University of Moratuwa
Faculty of Engineering
Department of Electronic & Telecommunication Engineering

EN2091 -Laboratory Practice and Projects

Group 04 -Automatic Solar Tracker

Project report

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Contents

Abstract

The objective of the project automatic solar tracker is to design and build a *PID controller* to rotate a solar panel which is capable of dynamically adjusting the solar panel to achieve its highest efficeincy. The feedback error control mechanism is established using PID to adjust the PWM signal. The PWM signal controls the speed and the direction of rotation of the motor which is connected to the axis of the solar panel. Two LDRs are fixed symmetrically at both sides of the solar panel. These LDRs are producing the error which says how much the solar panel is deviated from its best efficiency position.

1 Introduction

The energy industry is shifting towards renewable forms of energy due to the economic, environmental and social benefits it has over traditional energy sources. Solar energy is a major source of renewable energy that is mainly harvested through solar panels. The orientation of solar panels is vital for it to receive a high intensity of light. Since the direction of sunlight falling on the panels can vary through the course of the day, a fixed orientation is not ideal. The purpose of this project is to design an automatic solar tracker that is capable of rotating the solar panel such that it receives the maximum intensity of light. Most modern solar trackers are built with digital electronics with the use of PID concepts. The objective is to design a similar solar tracker using analog electronics with a PID control circuit.

2 Method

2.1 Functionality

2.1.1 Input

The solar tracker comprises 2 LDR sensors placed at either ends of the panel. The potential at the midpoint between the 2 LDRs is subject to change depending on the intensity of light falling on each of them. This value is compared with the set point (the value obtained if both LDRs receive the same amount of light), and the difference (error) between the 2 readings is calculated using a differential amplifier.

Here Set Point is virtual Ground.

$$Error = \frac{V \times \{RLDR1 - RLDR2\}}{2 \times \{RLDR2 + RLDR1\}}$$

By Using the Differential amplifier Error is feeded
To the input of the PID controller.

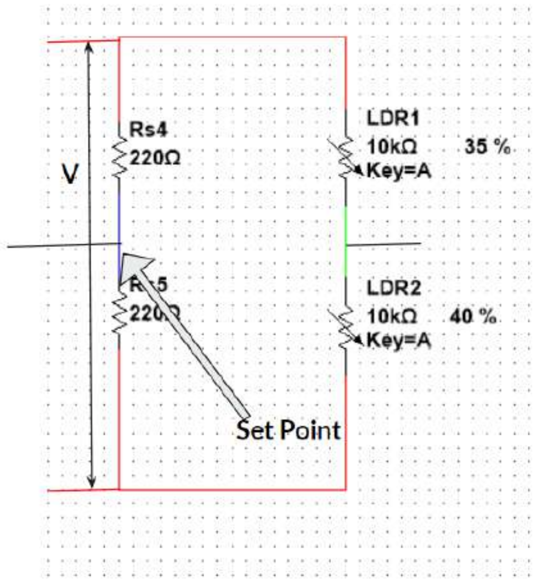


Figure 1: Input part

2.1.2 PID Control

The error obtained is fed into the PID control circuit. The PID control circuit acts as a feedback system that will adjust the panel's orientation depending on the error calculated. It comprises of 3 operational amplifiers configured to perform proportional, integral and derivative operations.

- **Propotional** The proportional part gives a gain to the error signal. Here an inverting op amp configuration is used to get the required gain, including variable resistors to adjust the gain of the error to the required value.

$$V1out = -Verror \times \frac{Rfp1}{Rp1}$$

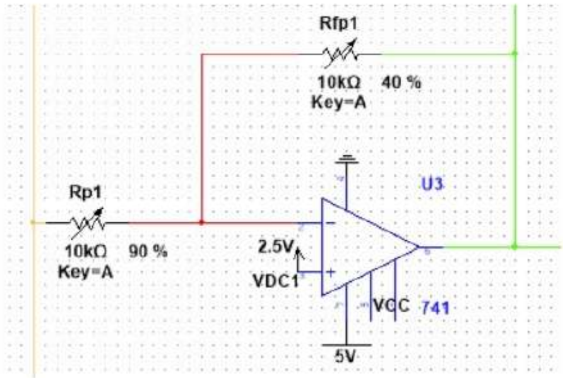


Figure 2: Propotional part

- **Integral**
  The integral part reduces the steady state error by accumulating the error over time. An op amp integrator is used for this task with variable resistors. Here the 1Mohm resistor is used in parallel with the capacitor of the integrator to prevent the integration of input offset voltage of the opamp and producing an incorrect output.

$$V2_{out} = -\frac{1}{R_{i1}C_{i1}}\int \text{Verror}\,dt$$

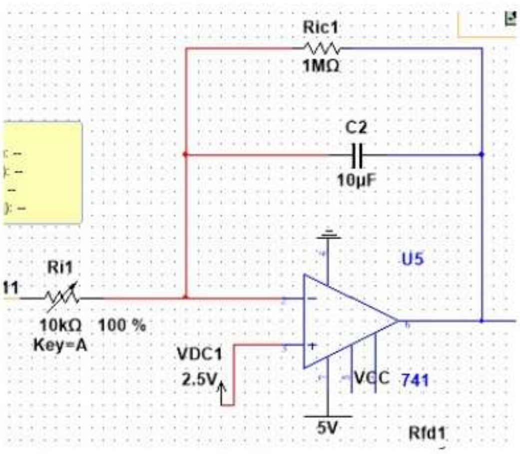


Figure 3: Integral part

- **Derivative**
  The derivative component produces the output signal proportional to the rate of change of the error. It reduces the overshoot and smoothens the control signal. An op amp differentiator circuit is used here including variable resistors to adjust the values. There is a resistor series to the capacitor of the differentiator to decrease the effects of noise by decreasing the high frequency gain.

$$V2_{out} = -R_{fd1}C_{d1}\frac{d\text{Verror}}{dt}$$

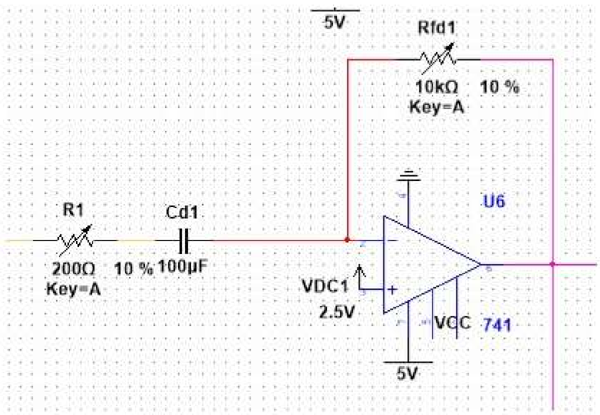


Figure 4: Derivative part

The outputs of the proportional, integral and differential components are connected to an adder circuit using variable resistors. These resistors are used to adjust the Kp, Ki, Kd values.

$$V_{out} = -R_9\left(\frac{V1_{out}}{R_{p2}} + \frac{V2_{out}}{R_{i2}} + \frac{V3_{out}}{R_{d2}}\right)$$

$$V_{out} = \frac{R_9}{R_{p2}}\cdot\frac{Rfp1}{Rp1}\text{Verror} + \frac{R_9}{R_{i2}}\cdot\frac{1}{R_{i1}C_{i1}}\int \text{Verror}\,dt + \frac{R_9}{R_{d2}}\cdot R_{fd1}C_{d1}\frac{d\text{Verror}}{dt}$$

2.1.3 Triangular Waveform Generation

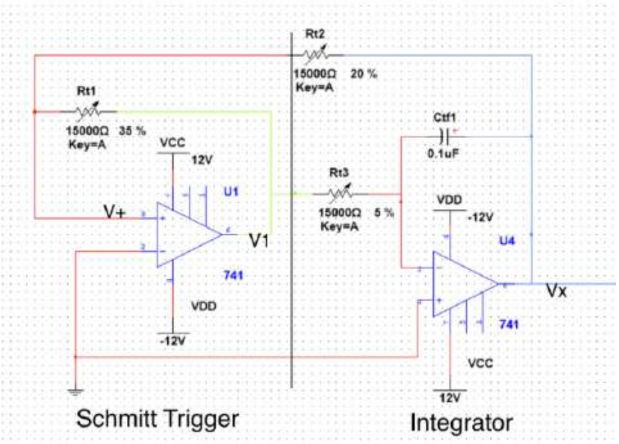


Figure 5: Triangular Wave Generation Circuit

V+ depends on both V1 and Vx.

By principle of superposition,

$$V_{+} = \frac{R_1}{R_1+R_2} V_x + \frac{R_2}{R_1+R_2} V_1$$

The upper and lower threshold voltages,

$$V_{x_2} = \frac{R_1 + R_2}{R1} V_{ref} + \frac{R_2}{R_1} V_{sat}$$

$$V_{x_1} = \frac{R_1 + R_2}{R1} V_{ref} - \frac{R_2}{R_1} V_{sat}$$

The peak to peak voltage of triangular waveform,

$$V_{p-p} = 2\frac{R_2}{R_1} V_{sat}$$

The frequency of the triangular wave is given by,

$$f = \frac{R_1}{4R_2R_3C}$$

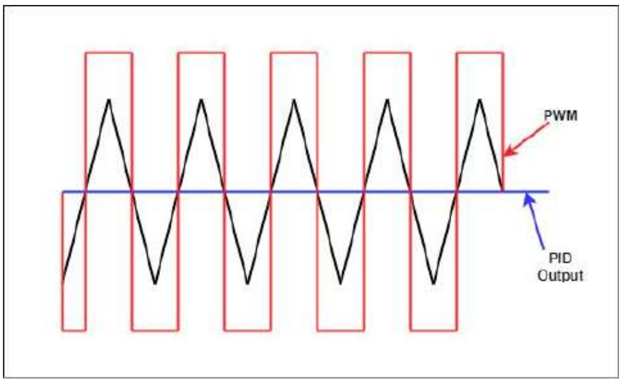
The motor is fed a PWM signal to control its rotation. To generate the PWM signal, a triangular waveform is used. To generate this triangular waveform, a squarewave is first produced followed by an integrator circuit.

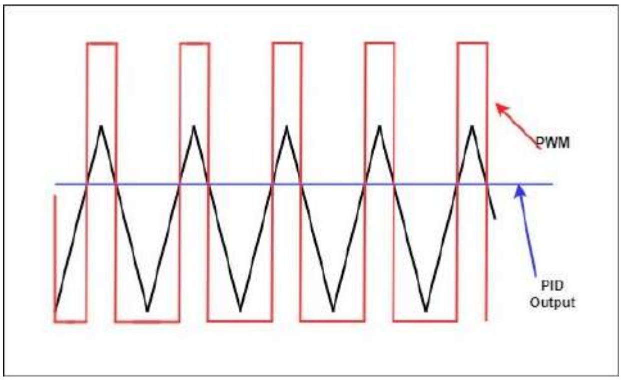
The first part of this circuit is the schmitt trigger circuit, then comes the integrator circuit. The schmitt trigger circuit is basically a comparator circuit. When the non inverting input rises or falls about the inverting input, the output of the schmitt trigger will be the two saturated supply voltages. This output is applied to the integrator circuit and it integrates this voltage for a finite time. The output of the integrator circuit is fed back as input into the schmitt trigger.

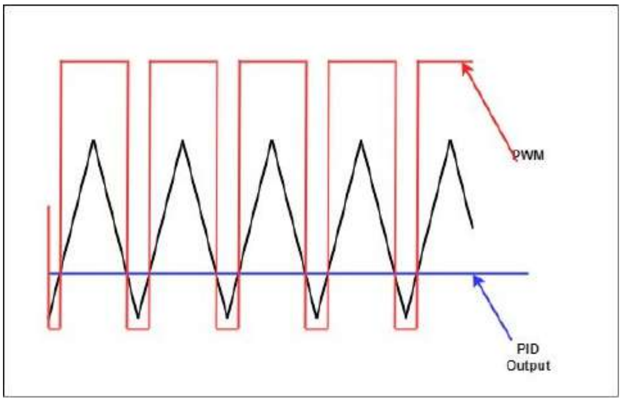
Suppose initially output of schmitt trigger is +Vs. This is integrated by the integrator circuit and fed into the schmitt trigger input and when this integrated voltage crosses the lower threshold value, the output of the schmitt trigger will shift from +Vs to -Vs. Now the integrator will integrate –Vs and its value is fed into the schmitt trigger. When this crosses the upper threshold voltage, the schmitt trigger output will again shift to +Vs. Here the resulting triangular waveform will be symmetric .

2.1.4 Motor Drive

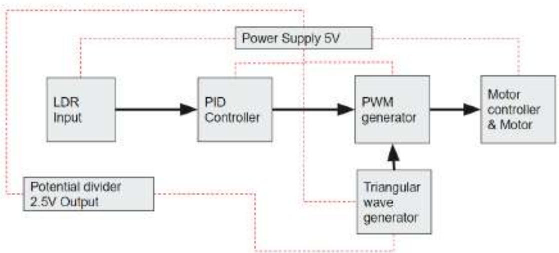
The PID circuit output is compared with the generated triangular wave using comparators. The comparator output will be a PWM signal whose pulse width will vary depending on the error. Here, 2 comparators are used to get 2 PWM signals, which are inversions of one another. These signals are given as input to the motor driver.







2.2 Block Diagram



2.3 Selection of components

2.3.1 Op amp selection

	LM741 (For general purpose)	LMC660 (For buffer)	LM339N (For comparator)
Differential voltage gain		126 dB	200 V/mV
Input resistance	2 M ohm	>1 Tera Ohm	
GBP		1.4 MHz	
CMRR	95 dB	83 dB	
Slew rate	0.5 V/us	1.1 V/us	
Input offset voltage	1 mV	1 mV	1 mV
Input bias current	80 nA	0.002 pA	25 nA
PSRR	96 dB	83 dB	
Supply voltage	Dual supply 15V	Single supply 4.75V – 15.5 V	Single supply 2V –36V
Applications	Comparators, Multivibrators, DC Amplifiers, Summing Amplifiers, Integrator / Differentiators	High-Impedance Buffer or Preamplifier, Precision Current-to-Voltage Converter	High precision voltage comparator

2.3.2 Motor selection

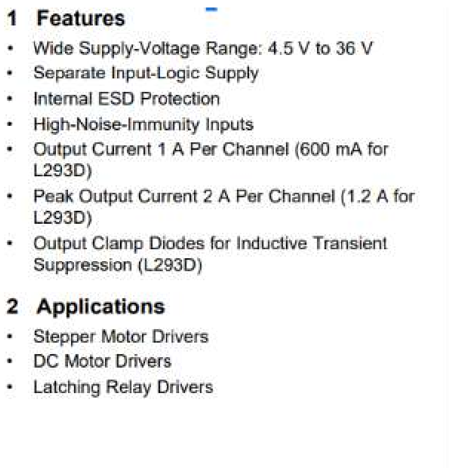
Motor designs for solar power applications, therefore, must stand up to extremes in temperature (both absolute and over a broad range), humidity and highly corrosive salt sprays, wind loads and abrasive airborne particulate matter.

Our choice- Brushed DC motors- simple, easy driving method and low cost. Control of dc motor is complex and life is short but we can replace brushes. As the solar panel can be affected by wind power high power motor is selected according to its weight and dimensions.

Selected motor - brushed dc motor
Voltage -12V
No load speed- 25 RPM
No load current- 60mA
Max torque- 16 kgcm
Stall current-0.9 A

2.3.3 Motor driver selection

According to our motor it drives a stall current of 0.9 A . so the maximum current of the motor driver should be greater than 0,9 A. Logic voltage os 5 V. our solar panel is in medium size (22 cm x 14 cm) , L93D is used.



1 Features

- Wide Supply-Voltage Range: 4.5 V to 36 V
- Separate Input-Logic Supply
- Internal ESD Protection
- High-Noise-Immunity Inputs
- Output Current 1 A Per Channel (600 mA for L293D)
- Peak Output Current 2 A Per Channel (1.2 A for L293D)
- Output Clamp Diodes for Inductive Transient Suppression (L293D)

2 Applications

- Stepper Motor Drivers
- DC Motor Drivers
- Latching Relay Drivers

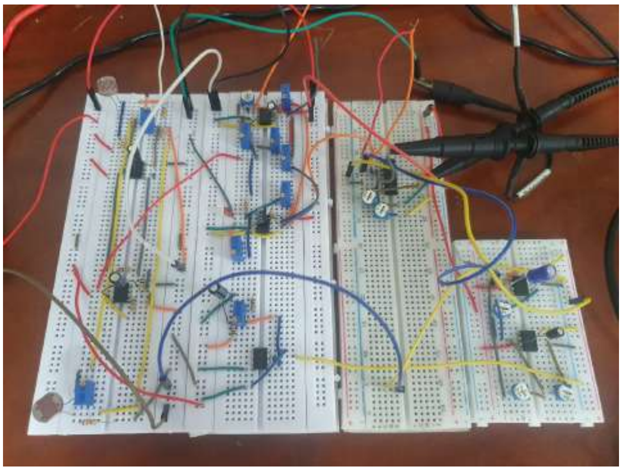


Figure 7: Breadboard implementation

2.4 Simulation using multisim

We implemented our circuit in Multisim to test the functionality of the circuit. We updated our circuit according to the results we got from the simulation. We identify the errors and further updates using the graphs generated using multisim.

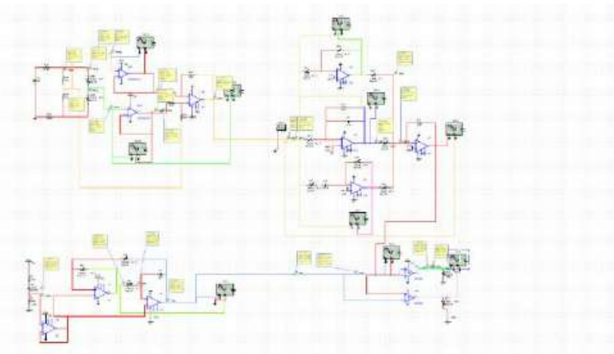


Figure 6: Circuit in Multisim

2.5 Breadboard implementation

The circuits were simulated and tested using NI Multisim simulation software. The simulated circuits were then implemented in breadboards and functionality was verified. The results obtained through the simulation and those obtained in the breadboard implementation had significant differences and slight changes had to be made to the circuit to obtain the desired results.

2.6 Schematic

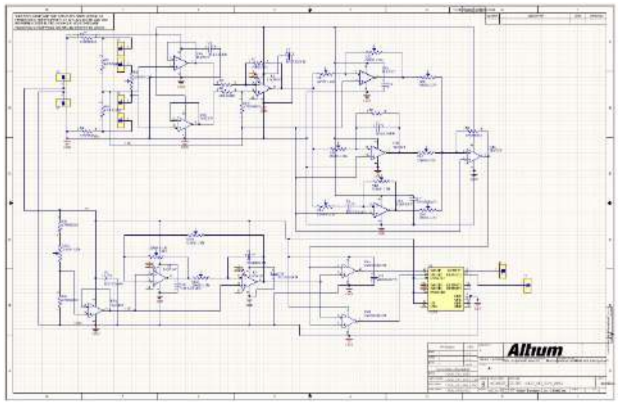


Figure 8: Schematic

2.7 PCB Design

After testing the circuit in breadboards and obtaining the desired output waveforms, the PCB was designed using Altium software for the final implementation. The output Gerber files were generated and sent to China (JLCPCB) for printing.

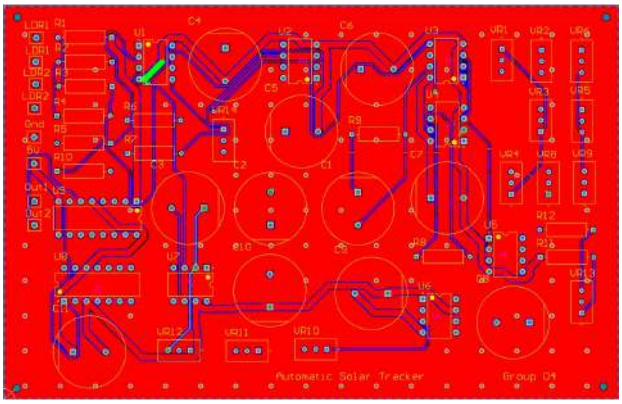


Figure 9: Top layer of PCB

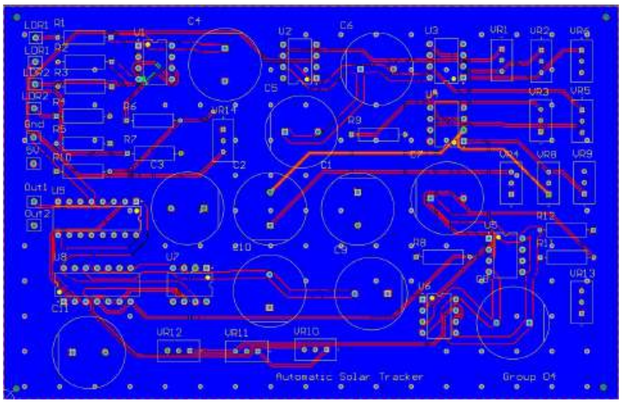


Figure 10: Bottom layer of PCB

Figure 11: PCB

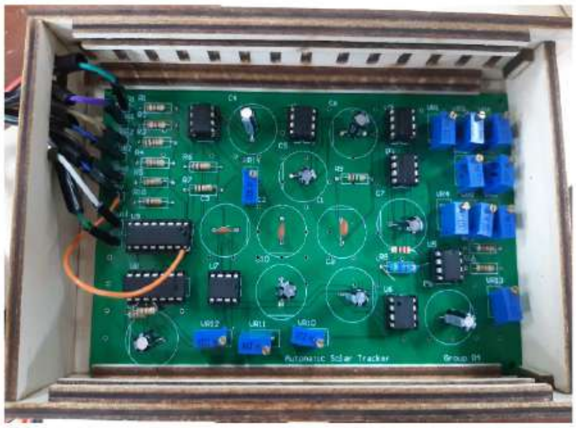


Figure 12: PCB

2.8 Enclosure Design

2.8.1 Stage 1

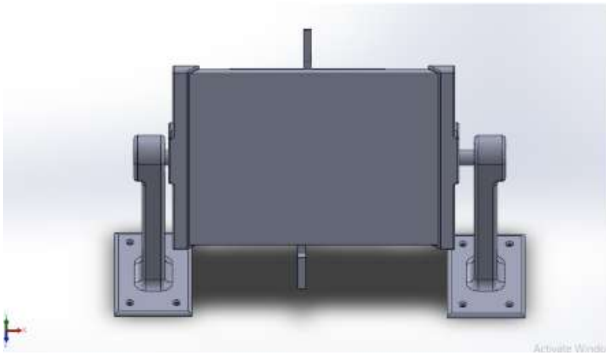


Figure 13: Enclosure design stage 1

First we designed our enclosure as shown in figure 13 . Two side connectors are used to connect the solar panel to two side supports. An external part is used to place LDR to get more accurate error reading (if exist).

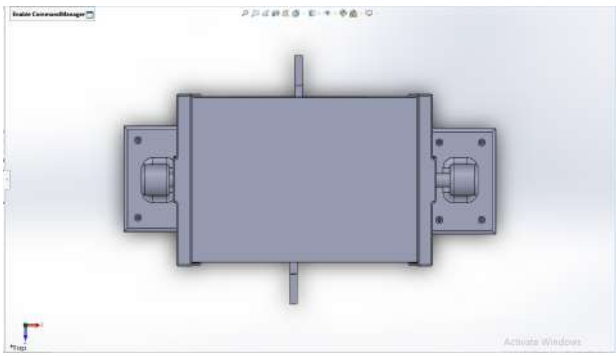


Figure 14: Enclosure design stage 1-Top view

Figure 15: Enclosure design stage 1-Front view

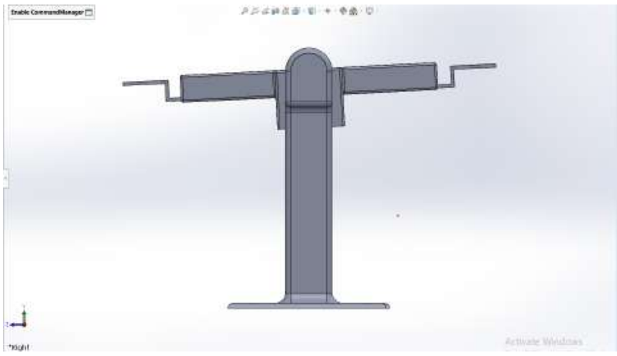


Figure 16: Enclosure design stage 1- Right view

2.8.2 stage 2

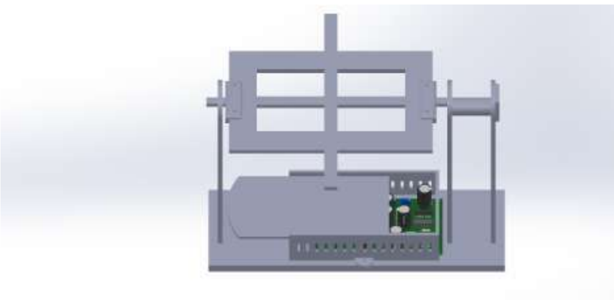


Figure 17: Enclosure design stage 2

Then we updated our design as in figure 17 to reduce cost. Here also two side connectors are used to connect the solar panel holder to two side supports. Two cylinders are placed around two LDRs to reduce the effect of reflected sunlight. An extra part is used to place LDR to get more accurate error reading (if exist).

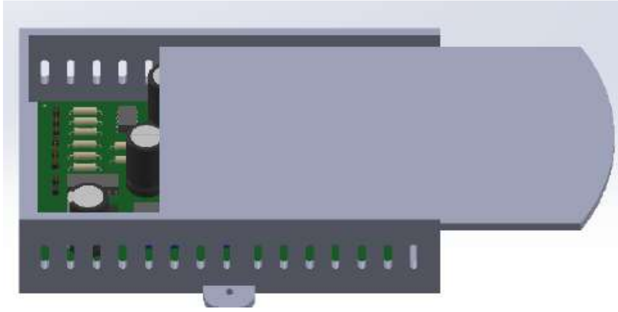


Figure 18: Enclosure design stage 2-Enclosure for the PCB

A separate enclosure is designed for the PCB as shown in figure **??** and then fixed that box to the base of solar tracker enclosure using nuts and bolts.

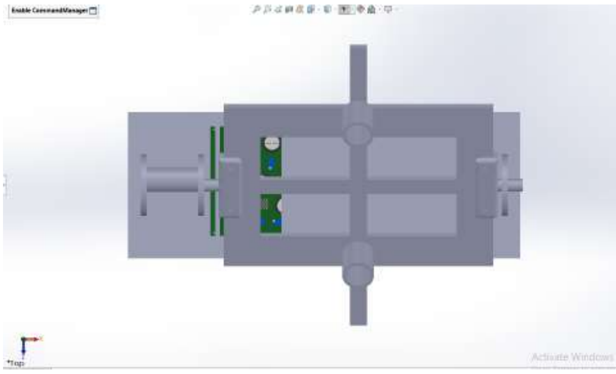


Figure 19: Enclosure design stage 2-Top view

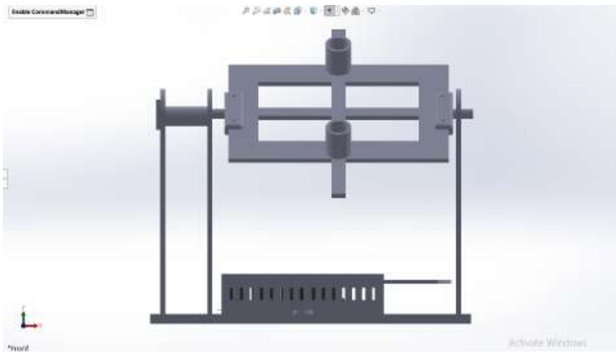


Figure 20: Enclosure design stage 2-Front view

Figure 21: Enclosure design stage 1-Right view

3 Results

3.1 Multisim Simulations

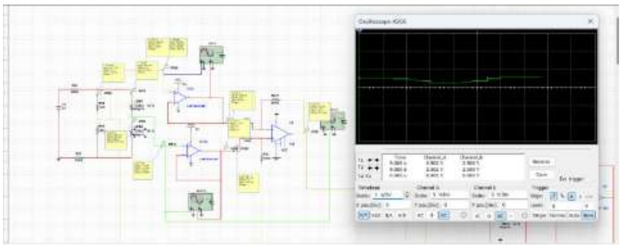


Figure 22: Input to the circuit when changing the LDR resistance

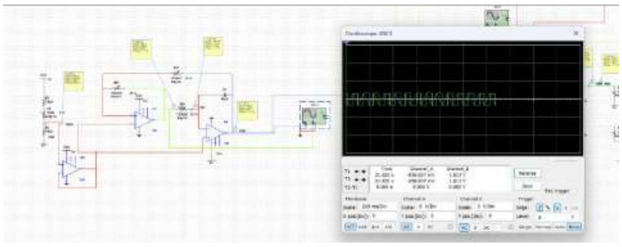


Figure 23: Triangular waveform

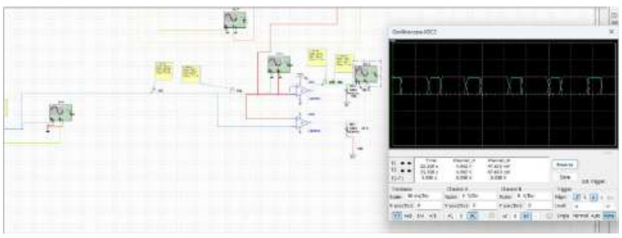


Figure 24: PWM signal

3.2 Oscilloscope outputs

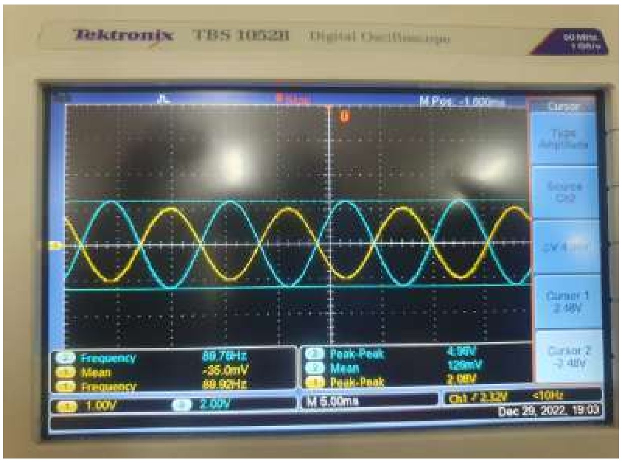


Figure 25: Output from the Propotional part of the PID circuit

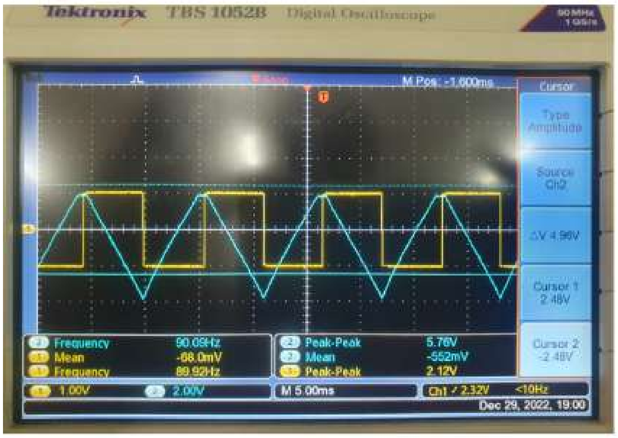


Figure 26: Output from the Integral part of the PID circuit

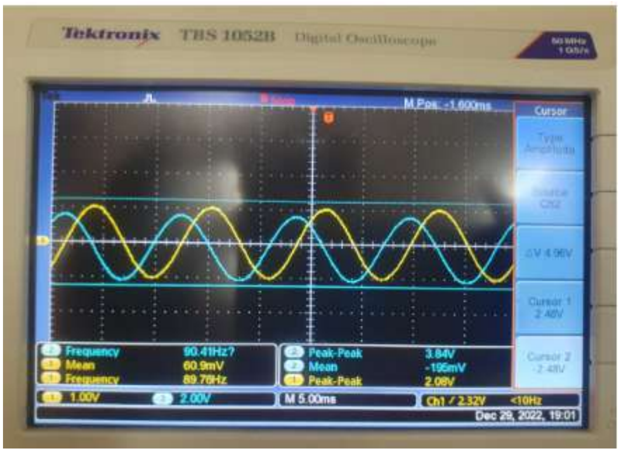


Figure 27: Output from the Derivative part of the PID circuit

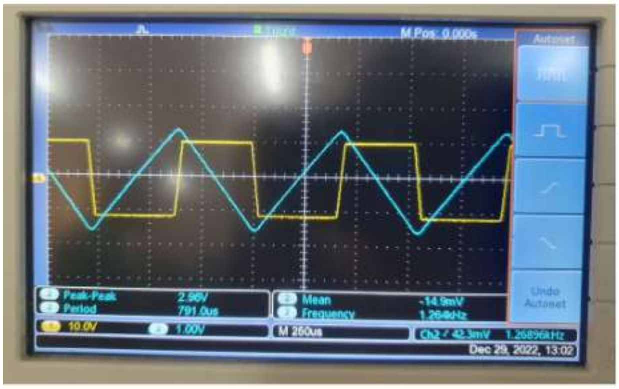


Figure 28: Output from the triangular waveform ganerating circuit

4 Individual contributions of each group member

Group Members	
Name.	Contribution
AMARASINGHE A.M.V.M. (200027R)	Enclosure designing (solidworks), simulation using Multisim , Circuit testing, documentation, Soldering
GUNAWARDENA M.N.(200201V)	Schematic drawing (Altium), Circuit testing, Soldering , Documentation
MALANBAN K.(200373X)	Circuit designing, Circuit testing and tuning, solderin, Documentation
RATHNAYAKE R.N.P.(200537F)	PCB designing (Altium), Circuit testing , soldering, Documentation,

5 Conclusion & Future Works

5.1 Conclusion

To get a smoother rotation of the motor more tuning should be done. Since the light conditions can change according to the environment and the season of the year there is a significant amount of attention needed for tuning to have a better motion of the motor.

Also we can increase the efficiency of power generated using solar panels using this solar tracker with a less power consumption. It will help to overcome the current energy crisis.

5.2 Future Works

We are planning to further develop this solar tracker as it is powered up by the voltage generated by solar panels itself.

Also a method can be developed to update the user with the aid of a mobile app by keeping track of the efficiency using graphs of voltage generated by solar panels.

6 Acknowledgement

The direction and assistance of multiple people was one of the aspects that contributed to the project's success. We are really grateful to Mr. Pahan, Mr. Ravindu , and Mr. Isuru, who served as our project mentors and whose constant commitment and genuine enthusiasm for our work made it possible for us to complete the project successfully. We would also like to thank the entire laboratory staff for being kind to keep the labs open for longer periods of time and for their guidance. We want to express our gratitude to everyone who helped make this project successful, no matter how tiny their contribution.

7 References / Bibliography

https://www.nutsvolts.com/magazine/article/the$_{pid_c}ontroll$

8 Appendix-I *Data Sheet*

Automatic Solar Tracker

FEATURES

- Supply Voltage - 5 V.
- Stall current of the circuit- 400 mA
- Maximum power - 2W
- Stall current of the motor- 300 mA
- Enclosure material - wood and PLA
- PCB -2 layer

APPLICATIONS

- Can used for existing solar panels to increase the efficiency.

DESCRIPTION

- Low power solar tracker

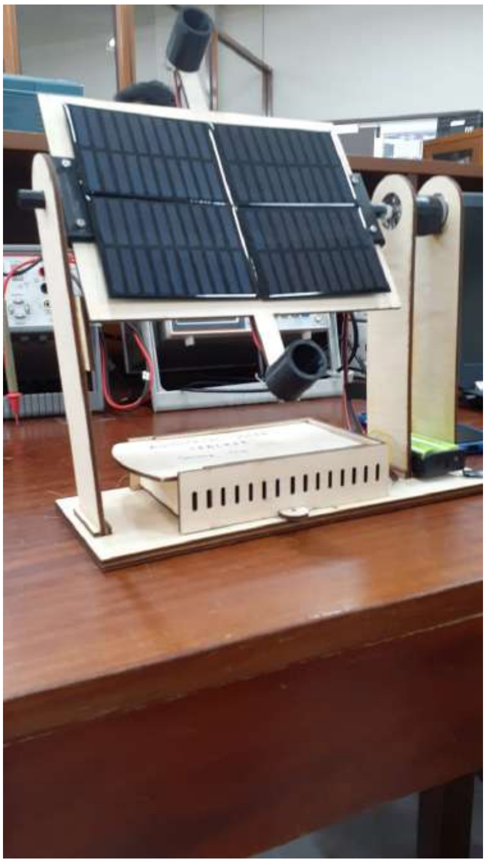


Figure 29: Our product

8.1 Appendix-II *Multisim Circuit*

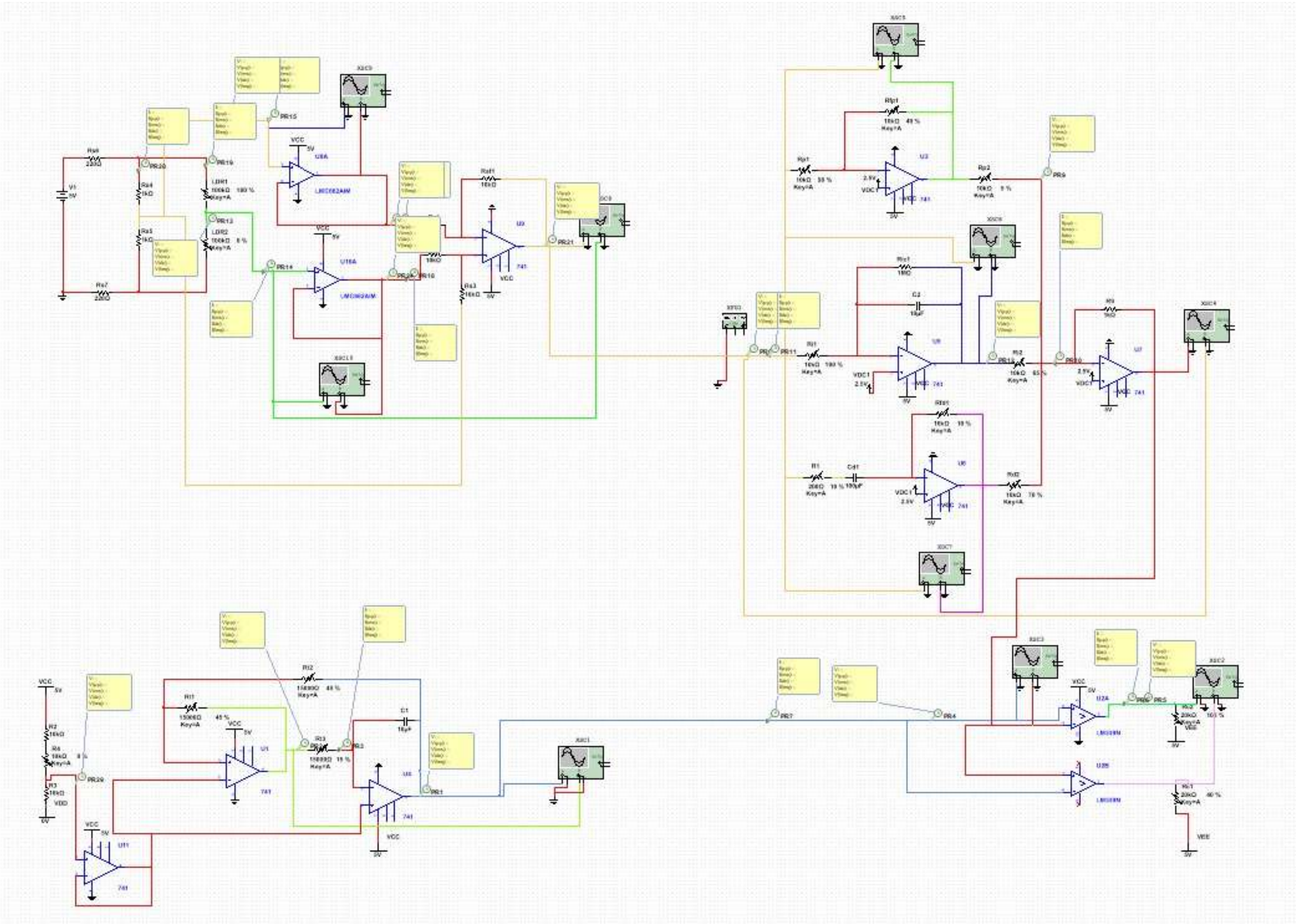


Figure 30: Multisim simulation Circuit

8.2 Appendix-III *PCB Schematic*

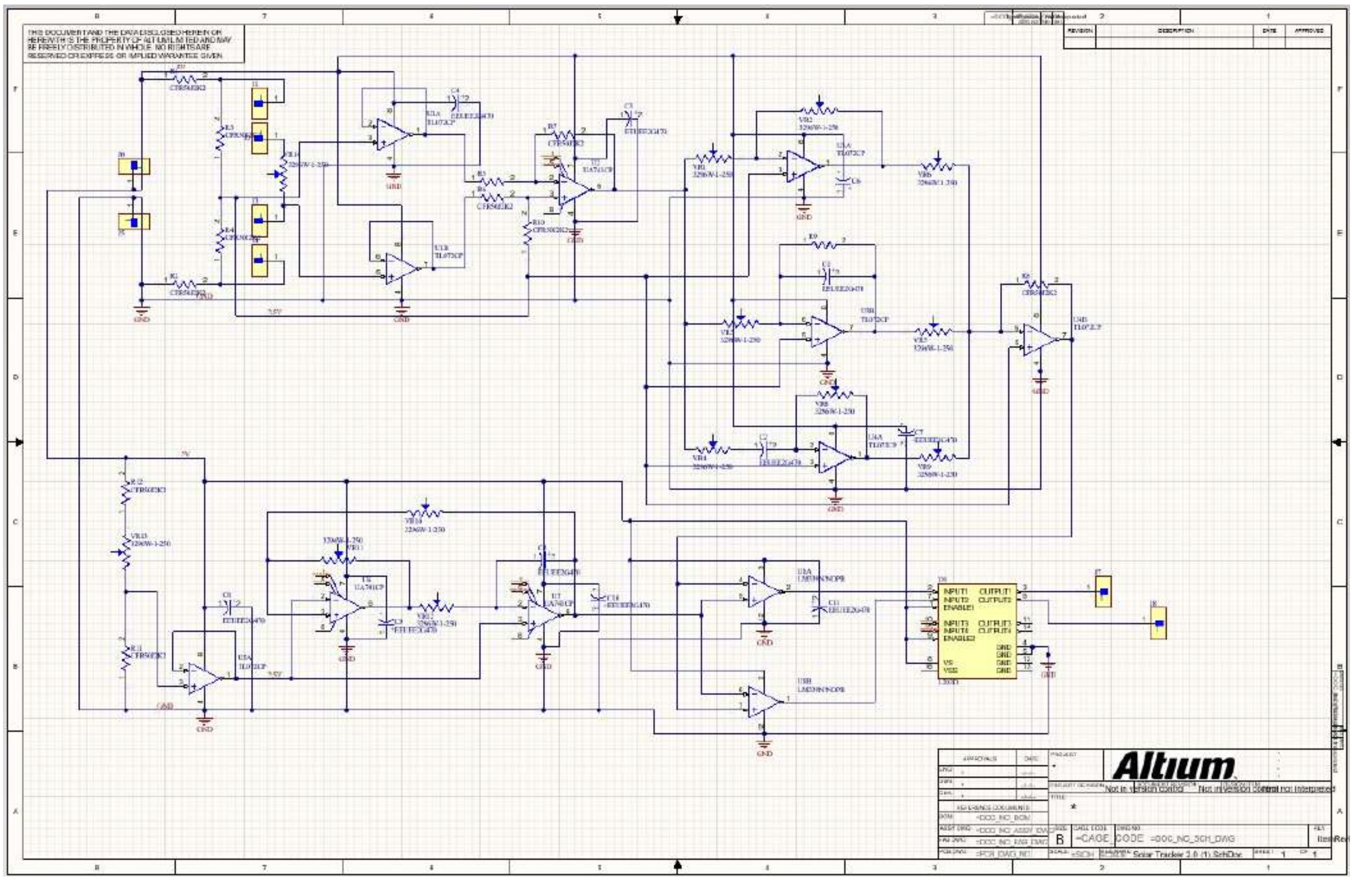


Figure 31: Altium schematic

8.3 Appendix-IV *Product enclosure*

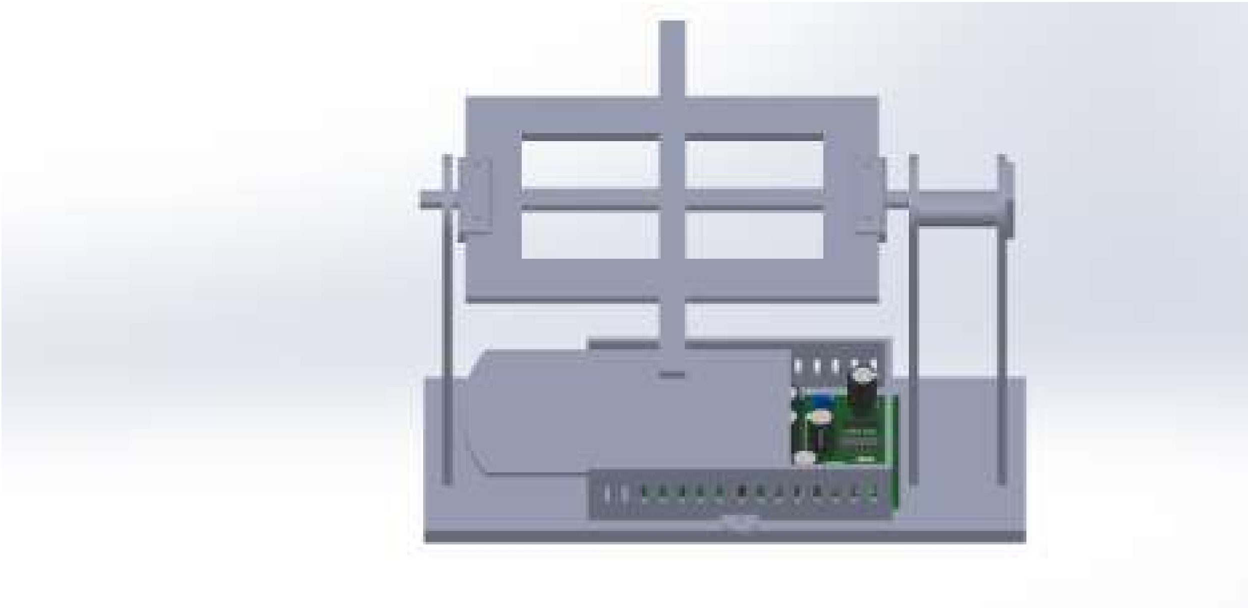


Figure 32: Product enclosure