Habib University

DHANANI
SCHOOL OF SCIENCE
AND ENGINEERING

Course Title: Principles of Feedback Control EE/CE 361L/353L-T1

Instructor: Dr Shafayat Abrar

Course RA:

Khuzaima Ali Khan

Group name:

UDAAN

Group Members:

M. Bilal Qureshi

Zaid Bin Khalid

1. Introduction:

a. Problem statement:

To balance a dual-copter on a beam. This project aims to implement a control which stabilizes a dual-copter which is pivoted on a beam and avoids its roll rotation being measured by an MPU sensor. The dual-copter is fixed in a way that no other translational or rotational movement (other than roll) can take place.

b. Application:

The application of this project comes from the stabilizing of the drones, as drones navigate, stabilizing it is very essential to ensure they can be controlled and perform their desired tasks properly without causing damage to themselves or to the environment. A lack of feedback control in the drone will essentially lead to its failure giving very limited control in tele-operation and almost zero control during autonomous navigation. This project shows how we can control the rotation of the drone in one direction, by avoiding disturbances as well, potentially.

c. Motivation:

The motivation of this project comes from the drones. This project will serve as a basis on how the drones are to be controlled. We can extend this dual-copter to quad-copter in future taking advantage from the control we implemented for one direction.

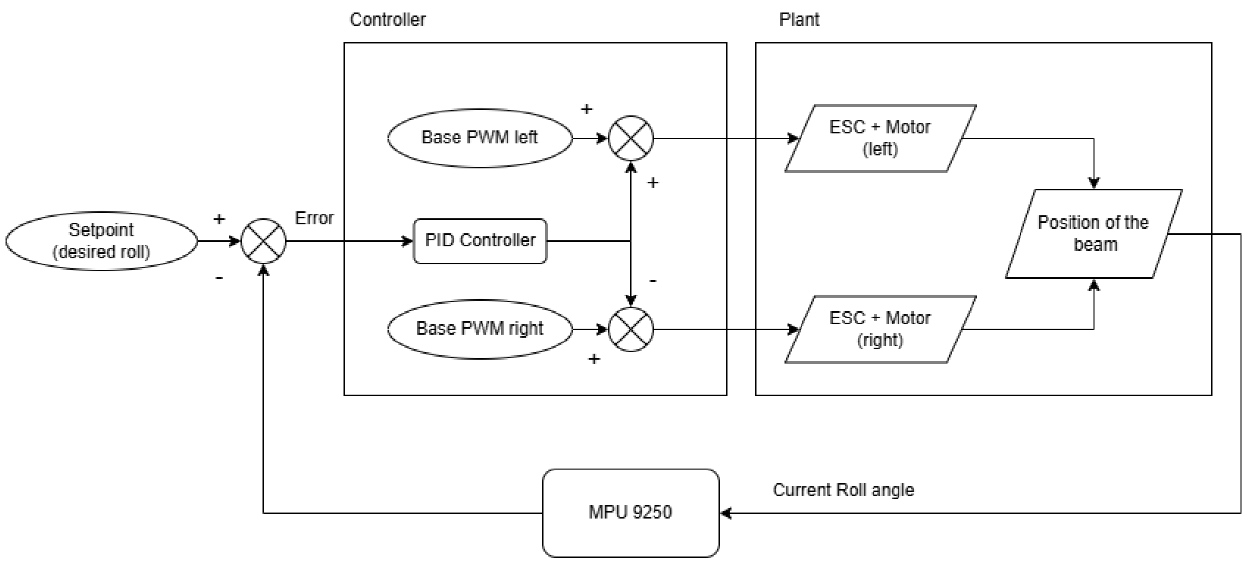
2. Method and Material:

a. Material Used:

Material	Specification	Quantity
MCU	ESP32 DevkitC	1
Motors	1400Kv BLDC	2
Electronic Speed Controller (ESC)	Simonk 30A	2
Propellers	1045	2
Battery	3S(11.1V) lipo 2200mah 30C	1
Sensor	mpu9250	1

The structure was created using wood, steel rod and a part of pvc pipe.

b. Block Diagram:

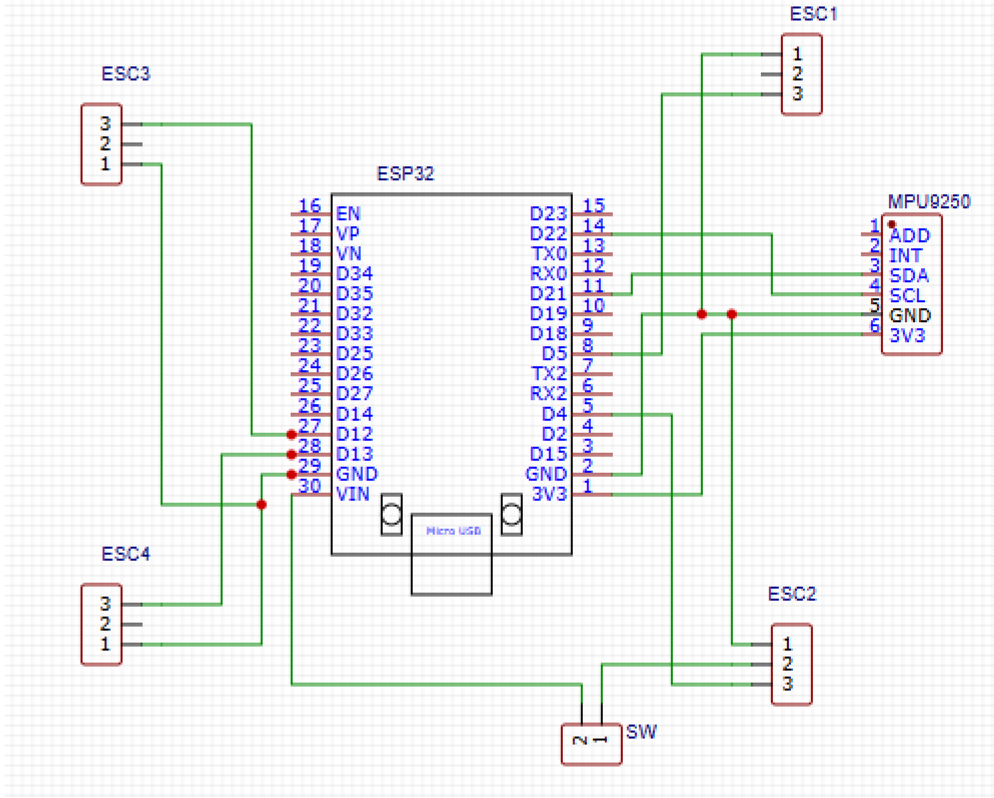


We have a setpoint, which is the angle when we keep our plant straight in the xy plane. Our controller is running at a frequency of 50 Hz, at every 20ms mark, it receives the data from the mpu 9250 and calculates the error from the setpoint. A pid controller is then implemented to the error.

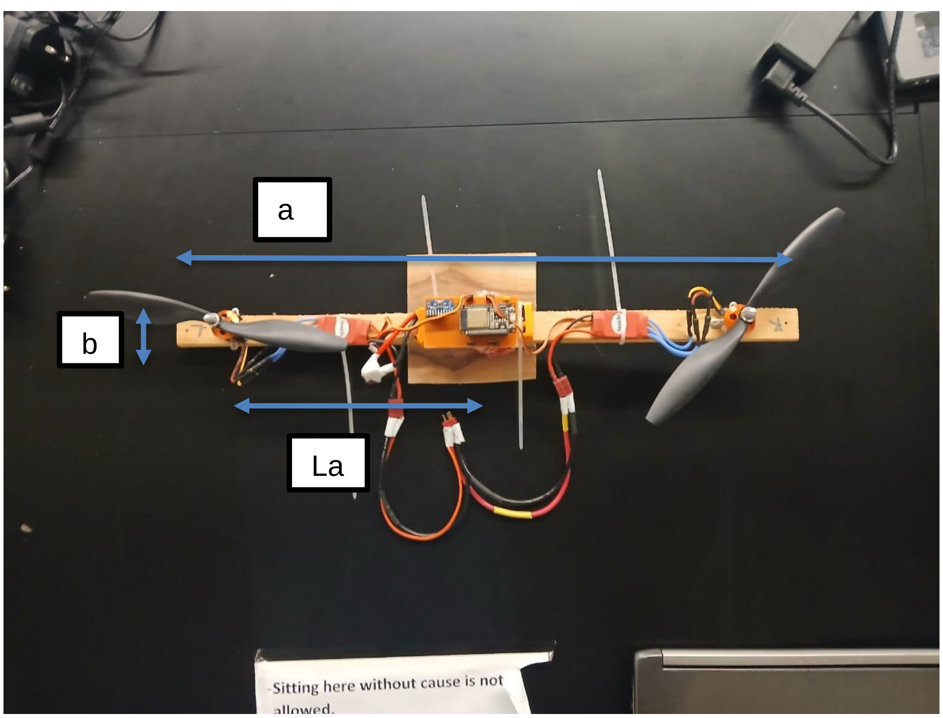
The output is then used to calculate the speed of the motors at each end. If the error is positive then it means our plant is tilting more toward the right side, wo we increase the rpm of the left motor and decrease the rpm of the right motor to tilt towards the left to be balance again, and if our plant tilts towards left and we receive a negative error, this then increases the rpm of the right motor and simultaneously reduces the rpm of left motor.

The system usually keeps on oscillating as our system inherently is not stable.

c. Circuit Diagram:



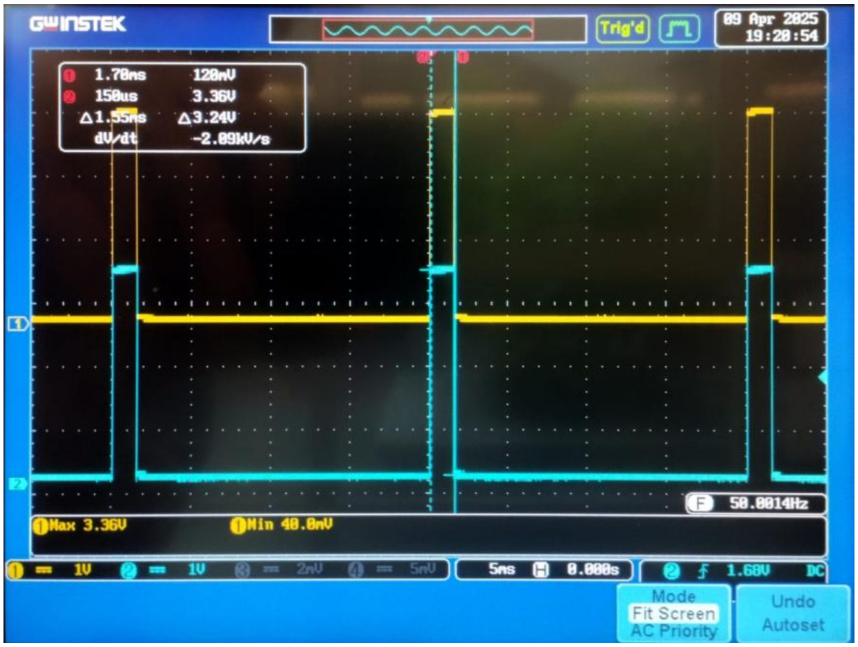
d. Plant



e. Methodology:

We followed a modular approach while making our project, to ensure everything is working properly and is relatively easier to resolve issues

i. Testing Motors:
We first tested our individual motors using our ESC. We calculated the current which flows which helped us in the modeling of the motor. Using the potentiometer, we tested the PWM generated by the microcontroller before adding batteries to ensure that ESC receives the pulse under which it operates, between 1ms to 2ms.
We then placed propellers and ensured they were rotating in the right direction to provide the lift in upward direction.



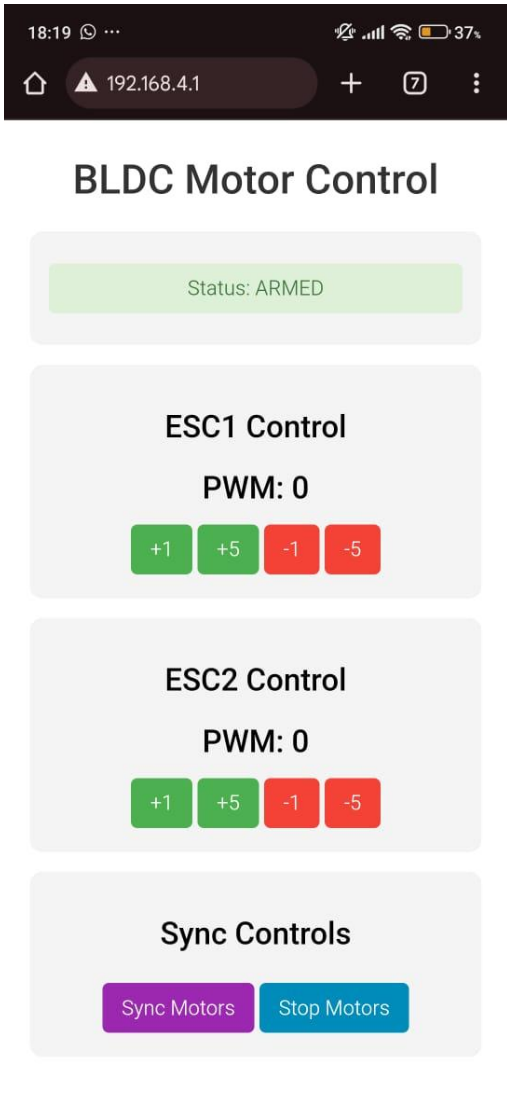
Varying PWM reading from output pins

ii. Testing Sensor:
We first tested our MPU sensor to get the raw values of linear and angular acceleration to ensure that our sensor was working properly. We then used the libraries to get the calculated value of roll pitch and yaw, tested that aggressively in different conditions to ensure that data received was correct.

iii. Building Structure:
The structure was built keeping in mind the safety, we ensured that our structure is strong enough to resist the thrust force applied by the propellers and also ensured that its height was enough for our beam to rotate completely without the propellers touching the base to ensure there are no accidents.

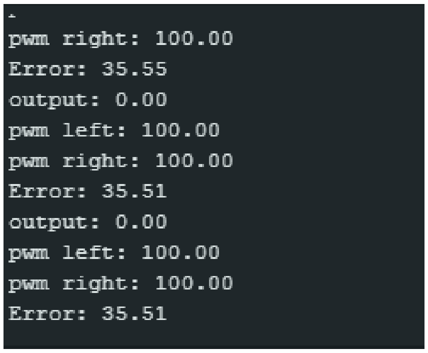
iv. Finding base PWM:
As due to the manufacturing difference of the ESC and the motor, we first

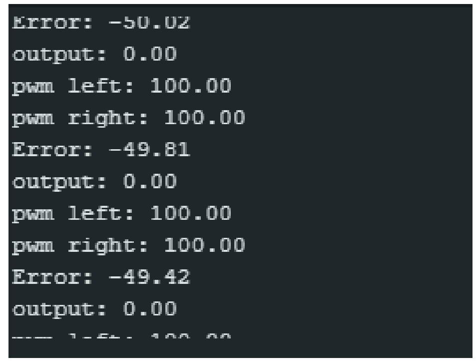
found out the base PWM of each of the motor using by adjusting the PWM and then selecting a PWM at which rpm was just enough to lift that side of the beam, as very high rpm was unsafe in the lab environment.



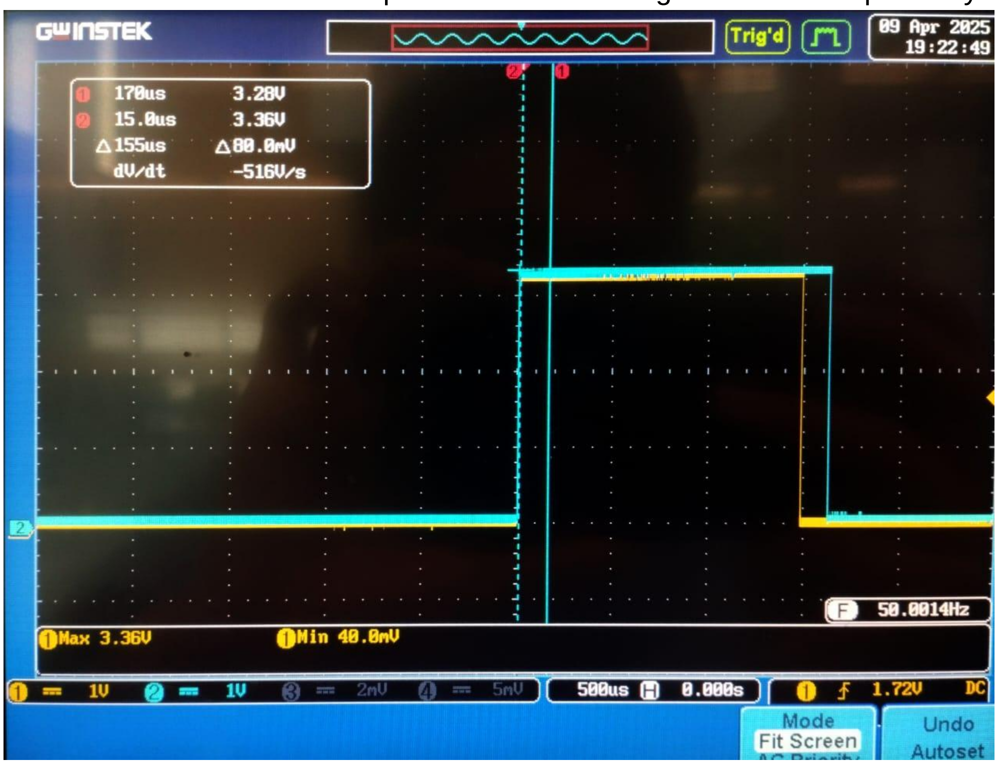
Controlling PWM manually using WiFi server of ESP32

v. Testing PID results manually:
Before implementing the whole code in the main plant, we first tested the output of the PID control manually to see if the PWM of both the motors varies as we change the roll in the desirable manner.





Error when we tilted the plant in the left and right direction respectively.



Varying PWM at different roll angle

3. Mathematical Modelling:

a. Transfer Function:

i. Motor Transfer Function:

We are using BLDC motors, which have the similar transfer functions as other DC motors and it is defined as:

$$\frac{U(s)}{V(s)} = \frac{K_T}{J_1 L s^2 + J_1 R s + K_T K_D}$$

K_T (Motor Torque Constant)	6.77e-3V/rad/s
J_1 (Motor Moment of inertia)	4.44e-6kgm^2
L (Inductance of Motor)	65mΩ
R (Resistance of Motor)	100uH
K_D (Back emf Constant)	6.77e-3V/rad/s

$$\frac{U(s)}{V(s)} = \frac{6.77e-3}{4.44e-10s^2 + 2.88e-7s + 4.583e-5}$$

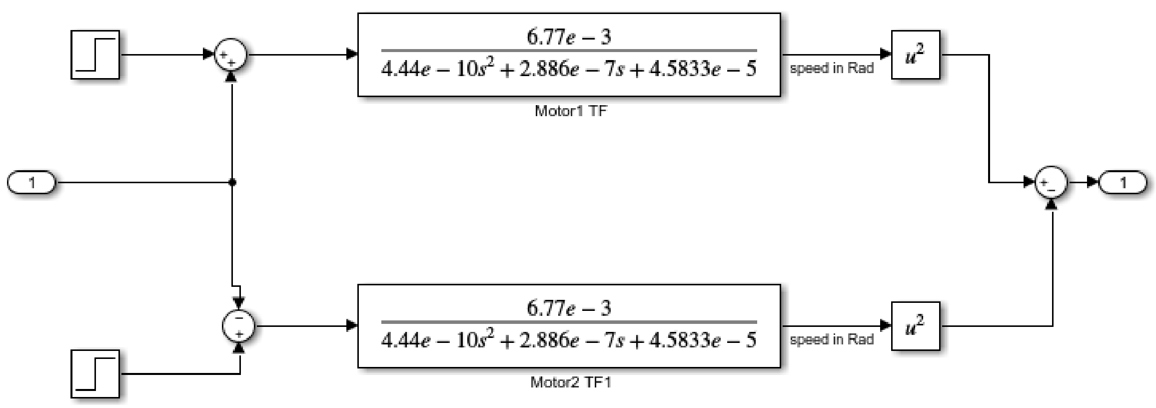
ii. Plant Transfer Function:

$$\frac{\Theta(s)}{U(s)} = \frac{C_T \rho A R^2 L_a}{J_2 s^2}$$

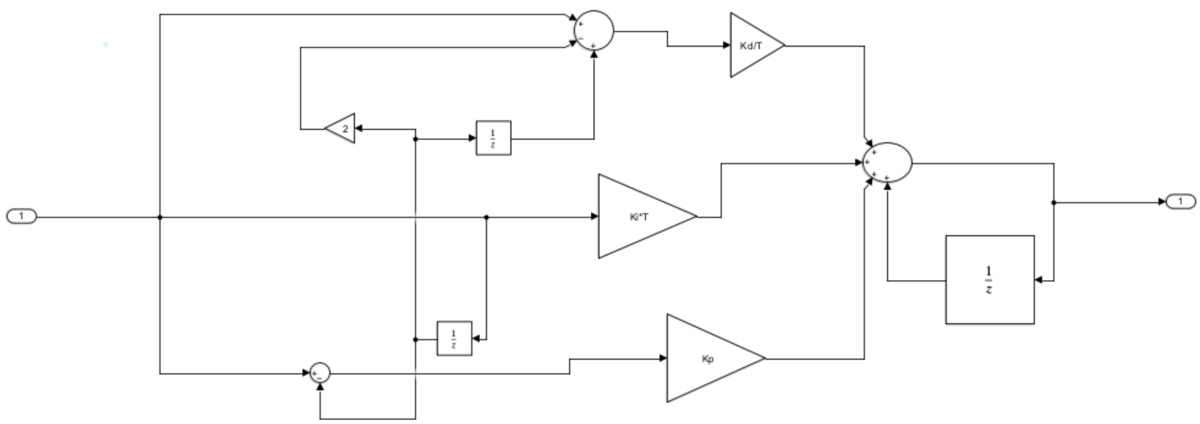
$U(s)$	$\omega_1^2 + \omega_2^2$
C_T(Lift coefficient)	0.035
ρ (air density)	$1.225 kg/m^3$
A (area covered by propellers)	$0.203 m^2$
R (radius of the propellers)	0.254m
L_a(distance from pivot to motor)	0.265m
J_s(mass moment of inertia)	$0.015 kg/m^2$

b. Simulation and Results:

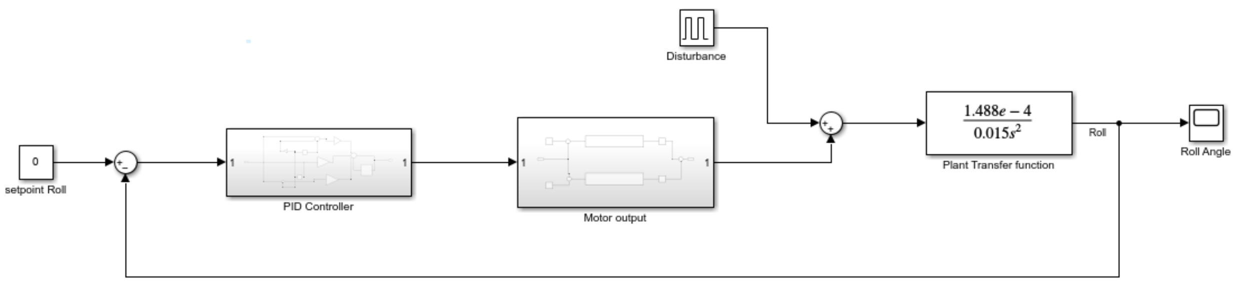
i. Model



Input of the plant



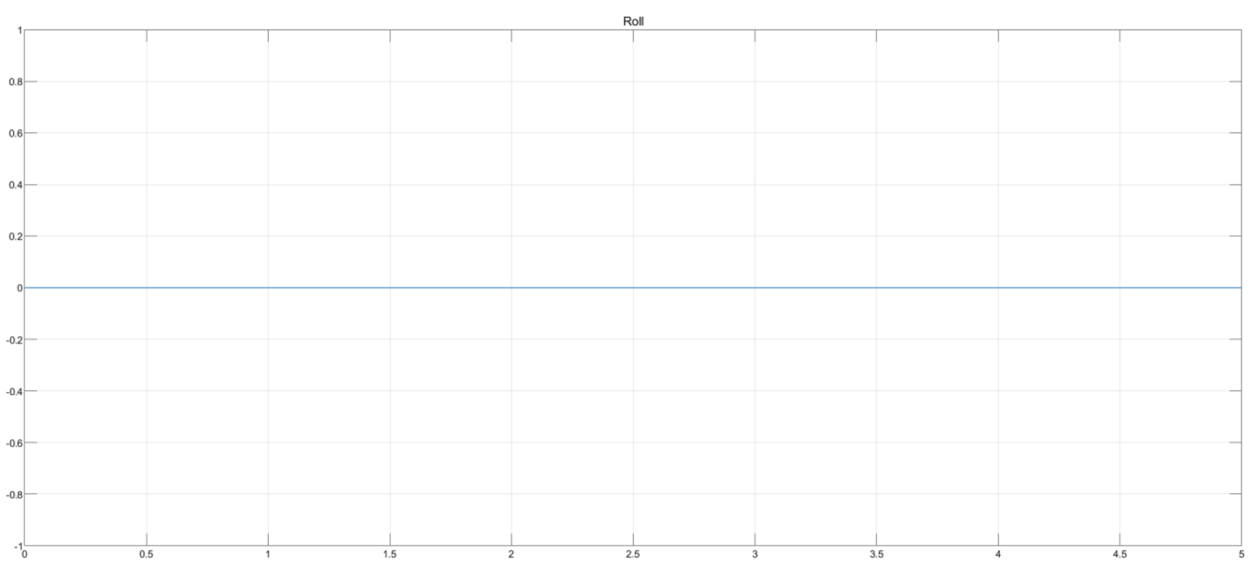
PID Controller



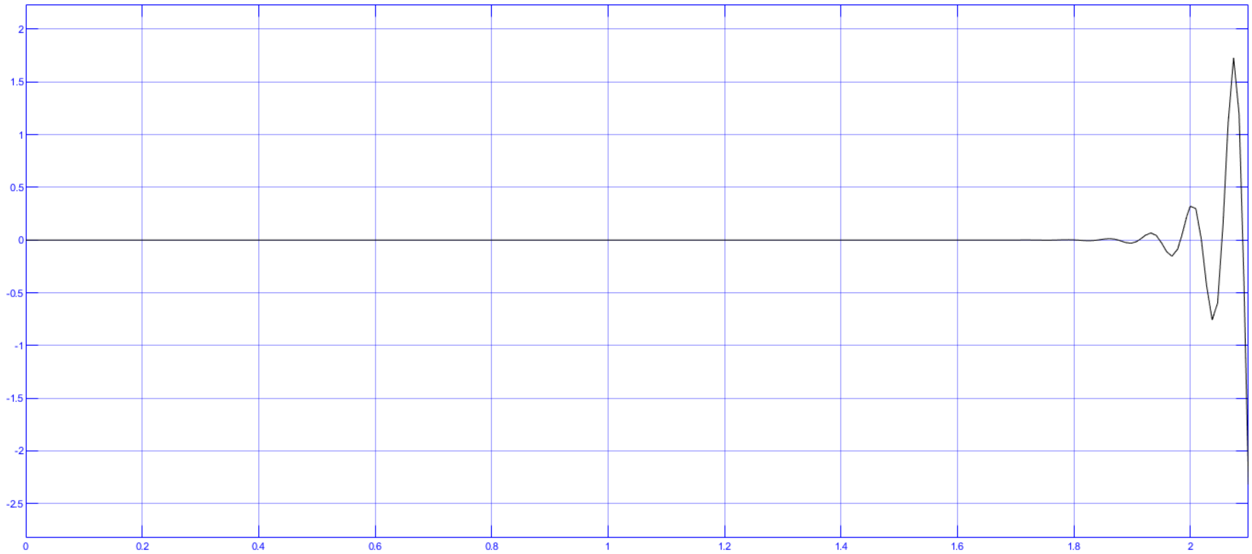
Complete Plant

ii. Results

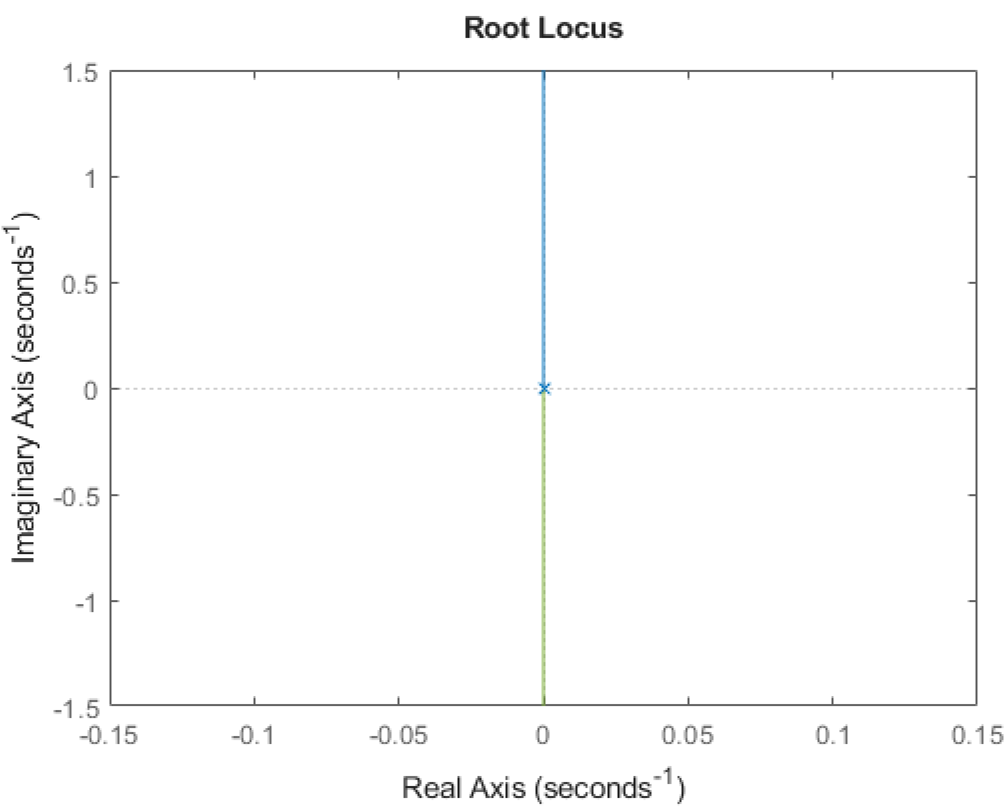
under no disturbance



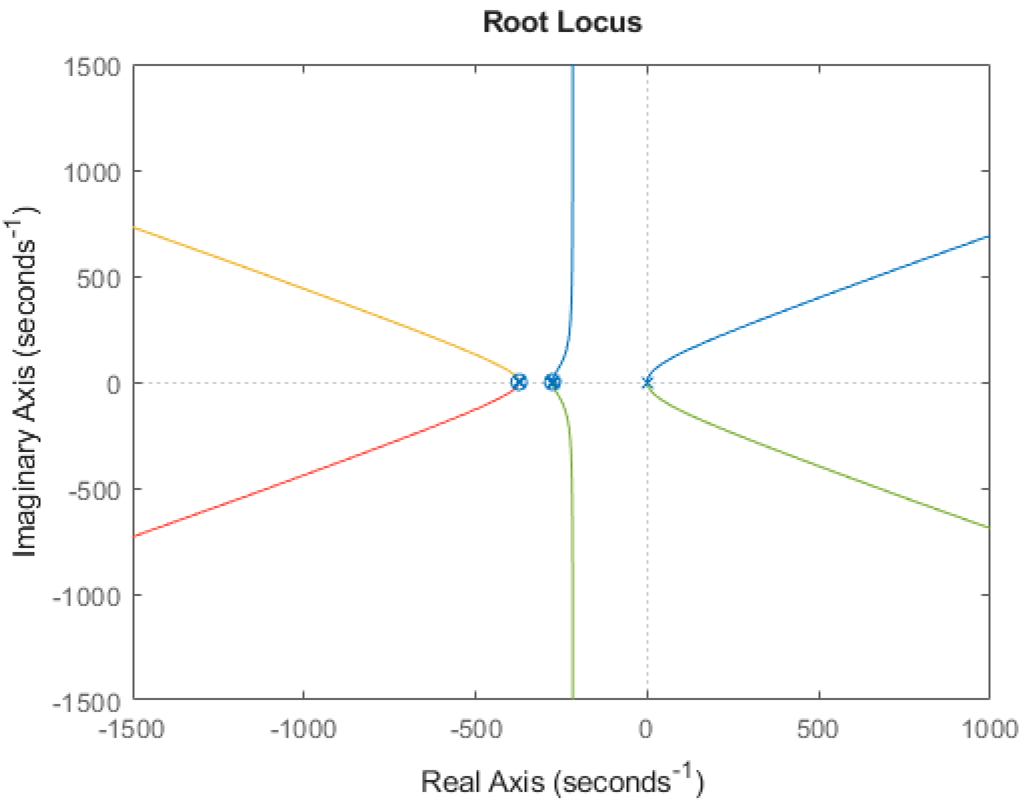
Under Disturbance



iii) Root Locus for the plant



Without controller



With controller

```
s= tf('s')
P_tf = 1.488e-4 / 0.015 / s^2;
M_tf = 6.77e-3 / ((4.44e-10*s^2)+(2.886e-7*s) + (4.5833e-5));
rlocus(P_tf) %without any controller
```

```
kp = 0.0055;
inp = (((1 + kp)*M_tf)^2) - (((1 - kp)*M_tf)^2);
total_tf = inp*P_tf;
rlocus(total_tf)
```

4. Conclusion:

We are required to tune the PID controller further to avoid the sudden change, our model is trying to resist the disturbance but is unable to reduce the steady state error.
The roots are at the origin and they tend to move towards the right hand plain making the system unstable, further enhancement in this can be made by adding lag compensator, which will add a zero and then it will shift the root locus to right hand plain. If that also does not work, we can apply the technique of Ziggler nicholos.

5. Appendix:

a. Plant Model Calculation

$$J\ddot{\theta} = L_a(f_1 - f_2) + f_d$$

Moment of inertia:

$$J = \frac{1}{12}m(a^2 + b^2)$$

$$J = \frac{1}{12}0.5(0.6^2 + 0.008^2)$$

$$J = 0.015kg/m^2$$

Lift Force:

$$f = C_t\rho AR^2\omega^2$$

$$f = k\omega^2$$

$$f = 0.035 * 1.225 * 0.203 * 0.245^2 * \omega^2$$

Transfer Function:

$$J\ddot{\theta} = L_ak(\omega_1^2 - \omega_2^2)$$

$$J\theta(s)s^2 = L_ak(\omega_1^2 - \omega_2^2)(s)$$

$$\frac{\theta(s)}{(\omega_1^2 - \omega_2^2)(s)} = \frac{L_ak}{Js^2}$$

6. References:

[1] https://github.com/MBilalQ/Quadcopter-Control

[2] Y. -C. Yu, D. Jeffrey and N. M. Htet, "A dual-loop control of a balance beam system," 2014 9th IEEE Conference on Industrial Electronics and Applications, Hangzhou, China, 2014, pp. 1579-1584, doi: 10.1109/ICIEA.2014.6931420.

[3] J. . -H. Lee, P. E. Allaire, G. Tao and X. Zhang, "Integral sliding-mode control of a magnetically suspended balance beam: analysis, simulation, and experiment," in IEEE/ASME Transactions on Mechatronics, vol. 6, no. 3, pp. 338-346, Sept. 2001, doi: 10.1109/3516.951371.

[4] Stamate, Mihai-Alin, Adrian-Florin Nicolescu, and Cristina Pupază. "Mathematical model of a multi-rotor drone prototype and calculation algorithm for motor selection." *Proceedings in Manufacturing Systems* 12.3 (2017): 119-128.