DESIGN AND DEVELOPMENT OF A PORTABLE STABILIZING PALTFORM

A Final Year Project Report

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In Partial Fulfillment
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Bachelors of Mechanical Engineering

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ABSTRACT

This report encompasses the work done in the design and control of a 2-Axis Inertially Stabilized Platform for a DSLR Camera. The need of the project arose due to the revival of the entertainment industry in Pakistan. To capture stunning movies stabilizing platforms are a must have and they must be provided to the industry at a very competitive price. The first step was to review all the commercially available designs and control schemes to get an idea of the design requirements and difficulties we may have to face. After review of design and control schemes design for a DSLR camera was brainstormed and control scheme for the design was prepared. After finalizing design and control scheme simulations were run to check the integrity of the design and the stability of the whole system. The results of the simulation lead to the tweaking of the design and control scheme and this process was repeated several times over until the target parameters and results were obtained. Simultaneously with this process motor selection process was carried out and this process was dependent on the design so motor for the platforms were also finalized with the help of final design. The work till this stage was presented to a panel of evaluators. The recommendations made by the panel are also discussed and they are taken into consideration. Future work that can be carried out in addition to the work done in this FYP is also presented at the last part.

ACKNOWLEDGMENTS

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ABBREVIATIONS

UTS	Ultimate Tensile Strength

NOMENCLATURE

T_1	Torque for motor-1
T_2	Torque for motor-2
b	Dynamic friction coefficient
L	Inductance
R	Resistance
K_e	Voltage constant for motor
K_m	Motor torque constant
J_1	Moment of inertia for motor-1
J_2	Moment of inertia for motor-2
K_p	Proportional gain
K_d	Derivative gain
K_i	Integral gain
M	Mass of pipe
m_p	Mass of platform/plate
R	Outer Radius of Pipe
r	Inner radius of Pipe
L	Lenth of plate
W	Width of plate
a	Half of plate's width

CHAPTER 1: INTRODUCTION

This chapter includes the motivation of work, problem statement, and objectives of the project.

1.1 Motivation

Inertially Stabilized Platforms finds its applications in a number of industries. It has its applications ranging from the defense industry to entertainment industry. The use of the technology in such a wide range of applications gives us an idea of its importance. Some of the major applications of this technology are as follows.

1.2 Entertainment Industry

From filmmaking cameras to sport broadcasting cameras all have a one thing in common, they all are inertially stabilized in order to get the best quality of videos during movement of camera.

1.3 Defense Industry

The defense industry around the World is incorporating Technology in its products at a very rapid pace. For location for potential threats to surveillance the defense industry is coming up with new products and most of these products like drones, quadcopters etc all have inertially stabilized cameras to keep the video quality at maximum during the motion of the machine.

So, with a variety of applications and so many industries at target the project really caught our eye. With the grasp on a single principle we could work with so many industries. In addition to this the entertainment industry in Pakistan specially the film industry in Pakistan is making a comeback and the equipment that they require will definitely include inertially stabilized platforms, so this opportunity pushed us to opt for the project.

1.4 Problem Statement

"Design and Development a stabilizing platform for pitch and roll axis of a DSLR Camera."

Stabilizing Platforms for mobile phones are already available in the Pakistani consumer market a good Mobile Phone stabilizing platform costs about 15,000 Rs but stabilizing platforms for DSLR cameras and movie cameras are nearly nonexistent at the moment. So, they have to be imported from China or other countries. The shipping time from China to Pakistan is almost 30-42 working Days and if you want to get your platform early, you'll have to pay a fair sum of money in delivery charges. When the product arrives in Pakistan you would also have to pay a fair amount of tax to the government. So, all these hurdles present a problem that we aim to solve. The price of the product gets doubles when it reached the consumer. So, to provide inertially stabilized platforms for DSLRs and even larger filmmaking cameras at a competitive price is the main aim of the project so that the consumer in the Pakistani market can use this technology in their work.

1.5 Objectives

The objectives of the project are as follows.

1. Manufacture a stabilizing platform for a DSLR camera for the pitch and roll axis.
2. Keep the price of the product competitive with other available products.

CHAPTER 2: LITERATURE REVIEW

This chapter explains the literature review carried out to make the project. It summarizes the existing knowledge in the area of the project while referring to significant publications (books, research papers) in the area of the research work.

As discussed in the introduction, stabilizing platforms find its application in industries ranging from defense to entertainment industry. Be it camera that needs to be stabilized or instrument attached in dynamic vehicle. Be it gunsights in tanks or anti-aircraft artillery in ships, stabilizing platforms are needed everywhere.

2.1 History:

Stabilizing concept came into being in 20th century (1905) by Brennan through gyroscopic stabilization technique.

2.2 Gyroscope:

A gyroscope is a device used for measuring or maintaining orientation and angular velocity. It is a spinning wheel or disc in which the axis of rotation is free to assume any orientation by itself.

When the external torques are applied on a platform placed on a gyroscope, it counteracts the torque and keep it at a position where required. One of the most popular examples of a gyroscopically stabilized vehicle is the Gyro X car developed by Alex Tremulis and Thomas O. Summers Jr. of Gyro Transport Systems Inc. This 840kg two-wheel car was designed and built in 1963.

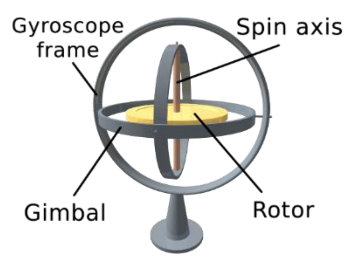


Figure 1: Mechanical Gyroscope [1]

We studied gyroscopic stabilization and found following disadvantages over Electrical Stabilizing Platforms which are:

1. Settling time of just less than 3mins which is much greater than what is required for camera stabilizing i.e. (<2s)
2. Much greater weight than Electrically stabilized platforms.
3. More sensitive to external disturbances,
4. Difficult to make it portable
5. Much greater steady state error.

Considering the disadvantages of gyroscopic stabilization, we moved on electrically stabilized platforms which consist mostly of a position sensor that measures the disturbed angle and passes it on to a microcontroller which works out a particular voltage that is to be provided to motors to be counter torques. [1]

2.3 Mechanical Designs Studied:

Below mentioned are the designs studied and compared for mentioned requirements.

2.3.1 Actively Controlled Stabilized Platform for Automobile:

One of many designs we studied was a gimbal table that provided a stable base for anything to be stabilized. This design has a fixed base and is predominantly designed for automotive use. In this design two independent frames takes the hold for stabilizing the platform in the pitch and roll axis. These frames are manufactured from aluminum. The frames are attached to the base and motors with the help of pins. Advantages of this design are that motors can transfer their power to the base without a coupling occurring among them and the vibrations of one motor don't superpose with the other motor's vibrations. Smooth transmission of power is possible here from the motor to the base independent of each other. Disadvantage of this design is that, it has a fix base and is not best suited for a camera stabilizing platform that can be used for filming while carrying in your hands. Our prime objective was to make a stabilizing platform that can give us best performance in stabilizing our camera and have a moving base. So, this design doesn't completely fulfill our need to have a stabilizing platform with moving base, but it did give us an idea of how we can avoid the coupling of both motors vibrations. This design also gave us an idea about possible material choice that we may use in our stabilizing platform.[2]

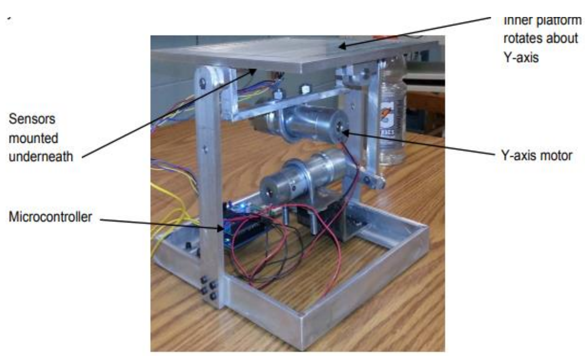


Figure 2: Actively Controlled Stabilized Platform for Automobile [2]

2.3.2 Handheld 2 DOF Gimbal:

In this design we can see that a handheld stabilizing camera is made to stabilize the camera in two axis i.e. the pitch and roll. Plastic is being used and gear assemblies are there to enhance the torque of motors. This design was not suited for our project as it is unfit for payload that we are designing our platform for. It is also not user friendly because of difficulty users can have in handling it with only one hand. But this design did point out an opportunity for us to use plastic as material for manufacturing of our basic structure. [3]

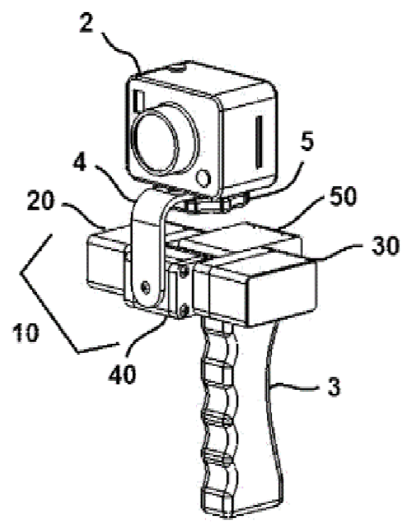


Figure 3: Handheld 2 DOF Gimbal [3]

2.3.3 Self Stabilizing Platform:

In this design the static base has a structure that holds a motor that controls the pitch of the platform. With this motor, the other motor is connected that controls the roll axis. Second motor has its body attached to the first motor's shaft. In this way both the motors have been coupled together and irregularities in one motor would affect the other motor eventually. Advantages of this design are it has minimized the torque on motor shafts by having short arms of motors and this design is also a simple one. Disadvantages are that it is unbalanced, have a static base which limits its use and this design have a problem of motor coupling. [4]

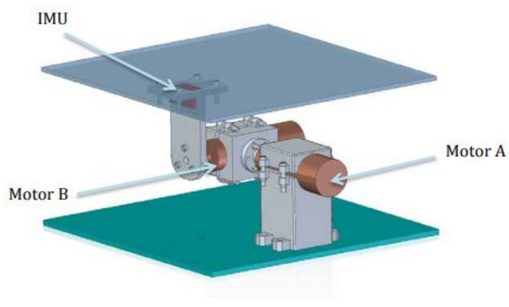


Figure 4: Self Stabilizing Platform [4]

2.3.4 Handheld Stabilizing Platform:

In this design the camera is sliding on a rail that is stabilized using motors in all three axis. Frames independently transfer motors' power to the camera. Frames with help of pins are connected to the motors and other structures. This structure is hand held. Advantages of this design are that it is handheld and can be supported by both hands. It has motors not transferring their vibrations to each other, can support big loads and it is almost stable statically. [5]

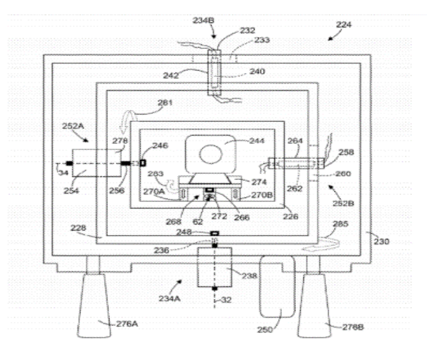


Figure 5: Handheld Stabilizing Platform [5]

2.3.5 Mechanical Gun Stabilizing Platform:

In this patent design the gun is being stabilized using two actuators for roll and pitch while using a spring for countering vibrations in z-axis. Tri-stand is being used with fixed base. This design isn't suitable for a gimbal because of its fixed base.[6]

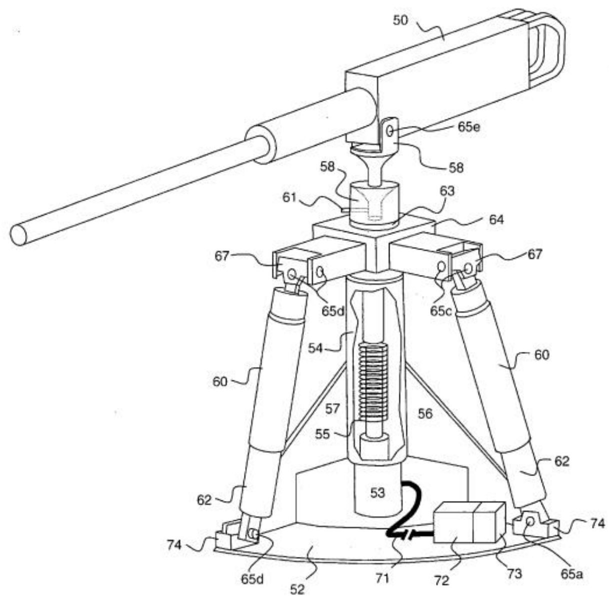


Figure 6: Mechanical Gun Stabilizing Platform [6]

2.4 Control Schemes

A number of control schemes are available for inertially stabilized platforms. The latest research going on in this field is to make the control system more accurate so that it can be incorporated into a greater number of products. The three main control schemes used are as follows.

2.4.1 PID Control

Proportional Integral and Derivative Controller is the most widely used control scheme in a number of commercial products. PID Control scheme was invented in 1914 and since then its use has grown ever since. This control scheme can be implemented with a number of commercially available controllers. Most of the cameras stabilizing platforms use this control scheme. Response of PID Control scheme implemented to stabilize a rotary inverted pendulum is as follows.

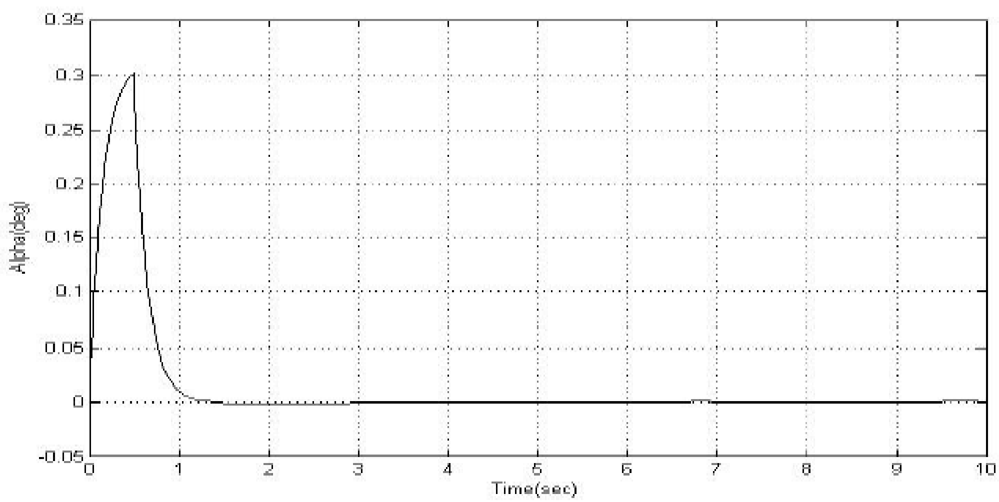


Figure 7: PID Control Response Graph **[9]**

2.4.2 Robust Control

Robust Control is a relatively new control scheme developed in the 1980s. Robust Control Scheme is widely used in military applications. Robust Controls are extremely response. Because of their fast response time they are used in military applications. The Robust Control Theory is still under development and a lot of research is going on in this field. Response of Robust Control scheme implemented to stabilize a rotary inverted pendulum is as follows.

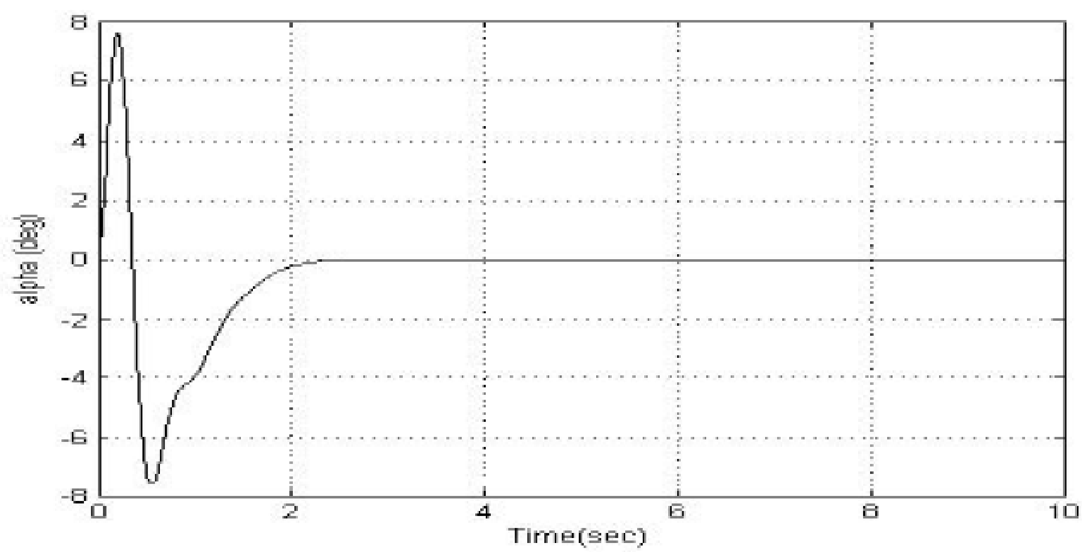


Figure 8: Robust Control Response Graph **[9]**

2.4.3 Fuzzy Control

Fuzzy Controls are the latest addition to the arsenal of control schemes used around the World. Fuzzy Controls are intelligent controls. Fuzzy Controls usually find their applications in areas where non-linearities are present. Fuzzy Controls were invented in the 1990s. The latest trend is to incorporate Fuzzy Logic Controls with PID and Robust Controls to make an adaptable controller that could change its parameters according to the situation at hand. Response of Fuzzy Control scheme implemented to stabilize a rotary inverted pendulum is as follows.

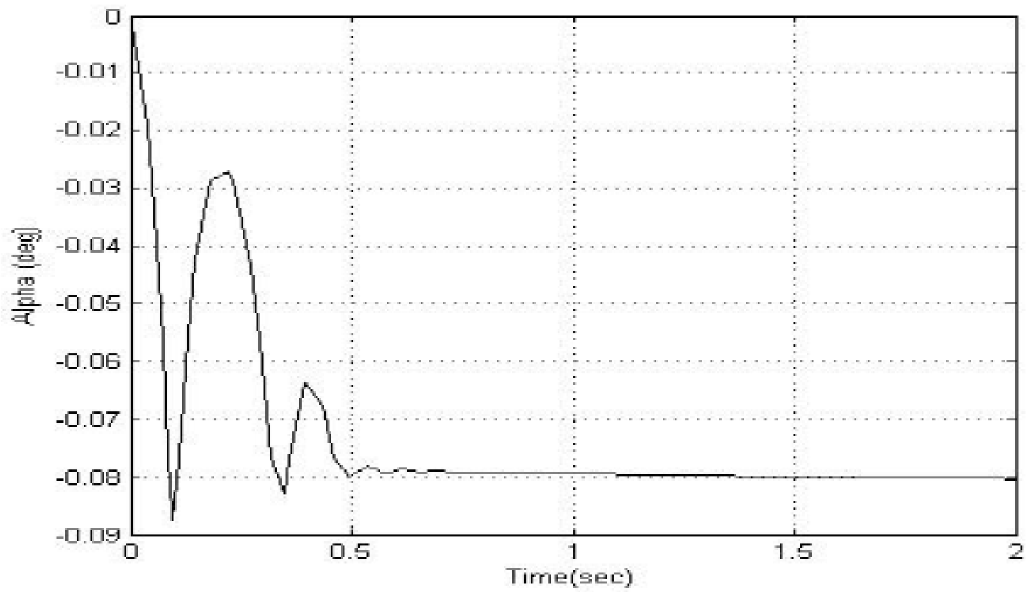


Figure 9: Fuzzy Control response Graph **[9]**

2.4.4 Conclusion

We are using PID Control scheme in our product because we are aiming to make a commercial product so the control scheme used in the product should be easily available and PID Controllers satisfy this criterion. Another factor that made us opt for the PID Control was the range of vibrations we are going to encounter in our product. The maximum frequency of vibrations in a inertially stabilized platform is 3 Hz and PID Control performs well in this range of vibrations.

CHAPTER 3: METHODOLOGY

This chapter discusses the design approach, motor selection criteria and control systems used. It contains information regarding hardware, software and electronics used in the project.

3.1 Design Approach:

Since we are targeting the entertainment industry, therefore our design should have the following characteristics:

1. It should be light.
2. Can be easily held for longer period.

3.1.1 Material Selection:

Keeping in view the above requirements, we studied quite a few materials. The material that we narrowed down were aluminium and polyvinylchloride (PVC).

The comparison of the two materials is given in the following table:

Table 1: Comparison of PVC and Aluminium

Properties	PVC (rigid)	Aluminium
Density (g/cm^3)	1.4	2.7
Yield Strength (MPa)	51	310
Elastic Modulus (GPa)	2.9	69
Ultimate Tensile Strength (MPa)	51	481
Price (Rs/meter)	20	200

From the above comparison we can clearly see that aluminium is far superior than PVC in terms of yield strength and elastic modulus but is 10 times costly. Moreover, the density of aluminium is greater than PVC which means greater weight. Our application did not require such high yield strength and elastic modulus, moreover, since our requirement is that the platform should be light and cost effective, we went for **PVC.**

3.1.2 Design:

After going through a variety of designs, we came up with the model as shown below:

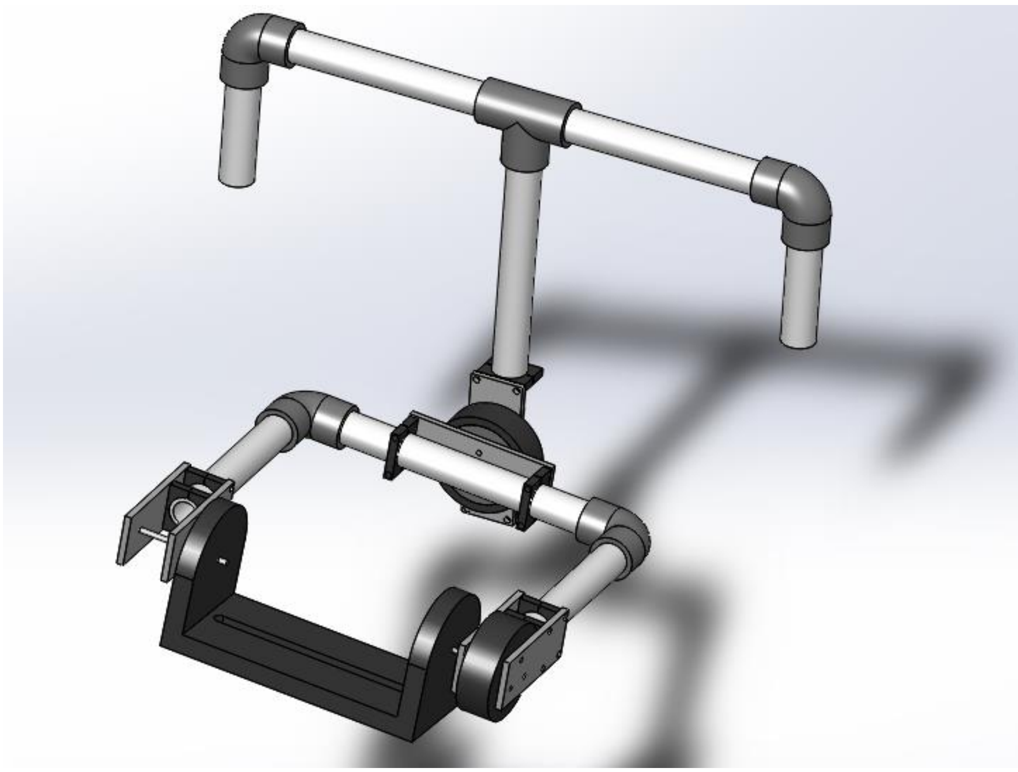


Figure 10: CAD Model of the Platform

This design has following characteristics:

1. It is simplistic
2. Negligible machining is required which brings down the cost.
3. The platform can be held with both hands, this distributes the weight of the gimbal in both hands and can be used for longer periods without getting tired.

Following are **the exploded view** of the model showing how the components are connected to each other.

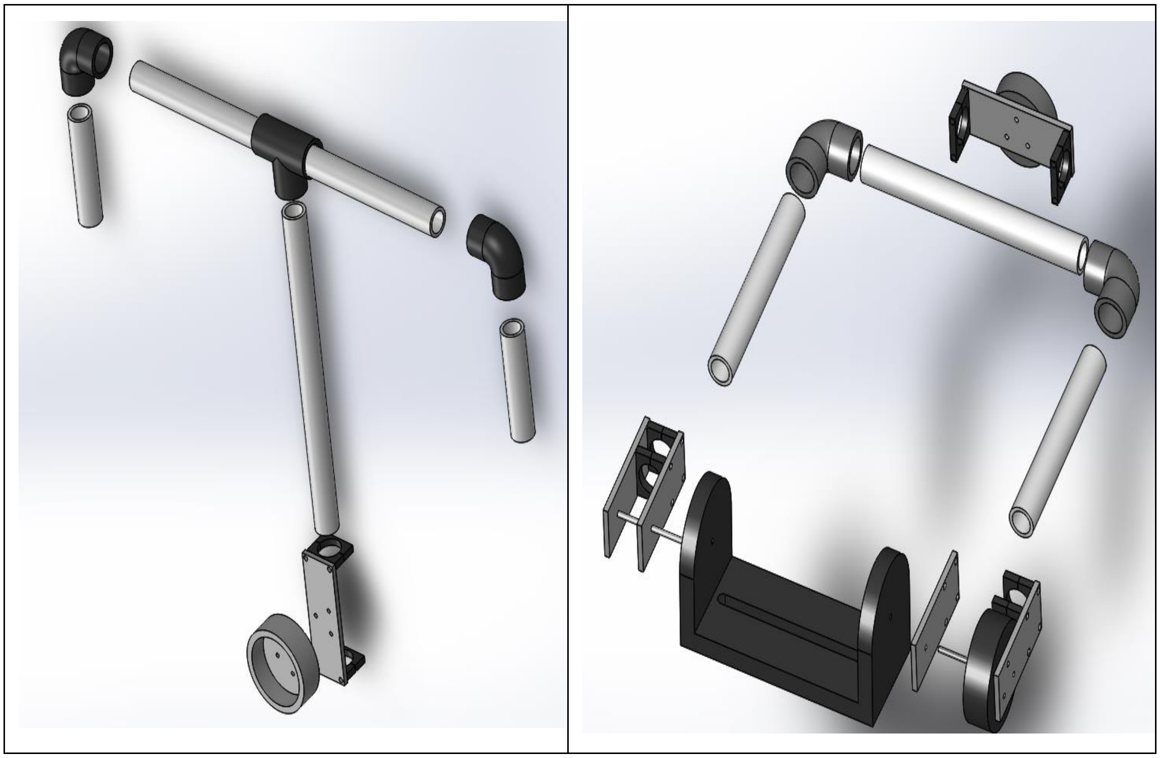


Figure 11: a) Upper Part

b) Lower Part

3.2 Manufacturing of the prototype and Final Design:

The prototype shown in figure 12 was manufactured in the Sheet Metal Bending and Machine Shop of Design and Manufacturing Resource Center (DMRC) of School of Mechanical and Manufacturing Engineering (SMME).

The PVC pipes were first cut according to engineering drawings using hex-saw, they were then connected using adhesive. Motor mountings were made up of 3mm aluminium sheet. Motors were bolted to the mountings. The mountings were then connected with the pipe assembly using U-steel clamps.

Camera platform was made from 3mm aluminium sheets. The platform was then bolted to motor on one side, whereas a shaft and bearing were used on the other side to provide pin joint and free rotation.

A single rectangular aluminium mounting was made for both controller and battery. This was connected to the upper part of the prototype using U-steel clamps.

Figure 12 Final Design

3.3 Motor Selection:

Agenda:

When the position of the camera placed on the Stabilizing Platform is disturbed, we need to provide a torque to the platform that will counter the disturbance. To achieve this task, we require two motors for the roll and pitch axis that will provide the counter torque and will keep the camera stabilized.

Motors to drive each subsystem need to be selected. For the selection of the motor the torque acting on each motor needed to be calculated. For calculating the torque, the forces acting on each motor.

Torque Calculations:

Motor 1

The Torque acting on Motor 1 is given by the following equation.

$$T_1 = w_c r_1 + w_{m2} r_2 \tag{1}$$

Motor 2

The torque acting on Motor 2 is given by the following equation.

$$T_2 = w_c r_3 \tag{2}$$

Wc = weight of camera

W_{m2}= weight of motor

r_1= distance between camera and roll axis

r_2= distance between motor-2 and roll axis

r_3= distance between camera and pitch axis

3.4 Control System Design:

Development of a stabilizing platform demands the Design and brain of the structure (controls system) to be made. Methodology of both the integral portions of the project is discussed as under:

Agenda: Our purpose is to stabilize the platform when disturbances in pitch and roll axis of the system are applied. Inertial measurement unit (IMU) sensor will measure the angle of disturbed platform in pitch and roll axis. The difference between reference angle and the measured disturbed angle is fed to the controller which calculates the respective voltage signal to be given to motors which provide counter torque to get the platform at reference angle. This process continues to happen in a closed loop until the difference between reference angle and measured disturbed angle is equal to zero.

The following block diagram explains the process.

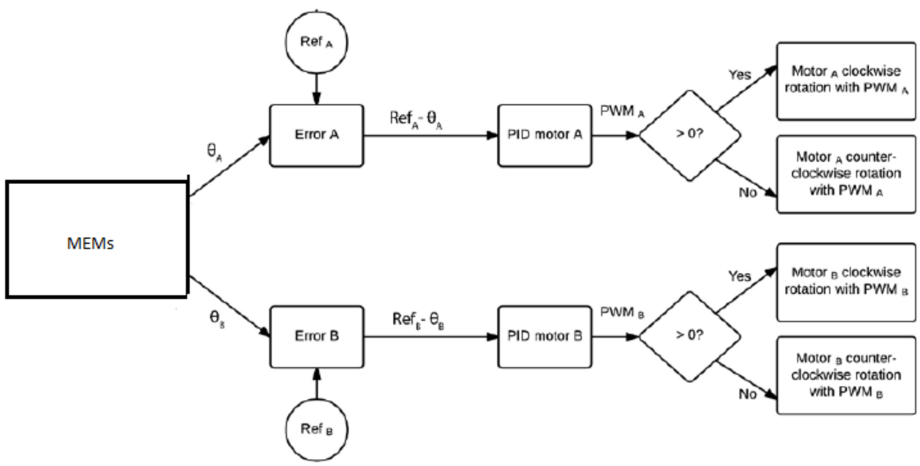


Figure 13: Block Diagram of Control System

3.4.1 Formulation of Transfer Function (For Plant/Motor):

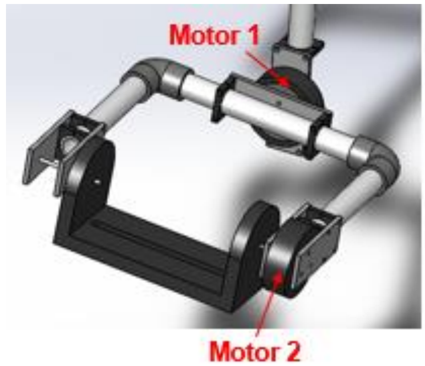


Figure 14: Platforms and Motors

For Motor 1:

The torque which motors need to produce in order to counter act the disturbance produced in roll axis is as follow:

$$\tau_1 = b\frac{d\theta}{dt} + J\frac{d\theta^2}{dt^2} - (w_{m2} \times r\cos\theta) \tag{3}$$

where

b = Dynamic friction coefficient

j = Moment of inertia in for Motor-1

W_{m2} = Weight of Motor-2

Taking Laplace transform of torque equation:

$$T_1 = b(s\theta_{(s)} + j(s^2\theta_{(s)}) - w_{m2}r(\frac{s^2}{s^2+\omega^2}) \tag{4}$$

Kirchhoff's Voltage law for the DC brushless motor:

$$L\frac{di}{dt}+Ri=V-k_e\frac{d\theta}{dt} \tag{5}$$

Substituting DC motor equation in torque equation of Motor-1 gives the following final form of transfer function for motot-1

$$\frac{\theta_1(s)}{V(s)}=\frac{K_M}{(bs+Js^2+(\frac{s^2}{s^2+\omega^2}\times m_2\times r))(Ls+R)+(k_e\times k_m\times s)} \tag{6}$$

Moment of inertia (J) for Motor-1:

Structure that is mounted on the shaft of motor-1 includes 3 pipes and a platform. The cross section of the platform is a rectangle and for the pipes it is hollow cylinder. Calculated moment of inertia of all 4 objects along the pitch axis using formulae mentioned below and then adding them up gave the ultimate value:

$$J(thin\ plate)=\frac{1}{12}ml^2$$

$$J(hollow\ cylindrical\ pipe)=\frac{1}{2}m(R^2+\mathrm{r}^2)$$

Hence:

J_1 = 0.015404 kgm^2 (calculated in Appendix A)

After plugging in all the values of constants, the transfer function comes out to be:

$$G_1(s)=\frac{0.0109s^2+10.75}{2.234\times10^{-6}s^5+0.02465s^4+0.003628s^3+24.34s^2+1.456s} \tag{7}$$

For Motor 2:

The torque which motors need to produce in order to counter act the disturbance produced in pitch axis is as follow:

$$\tau_2 = b\frac{d\theta}{dt} + J\frac{d^2\theta}{dt^2} \quad (8)$$

b = Dynamic friction coefficient

j = Moment of inertia in for Motor-2

Taking Laplace transform of torque equation:

$$T_2 = b(s\theta_{(s)}) + j(s^2\theta_{(s)}) \quad (9)$$

Kirchhoff's Voltage law for the DC brushless motor:

$$L\frac{di}{dt} + Ri = Vk_e\frac{d\theta}{dt} \quad (10)$$

Substituting voltage equation in torque equation in torque equation gives final form of a transfer function for motor-2

$$\frac{\theta_2(s)}{V(s)} = \frac{K_M}{(bs + Js^2)(Ls + R) + (K_e \times K_M \times s)} \quad (11)$$

Moment of inertia (J) for Motor-2:

Structure that is mounted on the shaft of motor-2 is the platform and its moment of inertia is calculated using formula:

$$J(thin\ plate) = \frac{1}{12}ml^2$$

J_2 = 2.7816 *10^{-3}kgm^2 (calculated in Appendix A)

After plugging in all the values of constants, the transfer function comes out to be:

$$G_2(s) = \frac{0.0109}{4.033 \times 10^{-7}s^3 + 0.004451s^2 + 0.001476s} \quad (12)$$

3.4.2 Simulink Model

After the transfer functions of the physical model were made the step in the process was to make a Simulink model of the system and check for system stability and calculate the PID Controller Parameters. The simulink model for the physical system is as follows.

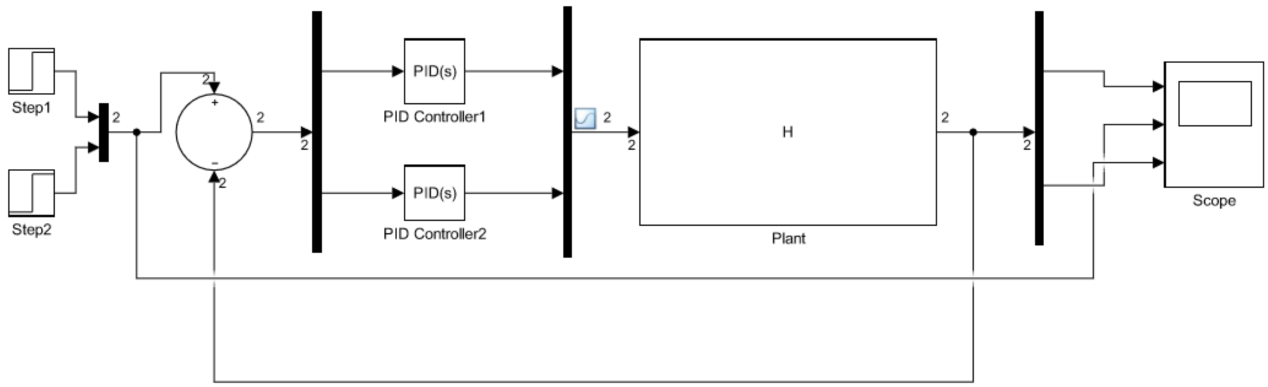


Figure 15: Simulink Model

The Linear Time Invariant Block in the model is of special importance here. In the LTI block the transfer function is defined as follows.

$$\begin{bmatrix} \text{Effect of input 1 on output 1} & \text{Effect of input 2 on output 1} \\ \text{Effect of input 1 on output 2} & \text{Effect of input 2 on output 2} \end{bmatrix}$$

The Simulink model was then used to compute the PID Parameters and then using these PID Parameters the response of both the subsystems was plotted. The computed PID Parameters and the response of the subsystems are discussed in the next session.

CHAPTER 4: RESULTS AND DISCUSSIONS

This chapter presents the outcomes of the project, the assessment of the outcomes and comparison against existing similar works.

4.1 Stress Analysis:

The stress strain analysis of the design was performed on Solidworks. The material selected in the analysis was PVC and the payload **2kg** i.e. the weight acting on the base plate is **19.6N**. Following results are obtained from the analysis.

The maximum stress on the platform came out to be around **17MPa**. Since the ultimate tensile strength of PVC is around **52MPa** so it gives a factor of safety around **3**. This shows that PVC is well suited for this application.

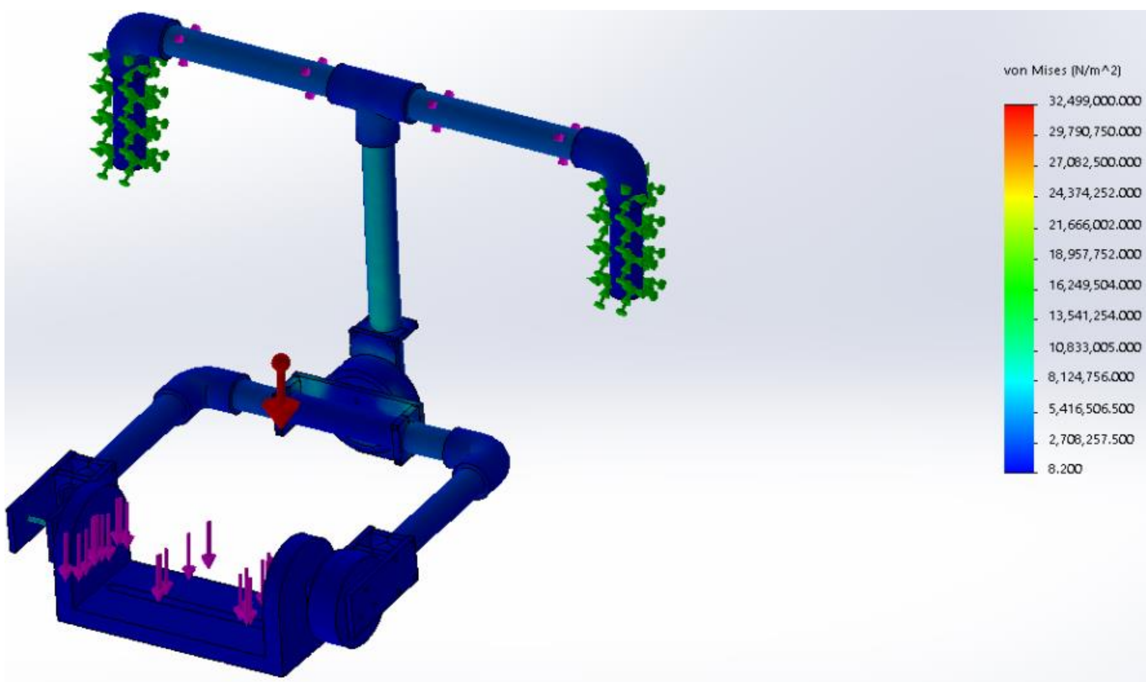


Figure 16: Stress Analysis

4.2 Motors

The torque calculated for each motor is as follows.

Table 2: Torques of Motors

	Motor 1	Motor 2
Torque (Nm)	0.7059	0.208

Based on the calculated torque and the type of application we opted for Brushless DC Motors. The motor selected is Turnigy HD 5206 Brushless Gimbal Motor.

Figure 17: Turnigy HD 5206 Brushless Gimbal Motor

Motor Comparison:

Two Type of Motors are used in Inertially stabilized platforms.

DC Servo Motors:

Advantage

The main advantage when it comes to DC Servo Motors is that their control scheme is relatively easy as compared to the DC Servo Motors. Arduino the most commonly used controller has a number of libraries easily available for the control of DC Servo Motors. So, choosing DC Servo Motors can reduce the effort in the controller design of the platform.

Disadvantage

The main disadvantage of the DC Servo Motor is that it has a particular resolution. It gives its output in the form of Steps. When the Motor gives its output in the form of steps, the platform also moves accordingly and glitches in the video quality are easily visible.[10]

DC Brushless Motors

Advantage

The main advantage of the DC Brushless Motors is that it gives a continuous output as a result when the platform receives continuous torque there are no visible glitches in the video recorded.[10]

Disadvantage

The disadvantage of the DC Brushless Motors is that its control is relatively difficult, and the controller needs to be carefully designed in order to get the correct output from the motors. The Arduino libraries for the DC Brushless Motors are also not readily available.

4.3 PID Parameters

The PID auto tuner module of MATLAB was used to calculate the PID Parameters for each subsystem. The auto tuner gave the following Gains for each system.

Table 3: PID Parameters for Motors

Parameters	Motor 1	Motor 2
Proportional	200	175
Integral	8	20
Derivative	65	35
Filter Coefficient	3043.1	6702.1

4.4 System Response

When a step input was given to the Simulink Model the following characteristics for each subsystem was obtained

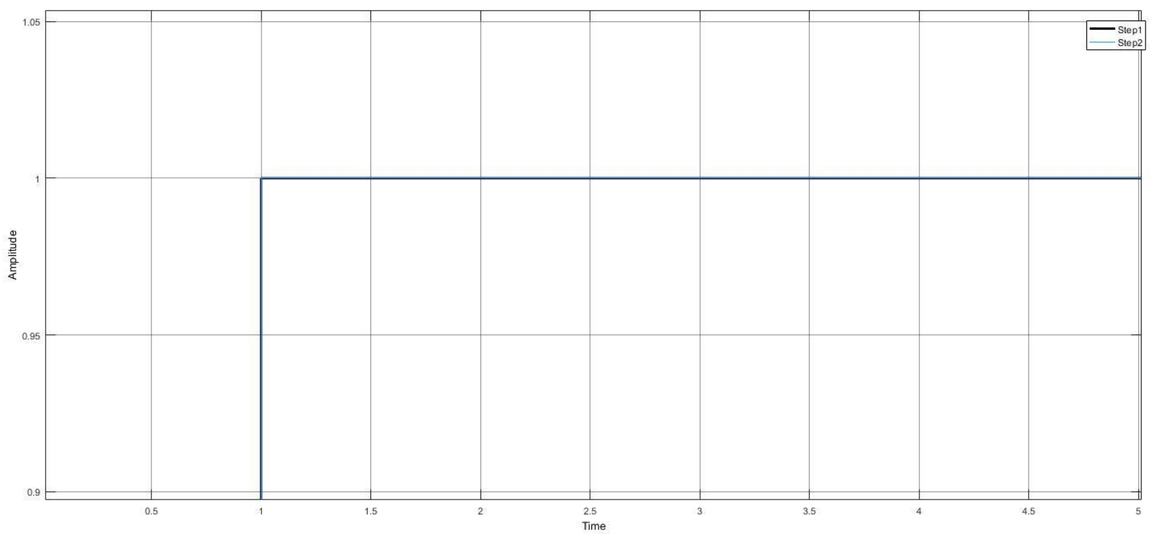
Table 4: System Response of Platform

Properties	Motor-1	Motor-2	Requirements
Rise Time (s)	1.2	1	<1
Overshoot (%)	7	4	<10
Settling Times(s)	2	1.6	<2
Steady State error	0.01	0	<1

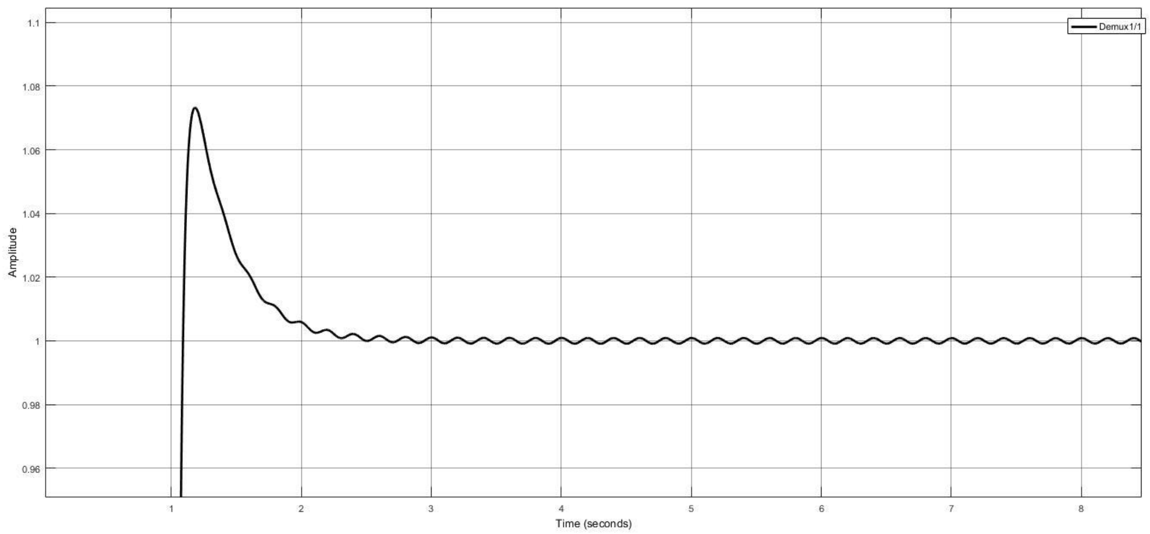
Response Graphs

The response graphs for each subsystem for a step input are as follows.

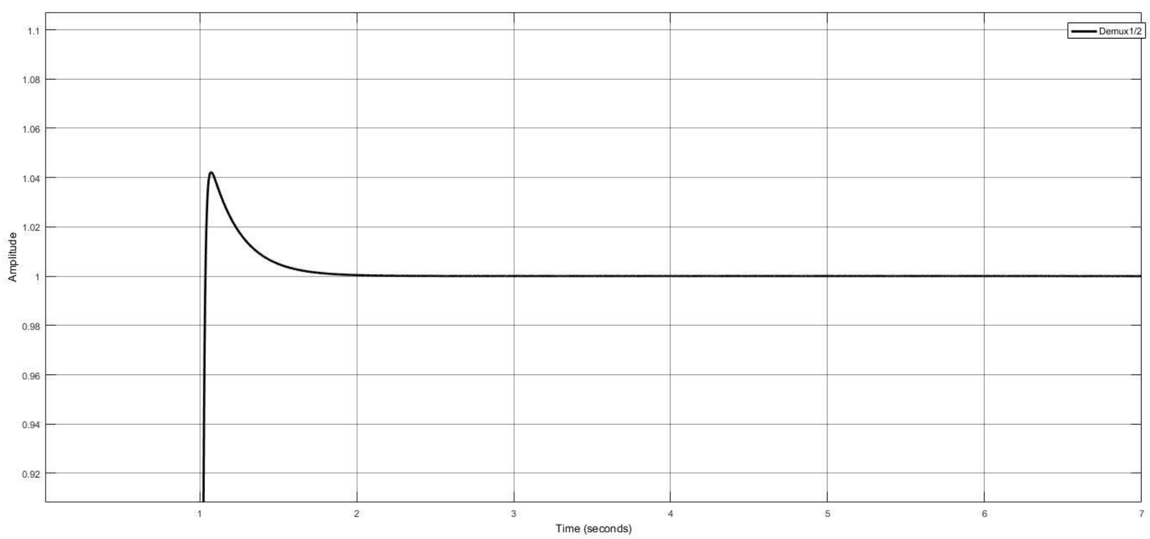
Input



Motor 1



Motor 2



Comparison with previous similar models

Electronic stabilizing platforms that are made on the similar principle but with very less pay load of 125g has following characteristics. Reference to this information is added in reference section.

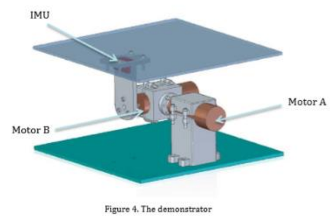


Figure 18: Self Stabilizing Platform **[4]**

Table 5: System Response of Reference System **[4]**

Properties	Motor-1	Motor-2
Rise time (s)	0.75	0.70
Overshoot (%)	0.8	0.9
Setting time (s)	1.35	1.3
Steady state error	0.57	0.57

Our project has relatively higher values of system properties because of much increased payload.

4.5 Controller Used

To run our product the controller used is 32-bit AlesMos DC Brushless Motor Controller that can take up the voltage of **8-25V** and a maximum current of **1.5 Amperes.** This controller is powered by a **4000mAH** battery connected to it.

4.5.1 Setting up Controller:

The controller when connected to motors and MPU-6050 sensor, calibration of both accelerometer and gyroscope in sensor is carried out and PID tuning of controller according to required rise time, steady state error and settling time is carried out.

4.6 Actual Results:

4.6.1 PID Parameters:

The actual PID parameters obtained after the experimentation for both motors are mentioned below.

Table 6: Actual PID Parameters for Motors

Parameters	**Motor 1**	**Motor 2**
Proportional	163	26
Integral	27	2
Derivative	176	30

The Difference in PID parameters generated by Simulink and obtained through DC Brushless Motor Controller is because of the following reasons.

- The weight of camera is taken as a point load in Simulink Model whereas the load is distributed over the platform.
- The “play” due to plastic pipes used is not catered in Simulink model.

4.6.2 Roll and Pitch Error:

The following errors were observed in the roll and pitch axis:

Roll Axis: $\pm 2^0$

Pitch Axis: $\pm 0.5^0$

<u>CHAPTER 5: CONCLUSION AND RECOMMENDATION</u>

This chapter provides a comprehensive conclusion of the project and recommendations. It also shows what can be farther done in this project.

5.1 Design:

From section 4.1 we see that our design and material gave **a safety factor of 3** which shows that both the material and design are well suited for the application.

Next step would be to apply this theoretical knowledge and verify the results by a physical model.

5.2 Control System

After implementing the control scheme in a Simulink Model, the results obtained were well within the target range we set for ourselves. Important system parameters such as rise time, % overshoot, settling time and steady state error all were within the target range. The results obtained from the simulation can easily lead to the conclusion that each subsystem in a closed loop control scheme is stable and the response of the system is up to the mark. The PID Parameters that the PID Auto tuner module in Simulink gives are very close to the actual gains of the PID Controller so now in the next step when the control scheme will be applied to a physical model the Gains of the controller can be further modified to get a better response for the system.

5.3 Recommendations

The following concerns were shown by the panel.

5.3.1 Computing Power of Controller

We were planning to implement the Control Scheme on the physical model with the help of an Arduino Circuit, the evaluation team raised concerns on the computing power of an Arduino. As an Arduino is an 8-bit computing chip and we had to implement two PID controllers with the help of a single chip so the computing power of the Arduino was not enough to sense signal and give output to two motors as the same time. As a result of this a lag will occur in the response of the motors and the video quality will get distorted.

Solution

To counter this problem, we have decided to use commercially available DC Brushless Controllers. Commercially available DC Brushless Controllers have a 32-bit computing chip as a result they can handle 2 subsystems simultaneously i.e. sensing the position change in both the axis and giving signal to both motors simultaneously.

5.3.2 Sensors

The position of the camera in the roll and pitch axis is going to be monitored by an accelerometer. The concern raised by panel was on the information that the accelerometer will feed our controller. Accelerometers don't give the exact change in position of the camera, they tell the controller in which direction the camera has been displayed and how fast it has been displayed from its equilibrium position. As a result, when the controller does not get the exact change in position of the camera the signal it will give the motors will also not be accurate as a result there is a chance that the camera will not be stabilized back to its equilibrium position. This problem will not only affect the performance of the product but will also make the controlling process more complex.

Solution

The solution purposed by the panel in regard to this problem was to use combination of accelerometer and gyroscope in the form of MEM chips. In MEM chips both the accelerometer and gyroscope are present. Gyroscope will tell the controller the change in angular position of the camera while the accelerometer will tell the controller how fast this change has occurred, with this information fed to controller, the signal sent by the controller to the motors will be more accurate. Hence the sensor used in our product is MPU-6050 which is a combination of both accelerometer and gyroscope.

Another solution proposed by the Panel was to use shaft encoders in addition to the accelerometer. Shaft encoders connected to the shaft of the motors will also tell us how much the camera is displaced in the roll and pitch axis. So, the combination of shaft encoders and accelerometer can also work and contribute to the performance of the product.

Out of the two solutions proposed by the panel we plan to go with MEM chips, as a single chip will make the system more compact as compared two shaft encoders.

5.4 Future Work:

In our current project we have limited our work to 2 axis, pitch and roll. For future work a 3rd axis (yaw axes) can be introduced. For that purpose, another motor has to be added along with changes in the design and additional work to be done in the control system area.

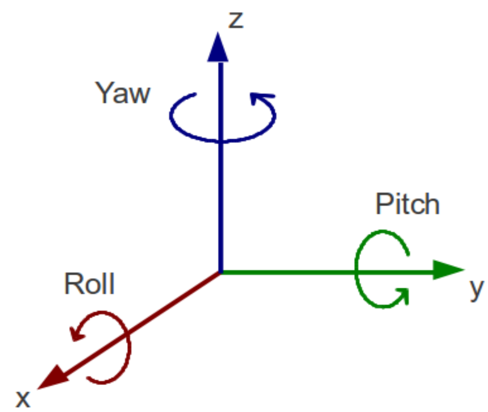


Figure 19: Roll, Pitch and Yaw axis

To further improve the quality of the final product, PVC can be replaced by carbon-fiber. This would increase the overall cost of the product but increase its built quality.

Another area of work can be the designing of the Brushless DC Controller. To keep the design compact, the controller and driver circuit should be present on a single board. This is an extensive area of work but can be done by having sound knowledge of control systems and electronics and the response time of the system can be made better by the introduction of DC motors with bigger powers.

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APPENDIX I: MOMENT OF INERTIA CALCULATIONS

Moment of inertia: the amount of resistance offered by a system towards rotational motion about a certain axis is called moment of inertia.

Moment of inertia for both the motors is different because of different mounting on each shaft.

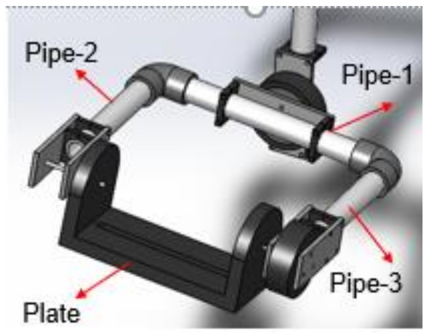

Figure 20: Labelled pipes

Moment of inertia for Motor-1

Methodology:

Moment of inertia for individual components mounted on shaft is calculated and then added to get the final value about each axis.

Moment of inertia of Pipe-1 about roll axis = $J_{p1} = \frac{1}{4}M(R^2 + r^2)$

Moment of inertia of Pipe-1 about roll axis = $J_{p2} = \frac{1}{2}M(R^2 + r^2) + Ma^2$

Moment of inertia of Pipe-1 about roll axis = $J_{p3} = \frac{1}{2}M(R^2 + r^2) + Ma^2$

Moment of inertia of Pipe-1 about roll axis = $J_{plate} = \frac{1}{12}m_pL^2$

Moment of inertia of Pipe-1 about roll axis = $J_{motor} = m_ma^2$

Net moment of inertia about roll axis :

$$J_1 = \frac{1}{4}M(R^2 + r^2) + \frac{1}{2}M(R^2 + r^2) + Ma^2 + \frac{1}{2}M(R^2 + r^2) + Ma^2 + \frac{1}{12}m_pL^2 + m_ma^2$$

$$\boldsymbol{J_1 = 0.015404\ kgm^2}$$

Moment of inertia for Motor-2

$$J_2 = \frac{1}{12} m_p w^2$$

$$\boldsymbol{J_2 = 2.7816 \text{ x } 10^{-3} \text{ kgm}^2}$$

Table 7: Model Dimension and Masses

Components	Lengths/width/ Radius (meters)	Mass (kg)
Pipe-1	0.254	0.0838
Pipe-2	0.1524	0.0503
Pipe-3	0.1524	0.0503
Plate length	0.17	0.55
Plate width	0.085	-
Pipe outer diameter	0.0127	-
Pipe inner Diameter	0.009525	-

Density of pipe = 1490 kgm^{-3}

Density of steel plate = 7650 kgm^{-3}