Project Report

# Pitch Perfect : ME2400 Project


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## Executive Summary

- This project set out to develop a control algorithm capable of balancing the pitch of a tandem rotor helicopter and demonstrate its effectiveness using a simplified physical simulator of a Chinook helicopter.
- By carefully selecting hardware and engaging in interdisciplinary collaboration, a fully self-contained simulator was constructed, complete with two vertical rotors and a control algorithm that could stabilize the pitch axis of the system at any requested angle within a range
- Overall, this project serves as a powerful demonstration of the potential of control algorithms to stabilize the pitch of a tandem rotor helicopter and emphasizes the need for interdisciplinary collaboration in developing complex systems.

## Introduction and Objective

- The Chinook helicopter is a unique and versatile aircraft, capable of carrying heavy payloads and operating in a variety of environments. Its tandem rotor design makes it a valuable asset in military and civilian applications, but also presents unique challenges in terms of stabilizing the pitch axis.

- This project aims to design, build, and test a simplified simulator of a Chinook helicopter and develop a control algorithm that can balance the pitch of the simulator by controlling the lift of two vertical rotors mounted on each end of the body.

- The simulator will consist of a 400 mm long body supported at its center of mass but free to pivot in the pitch axis. Two vertical rotors with propellers will be mounted on each end of the body to provide lift and balance the pitch of the simulator.

- The control algorithm will be developed using an Arduino UNO/ESP32 and a suitable sensor, and will be responsible for controlling the lift of the two rotors to balance the pitch of the simulator. The control algorithm should be able to balance the simulator at any pitch angle within a specified range .

- The project kit items include two motors with propellers, an Arduino UNO, MPU6050, a motor driver IC, breadboard, jumper wires, double-sided tape, propellers, a USB cable, wire stripper and cutter, an appropriate battery, and a body made of wood.

## Component List and Sizing Justification

Components used to design the prototype:

- A wooden block
- Wooden cutouts(shown in Fig. 1)
- A metal rod
- Propellers
- Double sided tape
- Zip Tags

Size Justification

- Wooden block
    1. Length = 30 cm
    2. Width = 7.5 cm
    3. Height = 2 cm
- Wooden supports
    1. Base width = 10 cm
    2. Distance of center of pivot hole from base = 6.9 cm
    3. Diameter of pivot hole = 6 mm

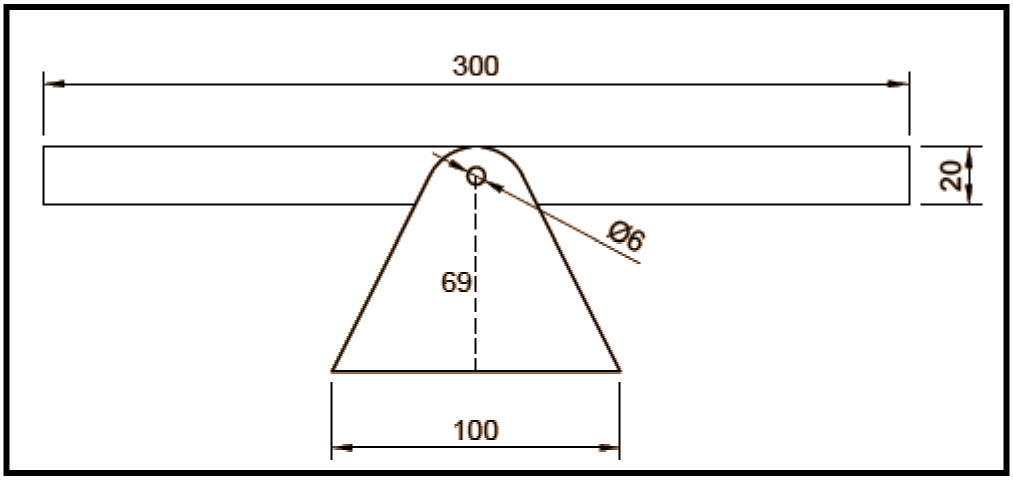


**Fig 1: Dimensions of Chassis and pivots**

## Mechanical Design of the System

- A cuboidal wooden block is used as the chassis, dimensions are chosen such that all the circuit components are placed perfectly, also the constraint of length is satisfied.
- Motors were fixed at both the ends, at a distance of 12.5 cm from the center line. 4 holes (lying on a circle of radius 16.5 mm) of radius 1.5 mm were drilled through, motors were fixed on top of these holes with the help of zip tags. (Fig. 2 & Fig. 3)
- A hole of 6 mm is drilled in the middle, along the width of the block to fix two supporting wooden pivots.
- Breadboard is placed on top, in the middle, such that the center of gravity is not disturbed. Arduino UNO and MPU-6050 were placed on the breadboard. Breadboard was fixed using double sided tape. (Fig. 3)
- Electronic Speed Controller's (ESC) were placed on the backside at some distance from both the ends, maintaining center of gravity. They were also placed using double sided tape.
- A metal rod was put through to pivot chassis to triangular arched shaped pivots. (Fig. 2(b))

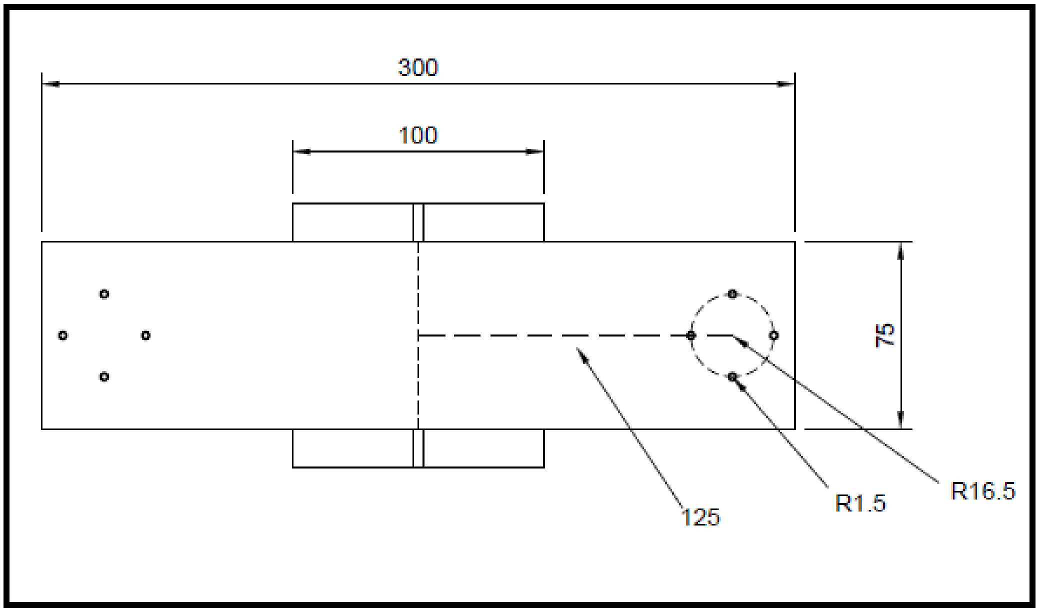


**Fig. 2(a) Top view of chassis (showing holes drilled for motor placement)**

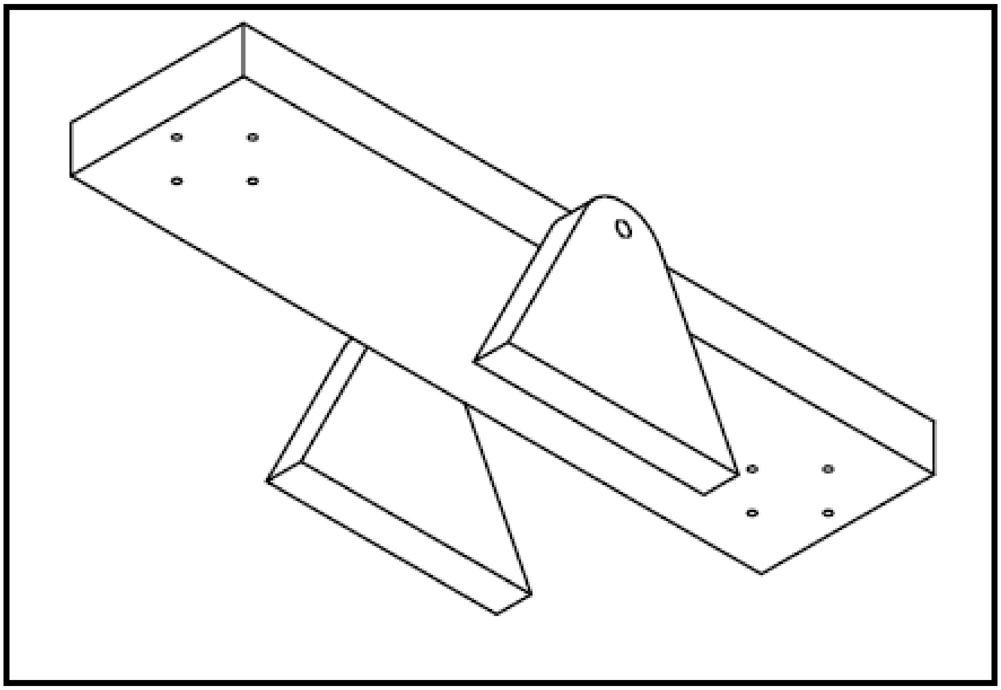

**Fig. 2(b) Oblique view of chassis (showing fixed pivots)**

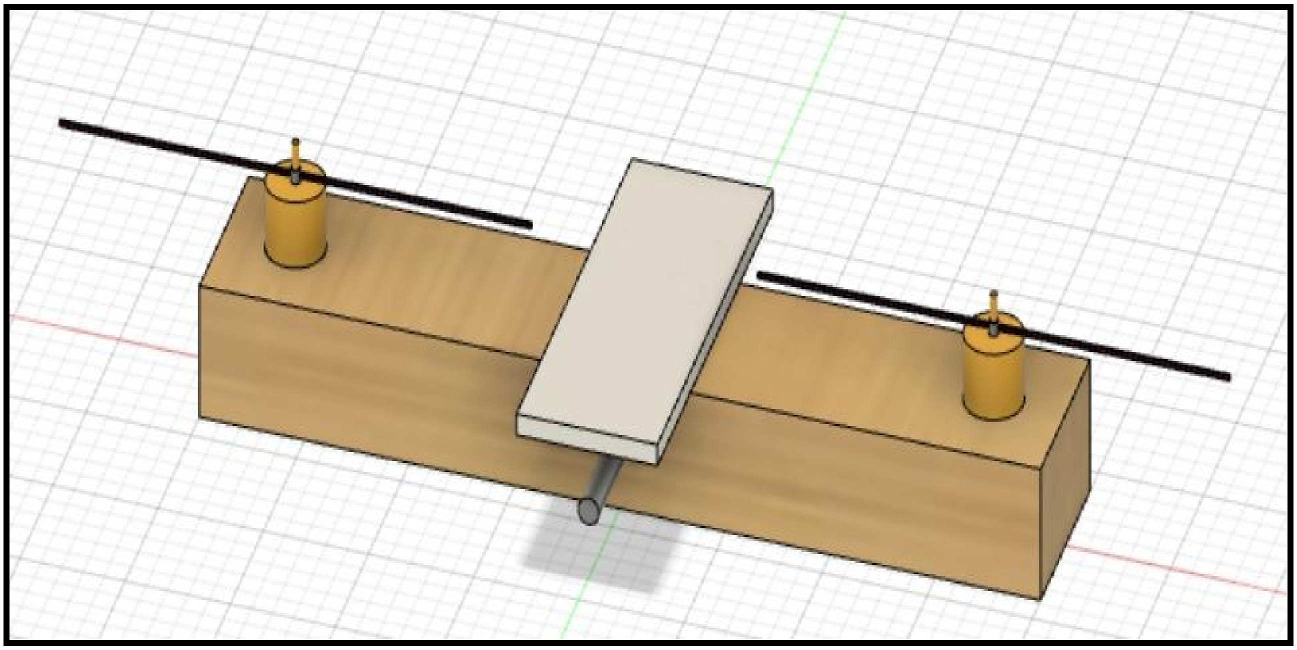

**Fig. 3 Showing placement of breadboard and motors on the chassis**

## Electronic Circuit Diagram

The components used to design the electronic circuit for the project had the following components in it

- Brushless DC Motor - 1000KV (2)
- Electronic Speed Controller - 20 A (2)
- Arduino UNO Board (1)
- MPU6050 6 axis (1)
- Breadboard (1)
- Jumper Cables - male to male and male to female
- Lithium Ion Battery - 11.2V (2)

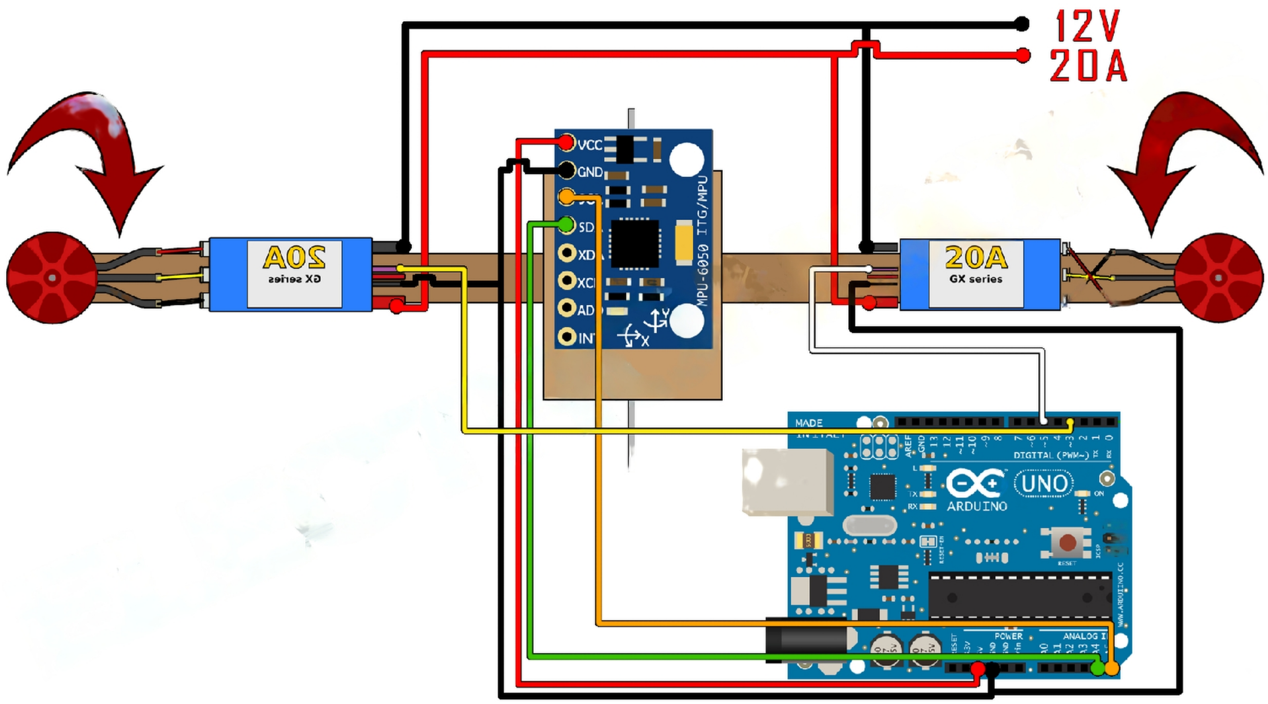


**Fig. 4 Representing the electronic circuit diagram schematically**

## Controller Design and Arduino Program

The project made use of a PD controller implemented on Arduino. The outline of the controller is as follows

```
float Kp  = 2.0;
float Kd  = 0.5;

float correction = -(Kp*roll + Kd*ang_vel);
Serial.println(correction);
if(((correction)<16)&&((correction)>-16)){
  speed1=70+correction*2;
  speed2=70-correction*2;
  }
else if((correction)>16){
  speed1=100;
  speed2=40;
  }
else if((correction)<-16){
  speed1 = 40;
  speed2 = 100;
}
```

**Fig. 5 Showing the outline of the controller code**

The Controller was tuned using the Ultimate Cycle Method followed by Ziegler Nicolson Estimation method to get the further parameters such as Kp and Td.

The final values of the PD constants were

- Kp= 2.0
- Kd= 0.5

The Arduino program has the following parts

- Setup - In the setup loop we calibrate the ESC between 1000-2000 (0-180 in the Servo module) PWM signals with 1000 for off and 2000 for maximum motor speed. We also initialize a base speed with which the motor will run during the balancing
- Data collection - In the loop, first we get the reading from the IMU using I2C protocol (the connections for which are shown above). The angle of concern for us was the roll and the corresponding angular velocity was read from

the MPU6050. We then applied a filter on it to smoothen out the error and averaged it over 3 values to further reduce the error and use that in the controller

- Controller Scheme - the controller calculates the correction corresponding to the roll and angular velocity and applies it to the speed of the motor.

The link to the code is here.

## Control System Block Diagram

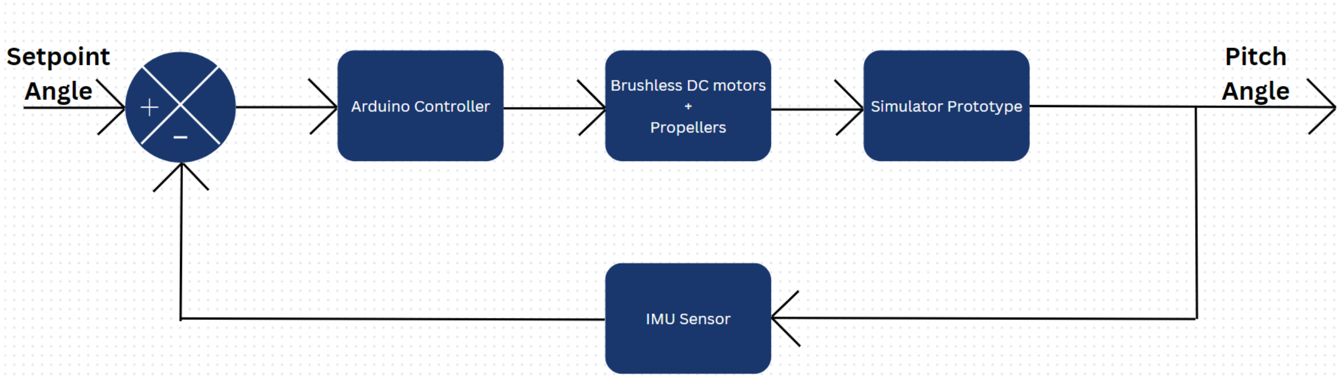


**Fig. 6 Control system block diagram for the entire setup**

## Simulink Model for Controller

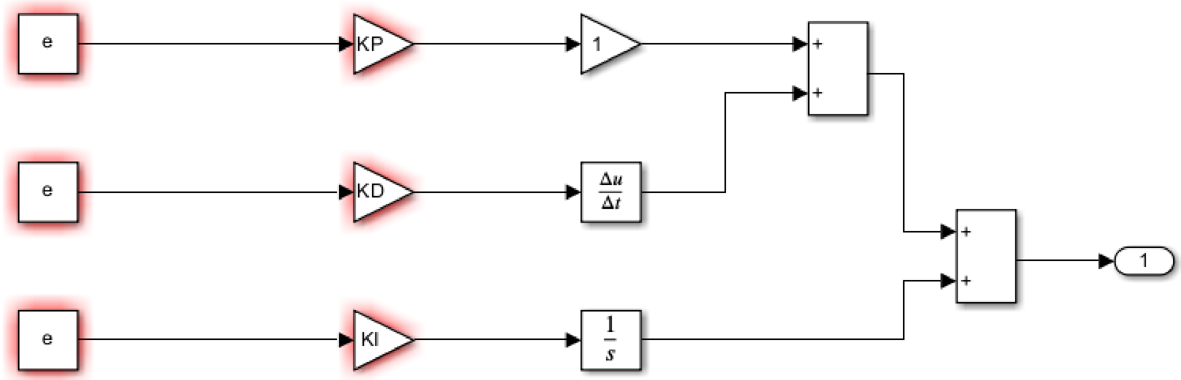


**Fig. 7 Screenshot of the simulink model for the controller**

Where e=error, Kp, Kd, Ki are the gains of P,I and D controls respectively, and 1 denotes the output.  In our case the final were Kp = 2.0, Kd = 0.5, Ki = 0.0

## Results

Link for video of working model: [LINK]

## Conclusion

Through this project, a simplified simulator of a Chinook helicopter was successfully designed, built, and tested. A control algorithm was developed to balance the pitch of the simulator using two vertical rotors mounted on each end of the body. The control algorithm was able to balance the simulator at any pitch angle within a specified range, demonstrating the feasibility of using a control algorithm to stabilize the pitch of a tandem rotor helicopter.

## Important Lessons

- Building a physical simulator can be a valuable tool for testing and refining control algorithms.
- The tandem rotor design of the Chinook helicopter presents unique challenges in terms of stabilizing the pitch axis. However, with careful design and control algorithms, it is possible to balance the pitch of a tandem rotor helicopter.
- The selection of appropriate hardware, such as motors, propellers, and motor driver ICs, is critical to the success of the project.
- The project highlights the importance of interdisciplinary collaboration between engineers, scientists, and designers in developing complex systems like helicopters.

## Photos

**Fig. 8 Picture depicting project building, team members, team-discussions**

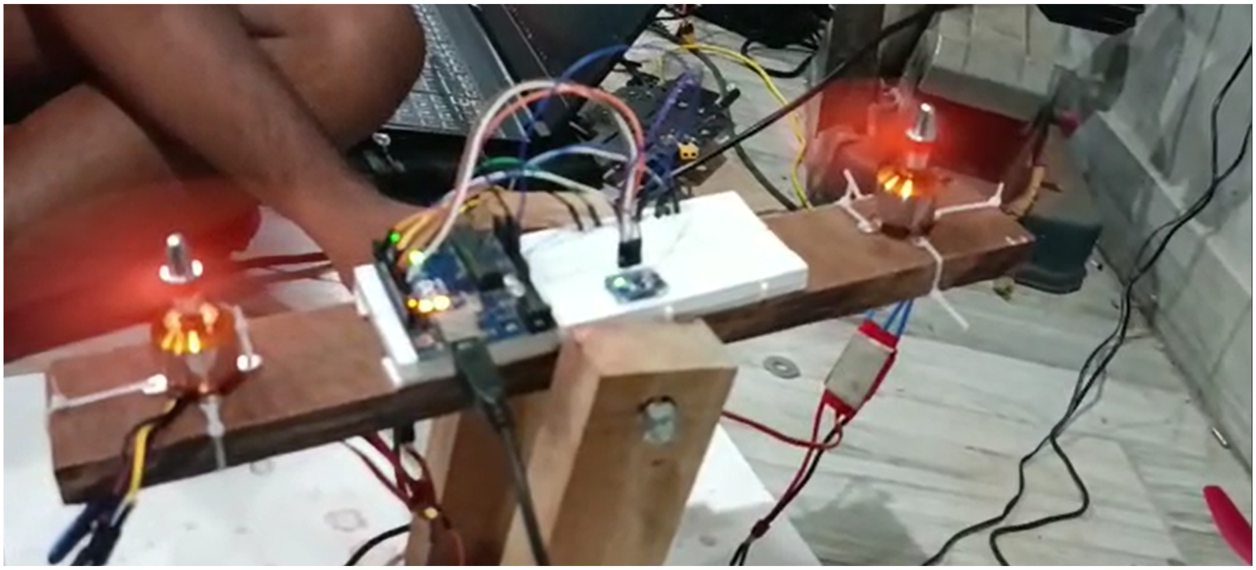

**Fig. 9 Working model**

## Team member contributions

- Aditya Arya: Manufacturing, testing, report writing - component list and sizing specifications, mechanical design of systems
- Arvind P: Manufacturing, testing, simulink, report writing - Control system block diagram, results,
- Ashish Srivastava: Fabrication. assembly, coding, electrical circuit design, testing, report writing - Electronic circuit diagram and controller design and arduino code
- Gokul krishnan: Testing, report writing - executive summary, introduction and objective, conclusions and lessons learned