University of Moratuwa
Department of Electronic and Telecommunication Engineering
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Semester 3
Wall Following Robot Using PID Controllers
Team - 23

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This report is submitted as a partial fulfillment of the module EN2091 Laboratory practice and projects.

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1 Introduction

Wall following robot is a common yet a popular project among the robotics enthusiasts.Using a microcontroller like ATMega328P, a wall following robot can be built with less effort and the approach is simple. Using analog components such as integrated circuits (IC), resistors and capacitors **only** to build a wall following robot is challenge which requires designing several circuits to achieve the requirements.

2 Functionality Description

The main goal of a wall following robot is to maintain a constant distance between the 2 walls which it follows. Additionally it should be able to maintain its middle path even when it is moving in a bend. In case of robot drifts away from its middle route, it should have the ability to adjust its course to the original route.
So, the first thing the robot should do is the distance from either sides of the robot to the walls.To measure the distance, 2 methods were proposed.

1. Using 2 ultrasonic sensors

2. Using 2 sharp IR sensors

Figure 1: Ultrasonic Sensor

Using ultrasonic sensors in this occasion is not a feasible option for measuring the distance from the walls because of the following reasons.

- The ultrasonic sensor should be triggered using a PWM signal to send the ultrasound wave. Since other circuits operate using analog voltages, the required PWM signal should be generated using a PWM signal generator to activate the ultrasonic sensor.

- The output of the ultrasonic sensor is again a PWM signal. Since other circuits operate using analog voltages, the PWM signal should be converted for a voltage for further analysis. So, a separate circuit is required to achieve the task.

- Since there are few conversions happening according to the above points mentioned, the accuracy of the generated voltage can be less. So it can affect the proper functionality of the robot.

Instead of ultrasonic sensors, sharp IR sensors are used to measure the distance from the walls to the robot. Using sharp IR sensors have the following advantages over ultrasonic sensors.

Figure 2: Sharp IR Sensor

- Unlike the ultrasonic sensor, sharp IR sensor doesn't require triggering in order to activate the sensor.Simply applying a 5V voltage source is enough to start operation.

- The output of the sharp IR sensor is an analog voltage which very useful in the future analyses. So, there will be no extra circuits required in the initial stage to convert a PWM signal to an analog voltage which reduces the cost.

- Although the sharp IR sensor behaves differently in different distances (ex: Below 15cm, proportionally and above 15cm, inverse proportionally), it can be overcome by placing the sensors on the robot chassis appropriately.

2 sharp IR sensors are used to measure the distance from both sides of the robot to the walls and the difference between the 2 output voltages are taken. Since the difference of the output of the sharp IR sensors is a small mV value, to reduce any interference caused by the power line, an instrumentation amplifier is used to get the difference between the putputs of the sharp IR sensors. The output of the instrumentation amplifier is the error signal which should be adjusted.

The second yet the main thing the robot should do is if there is an error is present (Drifted away from the wall),that signal should be corrected and then should be given to the system to adjust the error. Therefore, a PID controller is used to correct any error signal. The output of the instrumentation amplifier is fed into the PID controller. PID ontroller is the main circuit present in the analog wall following robot where the error signal is adjusted and given to the system to reduce the error.

It should be considered that always a signal should be given to the motors to go forward and the adjusted signal from the PID controller should be given to that signal.2 motors will be used for the robot. Therefore the signal of one motor, that error should be added and should be subtracted from the signal of the other motor. Therefore, another important circuit comes into play, the turn adjustment control circuit which does the above task. Along with the turn adjustment, the forward speed of the motors is also regulated from this part of the circuit. The speed of rotation f motors is very important because it should match with the response time of the sharp IR sensors. Reducing the speed of the motors so the IR sensors can detect any change in the distance to the wall is recommended.

Until the turn controller circuit, all the signals were analog and there were only voltages which subjected to many changes. But for the motor driver module which is used to drive the motors of the wall following robot, a Pulse Width Modulated Signal (PWM Signal) should be given. Therefore, after the turn adjustment circuit, there must be a way to convert the analog voltage signal to a PWM signal.

One way of converting a voltage signal into a PWM signal is using a triangular wave generator circuit. The triangle signal generator provides the frequency required for the basic PWM signal and the necessary ramp voltage (rise and down) to produce the PWM signal. By comparing the ramp voltage with the voltage output of the turn controller using a comparator, the required PWM signal can be generated. After generating the required separate PWM signals for the motors, the output

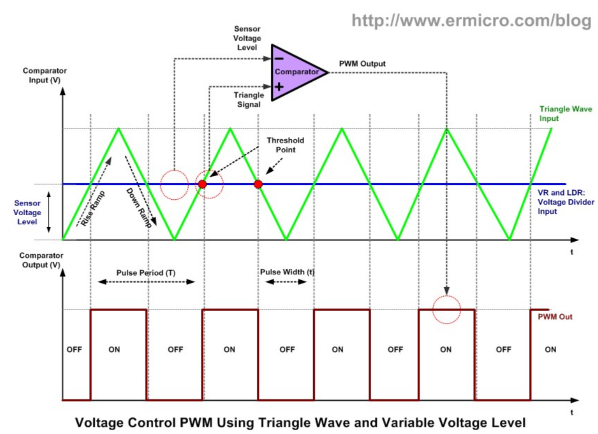

Figure 3: PWM Signal Generation

should be given to the motor driver module. It will then drive the 2 motors moving the robot forward while keeping its middle path.

3 System Model with Design Parameters

The initial block diagram for the robot is as follows.

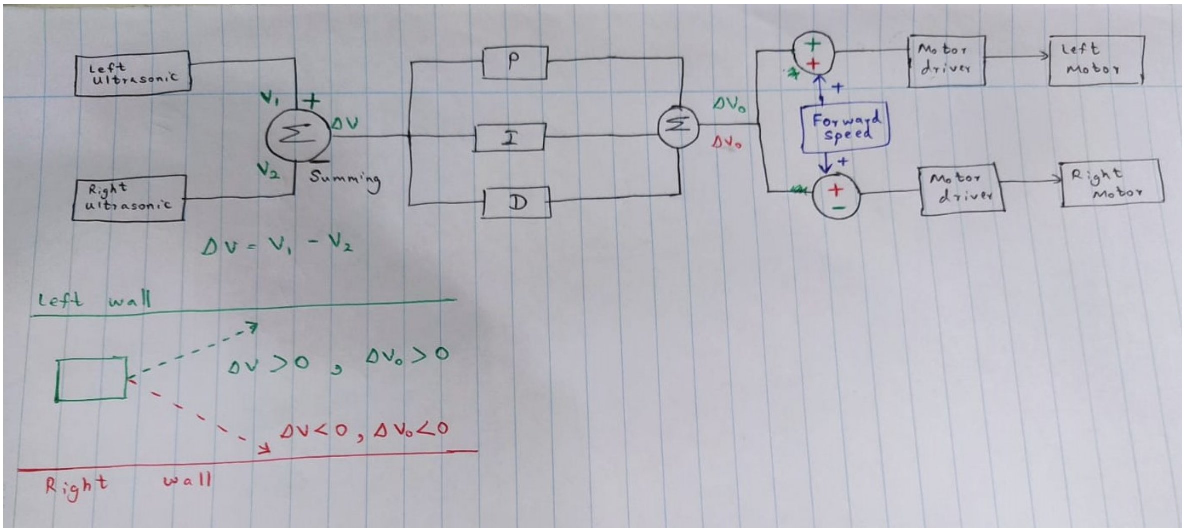

Figure 4: Initial Proposal for the Block Diagram

But after revising the initial idea, the block diagram was updated to the following.

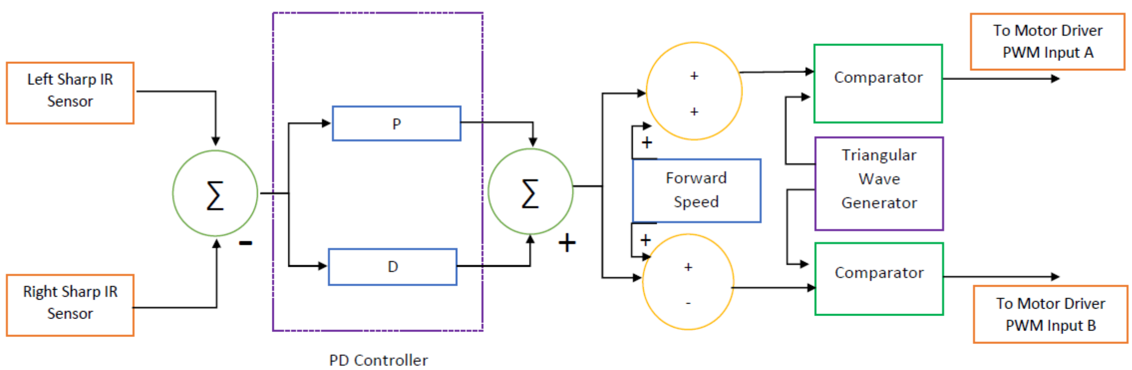

Figure 5: Updated Block Diagram

3.1 Circuits Used for The Robot

- Instrumentation amplifier circuit
- PID controller circuit
- Triangular waveform generator circuit
- PWM signal generator circuit and turn adjustment circuit
- Motor driver circuit

3.2 Design Specifications of The Robot

- Length of the robot chassis - 15 cm
- Width of the robot chassis - 14 cm
- Height of the robot chassis - 10 cm
- Number of motors used - 2
- Number of layers(Sections) in the robot chassis - 2

3.3 Components and Modules Used

- Operational amplifier - LM324N
  - This Op-Amp is one of the best high gain Op-Amps which can operate from a single power supply over a wide range of voltages. It is cheap in price and reliable.
- Motor driver - L298N
  - This motor driver is a widely used motor driver in robotics.It can drive 2 motors with direction and speed control. In this project, the motor diver is configured to drive the motor in the forward direction only. Configuration of the pins of the motor driver to do so is as follows.
    * IN1 - Logic High (5V)
    * IN2 - Logic Low (0V)
    * IN3 - Logic High (5V)
    * IN4 - Logic High (0V)

    An added benefit of using this motor driver is that it has a 5V regulated power supply output which can be used to power up the LM324N Op-Amp. The supply voltage given to the motor driver is 11.1 V.

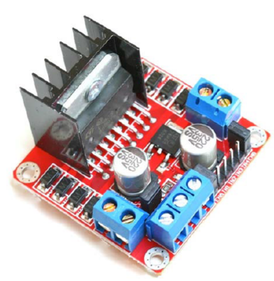

Figure 6: L298N Motor Driver

- Resistors - 1 kΩ, 10 kΩ, 12 kΩ, 470 kΩ
- Capacitors - 0.01 μF, 2.2 μF, 27 pF, 4.7 pF
- Power
  - Three DE 18650 Li-ion 3.7 V batteries to get 11.1V to power up the motor driver
  - 9V Dry cell to power up the triangular waveform generator

4 Schematics

The schematic diagrams of the circuits designed for the wall following robot are as follows.

4.1 Instrumentation Amplifier

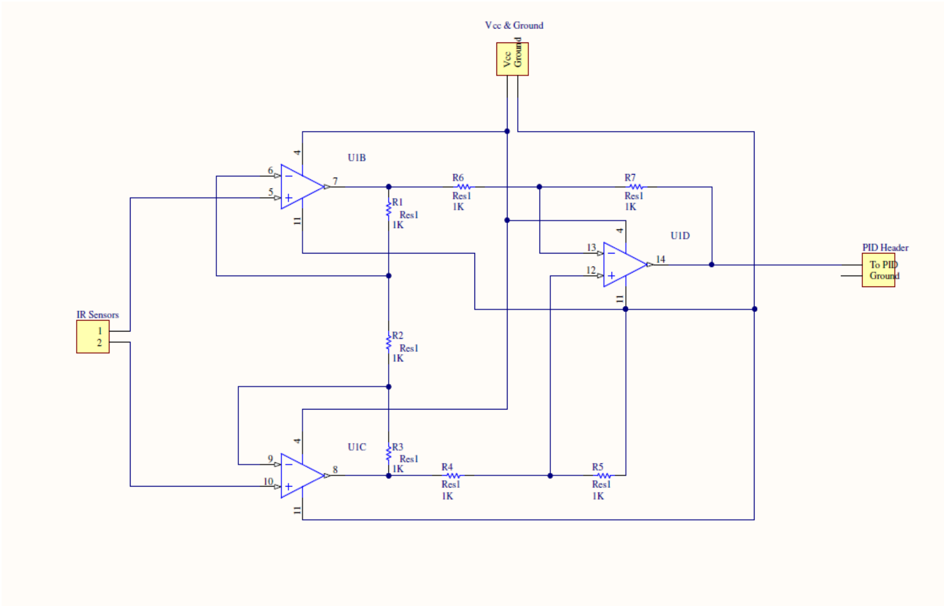

Figure 7: Caption1

4.2 PD Controller

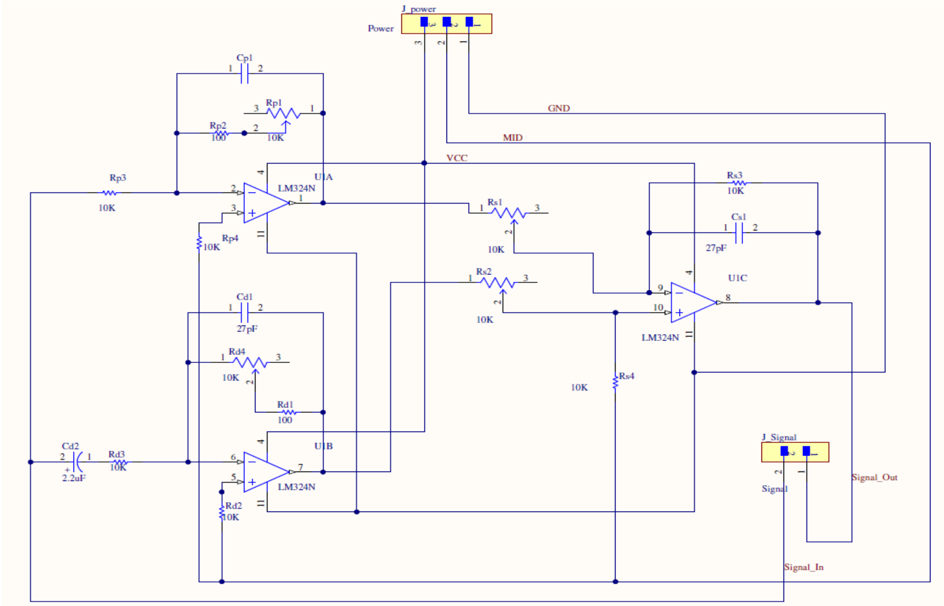

Figure 8: Caption1

4.3 Triangular Wave Generator

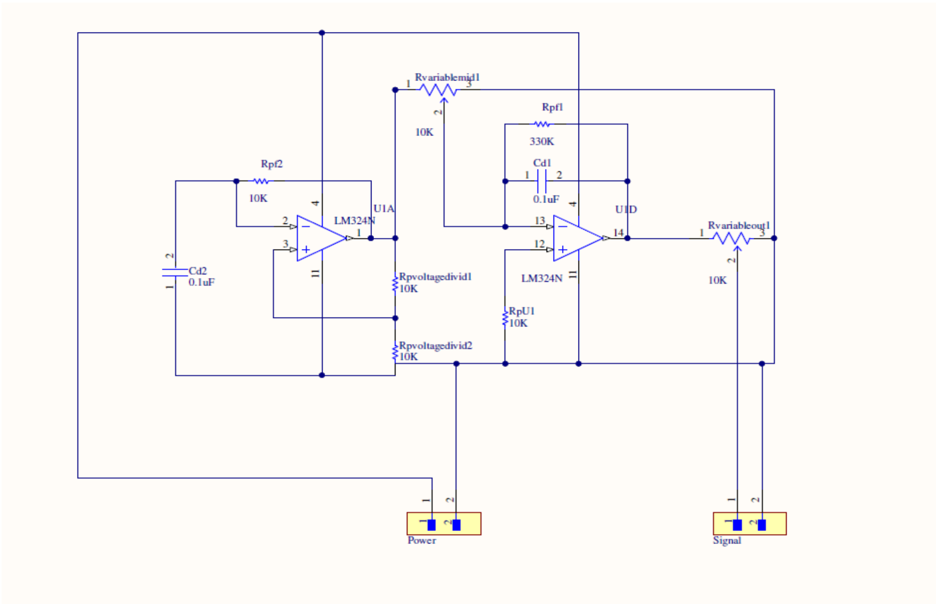

Figure 9: Caption1

4.4 PWM Signal Generator and Turn Adjustment Circuit

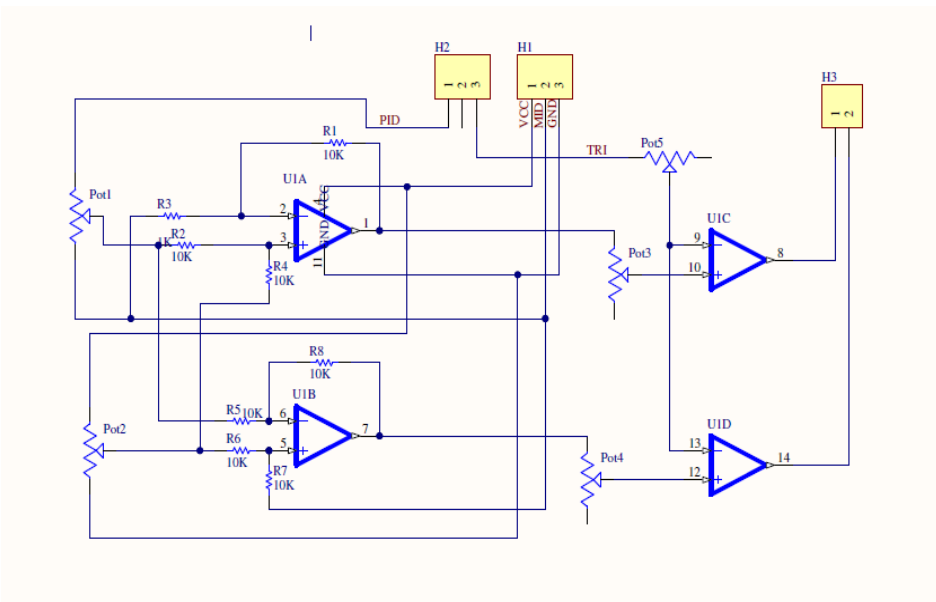

Figure 10: Caption1

5 PCB Design

The PCBs of the circuits designed for the wall following robot are as follows.

5.1 Instrumentation Amplifier

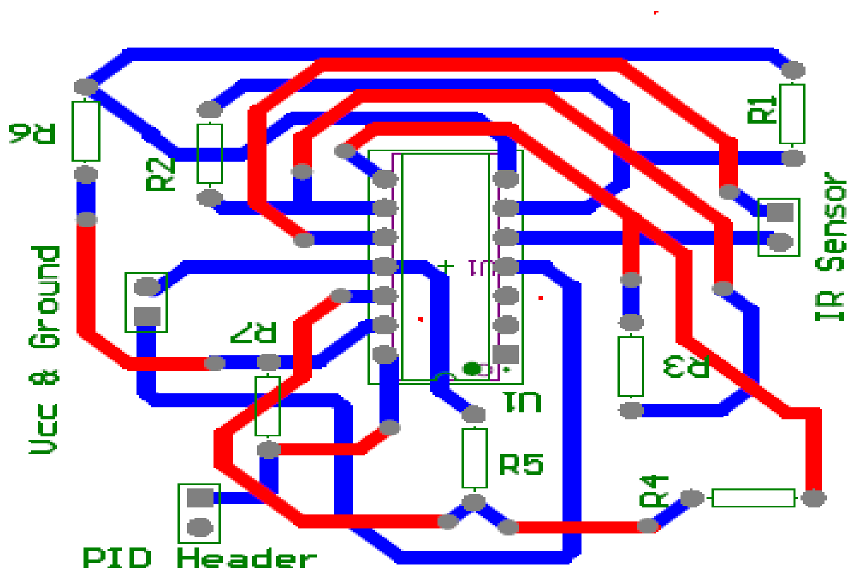

Figure 11: Caption1

5.2 PD Controller

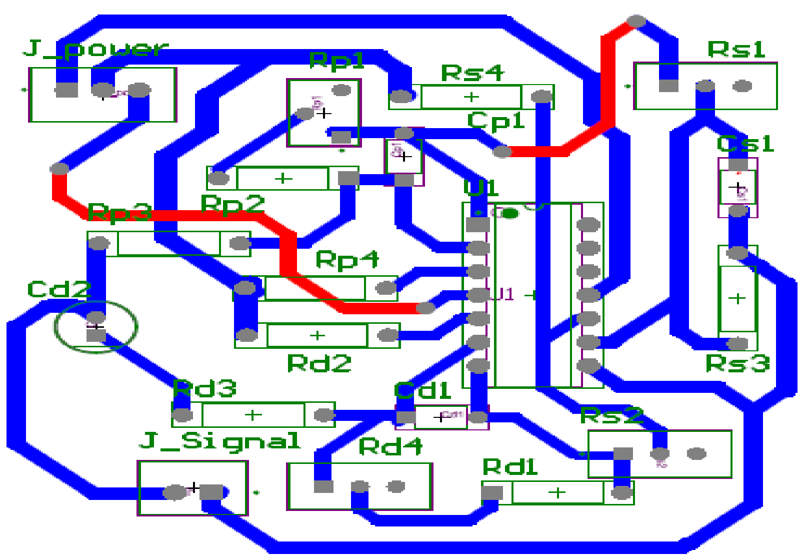

Figure 12: Caption1

5.3 Triangular Wave Generator

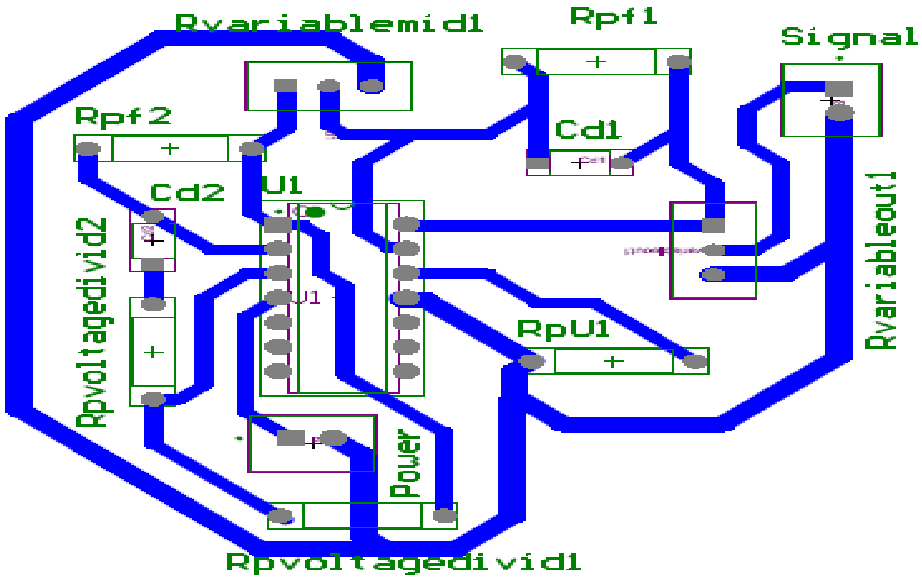

Figure 13: Caption1

5.4 PWM Signal Generator and Turn Adjustment Circuit

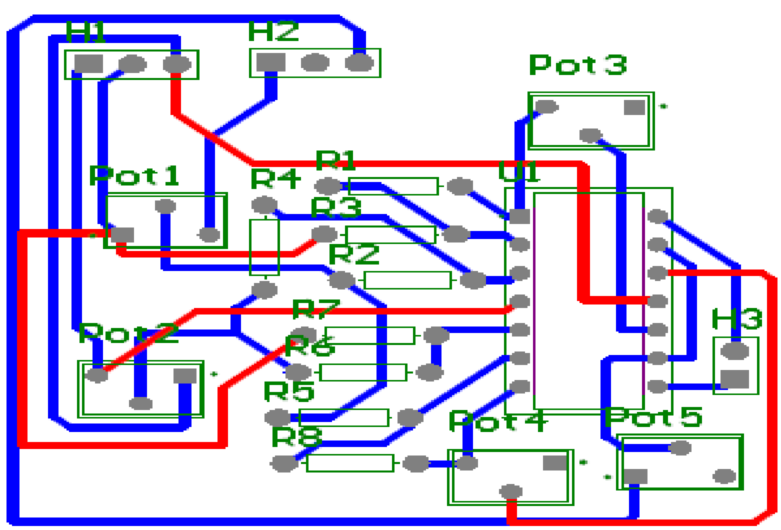

Figure 14: Caption1

6 Enclosure Design

The enclosure design of the wall following robot is as follows.

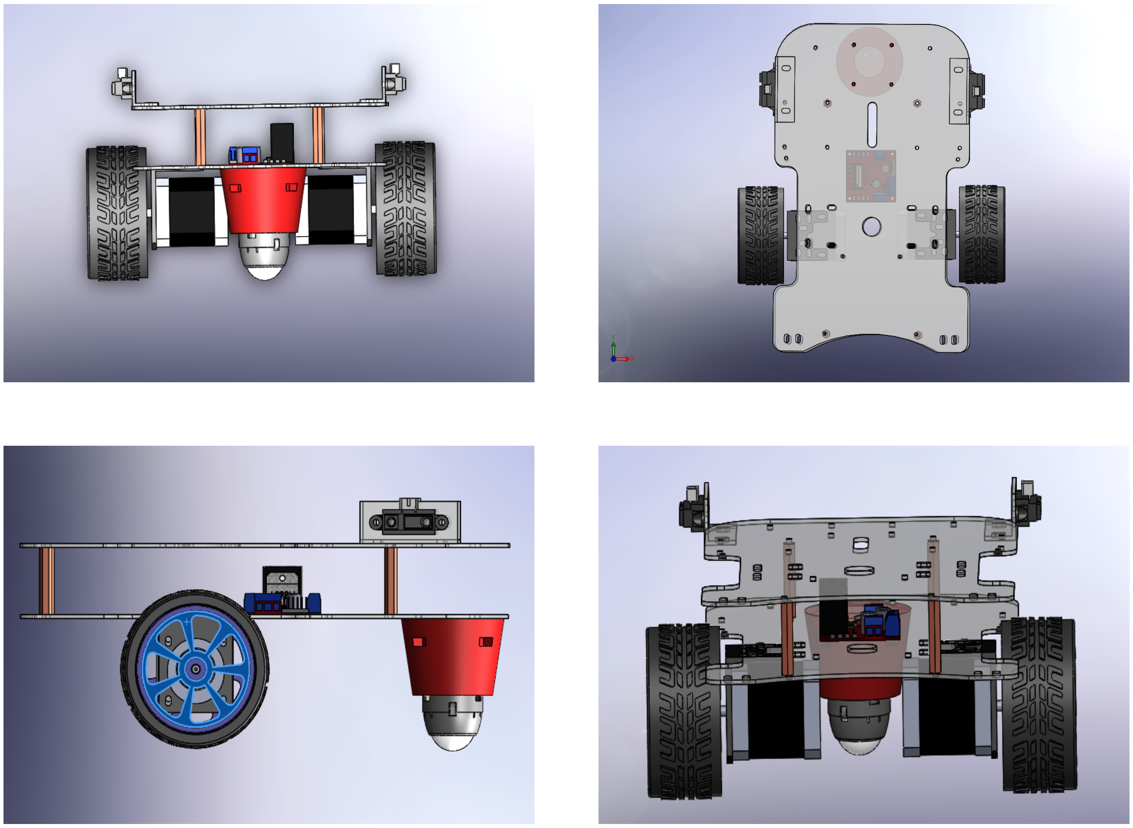

Figure 16: Caption for this figure with two images

since the designed enclosure was a match for the robot chassis available in the market, it was decided to go with the readily available robot chassis.

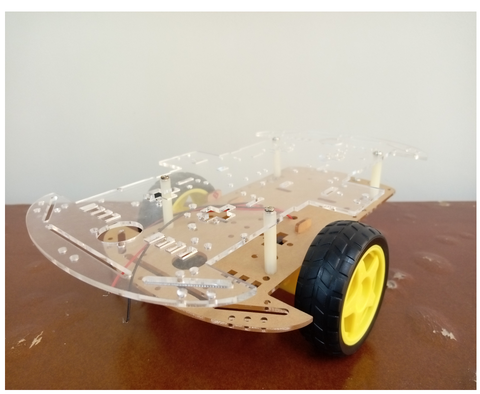

Figure 17: Robot Enclosure

7 Individual Contributions of Each Group Member

- Dilhara A.D.U (200128D) - PWM signal generator and turn controller circuit, Enclosure design, Final testing and debugging
- Liyanarachchi D.S.G.L.S (200345N) - PD controller circuit, Final testing and debugging
- Rajarathna G.K.M.I.D (200500L) - Triangular wave generator circuit, Simulation and mathematical model, Final testing and debugging
- Wijetunga W.L.N.K (200733D) - Instrumentation amplifier, Documentation, Final testing and debugging

8 Simulation Results

To evaluate the proposed idea for the analog wall following robot, it was recommended to simulate the proposed circuits before the breadboard implementation.
So, to find out the K_i,K_p and K_p constant values for the PID controller, the following program was developed including all the necessary parameters of the robot. The program was implemented using Python language.

```
def subr (v1,v2):
    #voltage at positive input is positive and other will negative
    diffence = v2-v1
    return diffence

##################

def pid (error,integral,diff):
    id_calculation=[]#first value will be integral
    prop = -error
    prop_out = 2*prop #2 is the propotional constant and need to change
    print(prop_out,'prop_out')#test#

    inte = (integral - error/0.01)
    #calculate integral error
    #need previous error
    #error multiplied by the time interval and devided by capacitance

    id_calculation.append(inte)
    inte_out = inte*0.0001
    #took integral constant as 0.0001 and need to change
    print(inte_out,"inte_out")#test#

    dif = (error*0.0000001 - diff)*1000
    #calculated diffrential
    # took time interval as 0.001 s

    id_calculation.append(error*0.0000001)
    dif_out = dif*0.5
    #took diffrential coeficient as 0.5 and need to change
    print(dif_out,"dif_out")#test#

    pid_val = dif_out-(prop_out+inte_out)
    print(pid_val,"pid_val5")

    return (pid_val,id_calculation)

################

#def sumr(v1,v2):

pd=[0,0]#1 integral 2 differential
#def robot(left_sensor,right_sensor,foward_motor):
while True:
#left_sensor = float(input("enter sensor reading : "))
#right_sensor = float(input("enter sensor reading : "))

```

```python
    sensors = (input())
    sensors = sensors.split(',')
    for i in range(0,(len(sensors)-1)):

        left_sensor = float(sensors[i])
        right_sensor = float(sensors[i+1])
        error = subr(left_sensor,right_sensor)####
        pidf,pd = pid(error,pd[0],pd[1])
        #need to add P, I, D and need to give the final output
        print(pd)

        pidf = pidf*0.0001
        # set pid output for sutable value #2 is just a constant


        left_motor = 5 + pidf
        # i add the error generated by  the pid to the left motor
        # but it may substract depending on the sensor

        right_motor = 5 - pidf
        pwm_signal_right = right_motor

        print(pwm_signal_right)

        pwm_signal_left = left_motor
        print(pwm_signal_left)
        i+=1
```

Listing 1: Python code to find PID constants

According to the program, the following results were obtained.

- Value of the proportional constant K_p - 1.9
- Value of the integral constant K_i - 0.0001
- Value of the derivative constant K_d - 0.5

Based on these results, it was decided not to use an integral circuit for the PID controller circuit. Before the breadboard implementation, all the circuits and the total circuitry was simulated using LTSpice.

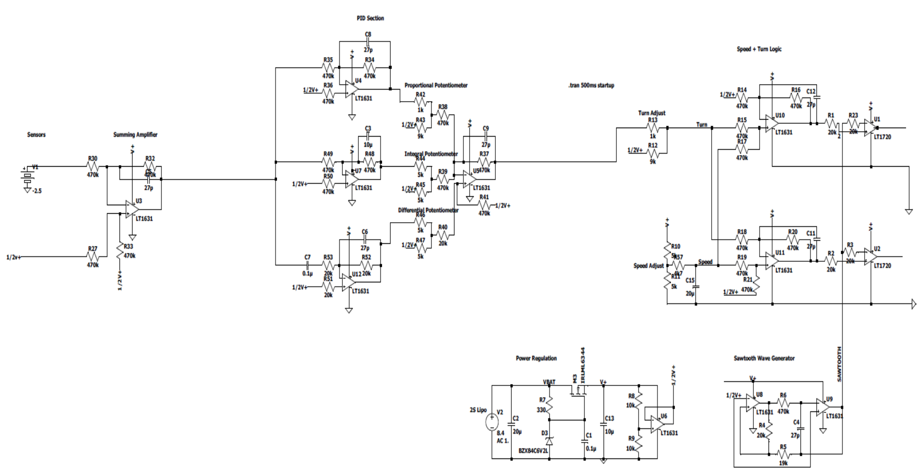

Figure 18: Circuit used for the LTSpice Simulation

9 Conclusion and Future Works

The breadboard implementation of the circuits of the all following robot was as follows.

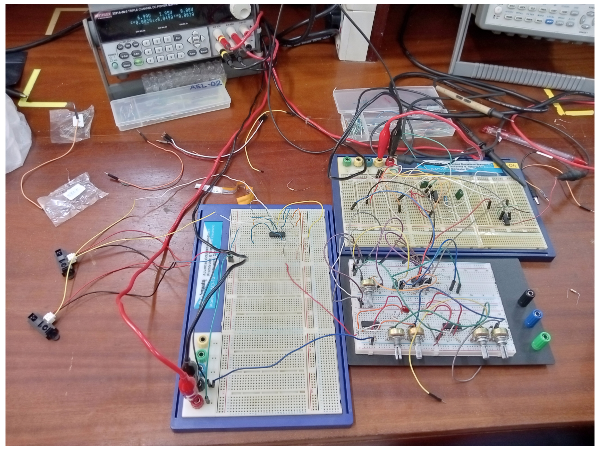

Figure 19: Breadboard implementation of the circuits

Although the breadboard implementation was easy to tune and get the required PWM signal, the practical implementation and bringing all the circuits to functioning state was extremely difficult and the final outcome of the analog wall following robot is as follows. The prototype made is functioning

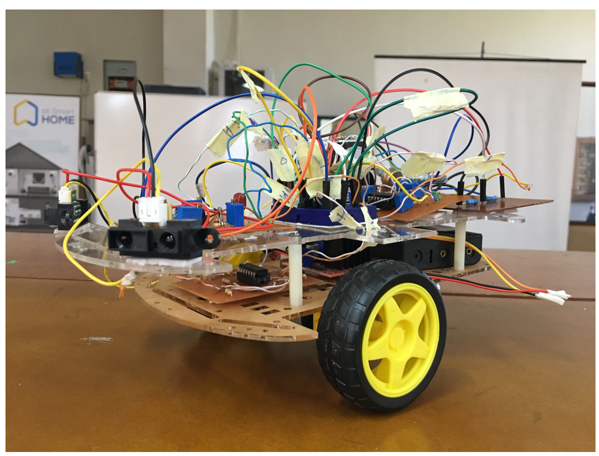

Figure 20: Final Prototype Analog Wall Following Robot

but the assembly of PCBs and components is not in a satisfactory level. Therefore as a future work, proper assembling of components should be done.
The circuit used as the triangular waveform generator worked well in the breadboard implementation and it was a failure when the PCB was build according to that circuit. In breadboard implementation, the output of the triangular waveform generator was 8V peak-peak which was reduced to 5V peak-peak using a potentiometer. But in the PCB, the output was 1.86V peak-peak. Since all the other circuits were tuned to work on that peak-peak voltage, for the final prototype, a different triangular waveform generator circuit was used. Another future work is that using a better triangular waveform generator for the robot.
Analog wall following robot is an interesting yet a challenging project for anyone. But the learning outcome of applying analog electronic knowledge to a practical scenario is definitely achieved. Special thanks goes to Mr.Pahan Mendis, Mr.Hiruna Vidumina and Mr.Hasantha Nadeeshan for the supervision and guidance. Anyone who is willing to go into the analog electronic sub-field and any robotics enthusiast is welcome to try this project and learn and have fun with analog electronics.

10 References

- About LM324N Integrated circuit
- Datasheet of LM324N operational amplifier
- Instrumentation amplifier
- PWM signal generator which is required to make the necessary PWM signal for the motor driver
- L298N Motor driver
- Inverting amplifier refernce