

# A laboratory method for obtaining two degrees of freedom gyro-scopic stabilizer transfer function

Mohammad Sadegh Mirzajani Darestani<sup>1\*</sup>, Seyed Zeynolabedin Moussavi<sup>2</sup>, Parviz Amiri<sup>2</sup>

<sup>1</sup> Department of Electrical & Electronics Engineering, Faculty of Engineering, Islamic Azad University, Parand, Iran

<sup>2</sup> Department of Electrical & Electronics Engineering, Faculty of Engineering, Shahid Rajaei Teacher Training University, Tehran, Iran

\*Corresponding author E-mail: [mohammadsadegh.mirzajani@yahoo.com](mailto:mohammadsadegh.mirzajani@yahoo.com)

## Abstract

Obtaining transfer function of electrical, mechanical, etc. systems can provide this possibility for the researchers to investigate the behaviours of desired systems based on different inputs in various working circumstances without need to laboratory equipment which it results in lower consumption of time and expense. The aim of current research is obtaining the existing gyroscopic stabilizer transfer function. The way we used in this article is the newest laboratory way for obtaining transfer function of gyroscopic stabilizers. This aim is achieved by using laboratory equipment such as a two degrees of freedom gyro stabilized platform that an imaging system is installed on it as the load, target simulator table with one degree of freedom, and electronic conversion board of RS488 to RS232 serial communication standard, etc. An input which excites all modes (search and track) of two degrees of freedom gyro stabilized platform is introduced to under test system and the system behaviour toward the introduced input is saved and finally the transfer function of existing two degrees of freedom gyro stabilized platform is obtained using system identification toolbox in MATLAB. At the end of this article, the step response of transfer function obtained through the desired experiment in the laboratory compared with the step response obtained through simulations that a %10 difference between them is observed.

**Keywords:** Degree of Freedom; Gyro Stabilized Platform; Gyroscope; Transfer Function.

## 1. Introduction

There are different trade and industrial systems in use today where two degrees of freedom platforms are utilized for imaging. Such systems must be so stabilized during identifying and tracking as well as imaging the target that image resolution is not lost as a result of constant vibration and shaking. Two degrees of freedom gyro stabilized platforms are usually mounted on the nose of a guided device and can search the space within their field of view (FOV) to find the target and imaging it while maintaining their stability. Like all other control systems, the desired output, i.e., the platform angle is compared with the reference input, i.e., the imaging system line of sight (LOS) angle, and, subsequently, a compensator is issued the proper torque command based on the error signal from the error signal. The criteria for the final performance of the gyroscopic stabilizer which carries the imaging system are quality and resolution of the image generated by the optical sensor in spite of target and carrier motion. Instability reduction is generally considered as a suitable criterion for determining the proper performance of the stabilizer. [1] is about designing controller for an electromechanical actuator with time delay. In this article the captured data, related to several test sets at different conditions for system identification, were used for model estimation and validation purposes. In [2], authors address three main topics; experimental identification, uncertainty modeling, and robust control design for a real EMA harmonic drive system. In this article, the linear model of the harmonic drive system is identified based on the test data. The captured data, related to several test sets at different conditions, were used for model estimation and validation purposes. In [3], a comparative study of adaptive vibration control

approaches is presented for the system identification for micro-electro-mechanical systems (MEMS) z-axis gyroscope. In [4] and [5], the structure and operation of inertial stabilized platforms were studied. In these articles, the equations of motion related to these platforms were also fully discussed. Researchers in [6] specifically studied the direct and indirect stabilization of imaging system in two axis platforms and the performance of these two methods were also discussed and compared to each other.

The transfer function of a system, the ratio of output to input of the system, can be obtained through different theoretical methods as well as practical experiments.

As mentioned above, this research is based on a two degrees of freedom gyro stabilized platform. Therefore, knowledge of the transfer function of this system would help us evaluate the performance and behaviour of this platform under different ambient and working conditions.

One common approach for obtaining the transfer function of a system is injecting a signal to the system input and storing the corresponding output, thus obtaining the transfer function (the ratio of output to input). In the present study, we obtain the transfer function of a two degrees of freedom gyro stabilized platform through conducting practical tests. We assume that the platform is only a "black box" about the technical and functional components of which we have no information. Through giving a specific input to the system, we obtain the corresponding output and then use the system identification toolbox in MATLAB to determine the transfer function of the platform and determine some of its functional characteristics.

Next sections of this article are as follow: In section 2, we will get familiar with structure and working procedure of two degrees of freedom gyro stabilized platform. Section 3 was assigned to the

explanation of proposed method in this article. Section 4 discusses the comparison of step responses obtained in laboratory and MATLAB/SIMULINK. Section 5 is the conclusion part of the article.

## 2. Structure and functioning of gyroscopic stabilized two degrees of freedom platform

Figure 1 shows a view of a two degrees of freedom gyro stabilized platform.



Fig. 1: A Sample Two Degrees of Freedom Gyro Stabilized Platform.

A very common application of two degrees of freedom gyro stabilized systems is the line of sight stabilization of a camera or imag-

ing system. A line of sight stabilization system is a system which maintains the stability of the line of sight of an electro-optical sensor under external disturbance (movement of the supporting base, etc.). Under such conditions, when a vehicle rotates about its axes, its line of sight must remain constant relative to the inertial reference frame so that image resolution can be preserved in spite of successive vibration and shaking of the base [7].

The studied system is a two degrees of freedom gyro stabilized platform which an infrared imaging system is placed on it and can rotate at an arbitrary angular velocity in both clock wise and counter clock wise directions, and can be stopped at any specified arbitrary angle. This platform is expected to rotate the camera at constant angular velocity on either side of its movable axes. To this end, it is necessary to deploy a precise speed sensor inside a speed control loop with an appropriate PID controller.

The block diagram in Figure 2 shows the elements of the two degrees of freedom gyro stabilized platform along both its axes. As shown in this block diagram, the torque motor and the potentiometer are positioned on either side of the gimbal and lie along either axis. Motion of the frames is generated via two high torque direct current (DC) motors. Two potentiometers are used to read the imaging system position relative to the fixed platform. These are connected via gears to the pitch and yaw axes. The potentiometer resistance changes based on the positions of the gears and the movement of each axis. Each axis position can be determined by reading the output voltage of the potentiometer. A rate gyroscope inside the gimbal senses the angular velocities about axes parallel with its own in the horizontal and vertical directions.

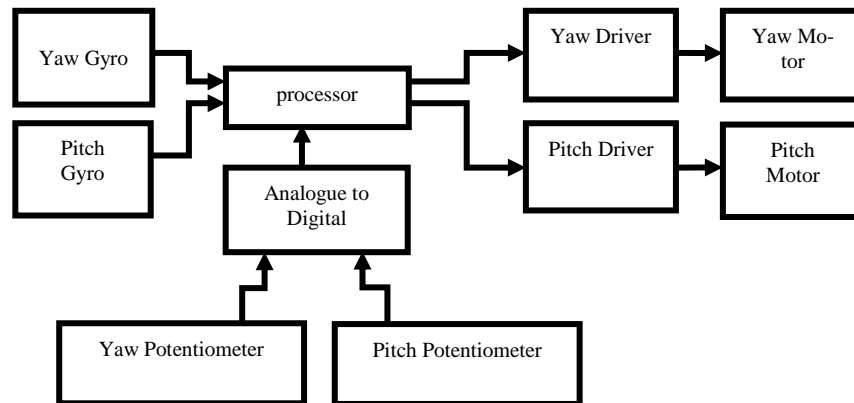


Fig. 2: Block Diagram Showing the Components and Internal Relations of the Two Degrees of Freedom Gyro Stabilized Platform.

This type of platforms generally includes a body and a gimbal consisting of two nested frames providing separate movements for the camera along horizontal and vertical directions. These movements can be independently controlled. Thus, displacement along one axis has no effect on the other axis. The outer and the inner frames provide motion along horizontal and vertical axes respectively. Two control loops exist in two degrees of freedom gyro stabilized platform include stabilization and tracking loop. Figure 3 shows the general method of controlling the system along yaw and pitch axis and the operation of two controlling loops. Angular velocity of imaging system in each axis is measured by a gyroscope according to the body of platform and the position of imaging system is measured by a potentiometers. The output of these sensors (gyroscope and potentiometer) is feedback into the input and then processor convert them into command signals for the motor actuating the respective axis. Command signals are applied to this motor through amplifiers particularly designed for this purpose. Direct Drive motor which is placed in yaw and pitch axis move the imaging system base on the received command from processor.

The high precision used for the related movements and the control system require that force transmission and measurement system

also act precisely [8]. Thus, a directly coupled power transfer system can be implemented.

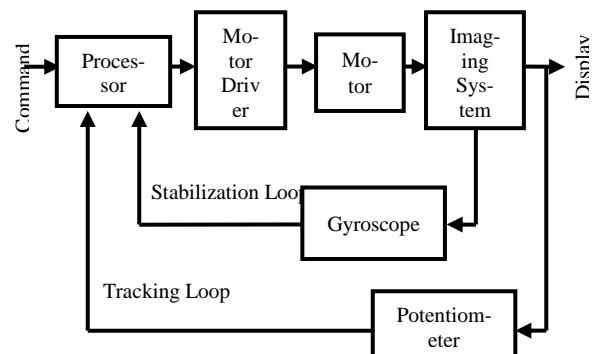


Fig. 3: Block Diagram for Controlling the Platform Through Computer or Any other Peripheral Device Equipped with the Proper Digital Interface.

Figure 4 shows the angles defined for describing the relative angular positions of the imaging target, the two degrees of freedom gyro stabilized platform, and the planar motion of the carrier axis of the two degrees of freedom gyro stabilized platform.

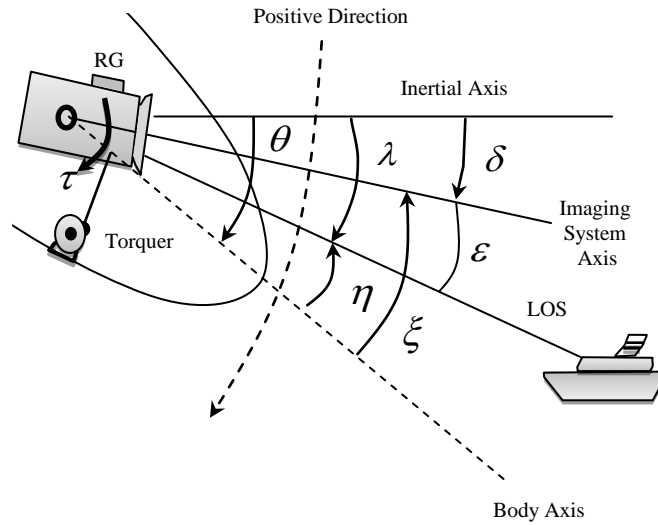


Fig. 4: Target Tracking Two Dimensional Geometry.

The angles shown in Figure 4 are:

- $\theta$ : Angle between the inertial axis and carrier body axis
- $\lambda$ : Angle between the inertial and axis imaging system line of sight
- $\eta$ : angle between the carrier body axis and imaging system line of sight
- $\epsilon$ : Angle between the imaging system line of sight and imaging system axis
- $\delta$ : Angle between the inertial axis and imaging system axis
- $\xi$ : Angle between the carrier body and imaging system axis
- LOS: Imaging system line of sight

Thus, two control loops acting in opposite directions are created for searching and tracking the target. The purpose of the tracking loop is to move the two degrees of freedom gyro stabilized platform and the purpose of the stabilizing loop is to fix the line of sight relative to the inertial frame [9]. Since the frequency domains for tracking and noise reduction are different, these two loops shall not interfere with each other's operation. Figure 5

shows the control loops for the two degrees of freedom gyro stabilized platform.

As shown in Figure 5, the potentiometer used in the platform measures the angle between the imaging system axis used in the stabilized platform and the platform body ( $\delta$ ) and feeds it as input to the system. Mechanical noise ( $\theta$ ) due to carrier movement is also included in the imaging system angle. The angle measured by the potentiometer ( $\zeta_M$ ) is compared at the input of tracking loop with a reference input ( $\zeta_{CM}$ ). The difference between these angles ( $e$ ) is entered into the compensator in the tracking loop. This compensator sends to the stabilizing loop an angular velocity command ( $\omega_{CM}$ ) for compensating the detected difference. Once this angular velocity command has been entered into the stabilizing loop, the torque motors guide the imaging system at the maximum allowable angular velocity ( $\dot{\delta}$ ) towards the desired angular position [10].

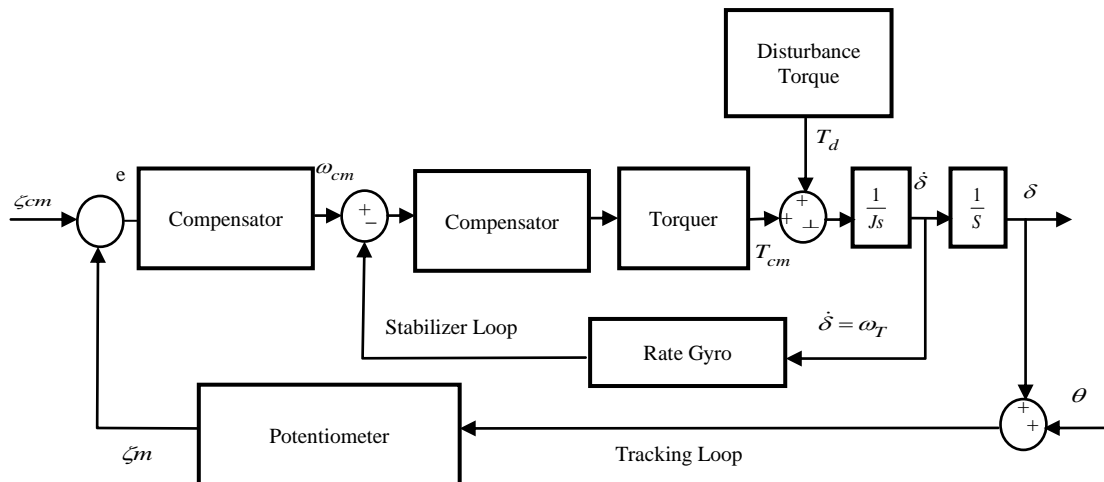


Fig. 5: Block Diagram for Control Loops of the Two Degrees of Freedom Gyro Stabilized Platform [10].

The gyroscopic stabilizer used in this study has two working modes, namely, search mode and track mode. The track mode is used to obtain the platform transfer function. In the track mode, the imaging system is locked on the target obtained through image processing algorithms during the search mode. In the track mode, the existing gyroscopic stabilizer is constantly trying to maintain the target near the field of view centre in the imaging system.

### 3. Proposed method

For obtaining the transfer function of two degrees of freedom gyro stabilized platform some essential equipment such as two degrees of freedom gyro stabilized platform, One degree of freedom target simulator, laptop, required cables, fixtures, and a serial board is needed. A picture of the one degree of freedom target simulator is shown in Figure 6.

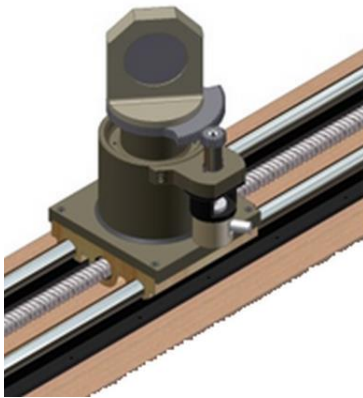


Fig. 6: A View of the One Degree of Freedom Target Simulator Table.

As mentioned in the section 2, an infrared imaging system is mounted on the two degrees of freedom platform. Thus, these types of platforms (with infrared imaging system) are also used for searching and tracking targets which emit infrared waves [11]. In fact, the one degree of freedom target simulator acts as a moving infrared target [12]. Therefore, the two degrees of freedom gyro stabilized platform can implement image processing algorithms to search for and track this infrared target. The target simulator is capable of moving at the desired frequency and angular velocity about the centre of it. To simulate the infrared target, a resistor which is connected to a power supply is applied.

The purpose of this test is to obtain the transfer function of the two degrees of freedom gyro stabilized platform through injecting the desired signal to the input of this system and storing the corresponding output. To realize this, first the two degrees of freedom gyro stabilized platform must be positioned in front of the target simulator in a way that the field of view (FOV) of the two degrees of freedom gyro stabilized platform can completely cover the motion interval of target simulator.

The gyroscopic stabilizer has a serial output port for online transmission of some of the important functional parameters of platform and signals in accordance with the RS488 serial communication standard as the platform moves. In fact, the data sent through this serial port to the output contain several columns each of which describes the status of one important functional parameter of the two degrees of freedom gyro stabilized platform (such as signals showing the platform movement for searching in yaw axis or pitch axis).

MATLAB was used to store the output data from the RS422 serial port of platform. The output data from the serial port were converted into the RS232 standard data and transferred to the serial port of the computer. Figure 7 shows data storing scheme.

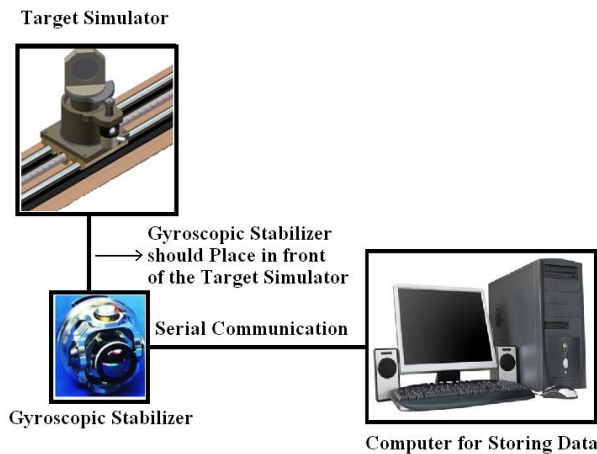


Fig. 7: Data Storing Scheme.

An m-file was created to store the data transferred to the serial port of the computer. Upon running the m-file, all the data related to functional parameters of the existing platform were stored. A

screen view of the stored data in the Workspace window of MATLAB software is shown in Figure 8.

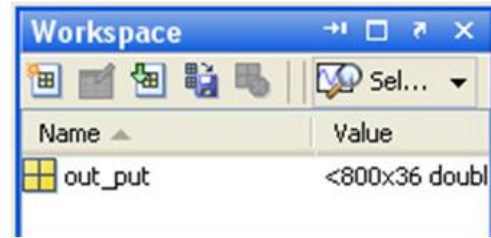


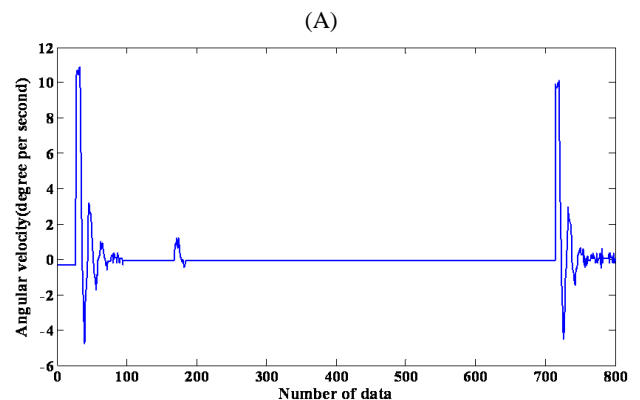
Fig. 8: Data Received from the Serial Port and Consequently Stored In the Workspace Window.

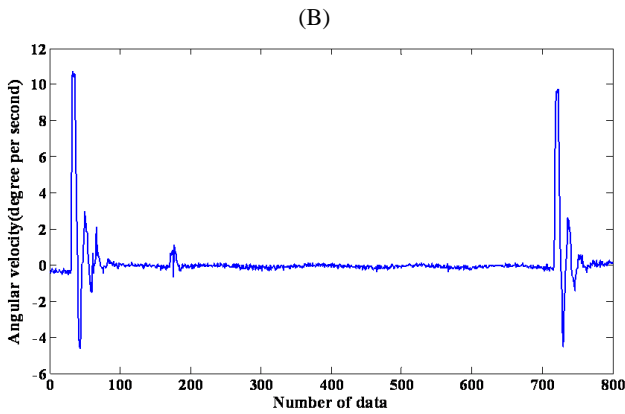
Another m-file was deployed to classify the stored data into separate signals under the desired topics for the purpose of individually analysing each signal. Upon executing this m-file, each of the existing signals were separately classified under the desired name in the Workspace window.

One input which can be used for identifying the system for the purpose of obtaining its transfer function is the command issued by the image processing algorithm to the two degrees of freedom gyro stabilized platform for searching about the yaw axis. Therefore, the output corresponding to this input would be a signal received from the gyroscope mounted in the direction of yaw rotation in response to the issued command. Thus, by storing both these signals, we can obtain the transfer function of the existing two degrees of freedom gyro stabilized platform using the system identification toolbox in MATLAB.

To start the test, we first adjust the two degrees of freedom gyro stabilized platform in front of the one degree of freedom target simulator in a way that the field of view of the two degrees of freedom gyro stabilized platform cover the target simulator's motion interval. Then, we rotate the target simulator at a specific frequency and angular range about its centre. Subsequently, the stabilizer is set at the track mode so that it can lock on the target and keep the target near the centre of the imaging system field of view. As such, the two degrees of freedom gyro stabilized platform can follow the target as the target rotates about the yaw axis. By running the first m-file in MATLAB, we can save the output signal of the existing platform's serial port (which actually includes the command signal sent from the image processing algorithm to the existing platform as well as the existing platform reaction to the transmitted input signal).

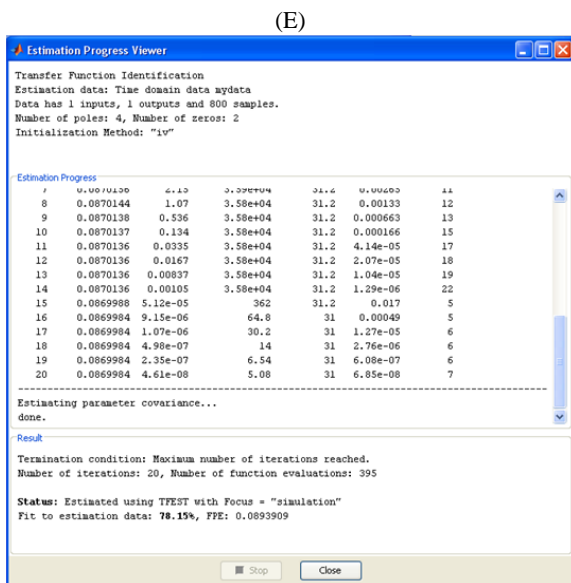
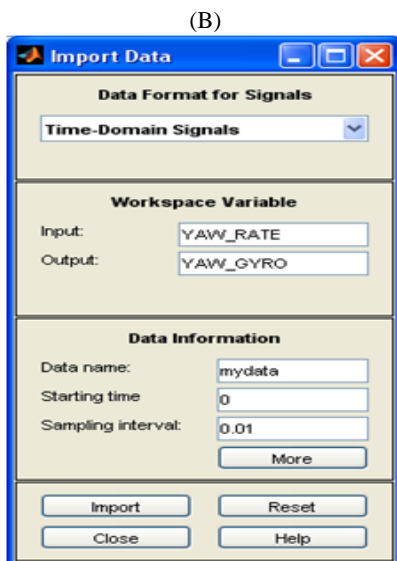
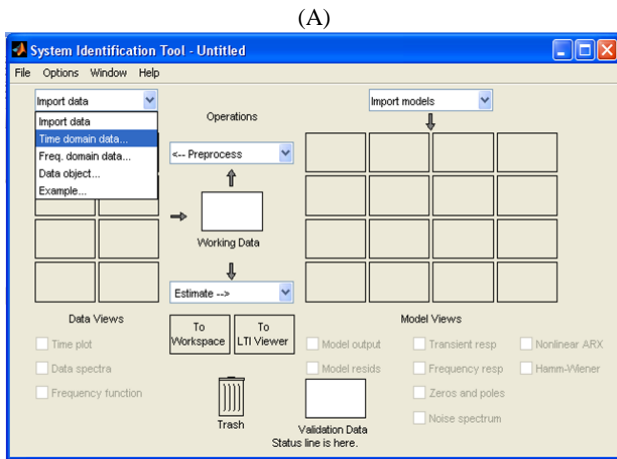
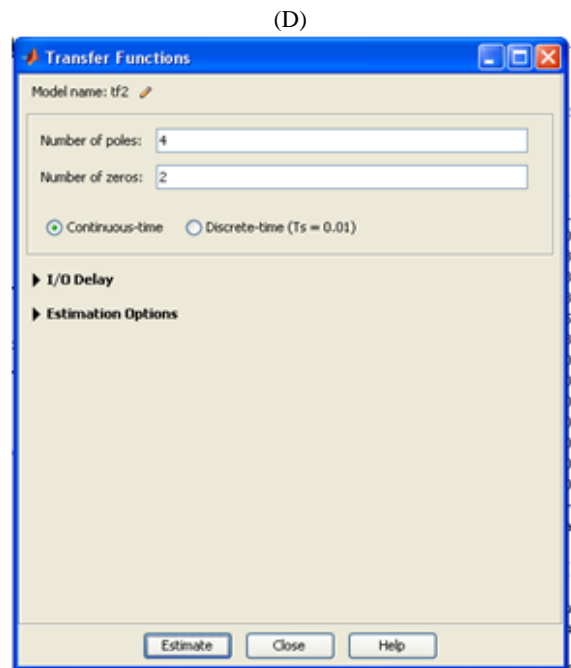
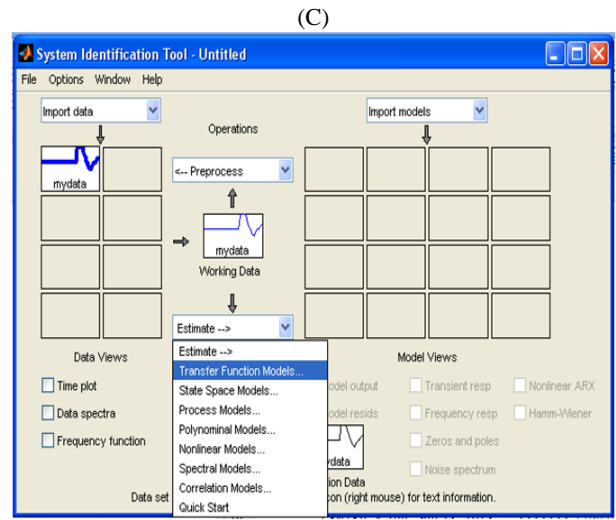
Figure 9 shows the command sent from the image processing algorithm to the studied two degrees of freedom gyro stabilized platform for searching about the yaw axis as well as the stored output signal obtained from the gyroscope mounted on the yaw axis in response to the command sent by the image processing algorithm to the existing gyroscopic stabilizer.





**Fig. 9:** (A) The Signal Corresponding to the Applied Command from the Image Processing Algorithm to the Two Degrees of Freedom Gyro Stabilized Platform; (B) the Output Signal from the Gyroscope Mounted on the Yaw Axis Resulting from the Command Applied by the Image Processing Algorithm to the Two Degrees of Freedom Gyro Stabilized Platform.

To obtain the transfer function of the two degrees of freedom gyro stabilized platform by using the input and output signals stored during the test, it is enough to specify the input and output of the system identification toolbox in MATLAB and obtain the transfer function corresponding to the given input and output signals. Figure 10 shows the different steps of obtaining the transfer function for the two degrees of freedom gyro stabilized platform used in the test.



**Fig. 10:** (A) The MATLAB System Identification Toolbox Window; (B) the Defined Input and Output Used for System Identification Process; (C) the Transfer Function Corresponding to the Defined Input and Output; (D) Determining the Number of System Zeroes and Poles to Obtain the Transfer Function; (E) Input and Output Analysis for Obtaining the Transfer Function Corresponding to the Defined Input and Output.



The transfer function obtained for the two degrees of freedom gyro stabilized platform used in this test was obtained as (1):

$$Tf = \frac{3002s^2 - 380.9s + 5.896e^{04}}{s^4 + 69.63s^3 + 2977s^2 + 1353s + 5.749e^{04}} \quad (1)$$

As it is clear from (1), the existing two degrees of freedom is unstable. It is necessary to pay attention that the purpose of this article is to obtain the transfer function of existing system not to stable it.

Figure 11 shows the step response of the above transfer function.

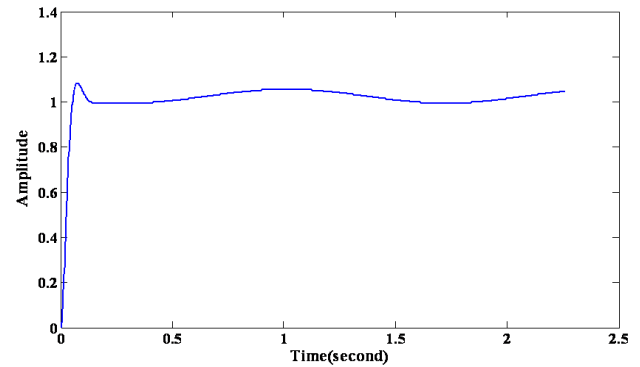


Fig. 11: Step Response of the Transfer Function Obtained for the Two Degrees of Freedom Gyro Stabilized Platform.

#### 4. Comparison between step response obtained from proposed method and step response obtained from simulation

Figure 12 shows the block diagram of the control system (for the yaw axis) used for obtaining step response of the system.

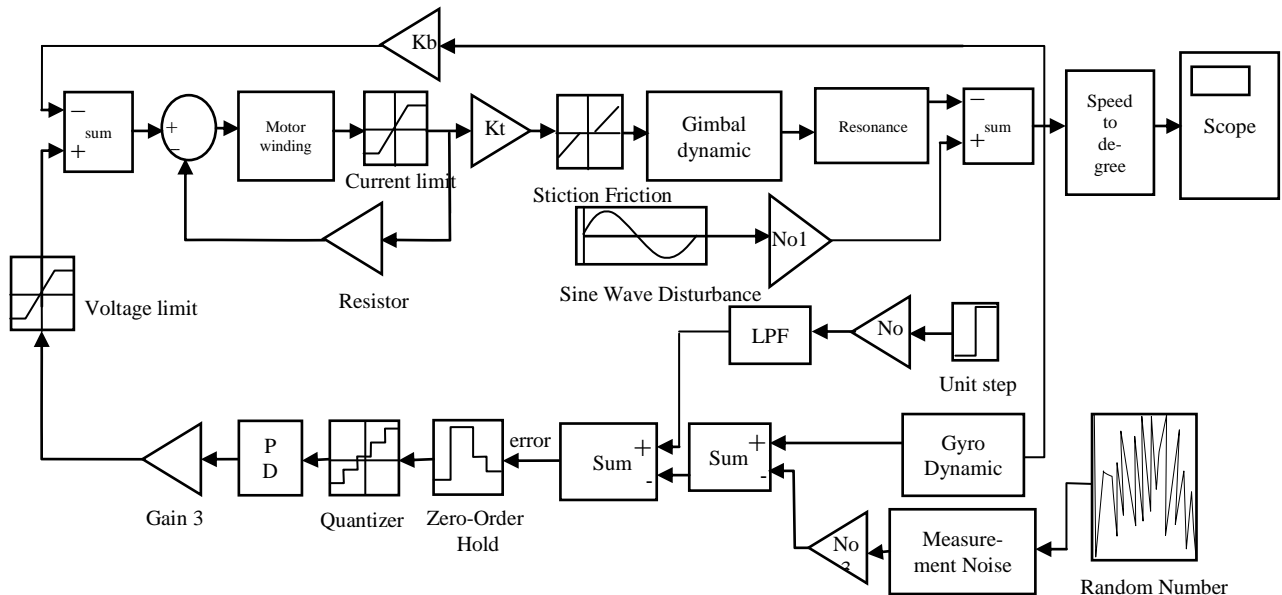


Fig. 12: Control System Block Diagram at the Yaw Axis.

The step response of the studied two degrees of freedom gyro stabilized platforms in the SIMULINK was obtained as follows: first, a step signal in the form of angular velocity was applied to the simulated yaw axis structure (Figure 12). The corresponding output to this input is shown in Figure 13.

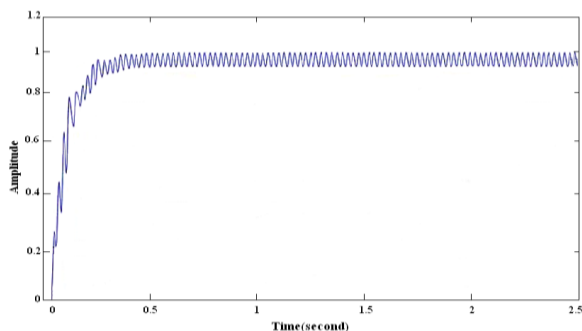


Fig. 13: Step Response of the Simulated Control System at the Yaw Axis Obtained for the Two Degrees of Freedom Gyro Stabilized Platform.

The corresponding response of the studied platform to the step signal obtained experimentally was compared to that obtained from the simulation in SIMULINK, yielding a difference within the 10% range. The most important reason can be expressed for this difference in results is the lack of equality in simulations conditions in SIMULINK with real conditions in laboratory.

To design a controller and check the stability of complicated systems, we must first model the system in the simplest possible way and design a controller for this simplified model, and then adapt this controller for the main system. Here, we make certain simplifying assumptions for reducing the existing complications in the design and stability check of the controller. To check stability, we use the stability check methods implemented for linear systems. To this end, we linearize the system if necessary. Stability analysis requires that the coefficients matrix A for state variables be obtained from the following relation:

$$\dot{x} = A.x + B.u + D \quad (2)$$

The angular velocity and angular acceleration terms are among the known terms in the above relation. Since we would not need these terms in our stability analysis, we set them all to zero. Therefore, the first assumption would be expressed as follows:

- 1)  $p = q = r = 0$  and  $\dot{p} = \dot{q} = \dot{r} = 0$
- 2) The working points of the system are assumed to be near the equilibrium point  $\theta = \varphi = 0$  where  $\varphi$  is the angle between the body and the outer frame, and  $\theta$  is the angle between the outer frame and the stabilized platform.

If we apply the above assumptions to the kinematic equations governing the system, we will obtain:

$$\omega_o = \begin{bmatrix} -\dot{\varphi} \\ 0 \\ 0 \end{bmatrix}, \omega_p = \begin{bmatrix} -\dot{\theta} \\ -\dot{\theta} \\ 0 \end{bmatrix} \quad (3)$$

$$\dot{\omega}_o = \begin{bmatrix} -\ddot{\varphi} \\ 0 \\ 0 \end{bmatrix}, \dot{\omega}_p = \begin{bmatrix} -\ddot{\theta} \\ -\ddot{\theta} \\ 0 \end{bmatrix}$$

In the above equation,  $\varphi$  is the angular velocity of the body relative to the outer frame,  $\theta$  is the angular velocity of the outer frame with respect to the stabilized platform,  $\omega_o$  is the absolute angular velocity of the outer frame, and  $\omega_p$  is the absolute angular velocity of the stabilized platform.

Upon substituting these kinematic relations in the dynamic equations for hinges, we obtain the simplified dynamic relations as:

$$-\ddot{\theta} = \frac{M_{o/py}^*}{I_{py}} \quad (4)$$

$$-\ddot{\varphi} = \frac{-\cos(\theta) \cdot M1 + \sin(\theta) \cdot M2 + M_{b/ox}^*}{C1} \quad (5)$$

In the above relations,  $M_{o/py}^*$  is the effect of the outer frame on the platform along the y axis,  $I_{py}$  is the moment of inertia of the stabilized platform along the y axis,  $M_{b/ox}^*$  is the sum of the viscous moment M1 and the control motor moment M2, and C1 is a parameter obtained from the following relations:

$$M1 = I_{px} \cdot K1 + \omega_{py} \cdot \omega_{pz} \cdot (I_{pz} - I_{py}) \quad (6)$$

$$M2 = I_{pz} \cdot K2 + \omega_{px} \cdot \omega_{py} \cdot (I_{py} - I_{px}) \quad (7)$$

K1 and K2 are obtained from the following relations:

$$K1 = -\omega_{ox} \cdot \dot{\theta} \cdot \sin(\theta) + \dot{\omega}_{oz} \cdot \sin(\theta) + \omega_{oz} \cdot \dot{\theta} \cdot \cos(\theta) \quad (8)$$

$$K2 = -\omega_{ox} \cdot \dot{\theta} \cdot \cos(\theta) + \dot{\omega}_{oz} \cdot \cos(\theta) - \omega_{oz} \cdot \dot{\theta} \cdot \sin(\theta) \quad (9)$$

$$C1 = I_{ox} + (I_{px} \cdot \cos^2(\theta) + I_{pz} \cdot \sin^2(\theta)) \quad (10)$$

Using (3), (8) and (9) can be rewritten as follows:

$$K1 = \dot{\varphi} \cdot \dot{\theta} \cdot \sin(\theta) \quad (11)$$

$$K2 = \dot{\varphi} \cdot \dot{\theta} \cdot \cos(\theta) \quad (12)$$

Upon substituting (11) and (12) in (6) and (7), we obtain:

$$M1 = I_{px} \cdot \dot{\varphi} \cdot \dot{\theta} \cdot \sin(\theta) \quad (13)$$

$$M2 = I_{pz} \cdot \dot{\varphi} \cdot \dot{\theta} \cdot \cos(\theta) + \dot{\varphi} \cdot \dot{\theta} \cdot (I_{py} - I_{px}) \quad (14)$$

Therefore, (4) and (5) can also be rewritten in the following form with due regard of (13) and (14):

$$-\ddot{\theta} = \frac{D_{\theta} \cdot \dot{\theta} + M_{Cy}}{I_{py}} \quad (15)$$

$$-\ddot{\varphi} = (-\cos(\theta) \cdot I_{px} \cdot \dot{\varphi} \cdot \dot{\theta} \cdot \sin(\theta) + \sin(\theta) \cdot (I_{pz} \cdot \dot{\varphi} \cdot \dot{\theta} \cdot \cos(\theta) + \dot{\varphi} \cdot \dot{\theta} \cdot (I_{py} - I_{px}))) + D_{\varphi} \cdot \dot{\varphi} + M_{Cx})/C1 \quad (16)$$

Equations (15) and (16) can be rewritten in the following forms:

$$\ddot{\theta} = \frac{-D_{\theta} \cdot \dot{\theta} - M_{Cy}}{I_{py}} \quad (17)$$

$$\ddot{\varphi} = -(\cos(\theta) \cdot \dot{\varphi} \cdot \dot{\theta} \cdot \sin(\theta) \cdot (I_{pz} - I_{px}) - \sin(\theta) \cdot \dot{\varphi} \cdot \dot{\theta} \cdot (I_{py} - I_{px}) - D_{\varphi} \cdot \dot{\varphi} - M_{Cx})/C1 \quad (18)$$

From (10), C1 can be obtained as:

$$C1 = I_{ox} + (I_{px} \cdot \cos^2(\theta) + I_{pz} \cdot \sin^2(\theta)) \quad (19)$$

$M_{Cy}$  and  $M_{Cx}$  are control moments and can be calculated using the integration proportional controller in the following forms:

$$M_{Cx} = -k_{p1} \cdot \alpha_{px} - k_{D1} \cdot \omega_{px} \quad (20)$$

$$M_{Cy} = -k_{p2} \cdot \beta_{py} - k_{D2} \cdot \omega_{py} \quad (21)$$

For the case of a nonmoving (fixed) base, (20) and (21) can be rewritten in the following forms:

$$M_{Cx} = k_{p1} \cdot \varphi + k_{D1} \cdot \dot{\varphi} \quad (22)$$

$$M_{Cy} = k_{p2} \cdot \theta + k_{D2} \cdot \dot{\theta} \quad (23)$$

Upon substituting (22) and (23) in (18) and (19) respectively, and then linearizing the resulting equations around the working point (where initial angular velocities and initial angles are zero), the linear equations of the system are obtained in the standard state matrix form as:

$$\begin{bmatrix} \dot{\varphi} \\ \ddot{\varphi} \\ \dot{\theta} \\ \ddot{\theta} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ -k_{p1} & -D_{\varphi} - k_{D1} & 0 & 0 \\ I_{ox} + I_{px} & I_{ox} + I_{px} & 0 & 1 \\ 0 & 0 & -k_{p2} & -D_{\theta} - k_{D2} \\ 0 & 0 & I_{py} & I_{py} \end{bmatrix} \cdot \begin{bmatrix} \varphi \\ \dot{\varphi} \\ \theta \\ \dot{\theta} \end{bmatrix} \quad (24)$$

To study and analyse a gyro stabilized platform, we select as examples the parameters given in Table 1 for Dynamic analysis. The value of parameters in Table 1 are exactly match with the value of real existing two degrees of freedom gyro stabilized platform.

**Table 1:** Physical Characteristics of the Stabilized Platform

Parameter	Symbol	Value
Moment of inertia of the outer frame about x axis	$I_{ox}$	0.045
Moment of inertia of the platform about x axis	$I_{px}$	0.05
Moment of inertia of the outer frame about y axis	$I_{oy}$	0.045
Viscous friction coefficient	$D_{\theta}$	0.04
Viscous friction coefficient	$D_{\varphi}$	0.04

The characteristic equation of the system is obtained as:

$$|s.I - A| \quad (25)$$

With due consideration of the initial problem and upon solving (25), the characteristic equation can be obtained as follows:

$$0.0105 \times (5.s^2 + (100.k_{D2} + 4)s + 100K_{p2}) \cdot (19.s^2 + (200.k_{D1} + 8)s + 200.k_{p1}) = 0 \quad (26)$$

To verify system stability, we used the routh-hurwitz method. According to the routh-hurwitz stability condition, for a system with a second order characteristic equation, all the coefficients must have a common sign. In other words, the following inequalities must hold:

$$(100.k_{D2} + 4) > 0$$

$$100K_{p2} > 0$$

$$(200.k_{D1} + 8) > 0$$

$$200.k_{p1} > 0$$

The following conditions must be met for the particular system under study here to be stable. In other words, if a controller is designed for studying system here, conditions in (27) should be satisfy.

$$K_{p2} > 0, k_{p1} > 0, k_{D1} > -0.04, k_{D2} > -0.04 \quad (27)$$

## 5. Conclusion

In this article, first an introduction was presented about two degrees of freedom gyro stabilized platforms and their applications in industry, trade, etc. Then, the structure and functioning of two degrees of freedom gyro stabilized platforms as well as components of a two degrees of freedom gyro stabilized platform was discussed. An experimental method was proposed for obtaining the transfer function of a two degrees of freedom gyro stabilized platform by applying a single signal at the input to this platform, storing the corresponding output using a system identification toolbox in MATLAB, and finally, obtaining the transfer function of the studied platform. Also, the step response of the studied platform obtained in the laboratory was compared to that obtained from MATLAB/SIMULINK simulation. The good agreement (within 10%) observed between these results confirmed the authenticity of the proposed method.

An important aspect in the two degrees of freedom gyro stabilized platforms which must be considered in their design is that these platforms are utilized under different ambient conditions which directly affect the behaviour of the prototype two degrees of freedom gyro stabilized platform. For this reason, further research can be conducted in the following respects: effect of temperature and humidity on the behaviour of the two degrees of freedom gyro stabilized platform and the general performance thereof, and effect of the changes in component behaviour due to environmental/working conditions on the step response and transfer function of these platforms. This research will be conducted in the future.

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