MTE 423

Automatic Control 2

2 DOF Helicopter

Assignment

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Submitted to:

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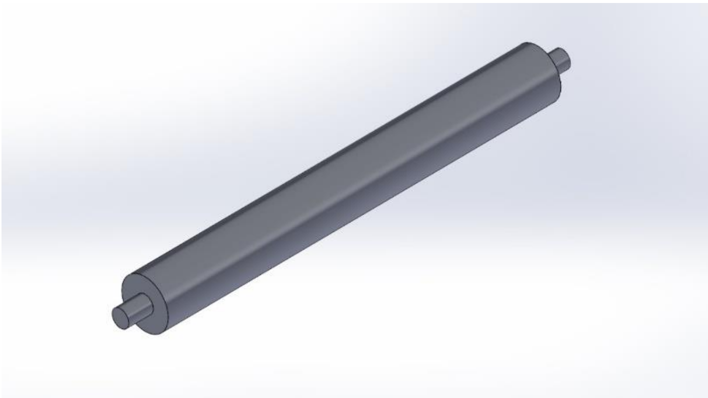
Abstract:

This report explores the application of a Proportional-Integral-Derivative (PID) controller in regulating the dynamics of a 2-degree-of-freedom (2-DOF) helicopter beam. The 2-DOF system is characterized by angular displacements and velocities, and the PID controller is implemented to stabilize the system, minimize oscillations, and achieve precise control. The report details the development of the PID control strategy, simulation results, and discusses the advantages of using PID control in this specific application.

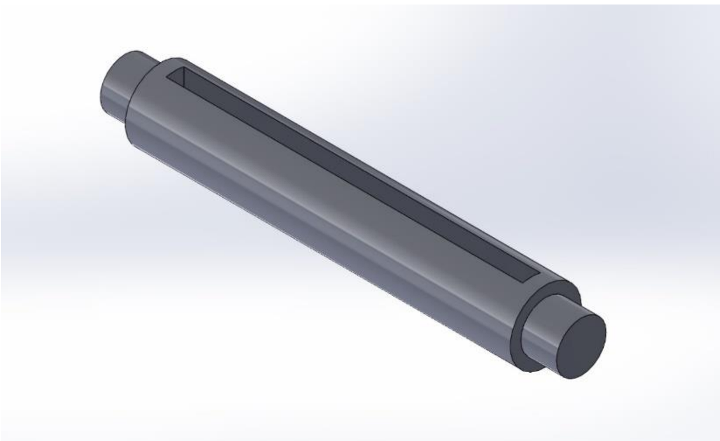
Project Parts:

- Arduino Uno
- Motor Driver L298

  (This was since the first motor driver we used eventually broke, which was the DRV8871 DC Motor Driver - 3.6A Max)
- 720 Coreless Motor with Propeller, 75mm (2 Motor, 2 Propeller)
- 3 rolling bearings
- 3D printed shaft for vertical height.

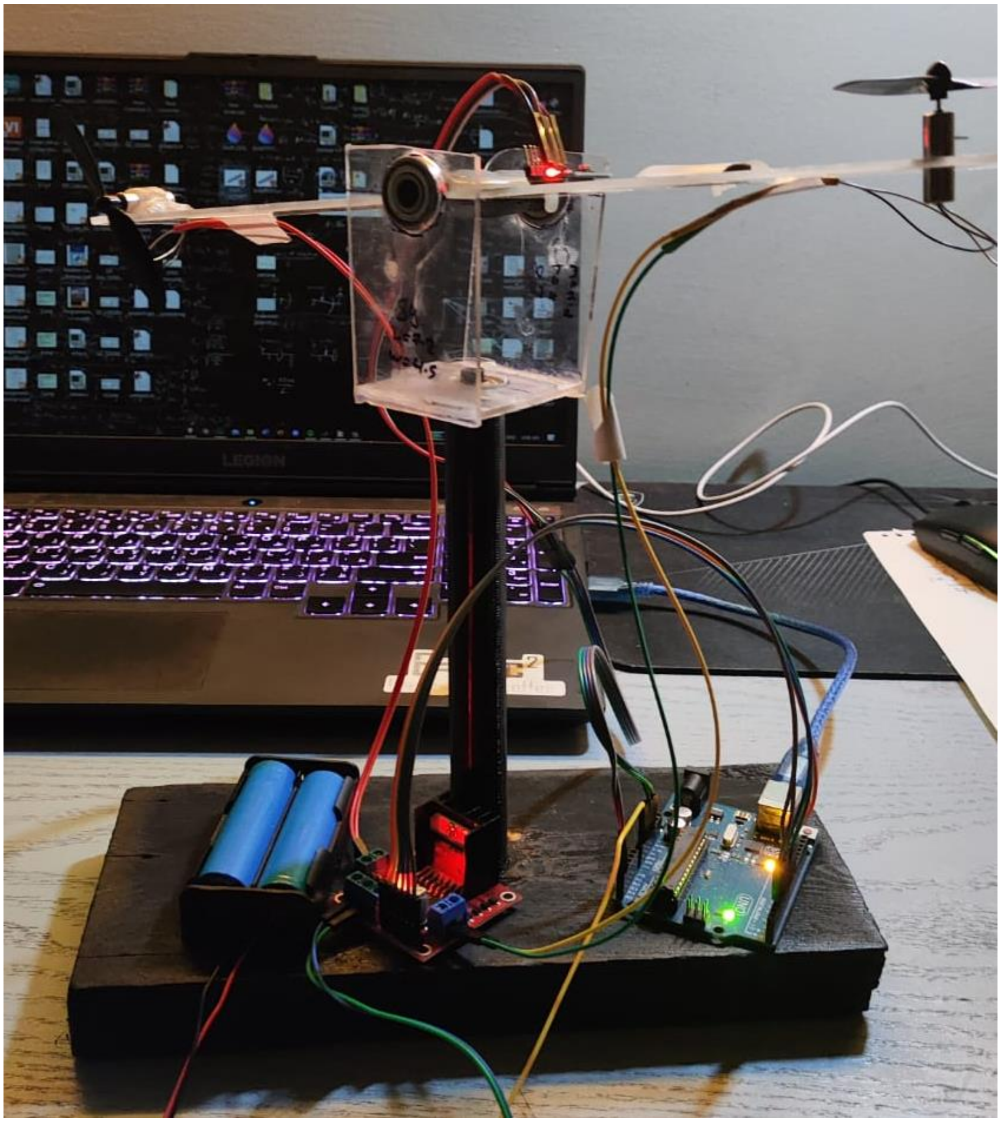


- 3D printed shaft with slot to fit beam to allow swinging motion about the x-axis in relation to the 2 bearings.



- Acrylic Beam
- Acrylic Base with bearing slots
- Wooden block for base
- Accelerometer/gyroscope
- Batteries

These parts were used to setup the system to make a 2-Dof helicopter beam and here is how the final system looked in the end:



State-Space Model:

The Euler Lagrange method is used to derive the nonlinear equations describing the motions of the helicopter. The potential energy due to gravity is

$$V = m_{heli} g l_{cm} \sin\theta$$

The total kinetic energy is

$$T = T_{r,p} + T_{r,y} + T_t$$

From the Eq. (2) is the sum of the rotational kinetic energies acting from the pitch,$T_{r,p}$, and from the yaw ,$T_{r,y}$, along with the translational kinetic energy generated by the center of mass, T_t.

The potential and kinetic energy expressed here are used to derive the equations of motions. Nonlinear equation of motion for the 2 DOF Helicopter, the Euler-Lagrange equations are

$$\frac{\partial}{\partial t}\frac{\partial L}{\partial q_1} - \frac{\partial L}{\partial q_1} = Q_1$$

$$\frac{\partial}{\partial t}\frac{\partial L}{\partial q_1} - \frac{\partial L}{\partial q_2} = Q_2$$

Where L is the Lagrange variable and is the difference between the kinetic and potential energy of the system,

L= T−V.

The generalized coordinates are

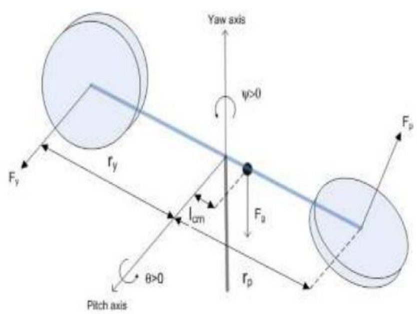
$$q = [\, q1\; q2\; q3\; q4 \,]^T$$

$$= \left[\theta\; \varphi\; \dot{\theta}\; \dot{\varphi}\right]^T$$

And the generalized forces are

$$Q_1 = \tau_P\left(V_{m,p}, V_{m,y}\right) - B_p\dot{\theta}$$

$$Q_1 = \tau_y\left(V_{m,p}, V_{m,y}\right) - B_y\dot{\varphi}$$



Equation (5) includes the viscous rotary friction acting about the pitch and yaw axes, B_p and B_y . The torques applied at the pitch and yaw axes are coupled. The torque applied at the pitch and yaw axis from the motors is

$$\tau_P\left(V_{m,p}, V_{m,y}\right) = K_{pp}V_{m,p} + K_{py}V_{m,y}$$

$$\tau_y\left(V_{m,p}, V_{m,y}\right) = K_{yp}V_{m,p} + K_{yy}V_{m,y}$$

Where $V_{m,p}$ is the input pitch motor voltage and $V_{m.v}$ is the input yaw motor voltage. The torques acting on the pitch and yaw axes are coupled. The torque constants used

$$K_{pp} = K_{f,p}r_p$$

$$K_{yy} = K_{f,y}r_y$$

$$K_{py} = \frac{K_{t,y}}{R_{m,y}}$$

$$K_{yp} = \frac{K_{t,p}}{R_{m,p}}$$

Where $K_{f,p}$ and $K_{f,y}$ are the thrust force constants of the pitch and yaw motor/propeller actuators found experimentally, $K_{t,p}$ and $K_{t,y}$ are the current torque constants of the pitch and yaw motors, and $R_{m,p}$, $R_{m,y}$ are the electrical resistances of the pitch and yaw motors.

Thus the main torque generated by the pitch motor on the pitch axis is $\tau_{pp} = K_{pp}V_{m,p}$and, similarly, the main torque acting on the yaw axis is $\tau_{yy} = K_{yy}V_{m,y}$. The torque generated by the yaw motor that acts on the pitch axis is $\tau_{py} = K_{py}V_{m,y}$. Likewise, the pitch motor generates a rotary force about the yaw axis $\tau_{yp} = K_{yp}V_{m,p}$.

Evaluating the Euler–Lagrange expressions
results in the nonlinear equation of motion.

$$(J_{eq,p} + m_{heli}l_{cm}^2)\ddot{\theta} = K_{pp}V_{m,p} + K_{py}V_{m,y} - m_{heli}gl_{cm}\cos\theta - B_p\dot{\theta} - m_{heli}l_{cm}^2\sin\dot{\theta}\cos\theta\dot{\varphi}^2$$

$$(J_{eq,p} + m_{heli}l_{cm}^2\cos\theta^2)\ddot{\varphi} = K_{yy}V_{m,y} + K_{yp}V_{m,p} - B_y\dot{\varphi} + 2m_{heli}l_{cm}^2\sin\theta\cos\theta\dot{\varphi}\dot{\theta}$$

The equivalent moment of inertia about the center of mass

$$J_{eq,p} = J_{m,p} + J_{body,p} + J_p + J_y$$

$$J_{eq,y} = J_{m,y} + J_{body,y} + J_p + J_y + J_{shaft}$$

Where $J_{m,p}$ and $J_{m,y}$ are the moment of inertias of the motor rotor given in the specifications and

$$J_{body,p} = \frac{m_{body,p}L_{body}^2}{12}$$

$$J_{body,y} = \frac{m_{body,y}L_{body}^2}{12}$$

$$J_{shaft} = \frac{m_{shaft}L_{shaft}^2}{3}$$

$$J_p = (m_{m,p} + m_{shield})r_p^2$$

$$J_y = (m_{m,y} + m_{shield})r_y^2$$

The equations of motion can be packaged in the matrix form

$$D(q)\ddot{q} + C(q,\dot{q})\dot{q} + g(q) = \tau$$

With the inertia, damping, gravitational, and applied torque matrices

$$D(q) = \begin{bmatrix} J_{eq,p} + m_{heli}l_{cm}^2 & 0 \\ 0 & J_{eq,y} + m_{heli}l_{cm}^2\sin\theta\cos\theta^2 \end{bmatrix}$$

$$C(q,\dot{q}) = \begin{bmatrix} B_p & m_{heli}l_{cm}^2\sin\theta\cos\theta\dot{\varphi} \\ -2m_{heli}l_{cm}^2\sin\theta\cos\theta\dot{\varphi} & B_y \end{bmatrix}$$

$$g(q) = \begin{bmatrix} m_{heli}gl_{cm}\cos\theta \\ 0 \end{bmatrix}$$

$$\tau = \begin{bmatrix} K_{pp}V_{m,p} + K_{py}V_{m,y} \\ K_{yp}V_{m,p} + K_{yy}V_{m,y} \end{bmatrix}$$

Now to linearize this model we will assume small angle theorem to get rid of the trigonometric functions.

The linear model of the 2DOF helicopter model is obtained from Euler-Lagrange method. The input variables are the voltages of main rotor and tail rotor, and the output variables are the pitch angle and yaw angle. The plant has two channels and there is an interaction between these channels. To reveal in full, the plant behavior the system should be considered as multivariable.

$$\dot{\theta} = 2.3610*V_{m,p} + 0.07870*V_{m,y} - 29.2985*\theta - 9.260 - 0.555*\dot{\varphi}^2$$

$$\ddot{\theta} = 2.361*V_{m,p} + 0.0787*V_{m,y} - 29.2985 - 9.26\dot{\theta} - 0.555*\dot{\varphi}^2*\theta$$

$$\dot{\varphi} = \frac{1}{0.0432 + 0.04733}[0.072*\varphi*Vm,y + 0.0219*\varphi*Vm,p - 0.318*\varphi^2 + 0.0958*\theta]$$

$$\ddot{\varphi} = \frac{1}{0.0432 + 0.04733}[0.072*Vm,y + 0.0219*Vm,p - 0.318*\varphi + 0.0958*\theta]$$

Symbol	Description
θ, φ	*Pitch and Yaw angle*
$\dot{\theta}, \dot{\varphi}$	*Vertical and horizontal angular velocity*
$J_{eq,p}, J_{eq,y}$	*Equivalent moment of inertia of pitch and yaw*
$B_{eq,p}, B_{eq,y}$	*Equivalent viscous damping of pitch and yaw*
K_{pp}, K_{py}	*Thrust torque constant acting on pitch/yaw axis from yaw/pitch*
$V_{m,p}, V_{m,y}$	*Control voltages of pitch and yaw motor*
m_{heli}	*Total moving mass of helicopter*
l_{cm}	*Length oh helicopter*

Controllers Used:

PID Controller: A PID controller is a feedback control system that incorporates three main components: Proportional (P), Integral (I), and Derivative (D). Each component contributes to the controller's output in a specific way:

Proportional (P): This term is proportional to the current error, which is the difference between the desired setpoint and the actual system output. The proportional component provides a corrective action based on the present error, helping to reduce steady-state error.

Integral (I): The integral term considers the accumulated error over time. It adds a corrective action based on the integral of the error, addressing any persistent steady-state error that the proportional term alone may not handle.

Derivative (D): The derivative term considers the rate of change of the error. It anticipates future system behavior and introduces a corrective action to dampen oscillations and improve system stability.

PD Controller: A PD controller is a simplified version of the PID controller, excluding the integral component. The PD controller uses only the proportional and derivative terms to adjust the control input based on the current error and its rate of change. This makes PD controllers effective in systems where steady-state error is less critical, and there's a need to address dynamic response and stability.

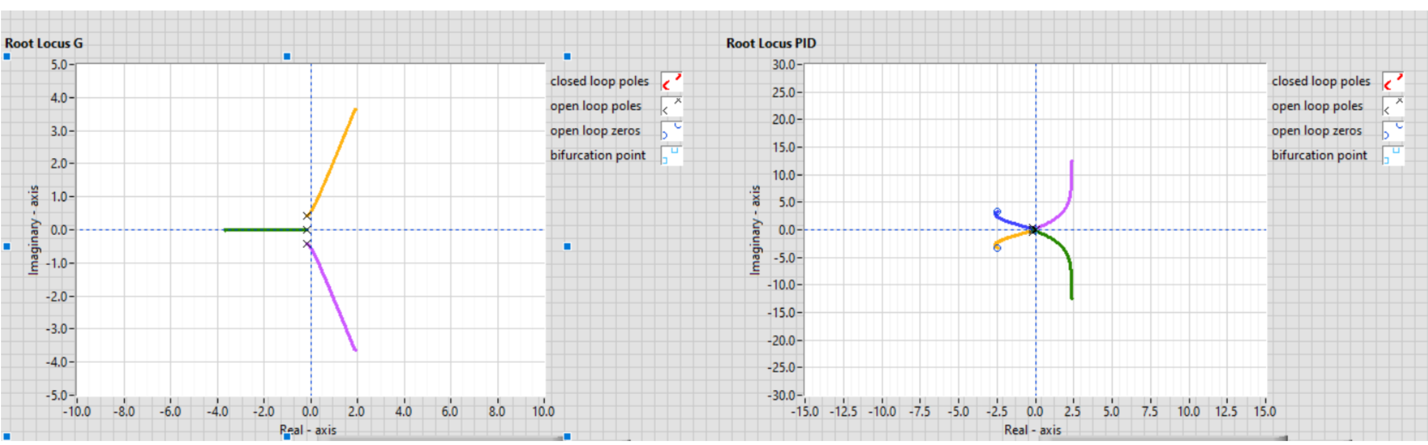
Choosing PID over PD: The decision to use PID over PD depends on the specific characteristics and requirements of the controlled system:

Steady-State Error: PID controllers are particularly advantageous when there is a need to eliminate or minimize steady-state error. The integral term in PID helps achieve this by considering the cumulative error over time.

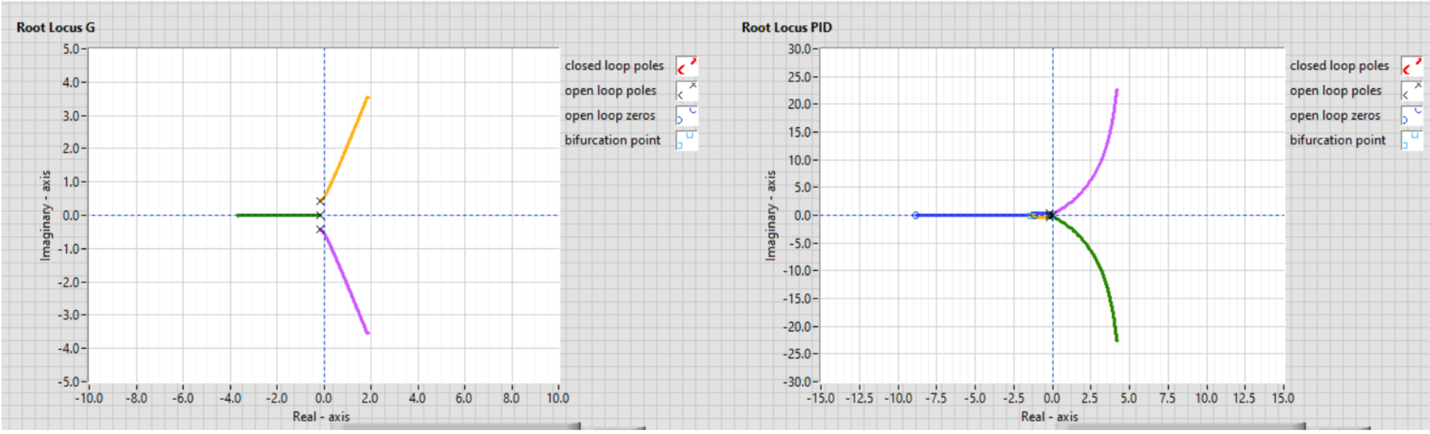
Complex Systems: In complex systems with varying dynamics and uncertainties, PID controllers provide more flexibility and adaptability. The integral and derivative terms contribute to improved performance in a wider range of scenarios.

Improved Stability: PID controllers are generally more effective in enhancing system stability, especially when dealing with systems prone to oscillations. The derivative term helps dampen oscillations and prevent overshooting.

At first, we tried to use PD control to control our system which we tried to make it function first by controlling over one degree of freedom first then the other then integrating both together, however the PD controller was extremely ineffective as we needed the Integration part offered by PID controller to control the steady state error. Therefore, in the end the controller that gave us the best results was the PID controller rather than the PD which had a very high accumulative error rate and relatively which was reduced when Ki was introduced to the system and tunned accordingly.



On the left is the uncompensated system, however on the right was the compensated system with the PID controller used to control the pitch values,



Here is the root locus for the same system with the PID controller used to control the yaw values.

<u>Conclusion:</u>

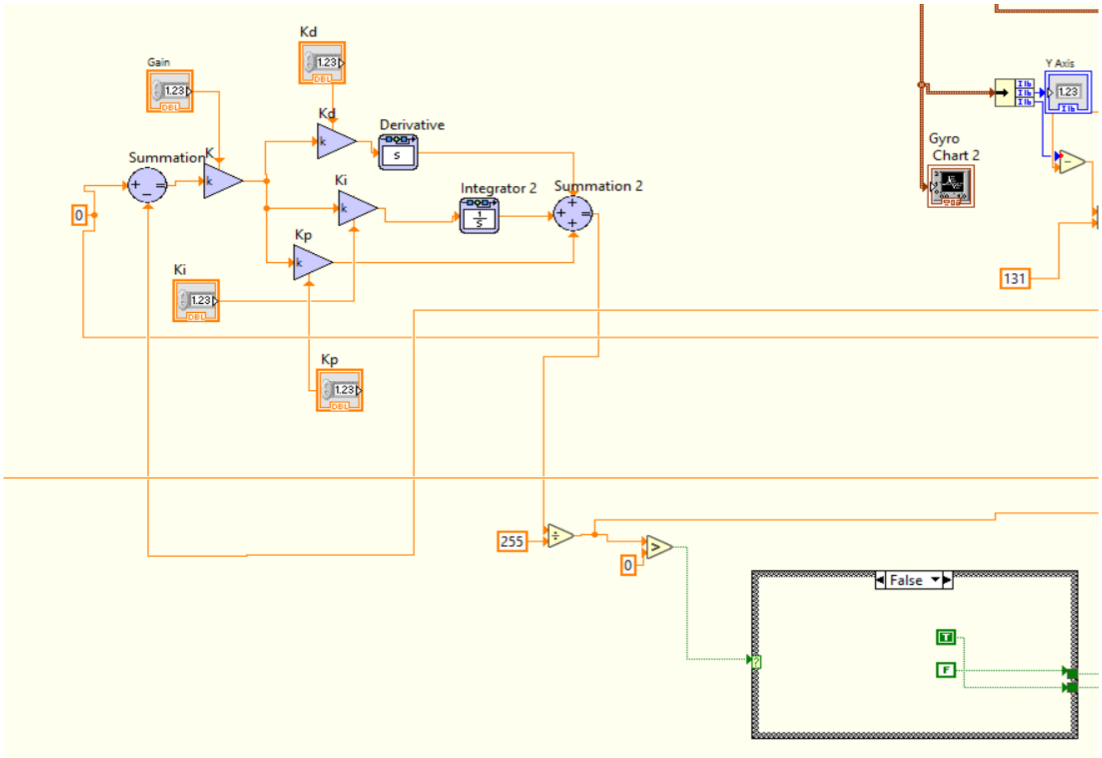
In summary, PID and PD controllers are fundamental tools in control systems engineering. While PD controllers offer simplicity and effectiveness in certain applications, PID controllers provide a more comprehensive solution by addressing steady-state error, improving stability, and offering better adaptability to complex systems. The choice between PID and PD depends on the specific characteristics and requirements of the controlled system.

<u>Labview:</u>

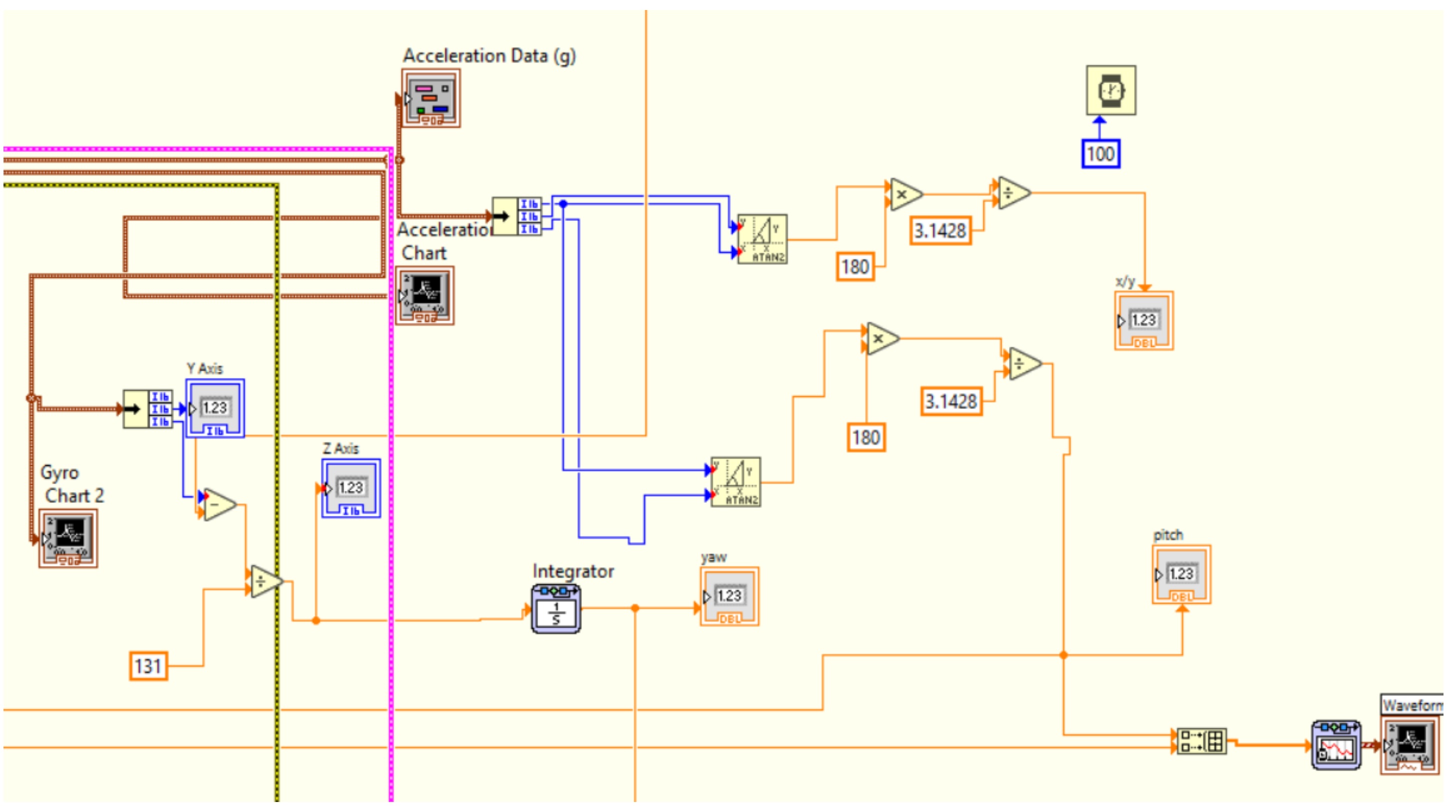
The labview used the LINX link frame to link both labview and Arduino together and allow them to communicate serially, and also read the values coming from the gyroscope.

Some of the problems faced was that the serial communication itself between using LINX was hard to setup at times as the port of the laptop used sometimes gave random errors showing that it was busy, another problem was the calibration and usage of the accelerometer as the connection itself that allows labview to show the readings from the accelerometer was extremely hard to set up and once setup, it needed to be heavily calibrated to minimize errors.

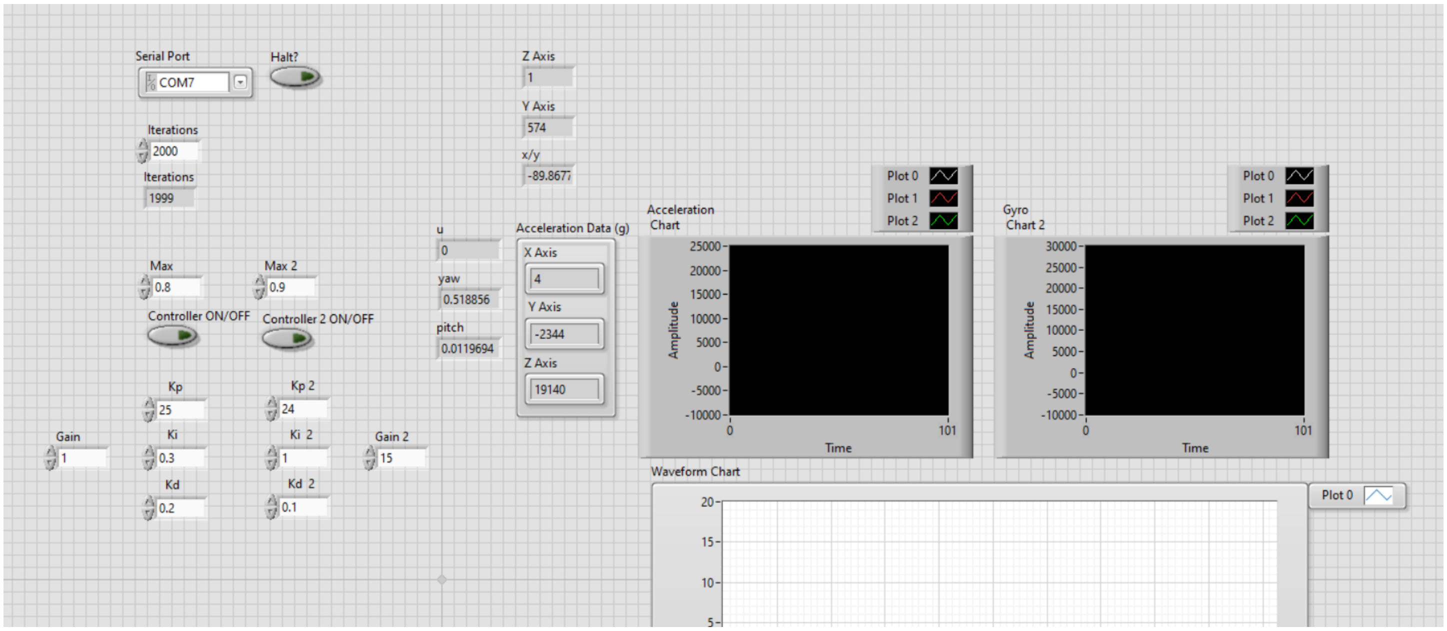
Here is the Labview Block Diagram used to make both PID controllers:



Here is the part that's responsible for the pitch and yaw readings:



Our final Front Panel:



Further research could explore advanced control strategies, such as adaptive PID or model predictive control, to enhance the robustness and adaptability of the control system. Additionally, experimental validation of the PID controller on a physical 2-DOF helicopter beam would provide practical insights into real-world applications.