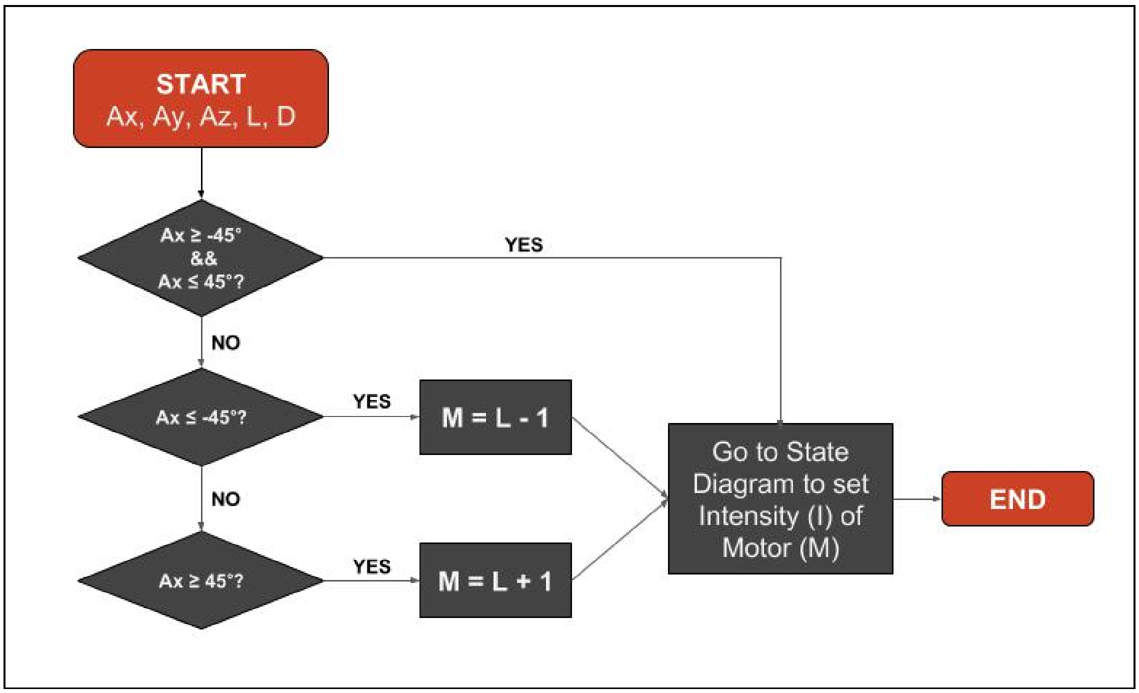

Figure 4: Software Flowchart

It can be possible that multiple laser sensors record readings of an incoming obstacle at the same time, the above flowchart will work for each sensor-motor pair individually, making sure that more than one motor gets activated, if need be.

2.6 Software State Diagram

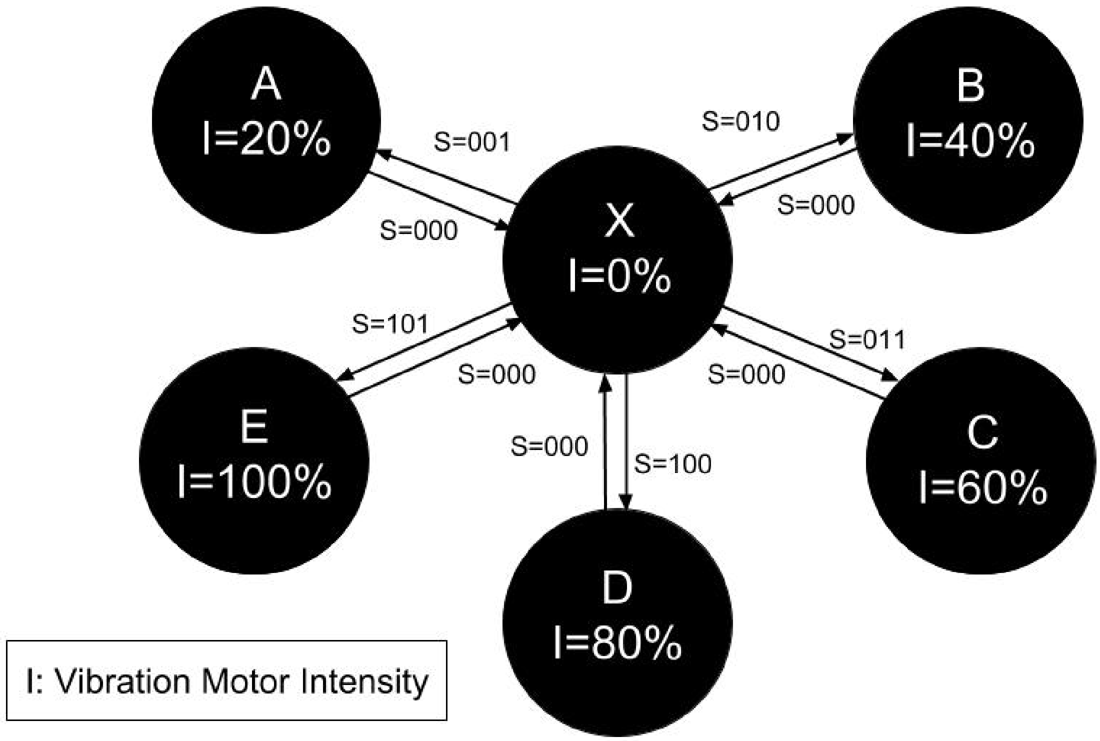

Figure 5: Software State Diagram

States	**A**	**B**	**C**	**D**	**E**	**X**
Measured Distance (D)	(1.5m, 2m]	(1m, 1.5m]	(0.5m, 1m]	(0.25m, 0.5m]	(0m, 0.25m]	>2m

- The states in the block diagram refer to inputs from each laser proximity sensor.
- After obtaining the select bits, S, and the Intensity, I, we will map sensors to respective motors in the belt unit based on the reading from the accelerometer and gyroscope.

2.7 Tolerance Analysis

The primary conduit for successful operation of this system is its ability to reliably detect obstacles within a certain horizontal and angular range. The required angular range of 100 degrees in front of the sensing array can be met almost universally by simply adjusting the number of sensing units attached to the pole. Intuitively, if sensors are used that have a very small angular range of sensing, the required 100 degrees is achieved by adding more sensors. The number of sensors *n* required with individual sensing ranges *r* is simply

Eq 1

$$n = \frac{100}{r}$$

However, it must also be noted that an upper bound is placed on the number of sensors the microcontroller can poll every second. In typical I2C communications, 2 bytes are reserved for header information (device addressing, acknowledgements). 7 of these bits are reserved for addressing, so theoretically only 128 devices may be connected to a single bus. The remaining message payload is determined by the individual device's requirements. The upper bound for the number of sensors a given microcontroller can handle is thus:

Eq 2

$$n_{max} = min(\frac{s}{x}, 128)$$

Where n_{max} is the theoretical upper bound, *s* is the number of transmitted bytes required to perform a poll of a single sensor (including headers), and *x* is the number of bytes per second the microcontroller can send through the I2C bus. This value itself is a function of clock speed and the corresponding microcontroller's MIPS speed.

The ATMega 328p microcontroller we will use will be clocked using a 15 MHz oscillator. According to the 328p datasheet, it is capable of executing 20 MIPS (million instructions per second) at a 20 MHz clock. This means that at 15 MHz, it should be capable of executing 15 MIPS. An extremely liberal estimate is that each poll of a sensor requires 500,000 instructions. Dividing the MIPS performance by the number of instructions per poll, we see that the upper bound for the number of sensors capable of being polled is

$$15,000,000 / 500,000 = 30$$

The field of view (FOV) of the VL53L1CXV0FY/1 is 27 degrees. Using equation 1, we see that we would need 3.7 sensors to cover the overall 100 degree FOV. This is well within the upper limit discovered using liberal estimates for the polling instruction cost.

3 Requirements and Verification

3.1 Power System [5 points]

Requirements	Verification
1. The power system should be able to maintain three voltage sources: 2.8V, 3.3V, and 5.0V with a tolerance of ±10% for each voltage.	1. A three step process needs to be implemented. To perform the test, disconnect the power supply from the rest of the circuit. Then, perform the following steps: a. Draw 900mA from the 5V source and measure the amount of voltage fluctuation b. Disconnect from 5V, and draw 900mA from 2.5V and measure fluctuation. c. Disconnect from 2.5 and draw 900mA from 3.3V source, measuring voltage fluctuation. If at any step in this process the voltage remains within 10% of the target voltage, the verification succeeded.
2. The power system's output must be fault protected so that no more than 1 amp of current can be drawn at any given point in time.	2. To test the fault protection, draw 1.5A from each source individually to see if the system will fault for singular sources. Then, draw 0.5A from each source at the same time to test that drawing 1.5A in total across all sources will also engage fault protection. If both of these tests succeed, then verification for the fault protection has succeeded.

3.2 Sensing System [15 points]

Requirements	Verification
1. The range-finding sensors should be able to detect an object within a cone around the array of 100 degrees (+- 27 degrees in either direction from each sensor)	1. Since this is only an angular test, we only need to test for an object that is well within the system's sensing range. Define 0° as directly in front of the sensor, -90 as left, and 90 as right. In a well-lit area (outdoors or a well-lit room), move a white piece of paper starting from -90° to 90°, keeping half a meter from the sensor. Note the angle at which the sensor begins to detect the object, and at which it ceases detection. If their difference ≥ 100°, this verification succeeded.
2. The sensing system should be able to detect obstacles with a 90% success rate at a distance of 1 meter in broad daylight.	2. To test this requirement, print out 10 pieces of paper that have varying degrees of darkness, from white to black. Place each piece of paper directly in front of the sensors, 1 meter away. If the system fails to detect at most 1 piece of paper, the verification succeeded.
3. The sensing system should be able to detect objects with 25% success at a distance of 2 meters.	3. Using 8 pieces of paper that have increasing gradients of black, individually test each paper by placing it 2 meters directly in front of the sensor, similar to verification 2. If the sensor fails to detect at most 6 pieces of paper, the verification succeeded.
4. The combined sensing system should be able to detect an object and deterministically identify an angle of detection relative to the holder of ProxiPole.	4. Have a blindfolded user hold the ProxiPole. Another person will randomly place a piece of paper 0.5 meters in front of the system within the 120° cone of sensing. The blindfolded user will point in the direction, the haptic motors indicate. 4 of these random angles will be selected. If the user fails to point directly at the piece of paper during any of the tests, the verification failed.

3.3 Microcontroller [15 points]

Requirements	Verification
1. The microcontroller must be capable of addressing 4 separate laser sensors through its GPIO pins with the I^2C protocol using a shared bus.	1. This verification is simply inherent in the design of the circuitry. If all 4 lasers can be communicated with using a shared I^2C bus, then the verification succeeded.
2. The microcontroller must be fast enough to allow it to poll all 5 sensors (4 proximity and 1 IMU) and activate the 5 feedback units (4 haptic motors and 1 audible alarm) at least 4 times a second.	2. The microcontroller will be operating in an infinite loop, continuously polling the sensors and activating the feedback system as needed. To test this, pick a free GPIO pin and program the microcontroller to toggle the pin at the beginning of its loop. Connect this pin to an oscilloscope and measure the frequency at which the pin oscillates. If it oscillates ≥ 4 times/sec, the verification succeeds.

3.4 Feedback System [15 points]

Requirements	Verification
1. The feedback system should be able to activate our motors given a microcontroller input.	1. Test to see that all of the motors are activated according to the direction of the detected object by individually placing a white piece of paper 10cm in front of each sensor.
2. The speaker should emit a characteristic tone that will indicate an imminent collision given microcontroller input.	2. Place a white piece of paper 1 meter away from the sensors and decrease its distance until the paper is touching the sensors. Note the point at which the audible alarm sounds. This point should be no less than 20 cm away from the sensors.
3. The driver circuit must be capable of activating all haptic motors at full power.	3. Place a white piece of paper 10 cm away from all sensors and test to see that all 4 haptic motors are activated. Confirm full power by measuring peak PWM voltage to each motor.

4 Schedule

Date	Description	Landon	Fernando	Arvind
9/29	Agree on which parts we will use			
9/30	Schematic draft completed		X	
10/2	Write majority of proposal	X	X	X
10/3	Proposal completely written	X	X	X
10/4	Design document due. Proposal cleaned up and submitted			
10/10	Part list finalized	X	X	X
10/11	Parts ordered	X		
10/12-10/13	Research hardware for walking stick, buy hardware			X
10/15	Teamwork evaluation I			
10/19	Soldering assignment			
10/20	Parts arrive. Construct prototype circuit.		X	X
10/24	Program for microcontroller finalized, uploaded, tested.		X	X
10/25	PCB Order deadline (first round)	X		
10/29-11/5	Catchup Week			
11/5	Individual progress reports			
11/8	PCB has arrived. Solder parts onto board	X		
11/8	PCB order deadline (final round)			
11/9	Last day for revisions to the machine shop			
11/12	First prototype of Proxipole completed	X	X	X
11/13	Verification of Proxipole. Identify issues, create action plan to address.	X	X	X
11/14-11/24	Rapid iteration of ProxiPole. Fix bugs as they arise, create multiple prototypes.	X	X	X
11/24	ProxiPole completed	X	X	X
11/25-12/2	Catchup week			
12/11	Presentation			
12/12	Final papers due			

5 Cost Analysis

Part Name	Quantity	Cost / Item	Cost	Cost (Mass Production)
3-Axis Gyro/Accelerometer IC - MPU-6050	1	$12.95	$12.95	$11.25
Arduino A000066 (ATmega328)	1	$22	$22	$20.00
Laser Proximity Sensors (VL53L1CXV0FY/1)	4	$6.43	$25.72	$22.00
Vibrating Mini Motor	12	$1.95	$23.40	$21.60
Motor Driver	4	$6.95	$27.80	$27.00
CSM-7X SMD CRYSTAL	1	$0.46	$0.46	$0.46
Voltage Regulator	1	$0.44	$0.44	$0.44
Terminal Blocks (Phoenix Contact 1935187)	7	$0.80	$5.60	$5.25
Piezo Speaker Module	1	$3.49	$3.49	$3.20
Lithium Ion Battery - 3.7v 2000mAh	2	$12.50	$25	$22.5
0805 2.2 kOhm Resistor	20	$0.084	$1.68	$0.80
0805 0.1uF Capacitor	20	$0.195	$3.90	$0.084
0805 1.0uF Capacitor	20	$0.081	$1.62	$0.064
0805 4.7uF Capacitor	20	$0.127	$2.54	$0.10
0805 2.2nF Capacitor	20	$0.046	$0.92	$0.036
0805 10nF Capacitor	20	$0.131	$2.62	$0.048
28 pin IC socket	5	$0.71	$3.55	$0.47
Total			**$163.69**	**$135.30**

In addition to the above cost of the inner product circuitry, we would like to include the price of other physical material included in the development of ProxiPole. A waterproof belt, that would hold the main PCB unit and the battery pack, would cost $10 and the hollow stick capable of housing inner wiring, sensors and speakers would cost about $15. However, for mass production these would be purchased at a subsidised cost of $7 and $10 respectively.

With 3 members on the team, who put in 12 hours/week valued at $35/hr, we spent 16 weeks building the prototype. This would add up to a labor cost of:
3 *x* (12 hours)/week *x* 16 weeks *x* 35 $/hour = **$20,160**

The total cost, including our development cost and labor cost, would be around $20,323.69

6 Safety and Ethics

6.1 General Ethics

This project was motivated by the lacking technology to aid the visually impaired. Part of our ethical requirements is to hold the health and safety of other people with high regard[6]. By tackling this project, we will be improving the safety and overall quality of life for the blind. Our goal is that the project will make navigation easier for the blind while reducing the amount of stress they get from that navigation, especially in new environments. Additionally, according to the 9th item from the IEEE code of ethics, we should be avoiding the injury of others in their property[6]. Our project will take every precaution in ensuring the safety of the users especially in those areas of highest risk such as those highlighted in the next section.

6.2 Laser Safety

The range finding sensors we propose to use are a class 1 laser of the infrared spectrum. Our design will use several of these sensors which could be pointed by the user in any general direction. According to IEC 60825-1:2007, Such class 1 lasers are completely safe under normal operating conditions and even if viewed by the naked eye under normal telescopes and microscopes[7]. With such a classification we can be assured that the lasers will be harmless in our application.

6.3 Lithium-Ion Batteries

Lithium batteries can be very dangerous if care is not taken to insure proper functionality. In general these batteries can overheat and become damaged very easily from a short circuit. Our design will take this into consideration and strive to eliminate this possibility. Furthermore, lithium batteries can be damaged from over discharge and overcharge. We plan on implementing over discharge protection into our power subsystem and purchase a 3rd party charger to keep the battery within acceptable voltages.

References

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[3] American Academy of Sleep Medicine. International Classification of Sleep Disorders, Revised: ICSDR (Diagnostic and Coding Manual). Chicago, Illinois: American Academy of Sleep Medicine, 2001.

[4] H. G. Choi, M. J. Lee, and S.-M. Lee, "Visual impairment and risk of depression: A longitudinal follow-up study using a national sample cohort", *Scientific Reports*, vol. 8, no. 1, Jan. 2018. License: http://creativecommons.org/licenses/by/4.0/

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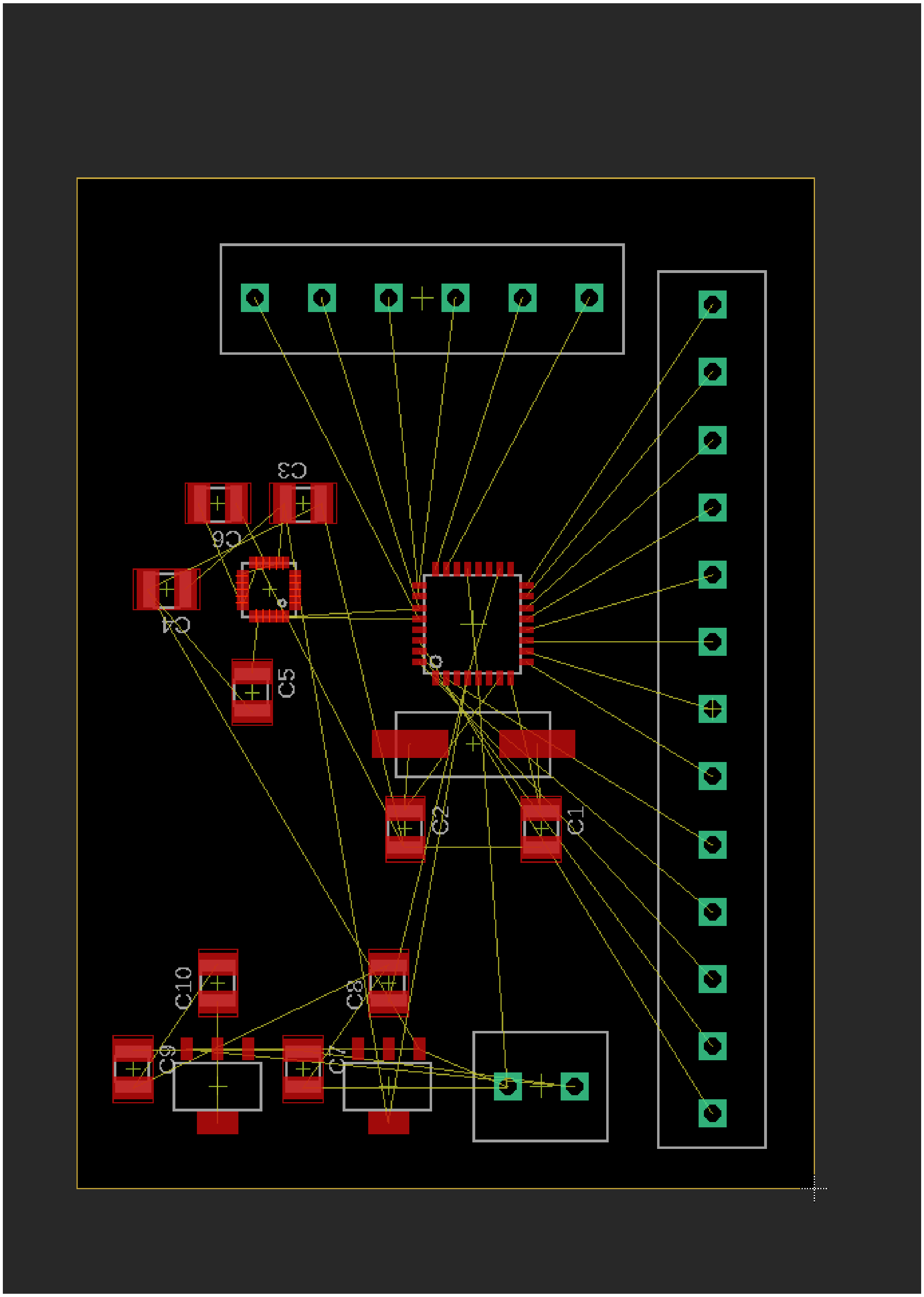
[6] "IEEE Code of Ethics," *IEEE - Advancing Technology for Humanity*. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 27-Sep-2018].

[7] World Health Organization. (2018). *Blindness and visual impairment*. [online] Available at: http://www.who.int/en/news-room/fact-sheets/detail/blindness-and-visual-impairment [Accessed 18 Sep. 2018].

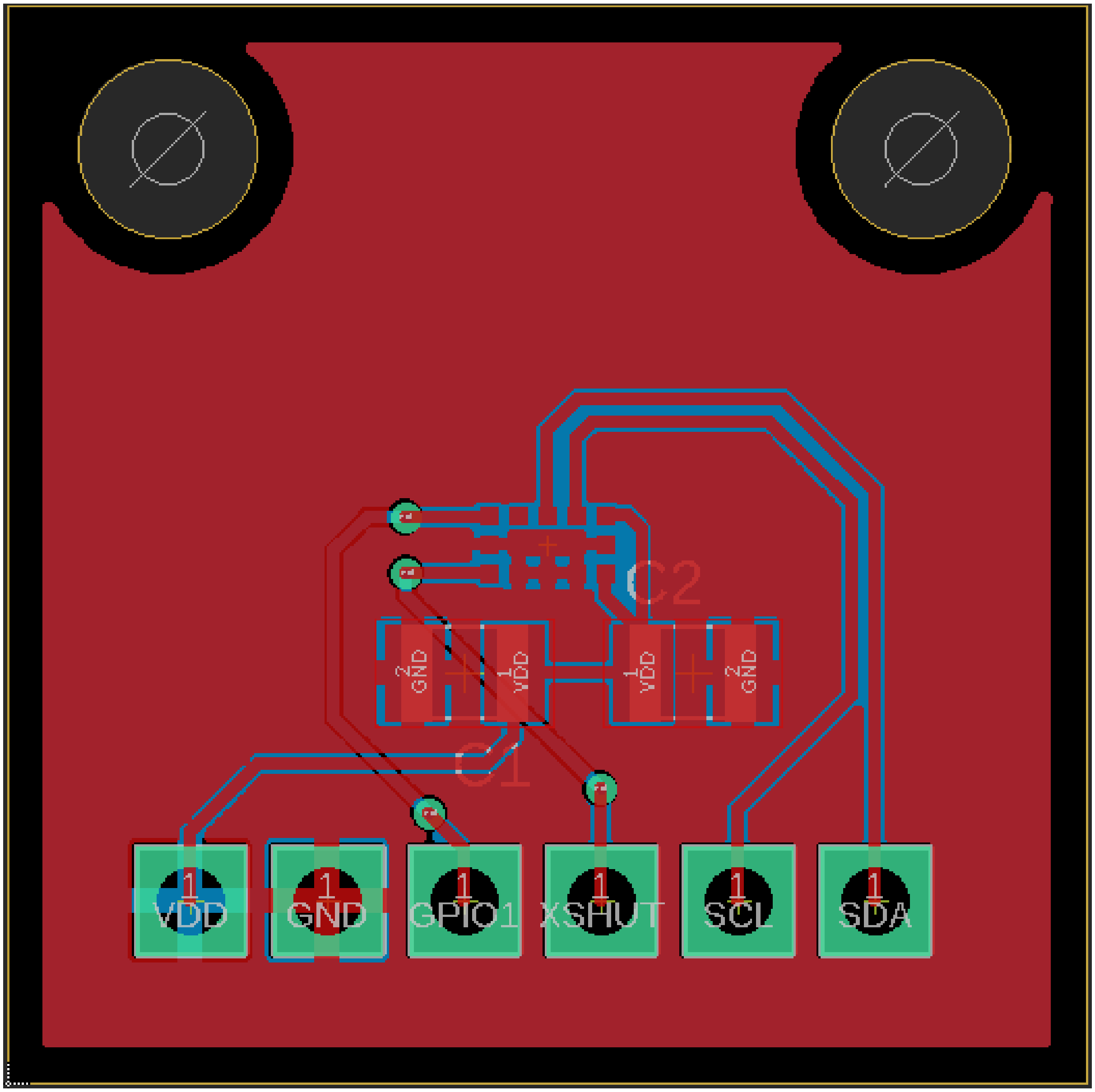
Appendix

Links to datasheets:

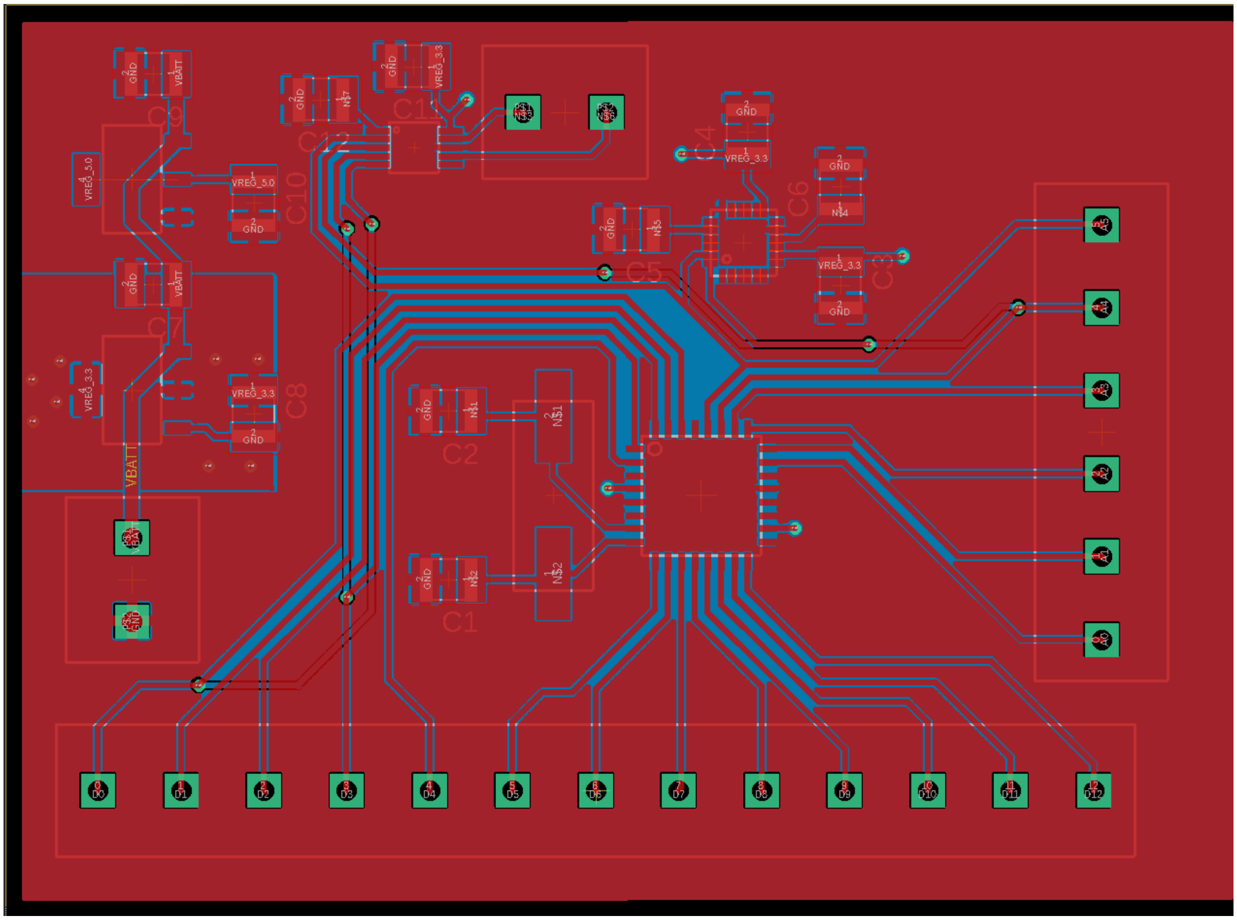
- 3-Axis Gyro/Accelerometer IC - MPU-6050 (https://cdn.sparkfun.com/datasheets/Components/General%20IC/PS-MPU-6000A.pdf)
- Laser Proximity Sensors (VL53L1CXV0FY/1) (https://www.mouser.com/datasheet/2/389/en.DM00452094-1315090.pdf)
- CSM-7X SMD Crystal (https://www.mouser.com/datasheet/2/122/csm-7x-1299.pdf)
- Voltage Regulator (https://www.mouser.com/datasheet/2/389/ld1117-1156241.pdf)
- Terminal Blocks (Phoenix Contact 1935187) (https://media.digikey.com/pdf/Data%20Sheets/Phoenix%20Contact%20PDFs/1935187.pdf)
- Atmega328p microcontroller http://ww1.microchip.com/downloads/en/DeviceDoc/ATmega328_P%20AVR%20MCU%20with%20picoPower%20Technology%20Data%20Sheet%2040001984A.pdf
- Charger: https://www.sparkfun.com/products/10217
- Battery: https://www.sparkfun.com/products/13855



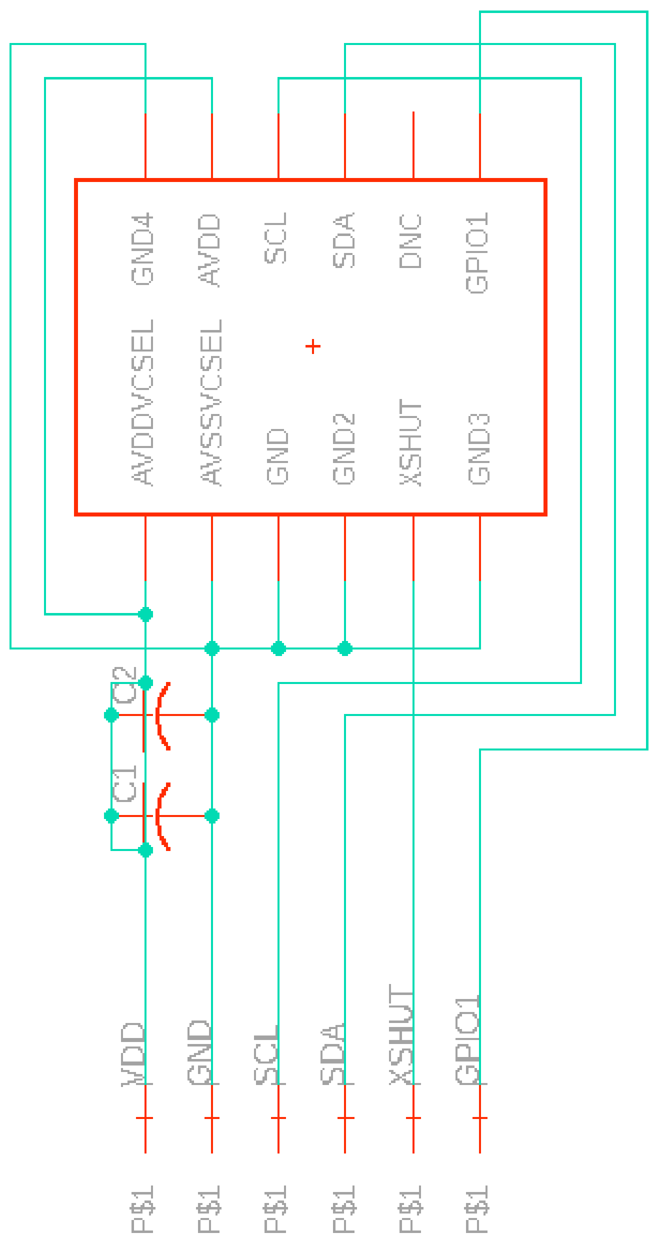
A: PCB Layout of Circuit, 75mm x 55mm



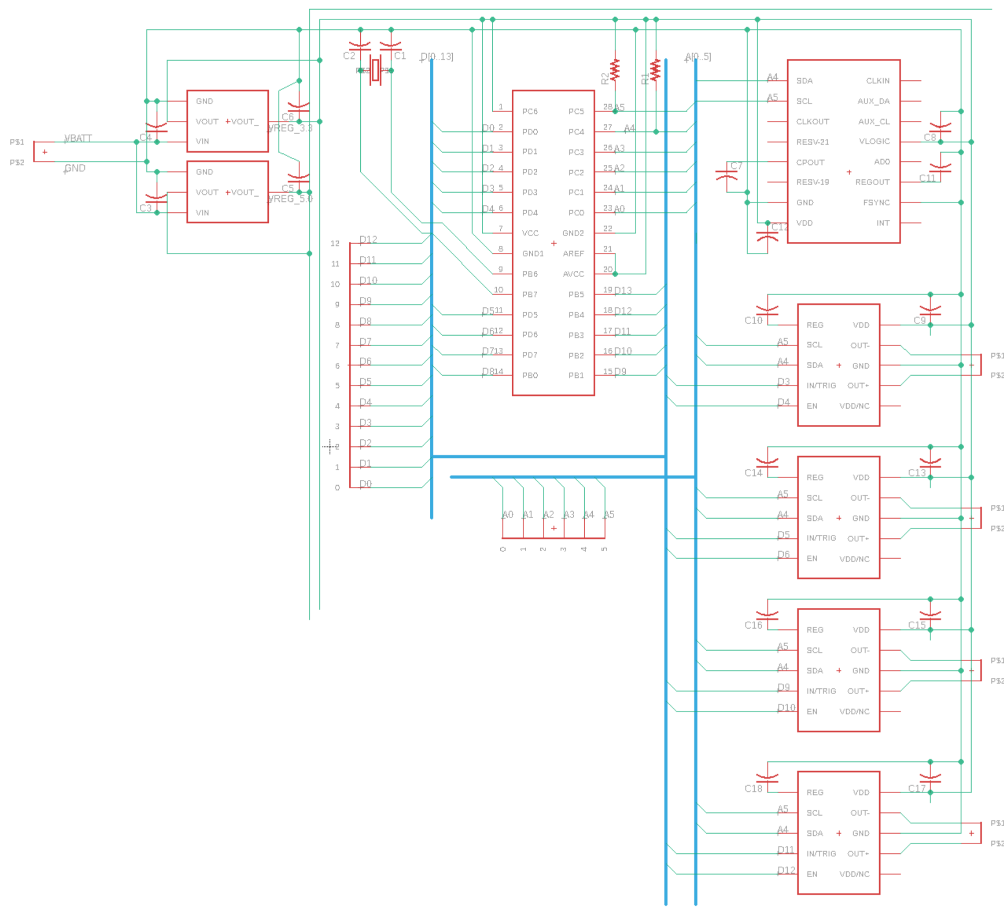
B: Laser sensing board

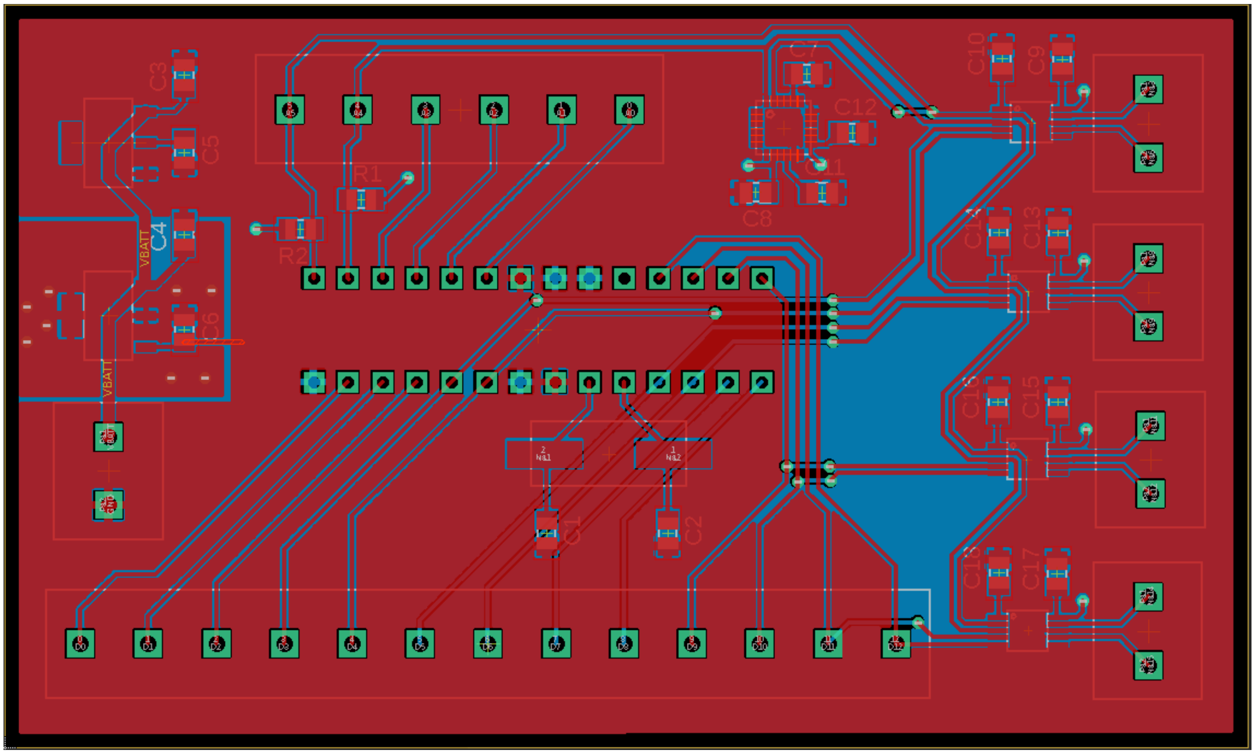


C: Bottom & Top layer PCB trace layout



D: Schematic of laser sensor breakout board




C3
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