Department of Electronic & Telecommunication Engineering
University of Moratuwa, Sri Lanka

Analog Wall Following Robot

Group Members:

220096T	DAYANATHAN.T
220480P	PIRATHISHANTH.A
220491B	PRAVEEN.V.V.J
220626V	SULOJAN.R

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Abstract

The objective of this project is to design and implement a wall-following robot capable of maintaining its position at the centerline between two parallel walls. To achieve this, we employ infrared (IR) sensors to measure the distance between the robot and each wall, providing the necessary feedback signals for a proportional-integral-derivative (PID) control loop. By incorporating multiple operational amplifiers (op-amps) and analog circuitry, we process and adjust these sensor signals to dynamically control the motor speeds and keep the robot accurately centered. The final configuration generates PWM signals with varying duty cycles, ensuring smooth and precise speed adjustments that maintain the robot's alignment throughout its operation

Contents

1 Introduction

In this project, we aimed to design, implement, and optimize a wall-following robot capable of maintaining its position precisely at the center between two parallel walls. To accomplish this, we did multiple stages of signal conditioning, executed using a significant number of operational amplifiers (op-amps), allowed the system to continuously adjust motor speeds to correct any positional deviations.

To realize this concept, we followed a series of iterative development steps. Initially, **the circuits were prototyped on breadboards**, enabling us to validate the design principles and fine-tune the functionality of each stage. Encouraged by the early results, **we proceeded to design a professional printed circuit board (PCB) layout** that housed six TL084CN integrated circuits, providing a total of **24 op-amps** for all signal conditioning and PID control tasks. By carefully sourcing both **surface-mount (SMD) and through-hole components** and meticulously soldering and assembling them onto the PCB, we built a robust and reliable hardware platform. Extensive calibration, testing, debugging, and iterative tuning ensured that the final system achieved smooth and precise control. The resulting wall-following robot is a testament to the effective integration of analog control systems, sensor-based feedback, and systematic hardware development.

2 Functionality

In this project, the primary objective is to process the signals from two infrared (IR) sensors positioned on either side of the robot, convert these inputs into a usable control signal, and subsequently generate a pulse-width modulation (PWM) output for the motors.

2.1 Main Subcircuits

1. **Instrumentation Amplifier:**
   This stage takes the outputs from the left and right IR sensors and provides a high-precision, low-noise differential measurement. By accurately amplifying the difference between the two sensor voltages, it converts the raw sensor readings into a usable error signal. This error signal directly reflects the robot's lateral displacement from the centerline, serving as the fundamental input for the subsequent control and correction stages.

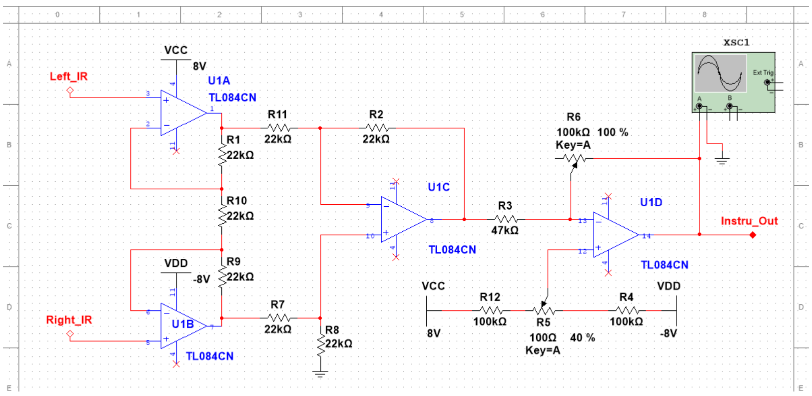


Figure 1: Instrumentation Amplifier

2. **PID Controller:**
The PID (Proportional-Integral-Derivative) controller receives the error signal from the instrumentation amplifier and calculates the necessary correction to steer the robot back toward center. - *Proportional* action provides immediate correction based on the current error magnitude. - *Integral* action accumulates the error over time to eliminate steady-state offsets. - *Derivative* action anticipates future trends by considering the rate of change of the error. The combined PID output ensures smoother, more stable corrections, preventing oscillations and ensuring the robot settles effectively on the centerline.

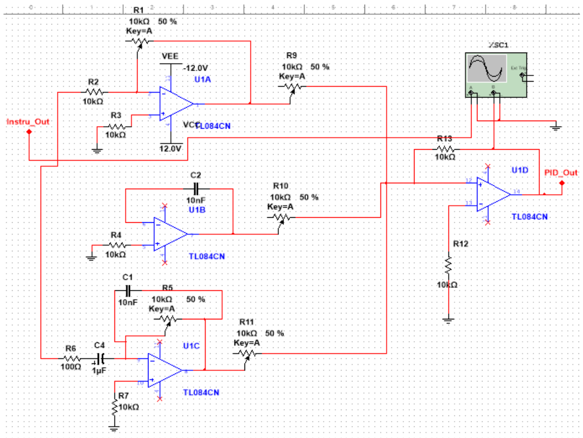


Figure 2: PID Controller Circuit

3. **Adder and Subtractor:**
After obtaining the PID output, we need to translate this correction into differential wheel speeds. This is achieved by adding the PID correction to a fixed "base" speed for one motor, and subtracting it from the same base speed for the other motor. As a result, one wheel might speed up slightly while the other slows down, causing the robot to turn and re-center. These operations produce two separate reference signals—one for the left motor and one for the right motor—thus allowing the robot to make fine steering adjustments based on the measured error.

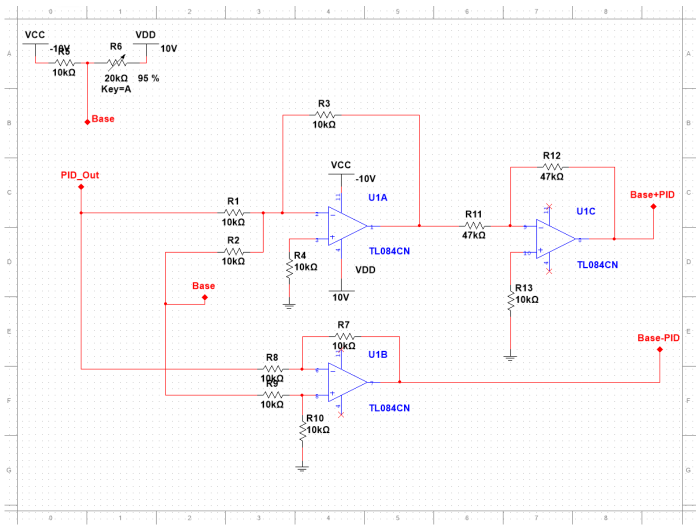


Figure 3: Adder and Subtractor

4. **Triangular Wave Generator:**
To implement a PWM scheme, we need a repeating reference waveform against which we can compare our motor speed references. The triangular wave generator produces a stable, linear ramp signal that oscillates between defined voltage limits. By continually comparing the motor reference voltages against this ramping triangular waveform, we can generate duty cycles that correspond to the desired motor speeds.

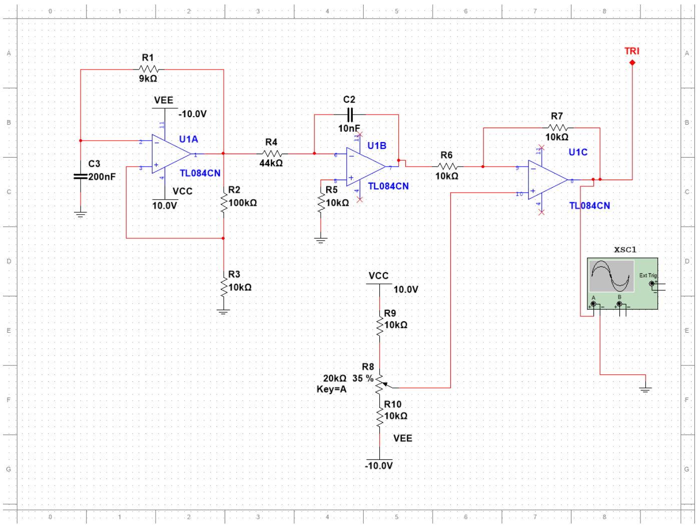


Figure 4: Triangular Wave Generator

5. **Comparator:**
Comparators form the heart of the PWM generation process. Each motor reference signal (Base+PID and Base–PID) is fed into a comparator, where it is compared against the triangular wave. - If the reference signal is greater than the instantaneous triangular wave voltage, the comparator outputs a high signal. - If it is lower, the output is low. As the triangular wave rises and falls, the comparator's output switches between high and low states, producing an AC square wave whose duty cycle directly encodes the desired motor speed adjustment.

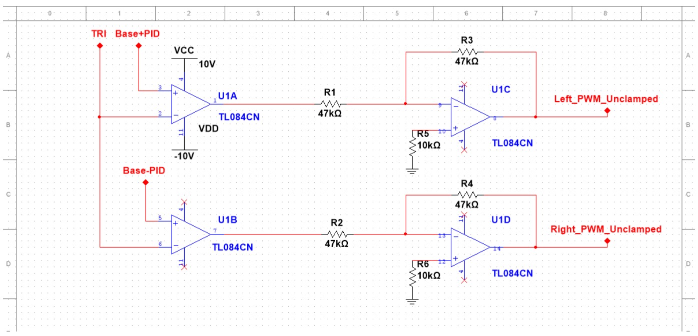


Figure 5: Comparator

6. **Clamper:**
   The raw comparator outputs are AC square waves that swing both above and below the baseline, which are not suitable as final PWM signals. The clamper circuit shifts and bounds these signals, ensuring they remain within a proper voltage range for driving the motors. By clamping the waveform to a stable DC level, we produce clean PWM signals with varying duty cycles. These signals directly govern the motor drivers, allowing each motor to run at an appropriate speed to maintain the robot on the centerline.

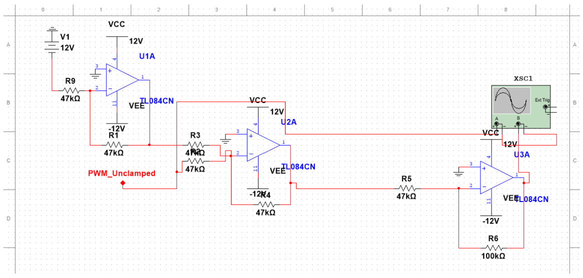


Figure 6: Clamper

3 System Architecture

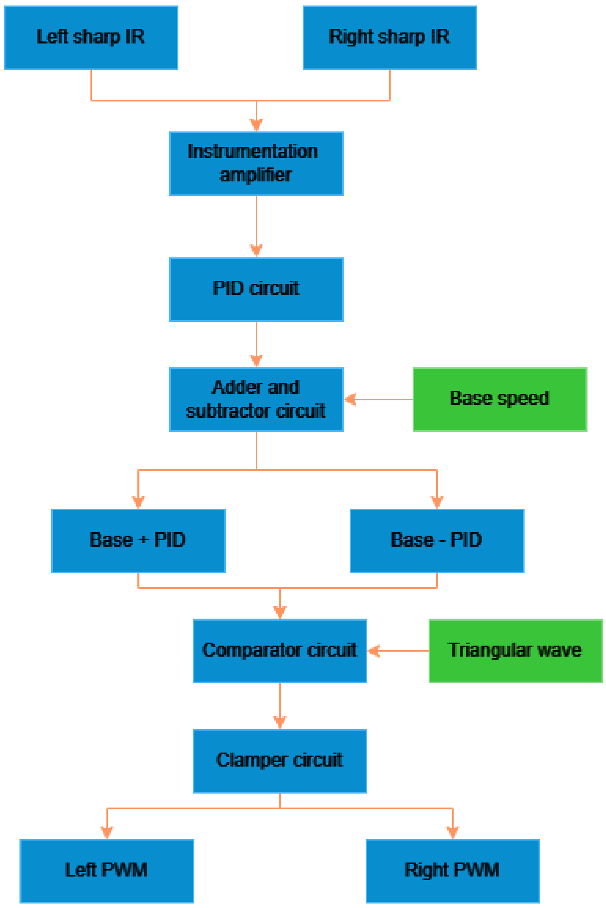


Figure 7: System Architecture

4 Component Selection

1. **TL084CN Opamp ICs :**
To optimize PCB space, which is critical in our design incorporating over 25 operational amplifiers, we strategically selected the TL084CN, a quad op-amp IC that integrates four op-amps into a single package. This choice significantly reduced the PCB area required, enhancing the overall compactness of the design.It has high slew rate than other opamps(12V/us) Additionally, the TL084CN demonstrated superior power efficiency, making it a more suitable choice compared to other available op-amps, thereby meeting both the functional and design requirements of our project.

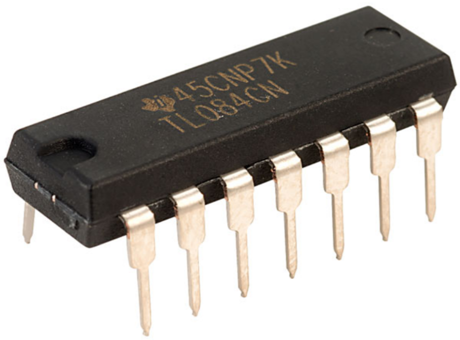


Figure 8: TL084CN Opamp ICs

2. **Sharp IR sensors:**
We opted for the SharpIR sensor instead of the commonly used ultrasonic sensor due to its distinct advantages. Ultrasonic sensors calculate distance by measuring the time delay between transmitted and received pulses, which can introduce complexities. On the other hand, the SharpIR sensor outputs a continuous analog signal directly proportional to the distance from the obstacle. This characteristic makes it an ideal choice for applications requiring precise analog measurements. We used such 2 sharp IR sensors.

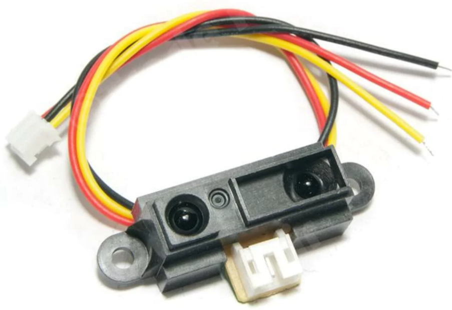


Figure 9: Sharp IR sensors

3. **L293D Motor Driver ICs:**
The L293D features two H-bridge circuits, allowing it to control the speed and direction of two DC motors independently. This dual functionality is essential for our project.The IC supports a wide voltage range (4.5V–36V) and a peak current output of 600 mA per channel. These specifications make it suitable for driving small to medium-sized DC motors, aligning well with the power requirements of our motors.The L293D is a readily available, cost-effective, and easy-to-use IC that does not require extensive external components, simplifying circuit design and reducing the overall project complexity.The IC includes built-in diodes for back EMF protection, which safeguards the circuitry and connected components from potential damage caused by inductive motor loads.The L293D's compact DIP (Dual Inline Package) form factor ensures it occupies minimal PCB space, making it ideal for space-constrained applications.

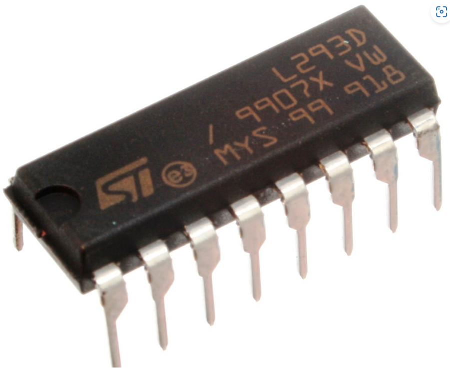


Figure 10: L293D motor Driver IC

5 Software Simulation

In this project, the entire circuit was simulated using **Multisim Software**. Multisim provides an intuitive and powerful platform for simulating analog, digital, and mixed-signal circuits with precision.

5.1 Simulation Overview

The circuit was constructed in Multisim to verify its behavior before hardware implementation. The following components and steps were involved in the simulation:

- The circuit schematic was designed using virtual components in Multisim.
- A DC power source was applied to provide the required operating voltage.
- The output signal from the Sharp IR sensor was approximated using a SINE voltage source or function generator.
- Load resistors and necessary passive components were added to reflect real-world behavior.

5.2 Simulated Circuit

The simulated circuit successfully demonstrated the desired output behavior. Below are the screenshots from the Multisim simulation:

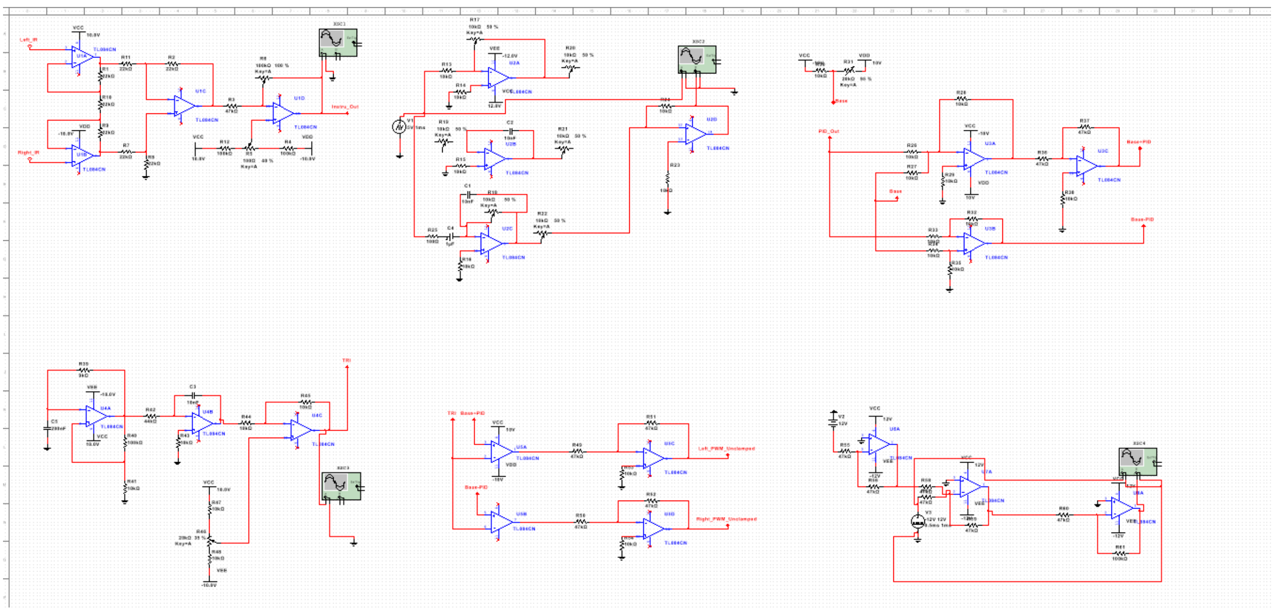


Figure 11: Circuit schematic simulated in Multisim.

5.3 PWM Signals for Left and Right Motors

The output signals for the left and right motors are shown in the oscillograms in Figure 12. These signals are Pulse Width Modulated (PWM) and are responsible for controlling the motor speeds. The two PWM signals exhibit different duty cycles due to the **PID control algorithm**, which uses the error values from the wall IR sensor as input.

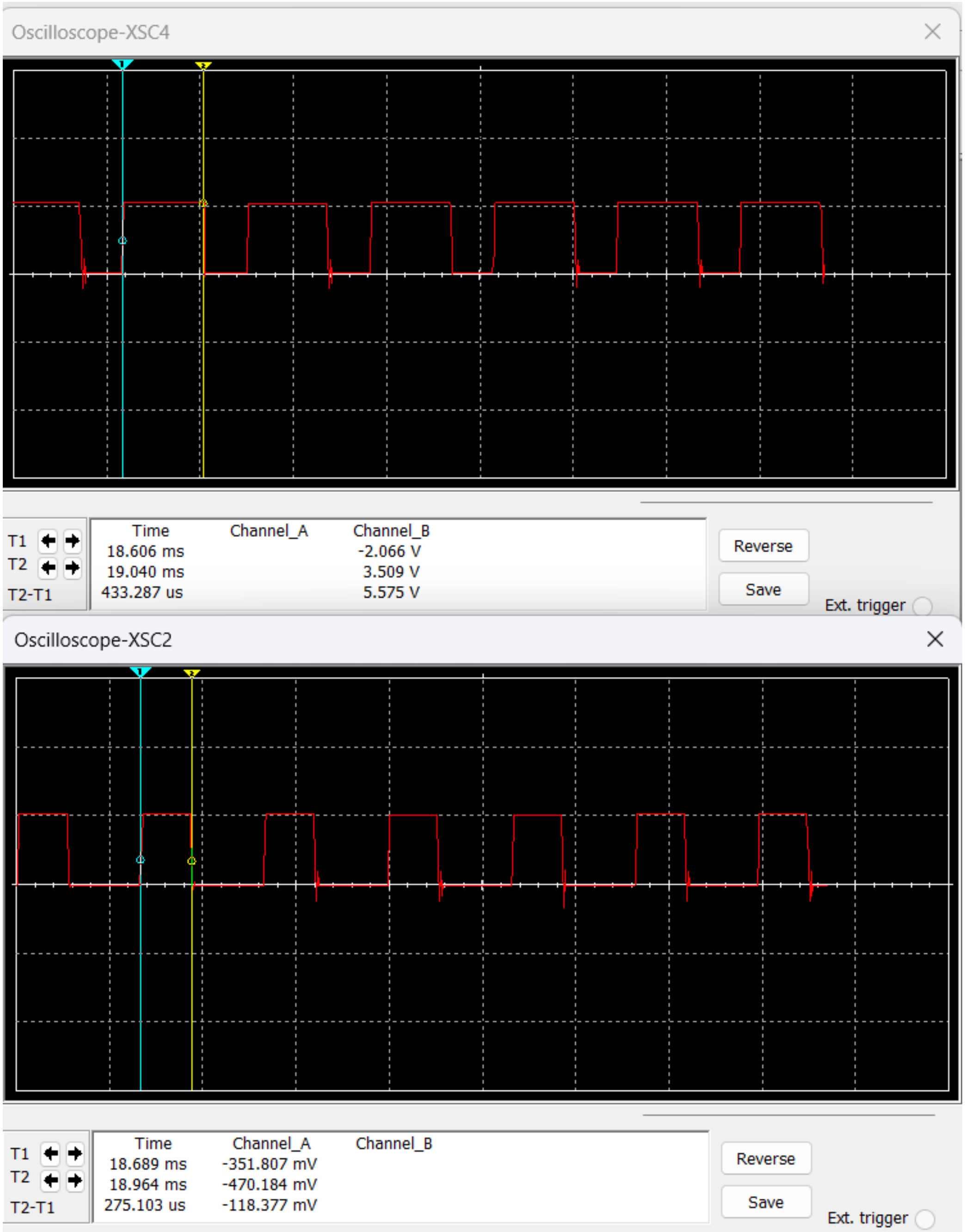


Figure 12: PWM signals for left and right motors.

5.3.1 Difference in Duty Cycles

The duty cycle of a PWM signal is defined as the percentage of the signal's period where it remains in the **HIGH** state. Mathematically, the duty cycle (%) is calculated as:

$$\text{Duty Cycle (\%)} = \frac{T_{\text{HIGH}}}{T_{\text{Period}}} \times 100$$

Where:

- T_{HIGH} is the duration the signal stays HIGH.
- T_{Period} is the total time of one cycle.

From the oscilloscope readings:

- For the **Left Motor** PWM signal (upper waveform):

$$T_{\text{Period}} = 500\,\mu s,$$
$$T_{\text{HIGH}} = 433.287\,\mu s\,\text{(approximate)}.$$

Therefore, the duty cycle for the left motor is:

$$\text{Duty Cycle} = \frac{433.287}{500} \times 100 \approx 86.65\%.$$

- For the **Right Motor** PWM signal (lower waveform):

$$T_{\text{Period}} = 500\,\mu s,$$
$$T_{\text{HIGH}} = 275.103\,\mu s\,\text{(approximate)}.$$

Therefore, the duty cycle for the right motor is:

$$\text{Duty Cycle} = \frac{275.103}{500} \times 100 \approx 55.02\%.$$

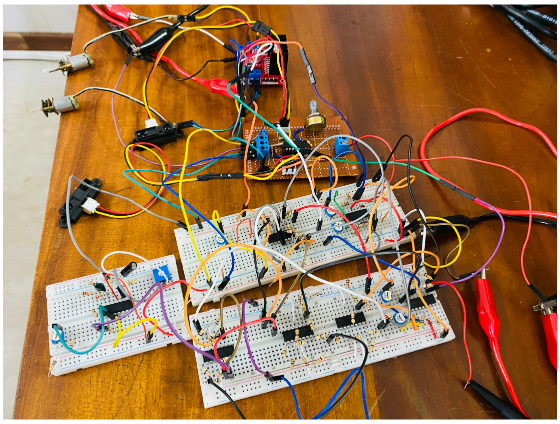
5.4 Impact of PID Control

The difference in duty cycles arises due to the error correction performed by the PID control algorithm. The wall IR sensors provide feedback about the robot's distance to the wall. If the robot deviates from the desired path:

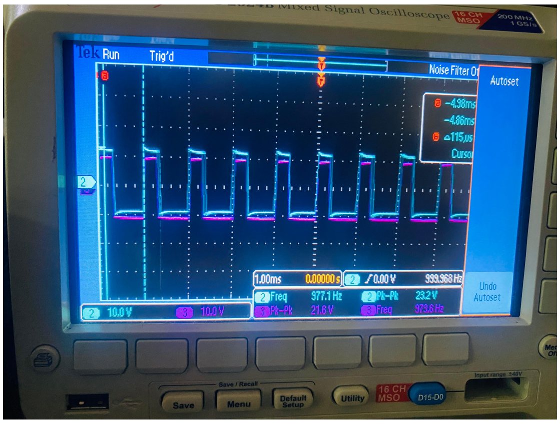
- The **PID controller** adjusts the duty cycles of the left and right motors proportionally to correct the error.
- A higher duty cycle corresponds to a faster motor speed, while a lower duty cycle slows the motor.

The PID adjustments ensure that the robot maintains the desired distance from the wall and travels along the correct path.

6 Hardware Testing



(a) circuit implementation



(b) PWM testing signal

In the PWM signal testing figure:

- The blue signal represents the output from the **Right PWM** circuit.
- The purple signal represents the output from the **Left PWM** circuit.

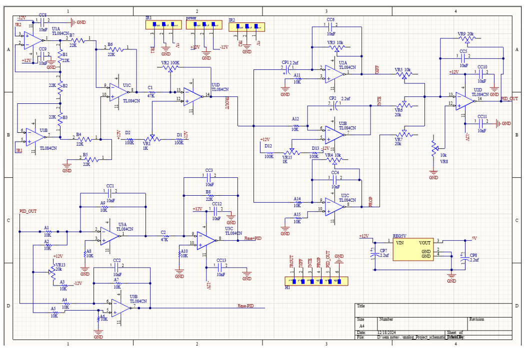
The behavior observed is:

> If the width of one signal increases, the width of the other signal decreases.

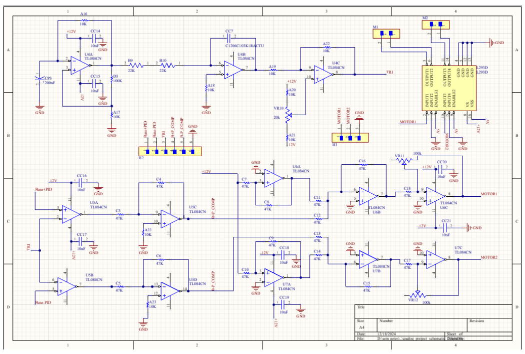
This demonstrates the inverse relationship between the outputs of the adder and subtractor circuits, validating their correct operation in generating the PWM signals.

7 PCB Design

7.1 PCB schematics



(a) Schematic 1



(b) Schematic 2

Figure 14: PCB schematics

7.2 Final PCB

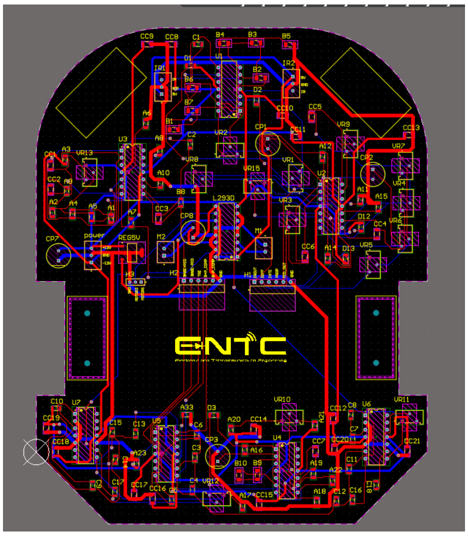


Figure 15: Top and bottom layer

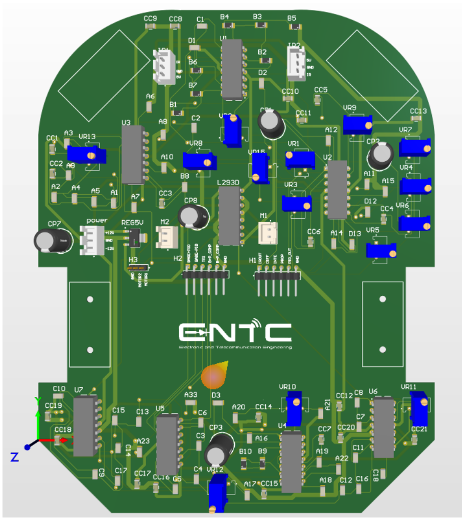


Figure 16: Top 3D view

With Altium Designer, we carefully crafted printed circuit boards (PCBs) tailored for our analog wall-following robot project.. The design incorporates SMD resistors and capacitors with 1 percentage tolerance, ensuring precision and reliability. We also used through-hole potentiometers for adjustable control and IC bases for easy replacement of integrated circuits in case of failure. Additionally, header pins were included to monitor circuit outputs for debugging purposes.

To enhance durability and current handling, we increased the width of the PCB traces. The design features a two-layer PCB, providing improved routing flexibility. Uniquely, the PCB doubles as the chassis for the robot, contributing to a compact and efficient design. However, we plan to develop a custom enclosure in the future to further refine the structure and functionality of the robot.

This approach emphasizes modularity and adaptability, setting the foundation for upgrades and improvements in subsequent iterations of the project.

8 Enclosure Design

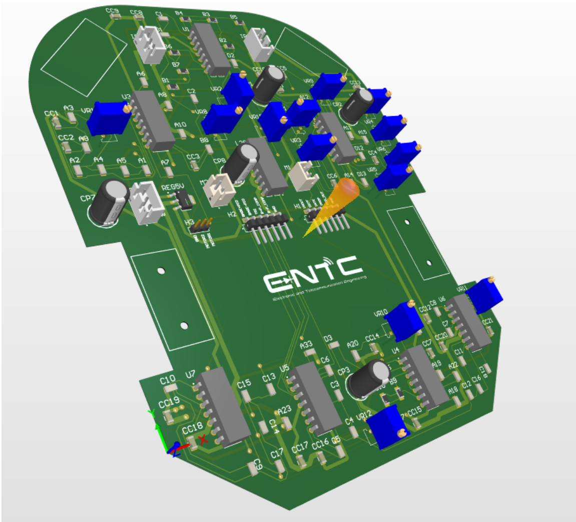


Figure 17: 3D view

We used the PCB of our robot as the chassis in our project to simplify the design and enhance efficiency. In the future, we plan to develop a fully covered enclosure for improved functionality and aesthetics.

9 Final Outcome

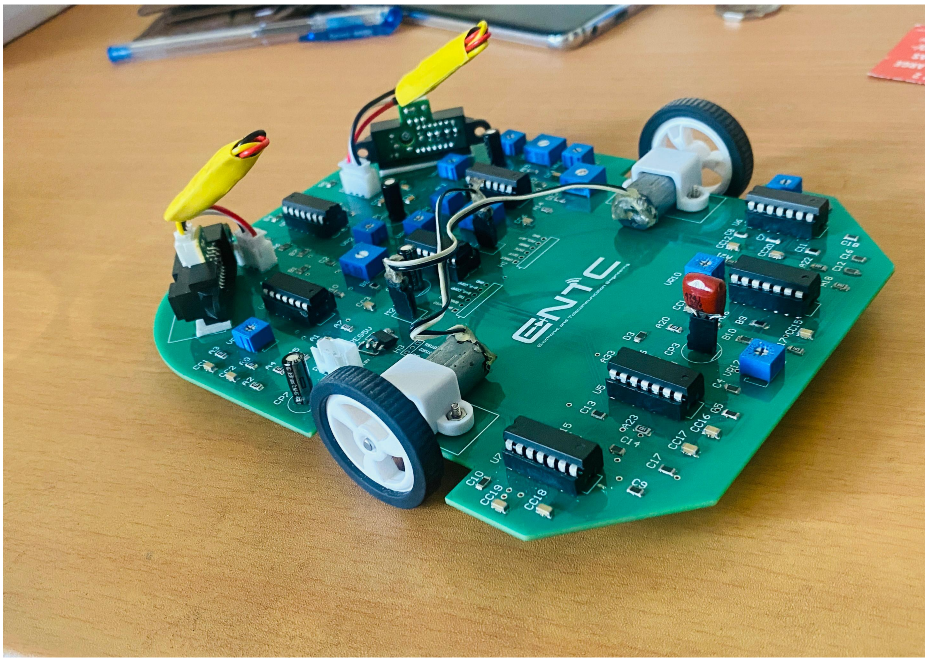


Figure 18: Final Robot - Side View

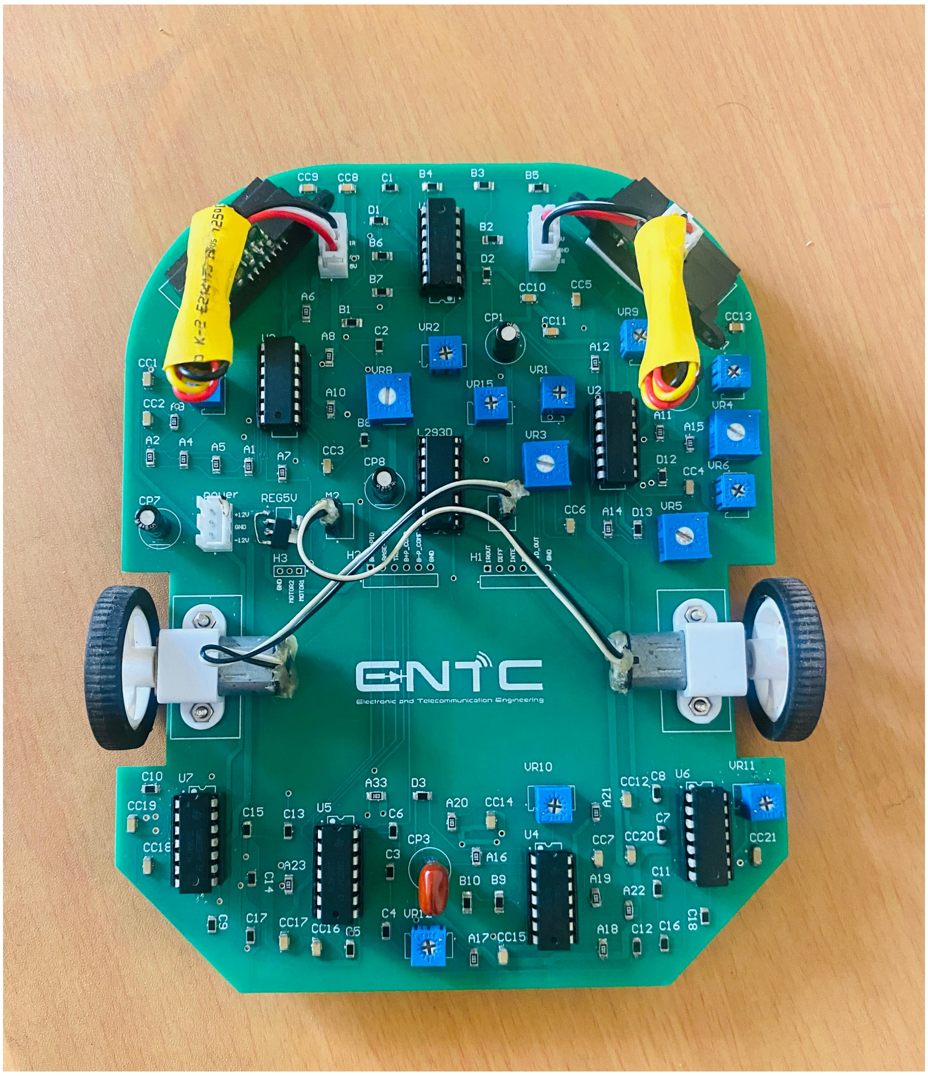


Figure 19: Final Robot - Top view

10 Conclusion & Future Works

To sum up, the analog wall-following robot created for this project has successfully illustrated how analog techniques can be used to provide accurate and responsive wall navigation. This method offers a fresh approach to wall-following applications by eschewing conventional microcontroller-based programming and employing analog circuitry. To carry out logical processes, the design makes use of operational amplifiers, PID algorithms, and other analog components. Furthermore, the versatility of analog approaches in interacting with motor driver integrated circuits is demonstrated by the conversion of analog signals to PWM signals for motor control.

In the future, we plan to develop a closed enclosure for the robot to enhance its durability and aesthetics. Additionally, we aim to incorporate more circuits for precise speed control and improved PID tuning, ensuring smoother navigation. Features such as mode selection, PID parameter adjustment, and advanced speed control will further enhance the robot's functionality, making it more adaptable and efficient.

11 Contribution of Group Members

The following table summarizes the contributions of each team member to the project:

Team Member	**Contributions**
SULOJAN.R (220626V)	PCB Design, SMD Soldering, Triangular Wave Generator and PWM Circuit Design
PRAVEEN.V.V.J (220491B)	PCB Design, Soldering, PID circuit design, PID Tuning and Testing
DAYANANTHAN.T (220096T)	PCB Design, Through-hole Soldering, Instrumentation Amplifier Circuit Design
PIRATHISHANTH.A (220480P)	Software Simulation, PWM and clamper circuit design, Component Assembling

Table 1: Team Member Contributions

12 Acknowledgment

We would like to extend our heartfelt gratitude to everyone who has guided, supported, and inspired us throughout the development of this project. Firstly, we express our sincere appreciation to our allocated supervisors, Mr. Lathika, Mr. Thilanka Udana, Ms. Dinithi Fernando, and Mr. Sandun Ranasinghe, for their unwavering guidance, invaluable feedback, and exceptional oversight.
We are also deeply grateful to Dr. Sampath Perera, Dr. Pranjeevan Kulasingham, Dr. Jayathu Samarawick Rama, and Dr. Wageesha Manamperi for their encouragement, insightful instruction, and thoughtful recommendations. Their perspectives, rooted in years of academic and industry experience, have greatly enriched our learning process and significantly contributed to the success of this endeavor.
In addition, we would like to recognize the exceptional dedication of our four group members, whose relentless effort and sacrifices ensured the successful completion of this project. Their hard work, collaborative spirit, and determination—despite long hours, intricate problem-solving, and challenging design iterations—have been pivotal in turning our concept into reality. We are also especially grateful to our batchmate, Rajinthan R., for his generous support in providing access to his boarding-based workshop and the necessary tools that enabled us to work more efficiently.
This project, in its entirety, represents the fusion of theoretical knowledge, practical skill development, and teamwork. It has offered us an opportunity to expand our horizons, enhance our understanding of control systems and robotics, and better prepare for future professional challenges. We are profoundly appreciative of everyone who contributed—directly or indirectly—to this journey. Your guidance, resources, and encouragement have transformed an ambitious idea into a meaningful and tangible achievement.

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