

# GYROSCOPIC STABILIZATION OF TWO-DIMENSIONAL GIMBALS PLATFORM USING FUZZY LOGIC CONTROL

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**Abstract-** This paper proposes an experimental analysis of the phenomena of stability of a two dimensional gimbals structure platform using MEMS (Micro Electro Mechanical System) based gyroscopic sensor. Gyro is placed on the gimbal structure platform to measure the angular tilt. The proposed method uses Fuzzy Logic Control technique to design the stabilizer. Two DC gear motors are used to control the azimuthal and pitch position of the structure. An H-bridge motor driving circuit is used to drive the dc geared motor. The random drift of MEMS Gyro data is eliminated by Kalman Filter.

**Keywords-** Fuzzy logic control, Gimbal structure, Kalman filter, H-bridge, MEMS Gyro.

## I. INTRODUCTION

The platform stabilization finds applications in i) the field of defense: the platform, where the gun module is mounted is required to be stable for the correct aiming at the target. ii) Industrial applications: the process variables like flow rate, temperature, level are measures using image processing for better accuracy. For this reason platform where the camera module is installed is required to be stable. iii) Satellite imaging system: Platform Stabilization is required in the satellite imaging and navigation system to take a blur free Image.

In the author describes Kinematic relationship between the different members of the gimbal structure and established the co-ordinate system relationship between the three axes of the gyro. This paper also derives the state equations of the Gimbal system. In the authors describe the block diagram of single frame mount stabilized platform and include kalman filter model to eliminate the drift error. In the authors describe single axis magnetic levitation system using fuzzy logic and includes the technology of interfacing MATLAB in real time. In the author describes the H-bridge technology and implement techniques to prevent shoot-through.

In this paper we design a 2-dimentional stable platform (pitch axis and azimuthal axis) using MEMS based gyroscopic sensor. The Platform is built by implementing the Concept of gimbals. Gimbals are essentially hinges that allow freedom of rotation about one axis. By incorporating bearing and motor we virtually achieve frictionless behavior of the platform. For measuring of the tilt angle error of the platform, we used MEMS based gyroscopic sensor. In comparison with the traditional mechanical, laser and fiber optics Gyro, MEMS gyro has some outstanding advantages including cheap, small volume, light, less

power dissipation, quick startup and shock resistance. Because of electronically induced noises, frictional forces and temperature gradient sampling, MEMS gyroscopic data includes random drift. To improve the signal of the MEMS gyro, kalman filter is implemented. Fuzzy logic based Open loop control is introduced into the system to achieve a better accuracy and improve the speed of response. The pitch and azimuthal axis of the platform is controlled by using two DC-gearred motor driven by H-bridge circuit. The H-bridge circuit drives the motor in both clockwise and anti-clockwise direction to nullify error angle.

## II. SYSTEM MODELING AND ANALYSIS

The structure of stabilization platform adopts two axis frame mount, internal frame axis (pitch) and external frame axis (azimuth).Both axes are orthogonal and can complete 360 degrees rotary movement in azimuth direction and 60 degrees rotary movement in vertical direction. The MEMS GYRO MPU6050 and the micro-controller is installed in the internal frame. The x-axis of the Gyro is parallel with the external frame axis, the y-axis is parallel with the internal frame axis and the Z-axis is parallel with the visual axis as in Fig.1.

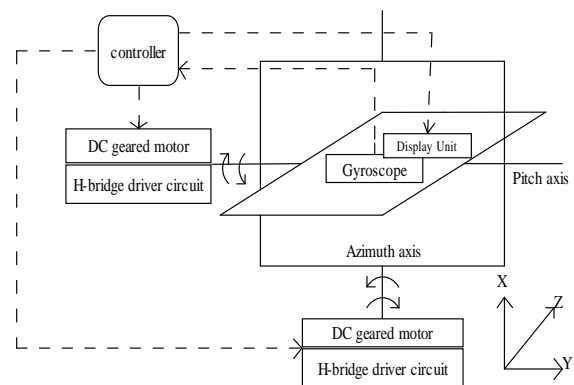


Figure 1. Diagram of structure of the stabilized platform

### III. MECHANICAL MODEL OF THE PLATFORM

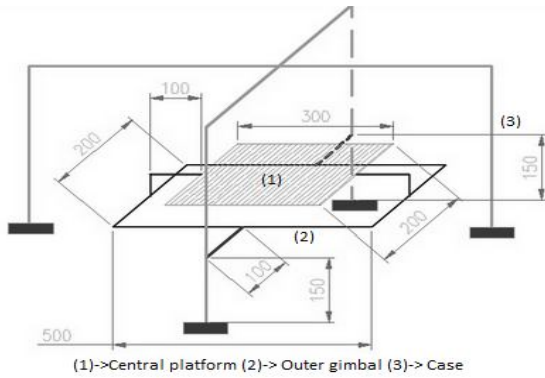


Figure 2. Diagram of structure of the stabilized platform

Mechanical structure of the platform are based on Gimbal structure property. Gyroscopic sensor MPU6050 provides measurements of gimbal angle. Two gimbals allow freedom of rotation while a central platform remains stationary with respect to inertial space System Dynamic Model.

### IV. SYSTEM DYNAMIC MODEL

#### A. Kinematic Relationship

Each member of the system is treated as a rigid body and the torque equation is developed:

$$\vec{M} = i \vec{H} \quad (1)$$

Where  $\vec{M}$  is the net torque on a given member of the system, and  $i \vec{H}$  is the inertial derivative of the body angular momentum.

The three-gimbaled inertial measurement unit (IMU) Supporting structure consists of the platform, inner gimbal, Outer gimbal, and the case. Each member is assumed to be rigid. The following definitions apply to the angles and rates relating the four members of the gimbaled system:  $\theta$  = relative angle between the inner gimbal and the platform, measured about the platform Y axis ( $Y_p$ ).  $\dot{\theta}$  = relative angular rate between the inner gimbal and the platform, measured about the platform Y axis ( $Y_p$ ).  $\phi$  = relative angle between the case and the outer gimbals, measured about the outer gimbal X axis ( $X_o$ ).

$\dot{\phi}$  = relative angular rate between the case and the outer gimbal, measured about the outer gimbal X axis ( $X_o$ ).

$\varphi$  = relative angle between the outer and inner gimbals, measured about the inner gimbal Z axis ( $Z_I$ )  
 $\dot{\varphi}$  = relative angular rate between the outer and inner gimbals, measured about the inner gimbal Z axis ( $Z_I$ ).

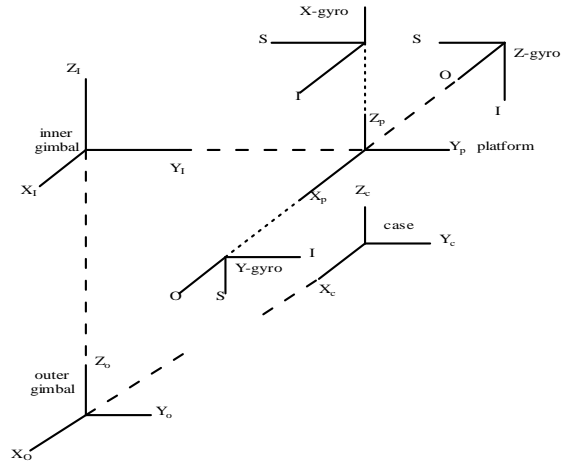


Figure 3. System Topology

#### B. Gimbal Co-Ordinate System

An orthogonal coordinate system is defined rotating with each member of the gimbaled system platform ( $X_p, Y_p, Z_p$ ) inner gimbal ( $X_I, Y_I, Z_I$ ) outer gimbal ( $X_o, Y_o, Z_o$ ), and case ( $X_c, Y_c, Z_c$ ).

$$[B_{PI}] = \begin{bmatrix} \cos \theta & 0 & -\sin \theta \\ 0 & 1 & 0 \\ \sin \theta & 0 & \cos \theta \end{bmatrix} \quad (2)$$

$$[B_{IO}] = \begin{bmatrix} \cos \varphi & \sin \varphi & 0 \\ -\sin \varphi & \cos \varphi & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (3)$$

$$[B_{OC}] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \phi & \sin \phi \\ 0 & -\sin \phi & \cos \phi \end{bmatrix} \quad (4)$$

The transformation from the coordinate system is formed by:

$$B_{PC} = [B_{PI}] [B_{IO}] [B_{OC}] \quad (5)$$

$$[B_{PC}] = \begin{bmatrix} \cos \theta \cos \varphi & \sin \varphi & -\sin \theta \cos \varphi \\ \sin \theta \sin \varphi - \cos \theta \cos \phi \sin \varphi & \cos \varphi \cos \phi & \sin \theta \sin \varphi \cos \phi + \sin \theta \sin \phi \\ \cos \theta \sin \varphi \sin \phi + \sin \theta \cos \phi & -\cos \varphi \sin \phi & \cos \theta \cos \phi - \sin \theta \sin \varphi \sin \phi \end{bmatrix} \quad (6)$$

#### C. GYRO Co-Ordinate System

The direction cosine transformations from the platform to the X, Y, and Z gyro floats are  $[B_{pgx}] [B_{pgy}] [B_{pgz}]$  where

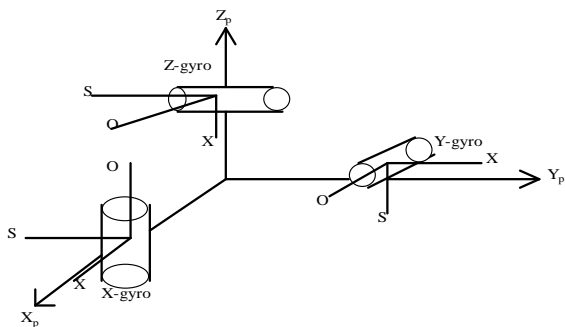


Figure 4. Orientation of gyro and platform axes.

$$[B_{pgx}] = \begin{bmatrix} \sin \alpha_x & -\cos \alpha_x & 0 \\ \cos \alpha_x & \sin \alpha_x & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (7)$$

$$[B_{pgy}] = \begin{bmatrix} 0 & \sin \alpha_y & -\cos \alpha_y \\ 0 & \cos \alpha_y & \sin \alpha_y \\ 1 & 0 & 0 \end{bmatrix} \quad (8)$$

$$[B_{pgz}] = \begin{bmatrix} 0 & -\cos \alpha_z & -\sin \alpha_z \\ 0 & \sin \alpha_z & -\cos \alpha_z \\ 1 & 0 & 0 \end{bmatrix} \quad (9)$$

**V. KALMAN FILTER FOR MEMS GYRO**

Gyro is the most important inertial sensor of the stabilization platform and affects the precision of the whole system. Because of electronics circuit noise, friction and temperature gradient MEMS gyro[2][5]-[6], output signal usually includes random drift. It is necessary to design a filter to improve the signal of the MEMS Gyro.

**C. Random drift model and kalman filter:**

MEMS gyro random drift model is a zero input system, and the system equation is:

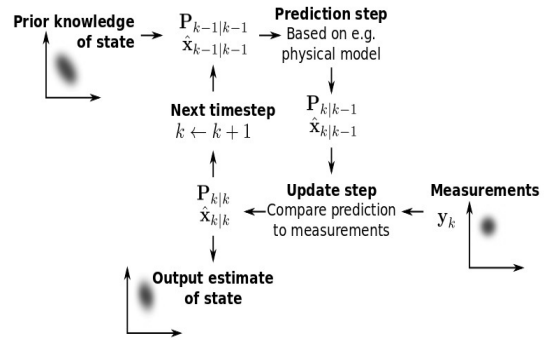
$$\begin{cases} X_K = \Phi_K X_{K-1} + G_K W_K \\ Y_K = H_K X_K + V_K \end{cases} \quad (10)$$

Where  $\Phi_K$  is the state transition matrix,  $G_K$  is the matrix of Process noise,  $H_K$  is the observation matrix,  $X_K$  is the system state variable,  $Y_K$  is the observed variable. The  $W(k)$  and  $V(k)$  are mutually independent random variables.

Filter is used to make an optimal estimation of the state Variable according the observed value. Kalman filter is a kind of linear filter based on minimum variance estimate. The discrete equations of Kalman filter are:

$$\begin{cases} \hat{X}_{K+1|K} = \Phi_k \hat{X}_{K|K} \\ e_k = Y_K - H_K \hat{X}_{K|K-1} \\ \hat{X}_{K|K} = \hat{X}_{K|K-1} + K_K e_K \\ P_{K+1|K} = \Phi_K P_{K|K} \Phi_K^T + G_K \hat{Q}_K G_K^T \\ P_{K|K} = P_{K-1|K} K_K H_K P_{K|K-1} \\ K_K = P_{K|K-1} H_K^T [H_K P_{K-1|K} H_K^T + \hat{R}_K]^{-1} \end{cases} \quad (11)$$

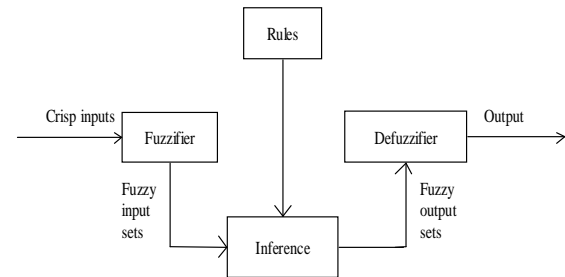
The algorithm used for estimation [10] is shown below



**VI. FUZZY LOGIC CONTROL**

Fuzzy logic is a computing method, comparing to the traditional Boolean sets where variables take only two value true or false. Fuzzy logic have two limits, completely true limit take '1' value, and completely false limit take '0' value.

There are a lot of models of FLC, but the most famous ones are the Mamdani model, Takagi-Sugeno-Kang (TSK) model and Kosko's additive model (SAM). This paper uses Mamdani's model as given in Fig.5. The operational features of the FLC is explained in following:



**Figure 5. Mamdani Model**

**Fuzzification:** Fuzzification means converting a crisp value of process variable into a fuzzy set In Fuzzy set, numbers are converted into letters.

**Rule Base:** It consists of the IF-THEN rules, many approaches taken in determining the relation of the fuzzy rule:

- Mamdani  $\mu_R(x, y) = \min[\mu_A(x), \mu_B(y)]$ .
- Zadeh  $\mu_R(x, y) = \max\{\min[\mu_A(x), \mu_B(y)], 1 - \mu_A(x)\}$ .
- Larsen  $\mu_R(x, y) = \mu_A(x) \cdot \mu_B(y)$ .
- Lukasiewicz  $\mu_R(x, y) = \min\{1, [1 - \mu_A(x) + \mu_B(y)]\}$

**Defuzzification:** Defuzzification operation is the reverse of the fuzzification operation which means the conversion of the fuzzy output values into crisp values [10]. There are many type of defuzzification:

- Mean of Maximum method (MoM)
- Center of Area (CoA)
- Center of Maximum (CoM)

### VII. FUZZY LOGIC CONTROLLER DESIGN

Fuzzy logic controller is applied to the Two-axes Gimbal Structure platform to stabilized it. The best choice to get robust, flexible, faster and real-time speed control was to use Mamdani model for fuzzy controller. In that one input error range from [0-255] and two output change of Duty Cycle of the PWM pulse range from [0-100], basically one output is the inverted version of the second. Five membership (triangular, Z membership) functions were used for fuzzification step with selected range [-1, 1] for the inputs and output. The Fig.6 shows the input membership function of the fuzzy controller and Fig.7(a) and 7(b) shows the membership function of output1 and output2 using GUI fuzzy toolbox of MATLAB software.

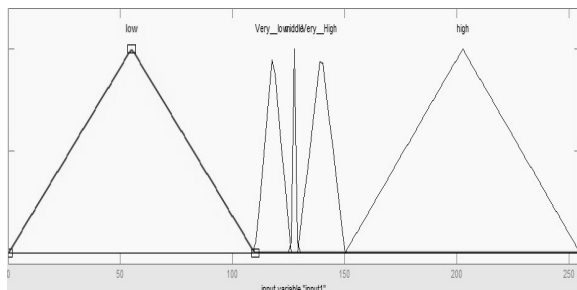


Figure 6.Fuzzy logic Input Membership Function

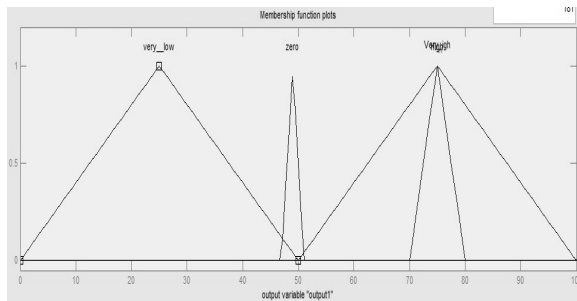


Figure 7(a).Fuzzy logic Output1 Membership Function

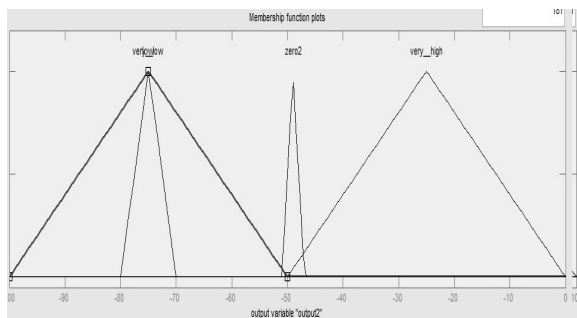


Figure 7(b).Fuzzy logic Output2 Membership Function

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1. If (input1 is middle) then (output1 is zero/output2 is zero2) (1)
2. If (input1 is low) then (output1 is very_low/output2 is low) (1)
3. If (input1 is Very_low) then (output1 is very_low/output2 is very_low) (1)
4. If (input1 is Very_High) then (output1 is Very_High/output2 is very_high) (1)
5. If (input1 is high) then (output1 is High/output2 is very_high) (1)
    
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Figure 8.Rule Base of the Fuzzy logic controller.

### VIII. H-BRIDGE TROPOLOGY AND SIMULATION

H-Bridge is an electronic power circuit that allows motor speed and direction to be controlled. The micro controller provides the instructions to the motors, but it cannot provide the power required to drive the motors. An H-bridge circuit inputs the micro controller instructions and amplifies them to drive a mechanical motor. The H-bridge takes in the small electrical signal and translates it into high power output for the mechanical motor.

The H-Bridge electronic structure as shown in Figure 8 and 9, where the Power MOSFETs are used for switching. If it is desired to turn the motor on in the forward direction, switches 1 and 4 must be closed to power the motor. Figure 8 below is the H-Bridge [9] driving the motor in the forward direction.

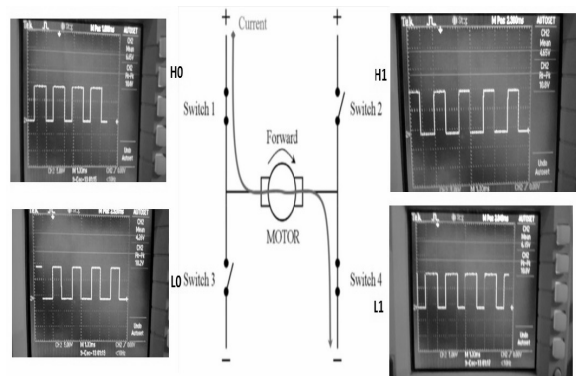


Figure 8.H bridge motor driver in forward direction

If it is desired to turn the motor on in the reverse direction, switches 2 and 3 must be closed to power the motor. Figure 9 below is the H-Bridge driving the motor in the reverse direction.

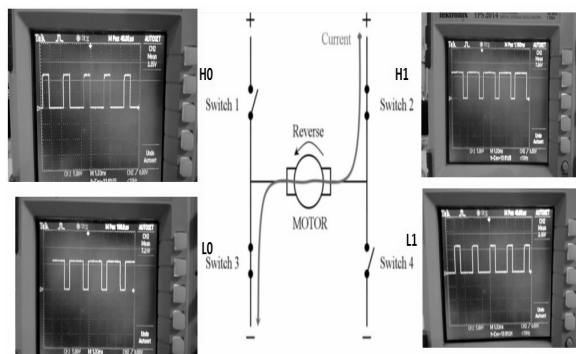
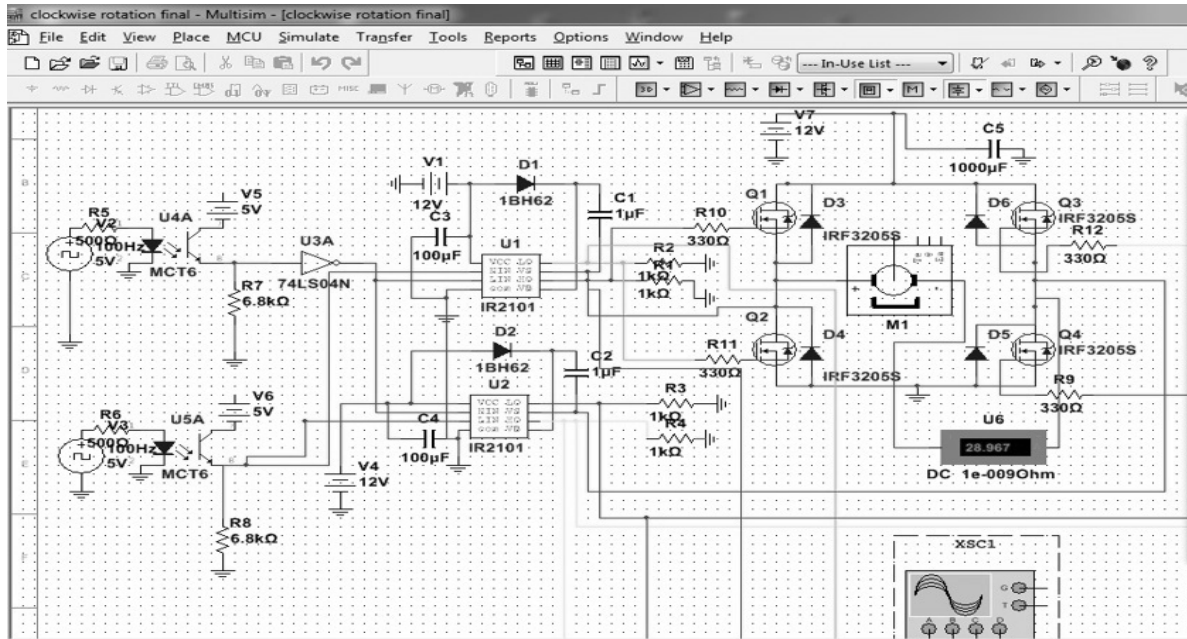


Figure 9. H bridge motor driver in Reverse direction

In order to implement direction control using H-bridge we have used PWM techniques where the duty Circle is varied according to the error angle and the frequency remain fixed.

Simulation of the H-bridge Motor driver circuit is carried out using MULTISIM.



If the top switch 1 and bottom switch 3 are on at the same time, even for a small amount of time the battery will be shorted out and the H-Bridge will literally blow up. This is called Shoot Through. To prevent the condition that causes shoot-through, a dead time is introduced into the system.

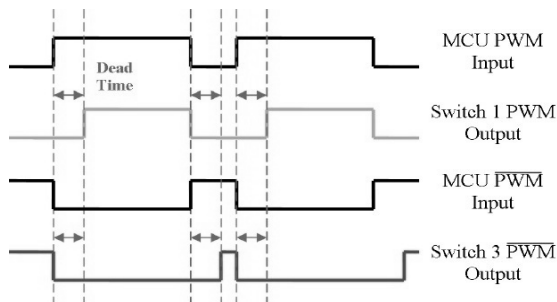


Figure 10.Shoot-through protection

**IX. FABRICATION OF THE SYSTEM**

**A. Fabrication of the two axes gimbal structure platform**

The AUTOCAD design of gimbal structure shown in fig.2 Is implemented as follows:

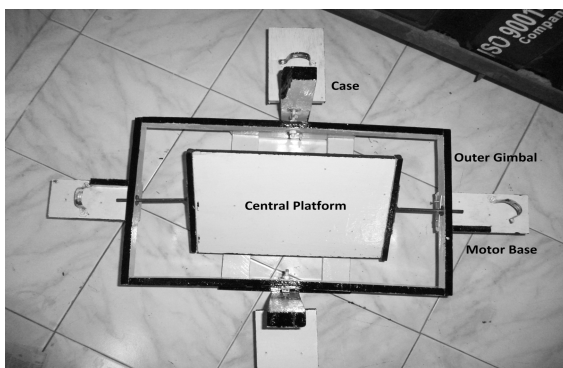


Figure 11.Diagram of two axes gimbal structure platform

**B. Fabrication of the complete Set-up**

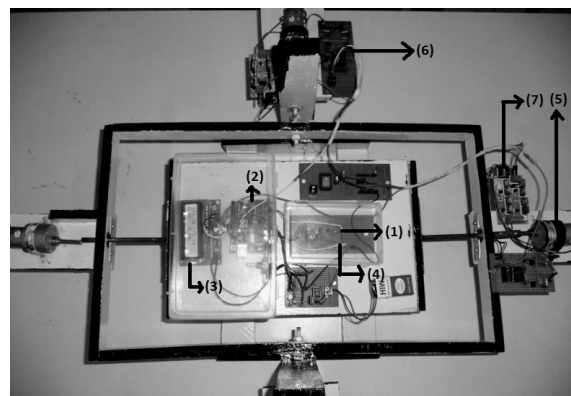


Figure 12.Experimental set-up

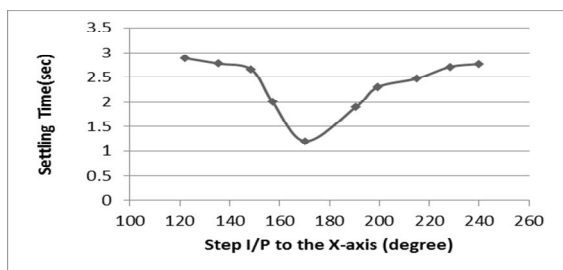
In the Fig12. We have implemented two axes gimbal structure stabilized platform. Motor (5) shafts are connected through ball-bearing with gimbals to rotate the gimbals freely. The reference plane for both the axes are selected as 180 degree. Whenever a tilt is introduced manually into the system gyroscope (1) measures the corresponding angular position of X and Y axis. This gyro data is fed into the micro-controller ATMEGA328 (2) through a level shifter circuit (4). The level shifter is used to implement compatibility between Gyroscope (operating voltage 3.3V) and Micro-controller (operating voltage 5V).

The microcontroller calculate the error angle by comparing the gyro data with the reference position(180'). Depending on the error angle it generates PWM signal with appropriate duty cycle and fed it to the H-bridge motor driver circuit(7). If the duty cycle is greater than 50% the motor will rotate in clock-wise direction or else it will rotate in anti-clockwise direction until the reduced to zero.

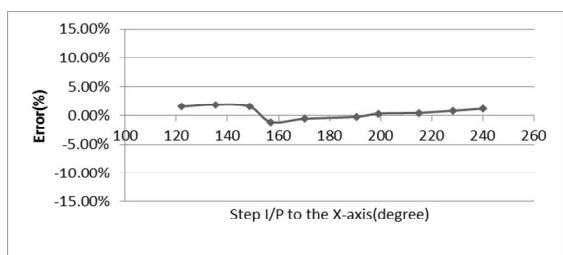
**X. RESULTS AND ANALYSIS**

**Table1: Experimental analysis**

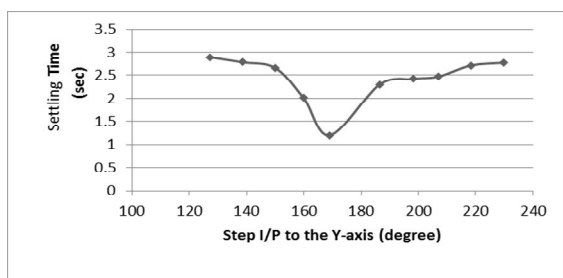
X axis Without pt tilt (degree)	Y axis Without pt tilt (degree)	X axis With pt tilt (Degree)	Y axis With pt tilt (degree)	Error X axis	Error Y axis	Settling time (Sec)	Error % after corrected action X axis	Error % after corrected action Y axis
177.26	175.46	-	-	2.73	4.45	0.9	-1.52%	-2.52%
179.10	177.90	170.30	169.10	9.70	10.90	1.2	-0.50%	-1.17%
178.10	179.20	157.10	159.90	22.90	20.10	2.01	-1.06%	-0.44%
180.68	176.32	199.20	186.58	-19.20	-6.58	2.3	0.38%	-2.04%
179.70	178.01	190.50	198.18	-10.50	-18.18	2.42	-0.17%	-1.11%
180.91	178.43	214.95	206.92	-34.95	-26.92	2.47	0.50%	-0.87%
181.55	178.79	228.22	218.31	-48.22	-38.31	2.71	0.86%	-0.67%
182.20	179.14	239.98	229.70	-59.98	-49.70	2.77	1.22%	-0.48%
182.84	179.49	122.06	127.18	57.94	52.82	2.89	1.58%	-0.28%
183.49	179.84	135.33	138.57	44.67	41.43	2.78	1.94%	-0.09%
182.87	180.19	148.60	149.96	31.40	30.04	2.66	1.59%	0.11%



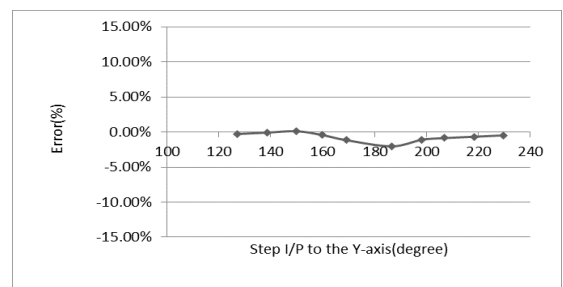
**Figure 13. Step Input to X-axis Vs Settling time**



**Figure 14. Step Input to X-axis Vs Percentage Error**



**Figure 15. Step Input to Y-axis Vs Settling time**



**Figure 16. Step Input to Y-axis Vs Percentage Error**

**CONCLUSION**

Design and development of algorithm for interfacing the microcontroller ATMEGA328 with MEMS based gyroscope MPU6050 has been done and validated. Microcontroller receives the raw data, analyses it processes and displays it on a LCD display. This sensor is placed on the gimbal structure platform to sense the disturbance caused by the tilted movement. The MPU6050 considers horizontal axis as absolute reference.

In this paper the platform (due to physical mounting limitations) can be tilted only from 120 to 240 degree keeping 180 degree as absolute reference. However, in practice complete angle range can be incorporated.

Design of a DC geared motor drive circuit using H-bridge driver IC and PWM signal has been implemented and validated. Here, the gyro itself is used as feedback.

Gyroscope sensor has been used to measure this tilt angle and in order to turn the shaft of motor clockwise or anticlockwise tilt (for cancellation of the unwanted angle) the microcontroller generates PWM signals to feed the motor and thus nullify the error caused by the platform tilt so that the gimbal platform remains stable.

In this paper two axes platform stabilization is achieved. The work can be extended to cover the third axis as well. The motor response time can also be improved by taking high rpm motors.

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