Department of Electronic & Telecommunication Engineering
University of Moratuwa

EN 2090 – Laboratory Practice II

Analog Line Following Robot - Report

Dissanayake D.M.S.S	190155L
Ekanayaka S.D	190162F
Ekanayake E.M.S.S.N	190164M
Epa Y.H.A	190166V

Supervisor: Mr.Lahiru Wijerathna

This is submitted as a partial fulfillment for the module
EN 2090 Laboratory Practice- II
Department of Electronic and Telecommunication Engineering
University of Moratuwa
7th May 2022

Table of Contents

1. Abstract

Line follower robot is an analog autonomous robot which follows a white line on a black surface or a black line on a white surface. In this project, we were given the task to design a robot which follows a 3cm wide white line on a black surface and stops when it reaches a perpendicular white line to the following path. Generally, these types of robots are designed using microcontrollers like Atmega328P and PIC. But in our case, we have to design a line follower robot only using analog components. So, we have to design and implement all the circuits on our own with the help of OP Amps, resistors, potentiometers, etc.

2. Introduction

Line follower robots are the first step into robotics for many people who are interested in robotics. The usual approach is taking readings from an IR sensor array and using a microcontroller to process them. But in our case, We are using only components such as operational amplifiers, resistors, capacitors, IR sensors, etc. We are using analog circuits built from basic op-amps for calculation purposes, instead of using microcontrollers and programmable ICs.

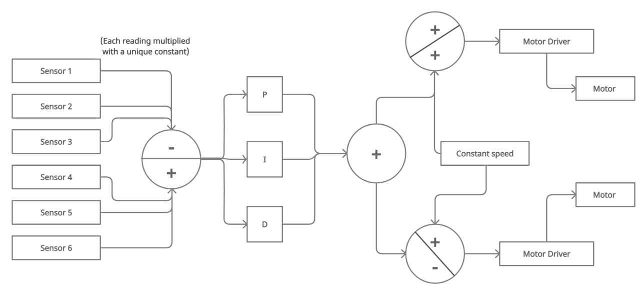
A PID algorithm is used which provides a continuous variation of output within a control loop feedback mechanism to accurately control the error. The line following process we used here can be stated briefly as follows.

1. Take readings from the IR sensor panel
2. Multiply those values with different gains and add them to produce the error signal
3. Process the error signal using a PID controller
4. Generating a PWM signal for each motor by comparing the error signal with a triangular wave
5. Using the PWM signals to control the two motors

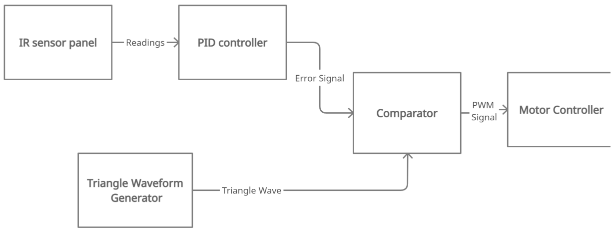
Calibrating the sensor circuit and the calculating circuit is a very important process in this project. Since we used the potentiometers, it was very easy to calibrate the circuit while changing the resistance values.

3. Methodology

3.1 Controlling - Block diagram



3.2 Circuits - Block Diagram



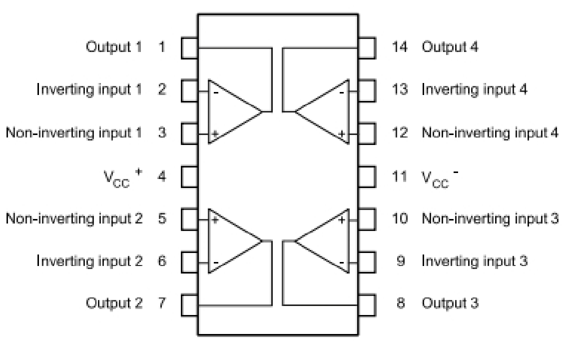
3.3 Circuits and Calculations

Complete circuit can be divided into the following subcircuits.

1. Sensor panel
2. Scaling adder to generate the error signal
3. PID controller
4. Triangle waveform generator
5. Scaling adder to generate motor speed signals
6. Motor driver
7. Power supply (Voltage Regulator)
8. Motor Stop Circuit

3.3.1 LM324MN Quad Op-Amp IC

LM324N is the opamp we used in all the circuits. It.consists of 14 pins with four independent op-amps in one package which are low power and high gain op-amps.

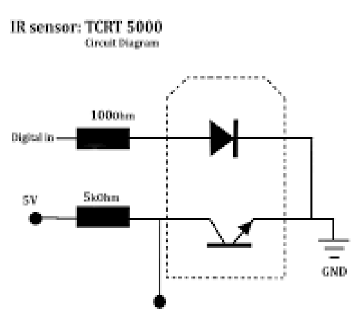


3.3.2 Sensor Panel

IR sensors are used to differentiate between the black surface and white line.

We have used six sensors, and the component we have used here is IR emitting LED coupled with a phototransistor. The IR beam which is emitted by the IR LED is reflected in different amounts by black and white surfaces. That beam is detected by the phototransistor.

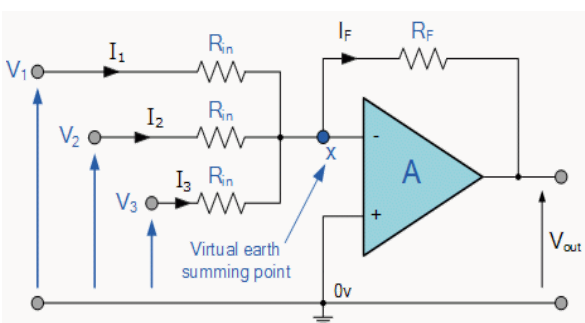
The analog output of the sensor is given to a comparator and digital output (0V and 5V) is taken out from it. We can change the threshold in the comparator to calibrate the ability to differentiate between black and white surfaces. We set the threshold voltage around 3.3V for all comparators. 6 IR sensors are placed 0.8 cm apart and the middle sensors are aligned with the center white line to get Zero error when the middle two IR sensors detect the line. We used two LM324N Op amp ICs to build 6 comparators. We set the IR panel at the edge of the PCB and we mount it onto the chassis with a significant gap between the IR panel and the floor.



3.3.3 Scaling Adder to Generate The Error Signal

Outputs of the six IR sensors are fed into a scaling adder. The LEDs we have used here are for reading the digital outputs of the sensors. It is very useful for debugging purposes. Six 330 Ohms resistors are used to limit the current through LEDs. Two scaling adders designed using LM324N Op Amps are used to add the digital outputs of the two sides separately with different gains. Since it's

required to have two polarities on the two sides the output of the right adder is used as an input of the left adder with a unity gain. Therefore it's possible to have negative voltages for left sensors and positive voltages for right sensors.Then it is fed into another adder to get the total error signal as output.



The magnitude of the error is set proportional to the deviation from the line. This is achieved by applying different gains to the different sensor outputs(1.33,0.66,0.33). 10k resistors are used as feedback resistors while 7.5k,15k, 30k resistors are used as input resistors.

Error signal = (-1.33)*S1 + (-0.66)*S2 + (-0.33)*S3 + (0.33)*S4 + (0.66)*S5 + (1.33)*S6

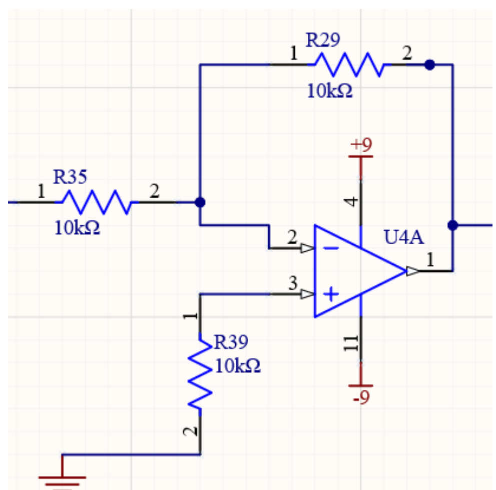
Here S1 to S6 are digital output voltages of six sensors from left to right. Error signals represent the position with respect to line and it provides the deviation from the initial state of the robot.

3.3.4 PID Controller

We have used a PID controller (proportional, integral, derivative) circuit to control the error signal. The integral controller part is emitted as proportional and derivative controllers are sufficient for line following. All the op amps used here are from the LM324N ic model.

Proportional Circuit

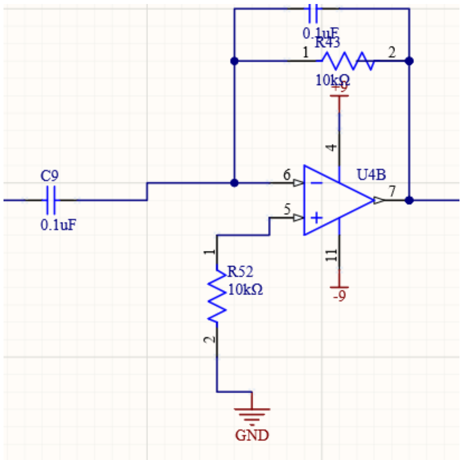
The proportional controller contains an op amp inverting amplifier.



Here we have used 10kΩ for all resistors which gives us an inverted unity gain output for the error signal.

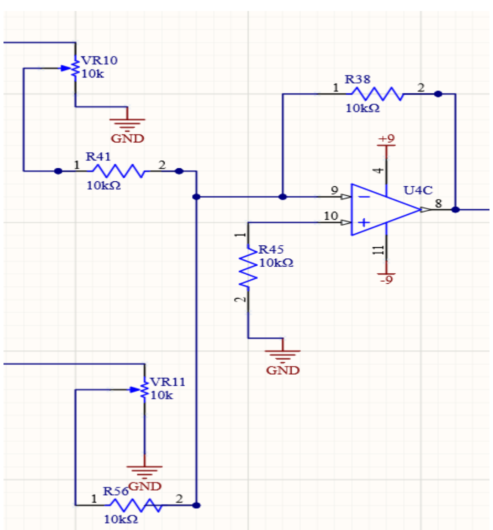
Differentiator Circuit

For the derivative controller, we have used an op amp differentiator as follows.



The capacitor across the feedback resistor is used to avoid the circuit being unstable at higher frequencies. This circuit differentiates the error signal, but the output is inverted and its amplitude is multiplied by 0.001 (differentiator gain = $R_f c$ = 10k ✕ 0.1u = 0.001).

After that, a scaling adder (inverting) is used to add the outputs from the above two circuits.



The equation for the output is,

$$Vout = Vamp\frac{10}{10+VR10} + Vdiff\frac{10}{10+VR11}$$

10k potentiometers (VR10 and VR11) are used so we can change the multiplying coefficients for amplified and differentiated signals. That means they can be used to tune the Kp and Kd values of the controller. As this circuit inverts the previously inverted signals, output of this circuit is not inverted compared to the error signal.

3.3.5 Triangular Waveform Generator

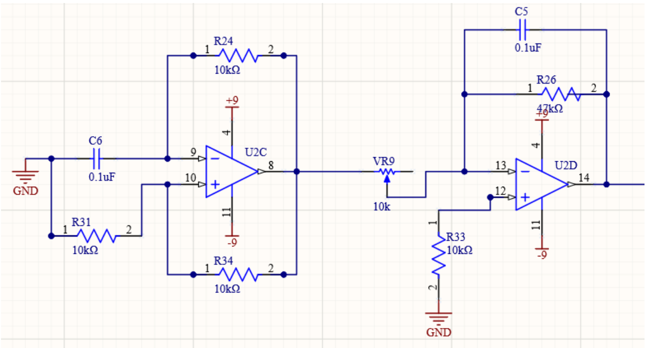
Triangle waveform generation part contains two OP Amps. First OP Amp generates a square wave and after that, the second OP Amp creates the triangle waveform using that square waveform.

Initially, the capacitor C6 is not charged. Therefore the voltage at the inverting terminal is zero. But there is a voltage drop across the R31 resistor which is equal to the voltage at the non-inverting terminal. This makes the OP Amp output terminal voltage +9V. Due to this voltage, the capacitor C6 starts charging. When the voltage across the capacitor is slightly greater than the voltage at the non-inverting terminal the output voltage of the OP Amp switches to -9V. Then with time, the capacitor discharges through the resistor R24. When the voltage at the inverting terminal is slightly less than the non-inverting terminal, the output voltage switches to +9V again. Likewise, this will continue giving a square wave at the output of the opamp. Then this square wave is given to an integrator circuit which outputs a triangular waveform. This triangular waveform is used to compare with the error signal to generate a PWM signal.

Characteristics of the generated triangular waveform,

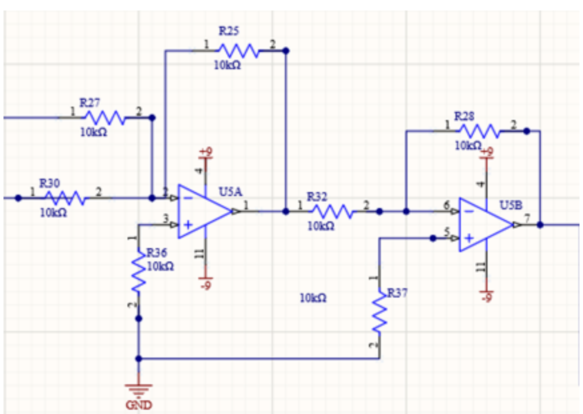
- Mean voltage - 1V

- Peak - Peak voltage - 7.68V
- Frequency - 747.3Hz

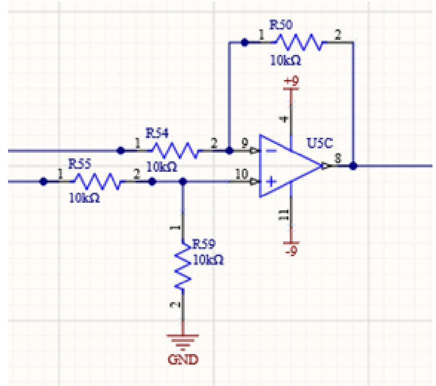


3.3.6 Speed Control Circuit

The speed of the motors are controlled by adding and subtracting the PID signal with the base voltage. The base voltage acts as the average speed of the robot when the net error is zero. The base speed of the robot can be changed using the 10k variable resistor. Here the op amps are used in adding and subtracting configuration. The op amps are supplied with –9V and 9V.



Base speed is added with the PID signal

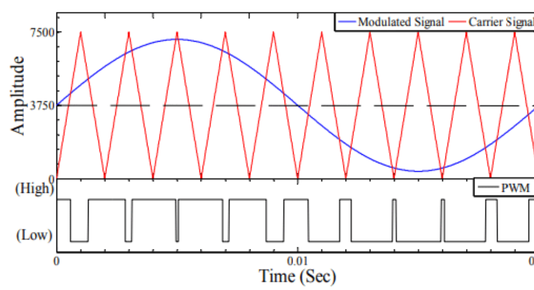


Base speed is subtracted with the PID signal

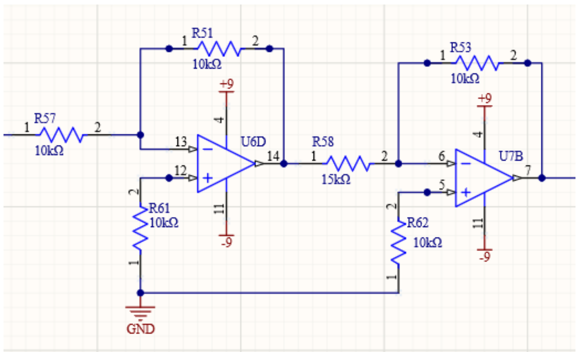
3.3.7 PWM Generator

The triangle waveform is compared with the outputs of the speed control circuit to generate the square wave signal.

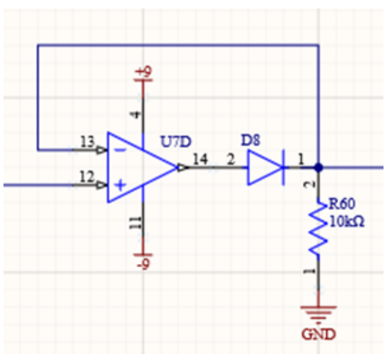
The width of the square wave signal is changed proportionally to the magnitude of the speed signal. The frequency of the PWM signal is dependent on the frequency of the triangle waveform.



The Generated square wave is passed through an inverting amplifier with a proportional gain of 0.67 and then passed through an inverting amplifier with a proportional gain of 1 to eliminate the inverting effect.

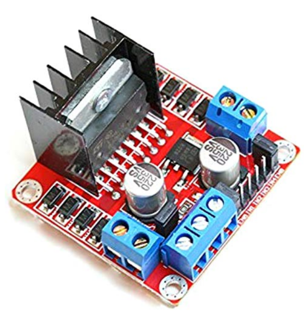


To obtain the PWM signal the negative part of the square wave signal is clipped using a non-inverting half wave precision rectifier. This ensures a perfect PWM signal.



3.3.8 Motor Driver Circuit

To drive the motors L298N motor driver module is used. The speed of the left & right motors can be controlled by inputting the respective generated PWM signals to the driver circuit.



L298N Motor Driver

We selected N20 120 rpm gear motors to move the robot. The low gear allowed for a higher torque which results in greater acceleration.

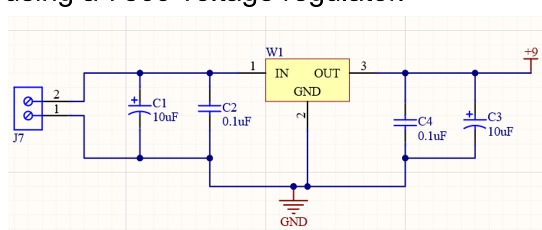
N20 Metal Gear Motor

3.3.9 Power Supply

Above circuits require +9V, -9V, +8V, and +5V for their operation. We used a four-cell LiPo battery (3.7×4 = 14.8V) and regulated them for +9V,+8V and +5V. a 9V battery is used to provide -9V.

7809 Voltage Regulator

Since +9V is only used for ICs, they do not draw high currents. Therefore to provide +9V, 14.8V from LiPo battery is regulated using a 7809 voltage regulator.

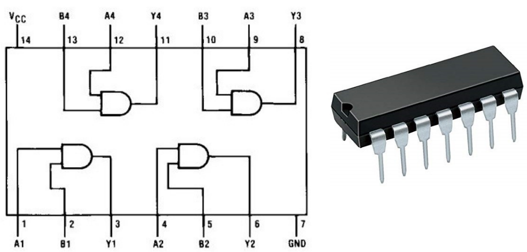


Buck converters

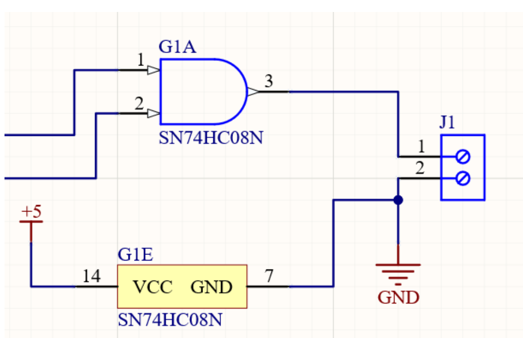
To provide +5V and +8V, step-down buck converters are used because they release less heat than linear voltage regulators and are more efficient. +5V is taken by feeding +9V to a step-down buck converter. +8V is taken the same way, but the input is fed by +14.8V directly from the battery.

3.3.10 Motor Stop Circuit

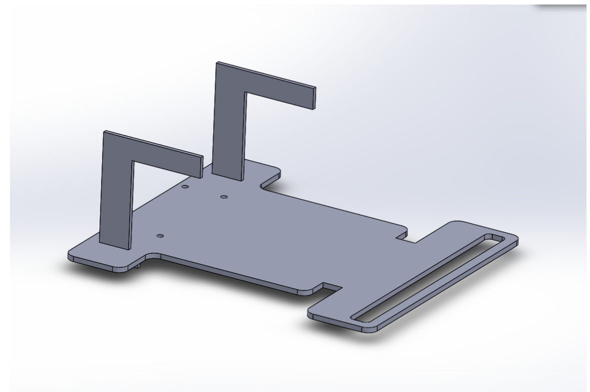
The robot has to stop when it comes to a white line which is perpendicular to the line it is following. At that time both edge sensors will give high voltage(3.3V). Otherwise, only one sensor can become high at a time. Thus we used a 7408 AND gate IC which gives 1 only when both the edge sensors give high voltage. This AND



gate output is fed to two motors and when it is 1, the motors will break making the robot stop, otherwise, the robot will continue following the white line.



3.4 Robot Design



Robot Chassis

For the robot design we used the above CAD model to hold circuit components and battery packs etc. The length and the width of the model is 15.5cm and 14 cm respectively. Thickness is 2mm. Basically, we used an aquiline board to build the CAD model.

The motors are placed at the left and right corners of the backside of the model and also we keep significant space between the two wheels. Battery pack and the motor driver were placed between two backing rods and we put them closer to the base in order to keep the center of gravity as low as possible.We try to build a lightweight design and we achieve it through this model.

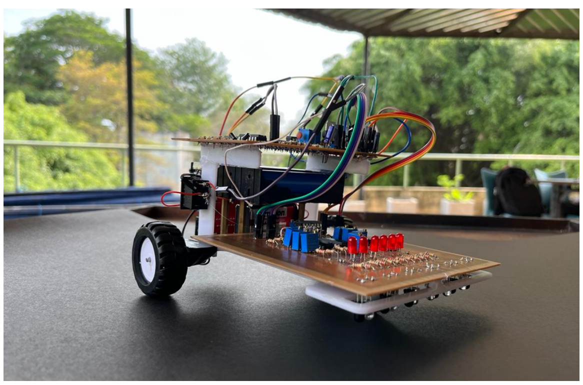
4. Results

Since the circuitry was complex as it consisted of many components. As a solution, we implemented the circuitry into two double-layer PCBs. The first PCB consisted of the sensor panel, triangular waveform generator, and stopping circuit. While the second PCB consisted of PID Controller, Speed control circuit and power supply circuit.

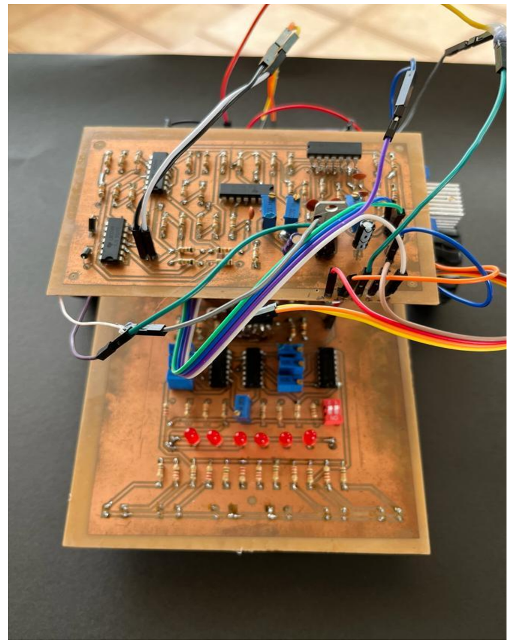
After soldering all the components to the circuit we ensured the working of the PCB by observing and measuring the generated waveforms.

Triangle wave generator output

After Ensuring the working of the PCBs we assembled the robot by mounting the PCBs, power supply units, switches etc.



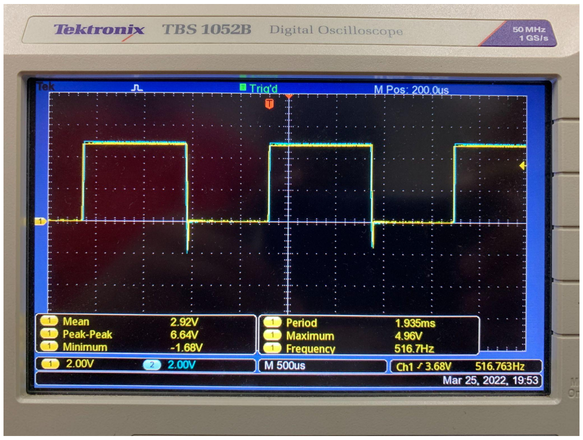
Assembled Line follower robot



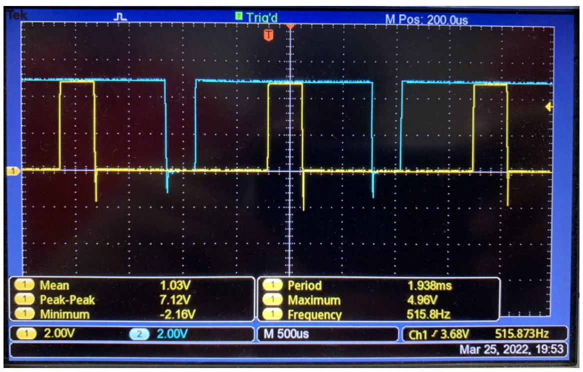
The two PCBs mounted in the line follower robot

Finally we tested our robot on the track made by ourselves. After doing several runs on the track we managed to tune our robot to follow the line smoothly with a considerably quick time. The base speed of the robot was adjusted to avoid it from moving out of the track. Since each of the 6 sensors could be calibrated individually it was easier to tune the robot.

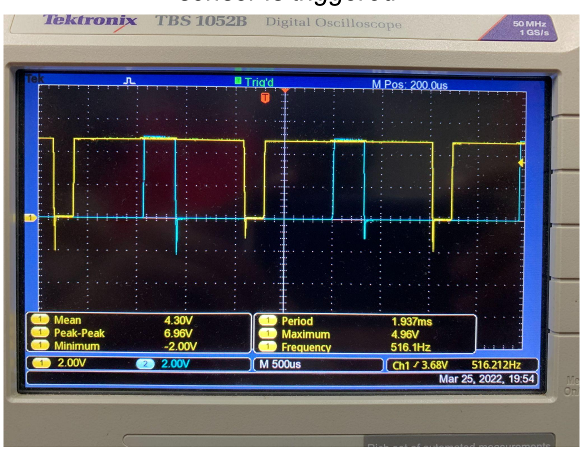
The use of N20 gear motors allowed for lower current draw from the batteries. Which allowed the robot to operate a longer time. The motors drew an average of 0.2A and had a stall current of 0.5A.
Below are some signals observed after successfully calibrating the robot to follow the line. In the following figures, the yellow and blue waveforms represent the PWM signals given to the left and right motors respectively.



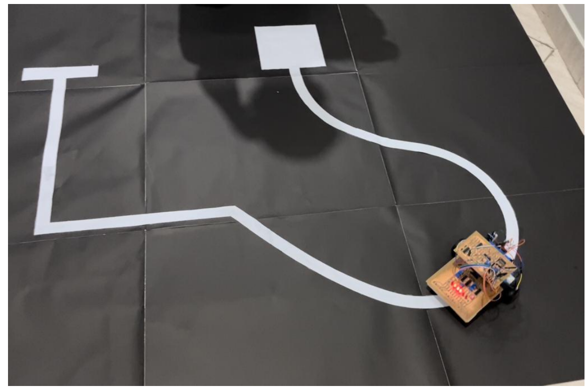
PWM signals for the two motors when no error is present.



PWM signals for two motors when the leftmost sensor is triggered



PWM signals for two motors when the right most sensor is triggered



Line follower robot in Action

5. Conclusion

Designing an analog line follower was a quite challenging task. First, we divided the circuit into subcircuits. Then we identified the necessary components and built the circuits on a breadboard. After all the sub circuits were tested individually, we assembled the breadboard circuits to check whether we got the expected results.

After that, we designed two PCBs according to the tested circuits. We faced some problems and challenges during this whole process. Soldering components on a double-sided PCB was quite challenging for us. As some ICs were damaged during the process, we had to check the connections and replace them several times.

Also, we had to tune the variable resistor values for changing the error, Kp and Kd values several times to make sure the robot follows the line accurately.

6. Acknowledgment

Our sincere gratitude to Eng. Kithsiri Samarasinghe and Mr. Jayathu Samarawickrama for giving us the basic knowledge on OP amps and its

applications. Also, the supervision and guidance of Mr. Lahiru Wijerathna was a great support and very useful to us. Under the guidance of all of them we were able to gain vast knowledge and experiences through this project. Also, we are very thankful to all the supervisors, lab assistants and our fellow batchmates for giving their kind helping hand to make our project a reality.

7. References

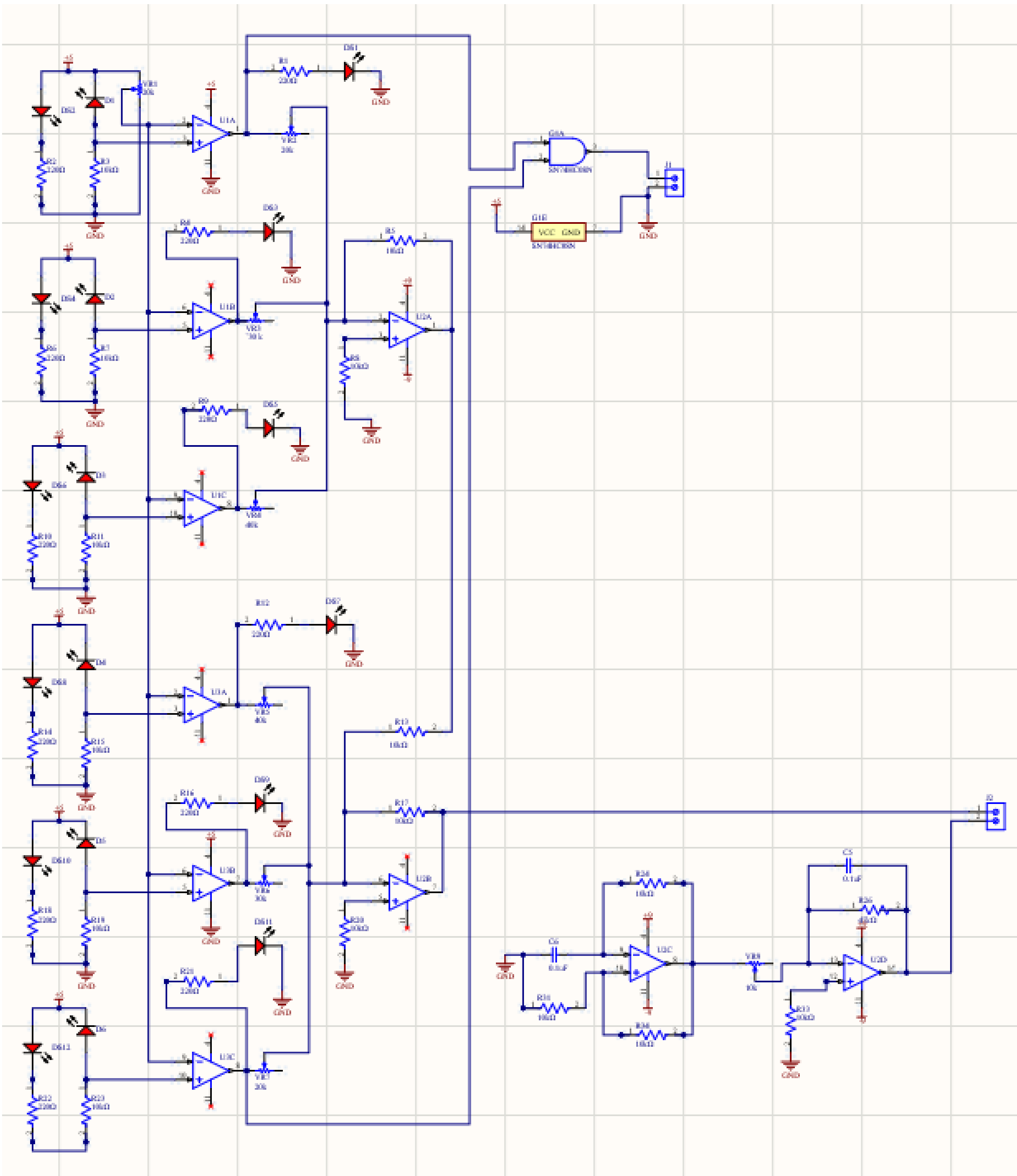
1. http://www.will-moore.com/analog-line-follower
2. https://www.maximintegrated.com/en/design/technical-documents/app-notes/3/3201.html
3. https://circuitdigest.com/electronic-circuits/half-wave-and-full-wave-precision-rectifier-circuit-using-op-amp
4. https://en.wikipedia.org/wiki/PID_controller

8. Contribution

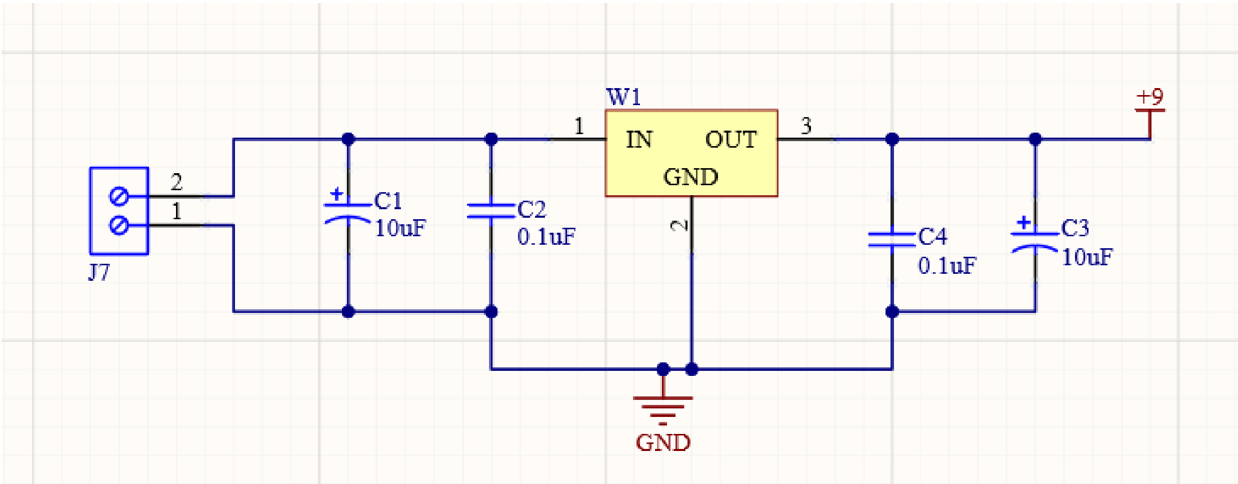
Name	Contribution
Seniru - 190155L	Speed Control Circuit and PWM Generator Circuit, CAD model designing and PCB Soldering.
Sasmitha - 190162F	IR sensor panel and error signal circuit, CAD model designing and PCB soldering.
Sevindu - 190164M	PID Controller Circuit,Stop Condition circuit and PCB designing.
Yasara - 190166V	Triangle Waveform generator circuit, power supply circuit and PCB designing.

9. Appendices

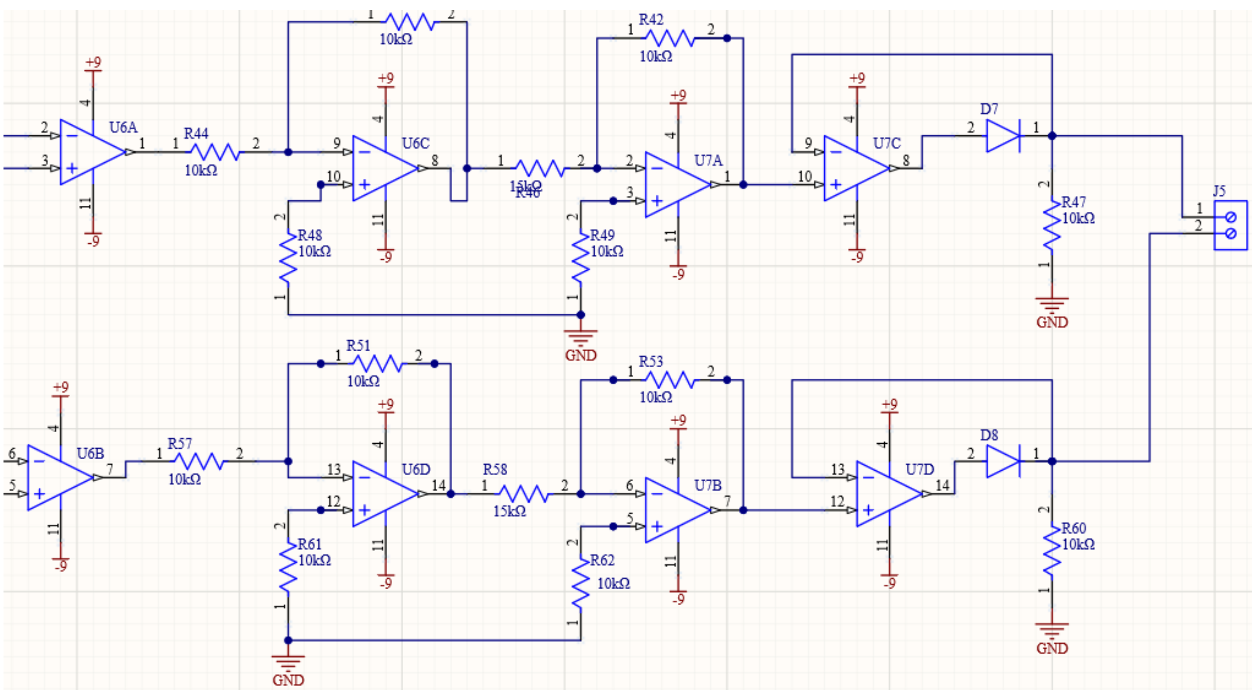
9.1 Appendix I - Schematic Designs



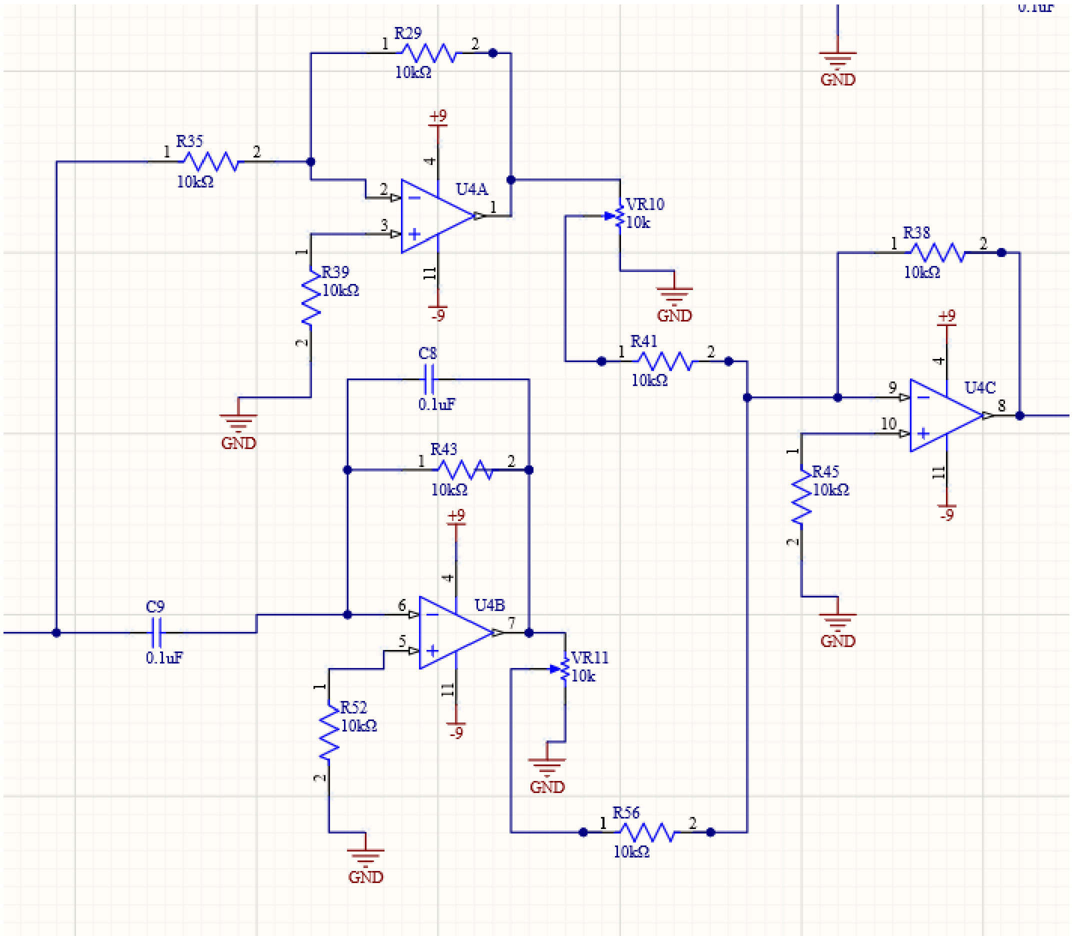
Sensor Panel, Error, and Triangle Wave Generator Schematics



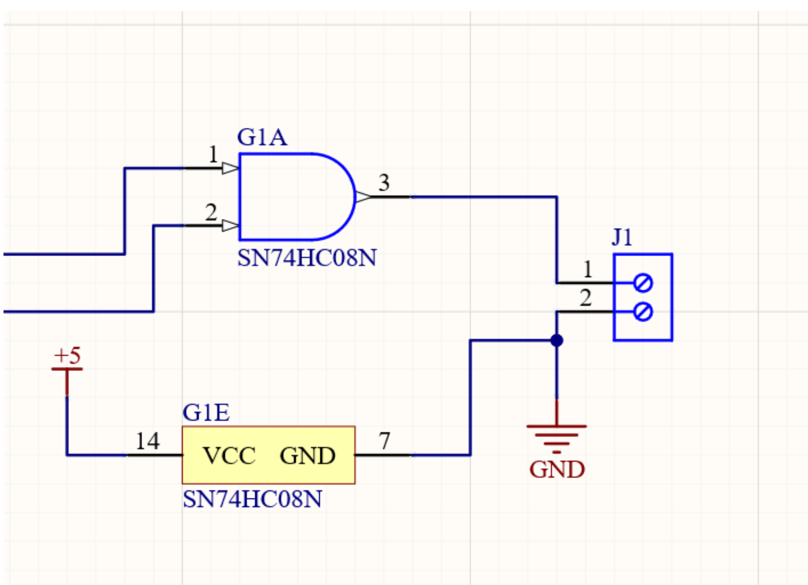
Voltage Regulator Schematic



Motor Controller Schematic

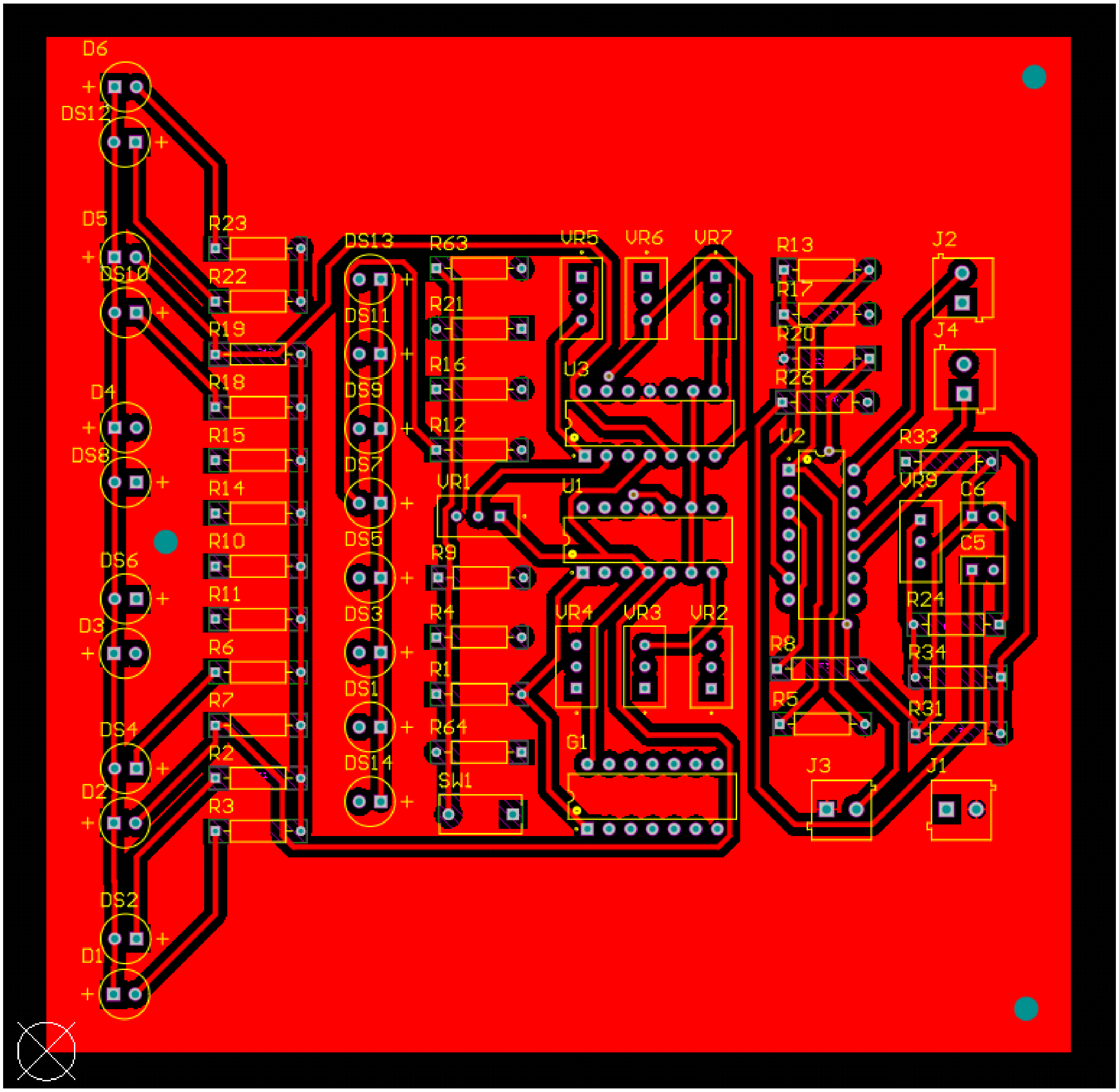


PID Controller Schematic

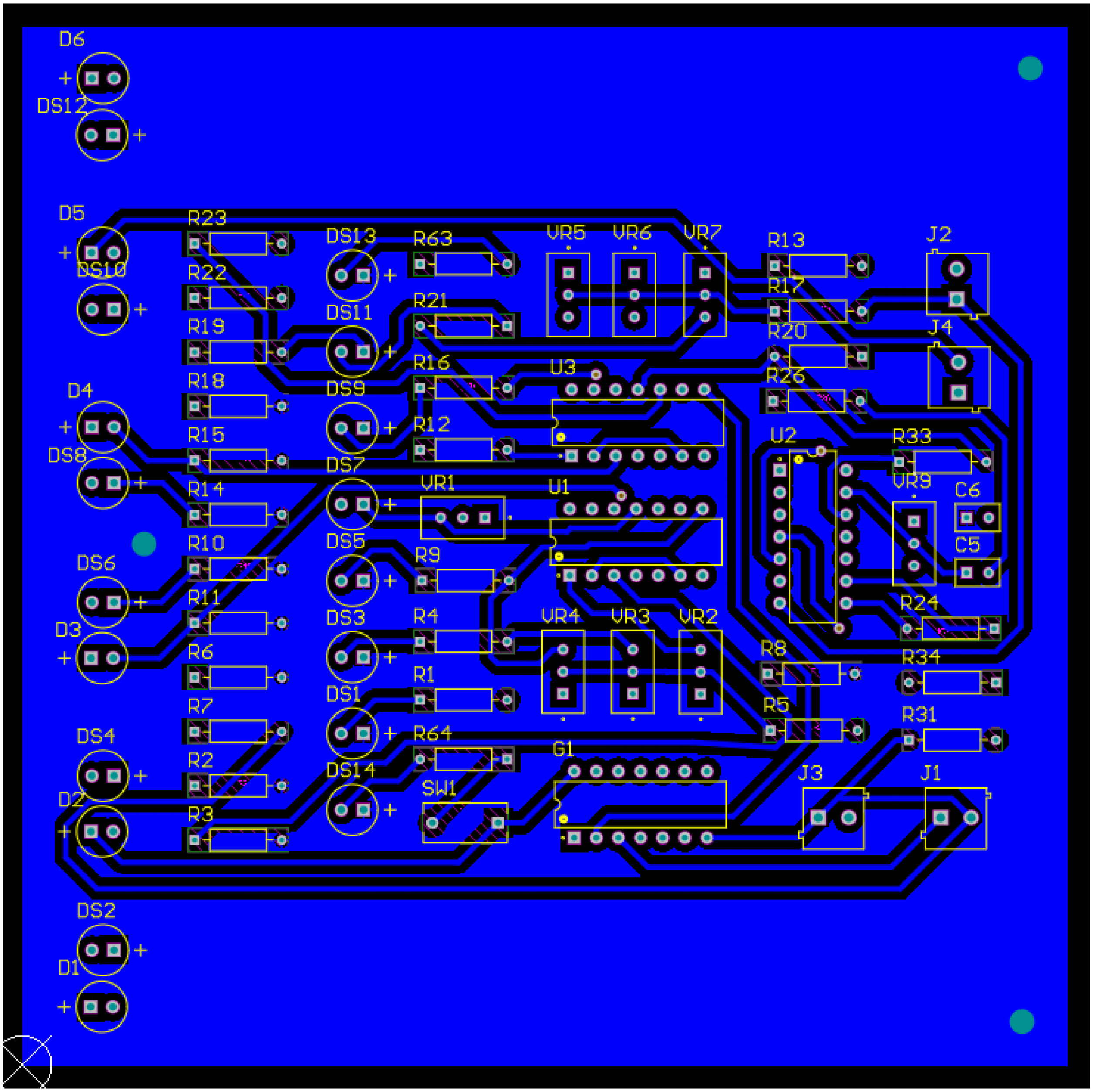


Stop Controller Schematic

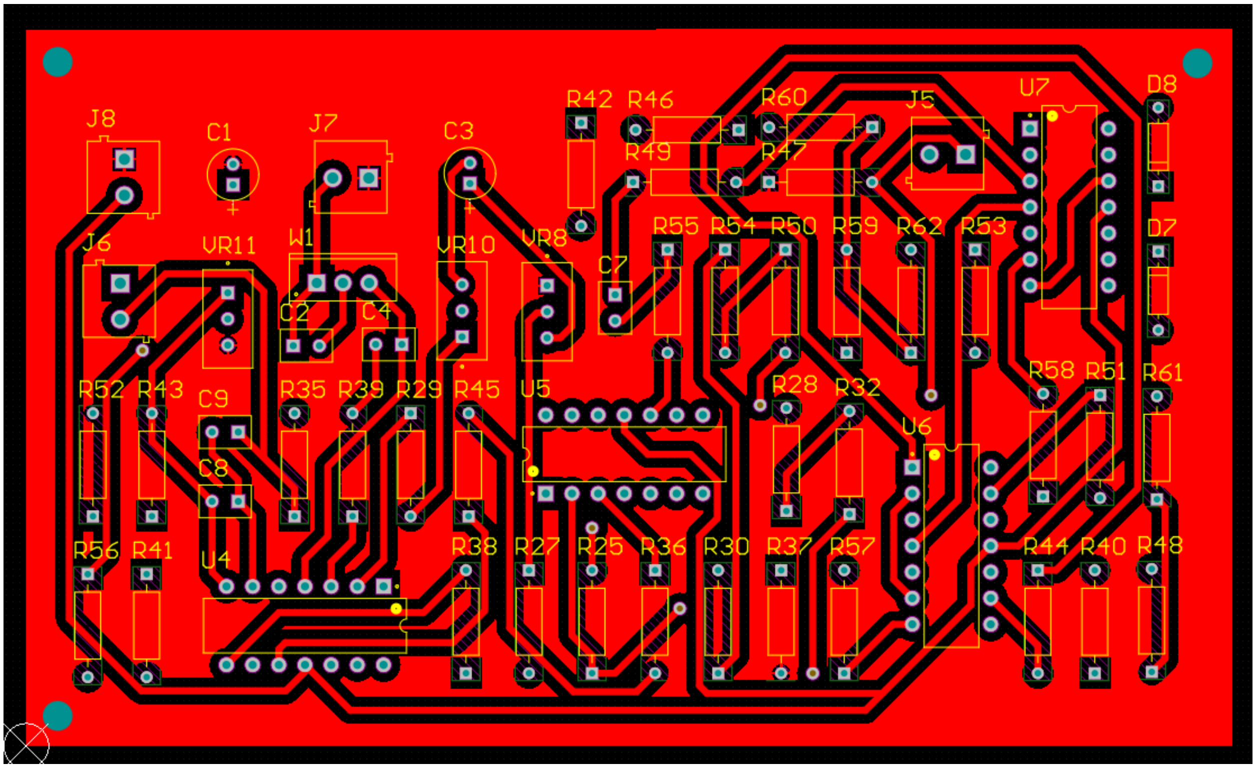
9.2. Appendix II - PCB Designs



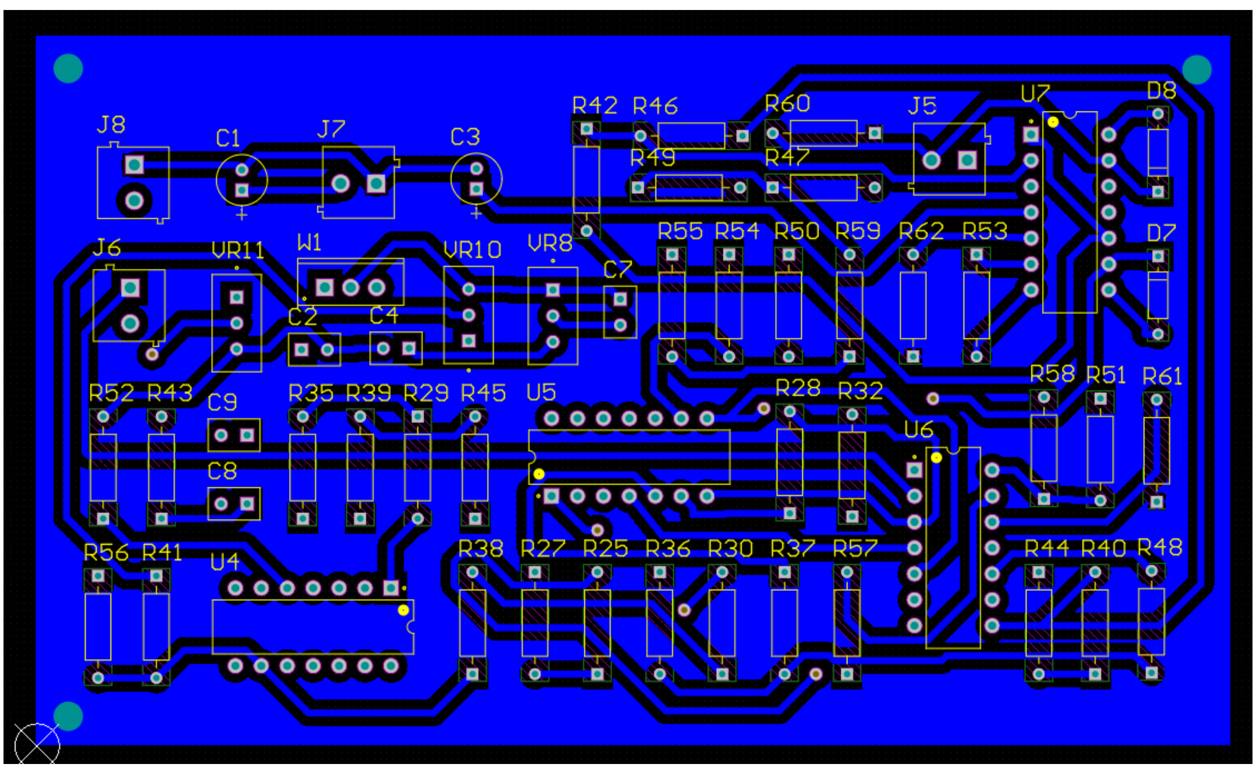
Top Layer of PCB 1 - Error Signal, Triangle Wave Generator and Stop Circuit



Bottom Layer of PCB 1 - Error Signal, Triangle Waveform Generator and Stop Circuit



Top Layer of PCB 2 - PID Controller, PWM Generator and Motor Controller



Bottom Layer of PCB 2 - PID Controller, PWM Generator and Motor Controller