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

Analog Wall Following Robot

Group Members:

210005H	Abeyrathna S.M.
210015M	Abeywardhane R.N.
210031H	Amarasinghe A.A.W.L.R.
210728C	Wijewickrama W.K.D.D.D.

Submitted in partial fulfillment of the requirements for the module
EN 2091 Laboratory Practice and Projects

6th December 2023

Contents

Abstract
The ability to follow walls is a common feature in many robots and micro-mouse vehicles, commonly designed using digital methods. However, our approach utilized analog methods exclusively. Every logical operation was executed through analog methods. Distances from the side and front walls were measured, and these measurements were processed through a PID algorithm-based circuit made with operational amplifiers and analog components. The resulting signals were then passed through adders and subtractors to generate appropriate signals for each wheel. Subsequently, the signals for motor control were generated by converting them with a PWM generator. Functionality was also added for selecting speed and tuning the PID. A PCB was designed to accommodate the circuit with Surface Mount Device (SMD) components, and a 3D-printed enclosure was designed and developed to support the structure created on the PCB appropriately.

1 Introduction

Wall following traditionally involves concatenating various logical elements through microcontroller programming. SharpIR sensors measure distances, and to refine the sensor outputs and eliminate noise, they are directed through instrumentation amplifiers. The logic for each wheel's speed is then governed by two Proportional-Integral-Derivative (PID) circuits. One PID circuit, dedicated to side walls, determines wheel turning decisions, while the other, focused on the front, sets the base speed. The "Adder Subtracter" circuit processes the PID outputs, generating distinct analog signals for each wheel. Since motor driver ICs do not accept analog signals, the obtained output signals are converted to Pulse Width Modulation (PWM) signals and fed to the motor driver IC. Additional functionalities include speed control, PID parameter tuning, and the ability to switch between linear travel mode and maneuvering bends.

Every functionality is meticulously implemented using analog circuits, divided into specific functional blocks:

1. **Inputs and Instrumentational Amplifiers:** Filtering signals from noisy inputs.
2. **PID Wall:** Following walls and executing turns.
3. **PID Front:** Decelerating during bends and controlling overall speed.
4. **Adder and Subtractor:** Generating separate signals for the left and right wheels.
5. **PWM Generator:** Creating PWM signals for the motor driver.
6. **Speed Selector:** Manually choosing the speed.

These functional blocks are uniquely crafted with operational amplifiers and other analog components.

2 Component Selection

2.1 SharpIR Sensor

Figure 1: SharpIR Sensor

Instead of using an ultrasonic sensor, which is commonly used, we opted for the SharpIR sensor. This choice was made from the fact that the output of an ultrasonic sensor is calculated based on the delay between two pulses. In contrast, the SharpIR sensor provides a continuous analog signal proportional to the distance to the barrier. This feature was identified as ideal for analog purposes.

2.2 L298N Motor Driver

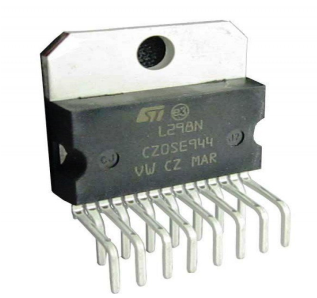

Figure 2:L298N Motor Driver IC

For efficient motor control and safety, we employ a motor driver to manage high currents. This component separates the logical analog circuit from the motor current, with motor control achieved through a PWM signal input.

2.3 TL084CN OP AMP

Figure 3: TL084CN OP AMP

To optimize PCB space, crucial for our design with over 50 op-amps, we strategically utilized the TL084CN, a Surface Mount Device (SMD) IC containing four op-amps. This choice significantly reduced the required area. Given our application's frequency requirements (below 200Hz), the slew rate became a less critical factor. Additionally, the TL084CN proved more power-efficient for our specific purpose compared to other op-amps available.

3 System Architecture

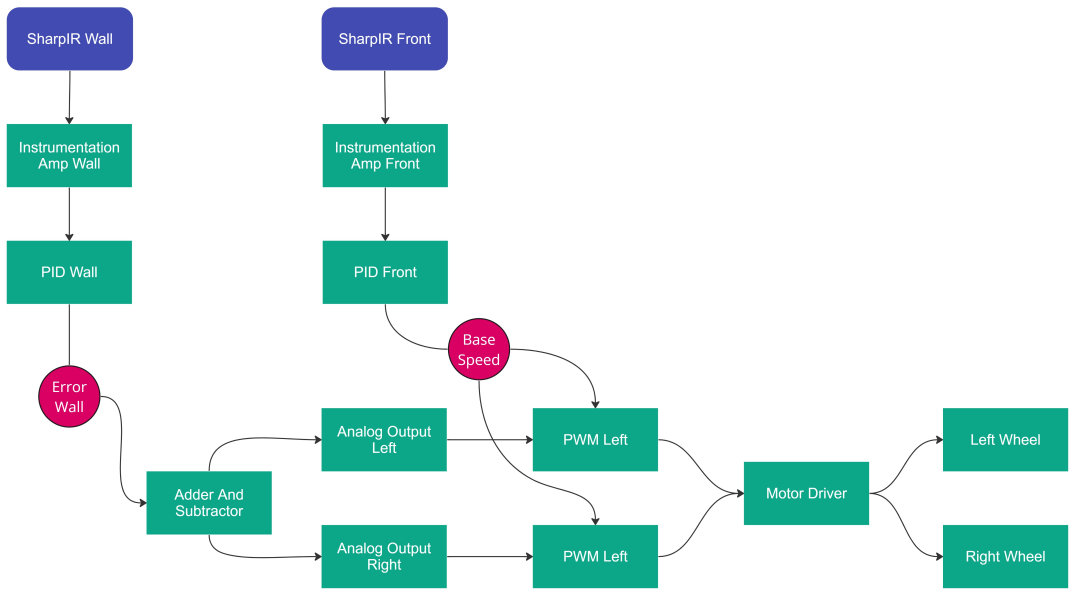

Figure 4: System Architecture

4 Functionality and Parameters

4.1 Instrumentation Amplifier

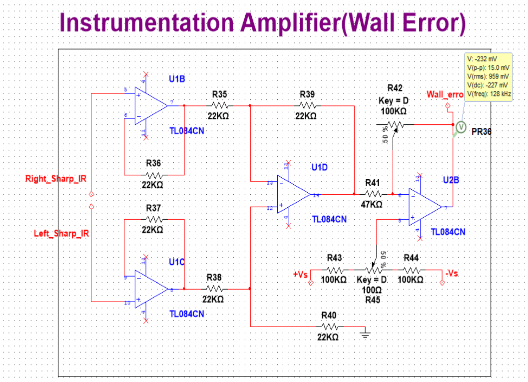

Figure 5: Instrumentation Amplifier

To address input signal noise in the PID circuit, we utilized an instrumentation amplifier. This component subtracts similar signals, minimizing the impact of disturbances. The input gain is adjustable with a potentiometer, ensuring precise control and effective noise reduction.

4.1.1 Output of the Instrumentation Amplifier

$$\text{Output} = \frac{R_{var}}{R_41}(V_{IN1} - V_{IN2})$$

4.2 PID Wall Error

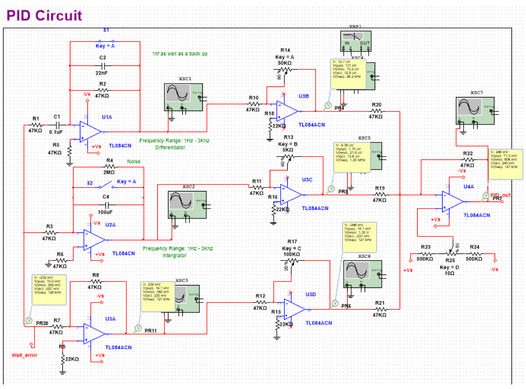

Figure 6: PID Wall Error

The wall error output from the instrumentation amplifier is directed to the PID circuit, determining the robot's turning direction. The PID circuit independently computes differentiated, integrated, and proportional gains, combining them to determine the turning direction and angle effectively.

4.2.1 Propotionality of PID

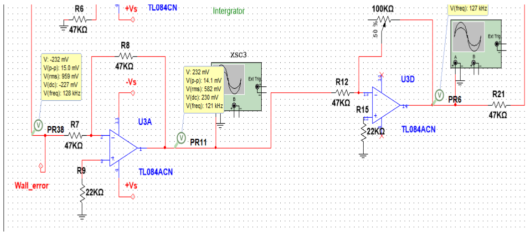

Figure 6.1: PID Proportionality

It identifies the disparity between the distances to the left and right walls in real-time, generating an error signal. This error signal aids the robot in maintaining a centered position within the path.

$$\text{Output} = \frac{R_{var}}{R}(WallError)$$

4.2.2 Differentiation of PID

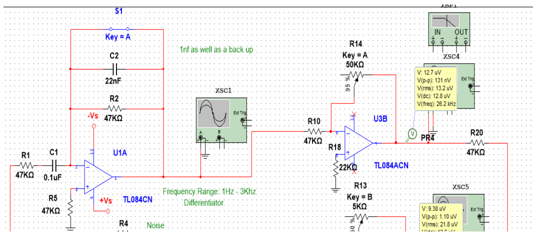

Figure 6.2: PID Differentiation

It identifies abrupt and gradual changes in the input, contributing to the robot's smooth wall-following behavior. Additionally, it mitigates the oscillations introduced by the proportional section, ensuring more stable and controlled movement.

$$\text{Output} = \left(\frac{R_{\text{var}}}{R}\right) \cdot \frac{d}{dt}\,(\text{Wall Error})$$

4.2.3 Integrator of PID

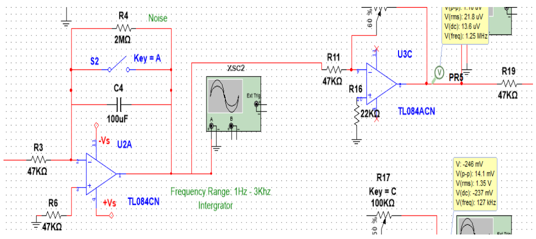

Figure 6.3: PID Integrator

While its direct impact on the final output is modest, this component plays a crucial role in improving the accuracy of wall following. It enhances stability, ensuring the robot maintains a correct center along the walls over time, preventing drift detected by the proportional section.

$$\text{Output} = \left(\frac{R_{\text{var}}}{R}\right) \cdot \int_0^t \text{Wall Error}\, dt$$

4.3 PID Distance Error

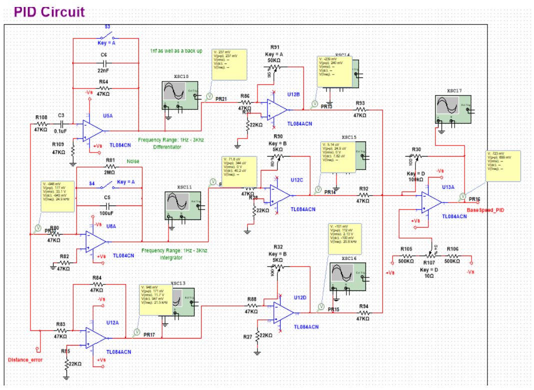

Figure 7: PID Distance Error

It evaluates the input from the front SharpIR sensor against a chosen base speed level. As the robot approaches a bend, the speed is proportionally reduced, facilitating precise and smooth turns. This process employs the familiar principles of proportionality, differentiation, and integration to compare with the established base speed.

4.4 Adder and Substractor

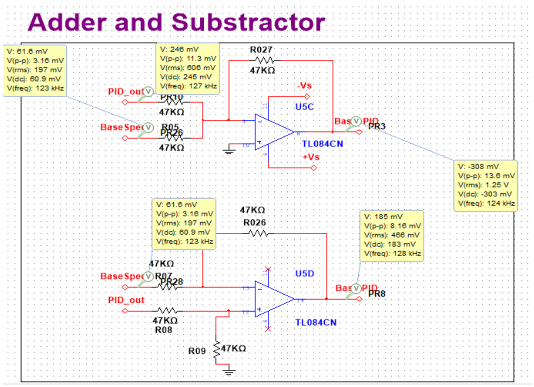

Figure 8: Adder and Substractor

It generates two distinct signals, namely Base + PID and Base - PID, providing separate outputs for the left and right wheels. This dual-signal approach contributes to differential control.

4.5 PWM Generator

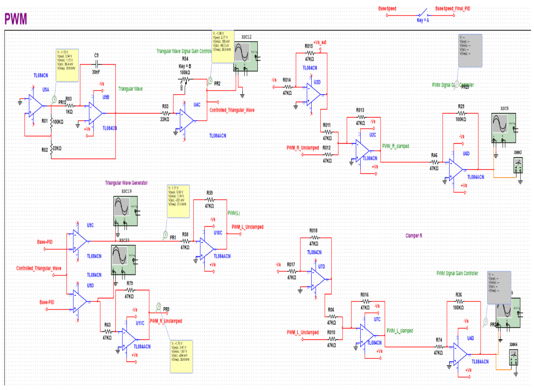

Figure 9: PID Wall Error

TTo accommodate the digital input requirement of the motor driver, the analog modulated signal is converted to a Pulse Width Modulated (PWM) signal. This process involves a PWM generator that initially generates a triangular waveform. Subsequently, it compares the triangular wave with the provided signal, and the resulting compared output is clamped to produce a PWM signal.

4.5.1 PWM - Triangular Waveform Generator

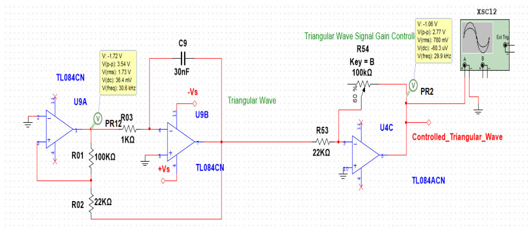

Figure 9.1: PWM Trangular

The triangular waveform generator is constructed by employing a ramp generator that undergoes inversion beyond a specific voltage threshold. The shape of the triangular waveform can be adjusted using a potentiometer, offering control over its characteristics.

4.5.2 PWM - Comparator

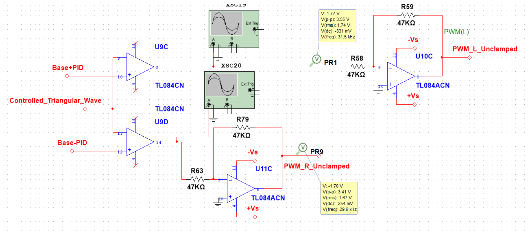

Figure 9.2: PWM Comparator

The generated triangular waveform is compared with the modulated analog signal, and the comparison results in cutoffs at various positions. The difference in positions where the cutoff occurs generates the Pulse Width Modulation (PWM) signal.

4.5.3 PWM - Clamper

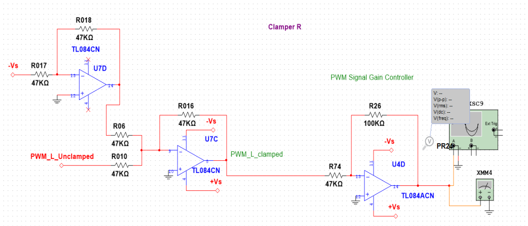

Figure 9.3: PWM Clamper

However, the output still consists of pulses with both positive and negative voltages. To obtain the desired Pulse Width Modulation (PWM) signal, the lowest voltage is set to 0, resulting in a signal that meets the required specifications.

4.6 Speed Selector

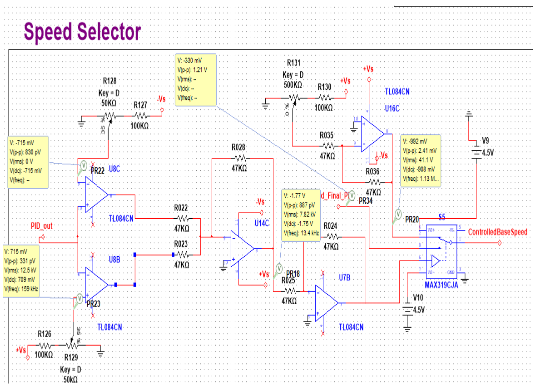

Figure 10: Speed Selector

This feature allows for the manual adjustment of the robot's speed by altering the base speed setting.

4.7 Voltage Regulation

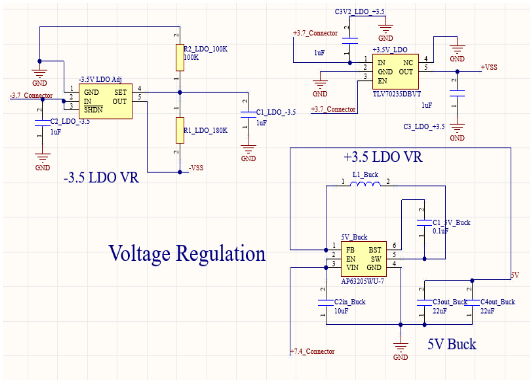

Figure 11: Power Supply Unit

This circuit segment takes power from the batteries and transforms it into 3.3V and 5V as needed for various sections of the robot.

5 PCB Design

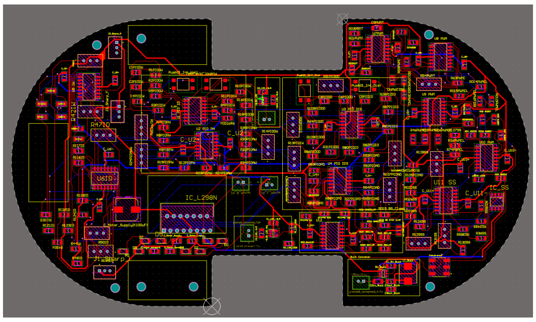

Figure 12.1:Top Layer

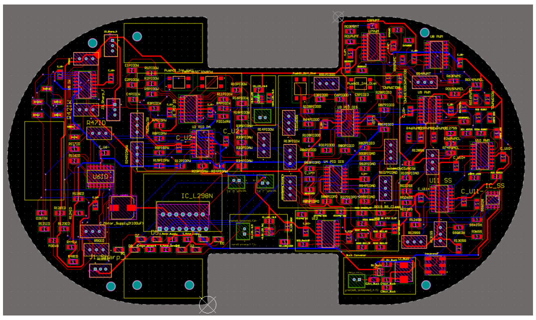

Figure 12.2:Bottom Layer

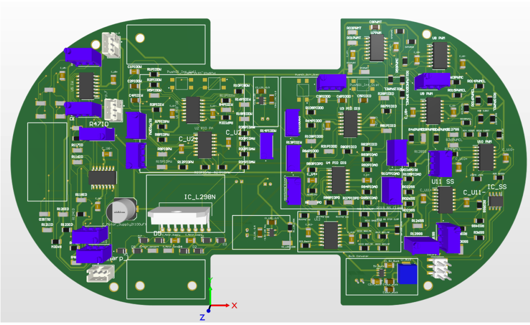

Figure 12.3: PCB 3d Top View

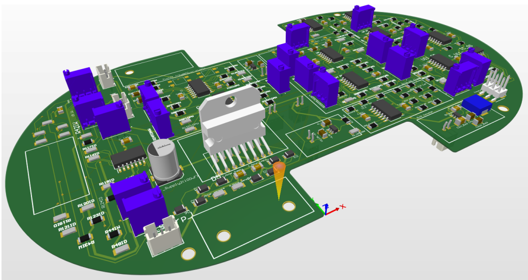

Figure 12.4: PCB 3d View

Utilizing Altium Designer, we meticulously crafted three printed circuit boards (PCBs) for the analog wall-following robot project: a power circuit, a wall-following circuit, and a motor control circuit. The PCB design employs multiple layers to optimize functionality. The top layer incorporates ground pour and +15V, seamlessly extending to the bottom layer for comprehensive routing. In the power supply PCB, a two-layer configuration is implemented, with one layer grounded to mitigate capacitance issues. Both lower layers feature integrated ground pours for heightened stability. To enhance versatility and ease of maintenance, IC bases are employed for all integrated circuits. The inclusion of pin headers and jumpers facilitates seamless connections between the ICs and external components, ensuring a modular and adaptable design.

6 Enclosure Design

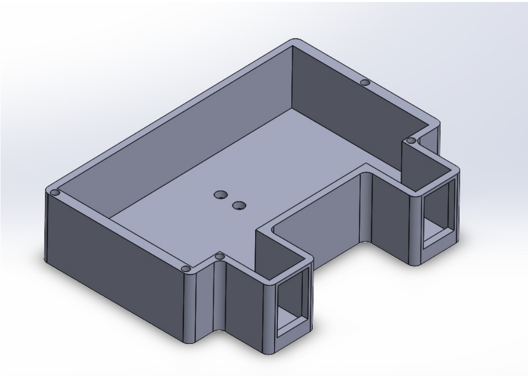

Figure 13.1:Battery Holder1

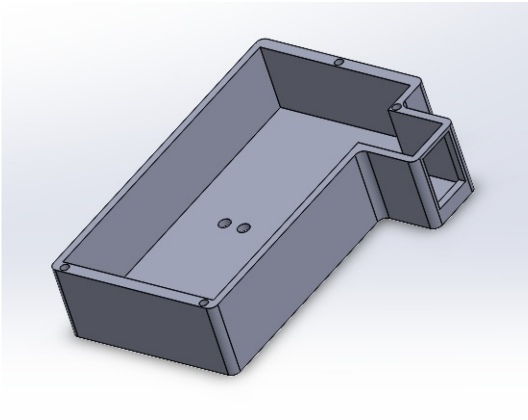

Figure 13.2:Battery Holder2

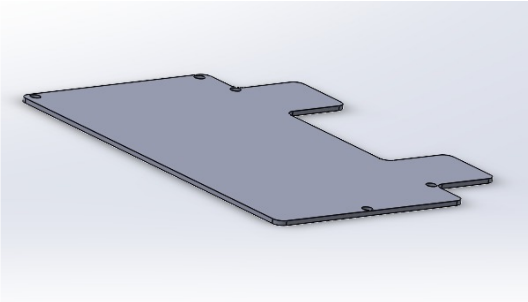

Figure 13.3: Battery Holder1 Cover

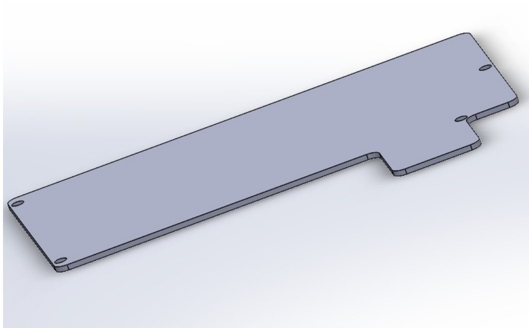

Figure 13.4: Battery Holder2 Cover

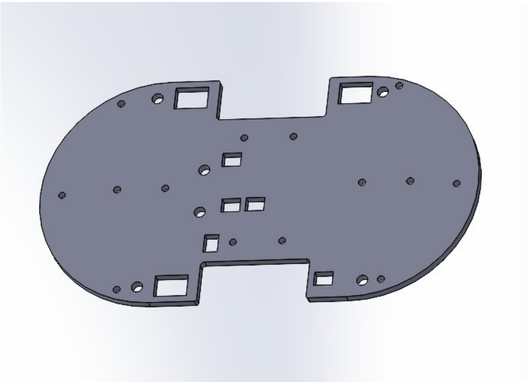

Figure 13.5: Chassis

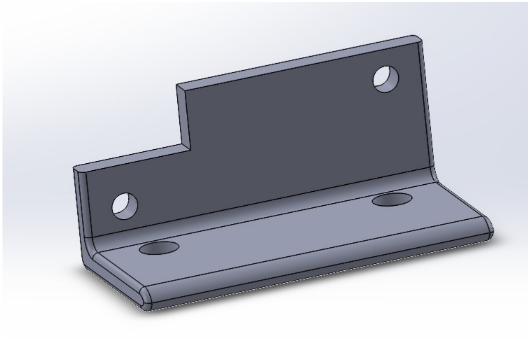

Figure 13.6: Sharp IR Sensor Holder

Using Solid Works, we designed enclosure designs for the analog wall-following robot project: three sharp IR sensor holders, two battery holders and the chassis.The chassis, modeled to adhere to the specified dimensions of 15 cm x 15 cm, serves as the structural backbone of the robot, providing a sturdy foundation for the electronic components. Precision in design was paramount, considering the 7 cm wall height and 30 cm width between walls, ensuring the robot can navigate through the designated space efficiently. The chassis is laser cut of plywood to make a simple design. The battery packs are 3D printed and attached at the bottom of the chassis. The sharp IR sensor holders are also 3D printed. Our enclosure design makes our robot a visually appealing robot.

7 Software Simulation and Hardware Testing

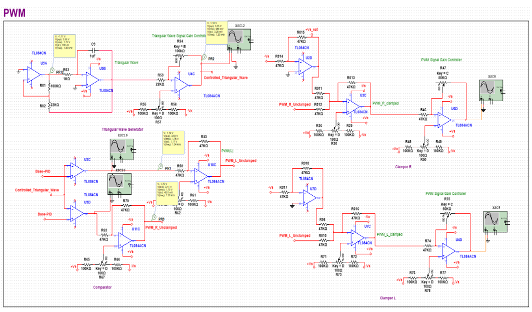

Figure 14.1:PWM Circuit Simulation

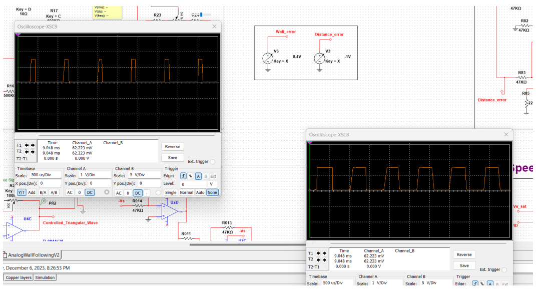

Figure 14.2:PWM Signals Simulation

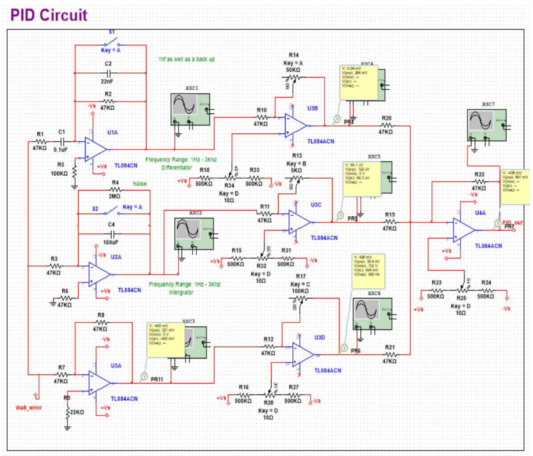

Figure 14.3: PID Circuit Simulation

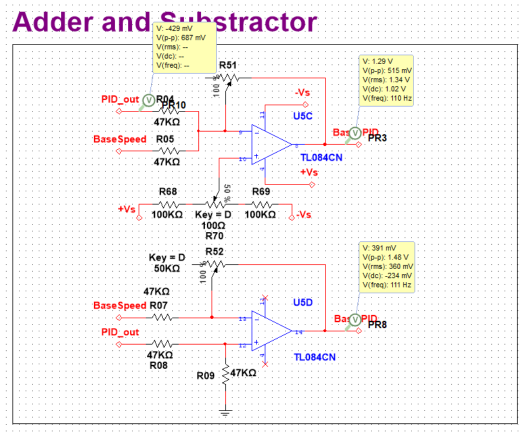

Figure 14.4: Adder Substractor Circuit Simulation

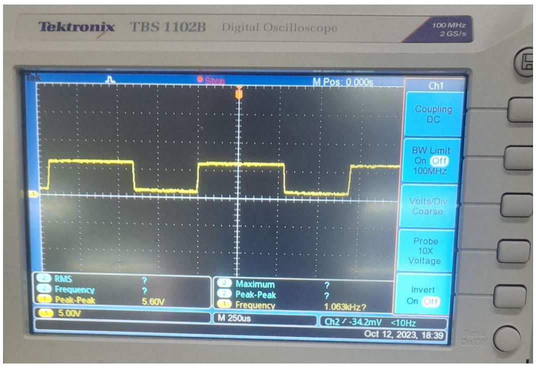

Figure 14.5: PWM signal testing

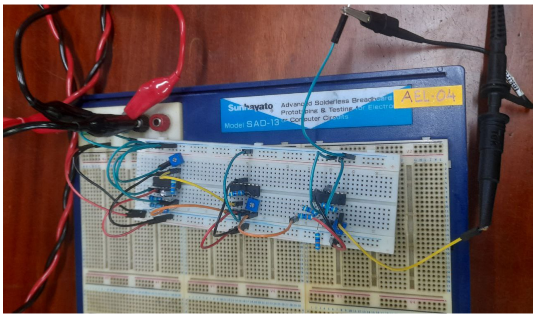

Figure 14.6: PID circuit testing

8 Conclusion & Future Works

In conclusion, our analog wall-following robot project has successfully demonstrated the efficacy of analog methods in achieving precise and responsive navigation along walls. By eschewing conventional microcontroller-based programming in favor of analog circuitry, we have showcased a novel approach to wall-following that leverages operational amplifiers, PID algorithms, and analog components for logical operations. The integration of SharpIR sensors, instrumentation amplifiers, PID circuits, and the "Adder Subtracter" circuit has yielded a robot capable of following walls with enhanced accuracy.

The conversion of analog signals into PWM signals for motor control further emphasizes the adaptability of analog methods in interfacing with motor driver ICs. The additional functionalities, including speed control, PID parameter tuning, and mode switching for linear travel and maneuvering bends, contribute to the versatility and user-friendliness of the robot.

Looking ahead, there are several avenues for future exploration and improvement. First and foremost, fine-tuning the PID parameters and optimizing the analog circuitry could enhance the robot's responsiveness to different wall-following scenarios. Exploring alternative analog components and sensor configurations may offer opportunities for performance enhancements. Additionally, investigating power-efficient mechanisms and exploring energy harvesting methods could contribute to prolonged operational periods.

9 Contribution of Group Members

Index Number	Contribution
210005H	Enclosure Designing
210015M	Circuit Designing & Simulation
210031H	Soldering & Testing
210728C	PCB Designing

Acknowledgment

We would like to express our sincere gratitude to everyone who contributed to the successful completion of this analog wall-following robot project. Our heartfelt thanks go to our project supervisors Sasmitha Aiya, Vakeesan Aiya and Rajitha Aiya for providing valuable guidance, insights, and continuous support throughout the development process. Special appreciation is extended to each team member for their dedication, hard work, and collaborative spirit, which played a pivotal role in achieving the project objectives.

Furthermore, we appreciate the constructive feedback received during project reviews from Dr.Sampath Perera, Dr.Jayathu Samarawickrama, Dr.Chamira Edirisooriya & Dr.Samiru Gayan who significantly contributed to refining and improving the overall design. The encouragement and assistance from our peers and colleagues are also acknowledged with gratitude.

This project has been a collective effort, and we are thankful for the collaborative environment that allowed us to explore, innovate, and overcome challenges. The invaluable experience gained from this project will undoubtedly shape our future endeavors.

References

- PID-Theory
  https://www.ni.com/en/shop/labview/pid-theory-explained.html
- DIY Circuit Design - Pulse Width Modulation (PWM)
  https://www.engineersgarage.com/diy-circuit-design-pulse-width-modulation-pwm/
- PID Controller
  https://www.elprocus.com/the-working-of-a-pid-controller/
- The Working of Apractical-Integrator
  https://www.electronics-tutorial.net/analog-integrated-circuits/op-amp-integrator/practical-integrator/
- Ultrasonic-or-Infrared-Sensors
  https://maxbotix.com/blogs/blog/ultrasonic-or-infrared-sensors/