Engineering Science and Military Technologies
Volume (2) - Issue (1) - 2018

ISSN: 0954 -2357
DOI:10.21608/ejmtc.2017.409.1005

Comparative Study Among Different Control Techniques For Stabilized Platform

Original Article

A. G. Habashi, M. M. Ashry, Mohamed H. Mabrouk, G. A. Elnashar

Military Technical College, Cairo, Egypt

Key Words:
Classical proportional-integral (PI) controller, disturbance rejection, genetically tuned pi controller, h_∞ controller, linear quadratic regulator (LQR) controller, linear quadratic gaussian (LQG) controller, noise attenuation.

Corresponding Author:
Mahmoud Ashry, **Email**: mmaashry@mtc.edu.eg, mmaashry@yahoo.com, **Tel**: 01003449660

Abstract

The controlling of the Line of Sight (LOS) for inertially stabilization platform system, which is subjected to uncertainty, is considered as a challenging problem where the mission capabilities of stabilized platform depend on its performance improvement. The work presented in this paper is based on performance comparative study among five different types of controllers designed to attain an improved accuracy and a reduced stabilized error for controlling the line of sight stabilization system. The designed controllers for the case study are Proportional-Integral (PI) controller tuned classically, genetically tuned PI controller, Linear Quadratic Regulator (LQR) controller, Linear Quadratic Gaussian (LQG) controller, and H_∞ controller. The controllers' ability of disturbance rejection as well as their ability to attenuate the outer noise are compered. The simulations results show the remarkably improved pointing accuracy for the case study under the presence of both outer disturbances, induced by vehicle running, and measuring noise which is derived from feedback sensors.

I. INTRODUCTION

Stabilization of LOS can be considered one of the most common applications for stabilization system. There are different equipments that can be fixed on moving vehicles, For instance sensing equipment (electronic imaging devices, cameras, radars, and navigation instruments). In harsh circumstances resulted from the disturbance of the vehicles during operation, these equipment may be affected and finally become out of functions. This leads to the importance of using LOS stabilization technology, in other words, using stabilized platform to isolate LOS sensors from vehicles' disturbance. The LOS stabilization system can be simply defined as a system that keeps the sightline of an electro-object sensor when it is exposed to external disturbance such as base motion[1].

Many contributions have influenced the basic control methodologies by the means of enhancing response and error minimization or both. The impact of these developed techniques on ISPs has been remarkable in many previous works. A composite scheme, which use a Proportional-integral-derivative (PID) and adaptive control to control a gyro mirror of LOS system, was proposed by K.K. Tan *et al.*[2]. The effectiveness and applicability of the proposed control scheme were verified by simulation and real-time experimental study. Another control scheme was proposed using a proportional-integral-double integral (PII2) controller for gyro stabilization electro-optical platform[3]. In this platform the most important index that must be put forward is the zero steady state error index. Analysis were based on two classical control schemes, the first scheme based on angle feedback using gyro designed in frequency domain. The second scheme was the rate gyro feedback scheme using PID compensator[4]. A stabilized platform has been introduced with double closed loop control system. Speed feedback loop was designed using PID controller and displacement feedback loop, which was designed using Fuzzy Neural Network (FNN) controller. A development of the angular rate kinematics equations was represented for the non-linear coupled mirror LOS stabilization system[5]. Another system for stabilizing platform of a ship carring antenna and its core component, was discussed to develop a control system composed of three control loops, each of which is associated with a single-variable controller[6]. First, PID controller was applied; then, Takagi-Sugeno fuzzy controller was used for controlling the platform. Simulation tests were established and the results have demonstrated the effectiveness of the proposed Takagi-Sugeno fuzzy controller.

PID controllers are commonly used, considering industrial controlled systems, due to the reduced number of tuned parameters[7]. Under linear operation condition, classic PID controller can reach the required performance. However, under the conditions of nonlinear constraints and uncertainties the classical PID controller is hard to achieve the system desired performance with the prescribed accuracy[8]. The uncertainties in the model may come from un-modeled dynamics, parameter variations, linearization of nonlinear elements, etc.[9, 10]

In this paper, an approach from a previous study is adopted where different controllers are designed for certain described line of sight stabilization system[11]. PI controller is designed and its parameters are tuned classically and are tuned again using GA. LQR, LQG and H_∞, controllers are also designed for the LOS stabilization system. The controlled system -in the previous paper - performances are compared in normal operating conditions and when the system is subjected to model uncertainty[11].

The key point in this paper is to present the comparative study of the system performance- in presence of carrier disturbances between the pervious designed controllers- is discussed. Also, the ability of each technique to attenuate the outer noise.

I. SYSTEM DESCRIBTION

Fig. (1) shows the power train flow chart of the system. The investigated system is a dual axes stabilized platform that consists of two gimbals; inner and outer. Each of position is determined by the elevation angle θ_1 and the azimuth angle θ_2 respectively. Two armature current controlled DC motor is used to drive each rotating axis. The inertial angular velocities in both elevation and azimuth directions are measured using two optical fiber gyros. In addition, two optical encoders are used to measure the angular position of each axis. These gyros and encoders are used for feedback control of the system.

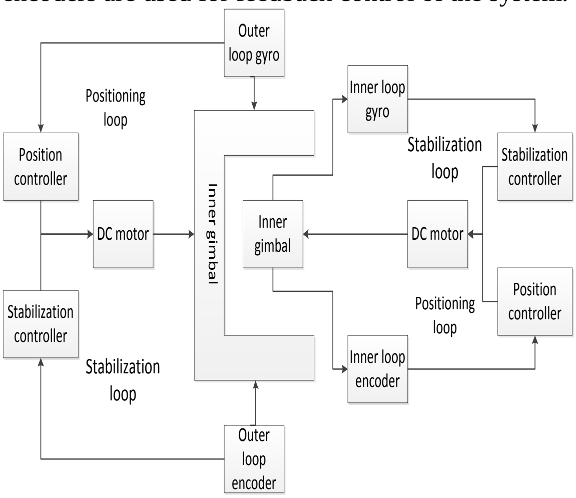

Fig. 1: the power train flow chart of the system[11].

The transfer functions of the inner and outer gimbals models as a relation between input voltage and output angular position can be written as in equation (1) and equation (2)[11]:

$$G_{el}(s) = \frac{\theta_1(s)}{V(s)} = \frac{\dfrac{K_m K_b}{R_a I_{Iy}}}{s\left(s + \dfrac{K_m K_b + K_{If} R_a}{R_a I_{Iy}}\right)} \quad (1)$$

$$G_{az}(s) = \frac{\theta_2(s)}{V(s)} = \frac{\dfrac{K_m K_b}{R_a I_{Oz}}}{s\left(s + \dfrac{K_m K_b + K_{Of} R_a}{R_a I_{Oz}}\right)} \quad (2)$$

Where:

$v_a(t)$ Armature voltage (volt).

K_m Motor torque constant.

K_b Back electromotive-force voltage constant.

K_f Field winding constant.

K_{If} Field winding constant for inner gimbal motor.

K_{Of} Field winding constant for outer gimbal motor.

R_a Armature winding resistance (ohms).

I_{Iy} mass moment of inertia around y axis for inner gimbal.

I_{Oz} mass moment of inertia around z axis for outer gimbal.

Every linear time invariant lumped system can be described by a set of equations of the form

$$\dot{x} = Ax + Bu \quad (3)$$

$$y = Cx + Du \quad (4)$$

For the system with p inputs, q outputs, and n state variables, A, B, C, and D are, respectively, n×n, n×p, q×n, and q×p constant matrices.

A set of state variables sufficient to describe the dual axis inertial stabilized platform, described by equations (1) and (2), are chosen as the angular position and change of angular position of the inner and outer gimbals. Therefore, the set of state variables can be defined as:

$$x_1 = \theta_1 \quad (5)$$

$$x_2 = \theta_2 \quad (6)$$

$$x_3 = \dot{\theta}_1 = \dot{x}_1 \quad (7)$$

$$x_4 = \dot{\theta}_2 = \dot{x}_2 \quad (8)$$

The equations that describe the behavior of the stabilized platform in terms of the state variables can be written as:

$$\dot{x}_1 = \dot{\theta}_1 = x_3 \quad (8)$$

$$\dot{x}_1 = \dot{\theta}_1 = x_3 \quad (9)$$

$$\dot{x}_3 = -\left(\frac{K_m K_b + K_{If} R_a}{R_a I_{Iy}}\right) x_3 + \frac{K_m}{R_a I_{Iy}} v_{a1}(t) \quad (10)$$

Engineering Science and Military Technologies
Volume (2) - Issue (1) - 2018

$$\dot{x}_4 = -\left(\frac{K_m K_b + K_{Of} R_a}{R_a I_{Oz}}\right) x_4 + \frac{K_m}{R_a I_{Oz}} v_{a2}(t) \quad (11)$$

The system state-space equation can be written as follow:

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\\ \dot{x}_3\\ \dot{x}_4\end{bmatrix} = \begin{bmatrix}0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\\ 0 & 0 & -\left(\frac{K_m K_b + K_{If} R_a}{R_a I_{Iy}}\right) & 0\\ 0 & 0 & 0 & -\left(\frac{K_m K_b + K_{Of} R_a}{R_a I_{Oz}}\right)\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ x_3\\ x_4\end{bmatrix} + \begin{bmatrix}0 & 0\\ 0 & 0\\ \frac{K_m}{R_a I_{Iy}} & 0\\ 0 & \frac{K_m}{R_a I_{Oz}}\end{bmatrix} u \quad (12)$$

$$y = \begin{bmatrix}x_1\\ x_2\\ x_3\\ x_4\end{bmatrix} = \begin{bmatrix}1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ x_3\\ x_4\end{bmatrix} + \begin{bmatrix}0 & 0\\ 0 & 0\\ 0 & 0\\ 0 & 0\end{bmatrix} u \quad (13)$$

Where:

u System input vector.

y System output vector.

III. COMPARISON BETWEEN CONTROLLERS BASED ON DISTURBANCE REJECTION

Simulations provide a powerful tool when analyzing the effect of several parameters on the platform performance and stability. The repeatability of simulations is especially valuable when studying disturbance performance, since the ambient conditions are very hard to be monitored and to be controlled when performing field experiments[12].

The platform is subjected to two different kind of disturbance. The first one can be seen in Fig. (2), which can be represent the abrupt change in vehicle directions (like steering action) where the platform is mounted. Fig. (3) to (7) respectively show the output responses of the controlled system by using the previous controllers (PI, GA-PI, LQR, LQG and H_∞.).

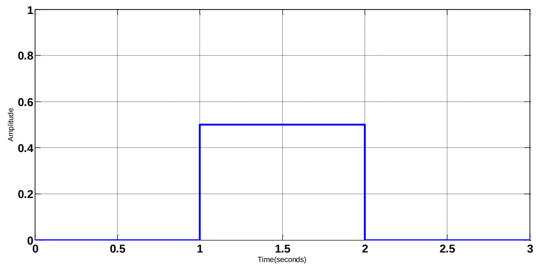

Fig. 2: Disturbance.

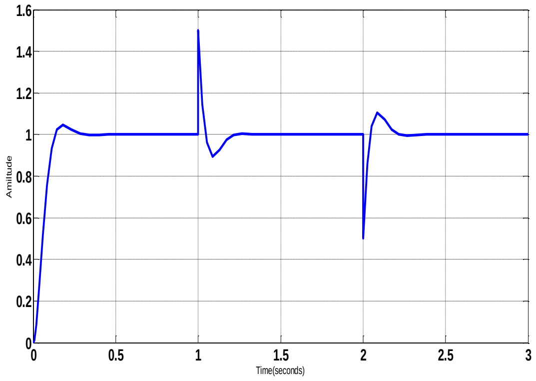

Fig. 3: PI controller step response when the system is subjected to external disturbance.

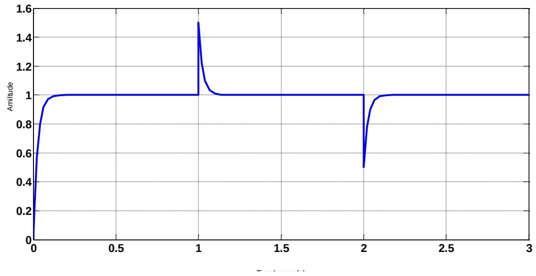

Fig. 4: GA-PI controller step response when the system is subjected to external disturbance.

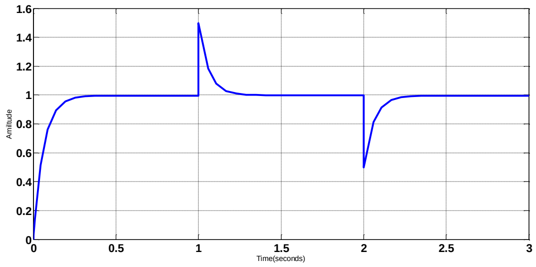

Fig. 5: LQR controller step response when the system is subjected to external disturbance.

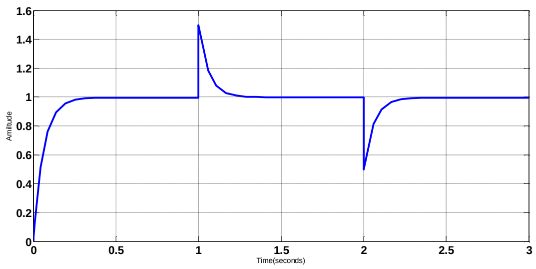

Fig. 6: LQG controller step response when the system is subjected to external disturbance.

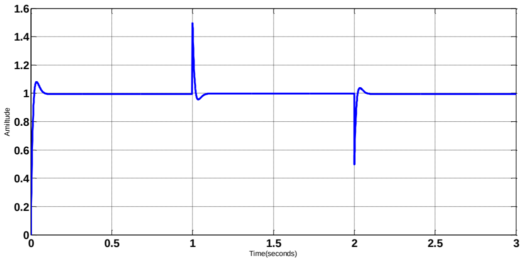

Fig. 7: H_∞ controller step response when the system is subjected to external disturbance.

It is clear from the result that the H_∞ control system is the best when dealing with external disturbance from the fastest response with the minimum acceptable overshooting point of view.

Fig. (8) to Fig. (13) shows another different kind of disturbance that can be resulted from the outer disturbance (sinusoidal disturbance). This kind of disturbance can be described as the disturbance from vehicle's movement on a rough terrain.

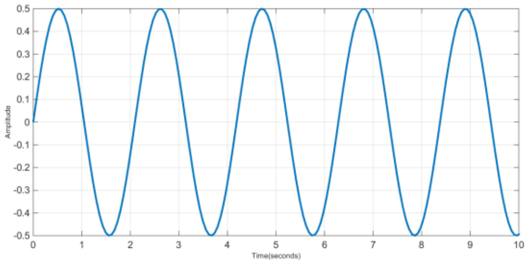

Fig. 8: Sinusoidal disturbance.

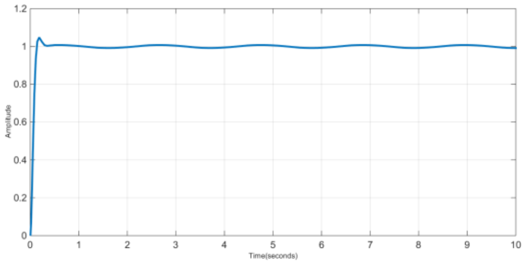

Fig. 9: PI controller step response with sinusoidal disturbance.

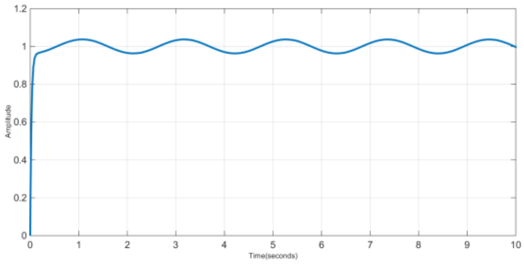

Fig. 10: GA-PI controller step response with sinusoidal disturbance.

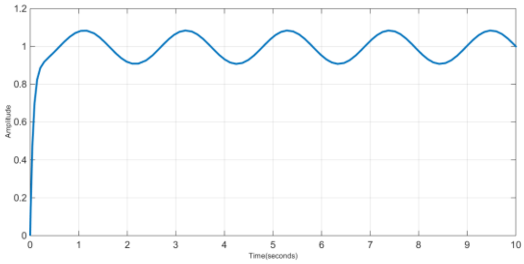

Fig. 11: LQR controller step response with sinusoidal disturbance.

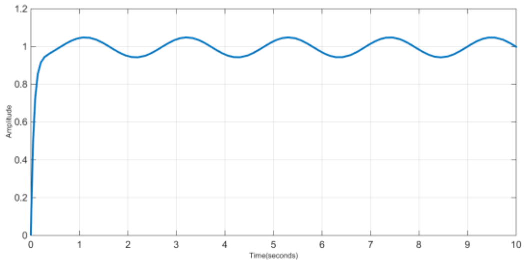

Fig. 12: LQG controller step response with sinusoidal disturbance.

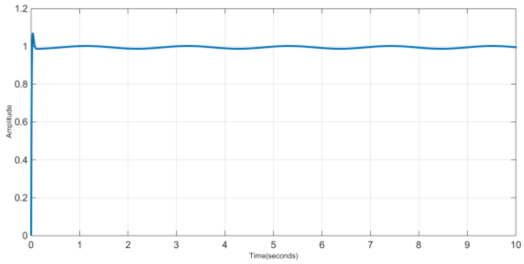

Fig. 13: H_∞ controller step response with sinusoidal disturbance.

As it is obvious from this section, the PI controlled system followed by H_∞ controlled system is the best when dealing with sinusoidal disturbance.

IV. COMPARISON BETWEEN CONTROLLERS BASED ON ABILITY TO ATTENUATE THE NOISE

The output sensors such as gyroscopes and speed sensor are the sources of measurement noise. They are used for the feedback control to be compared with the desired inputs. A drawback with feedback based techniques is that the controller feeds measurement noise into the system[13]. It is important that the control actions generated by measurement noise are not too large. Since measurement noise typically has high frequencies, the controller should achieve small loop transfer function for high frequencies which is called high frequency roll off[13].

For the case studied, the gyroscope and the speed sensor are considered as the source of measuring noise. In simulation, these noise are considered to be white noise as shown in[14]. Fig (15) to Fig (19) show the output responses with noise consideration.

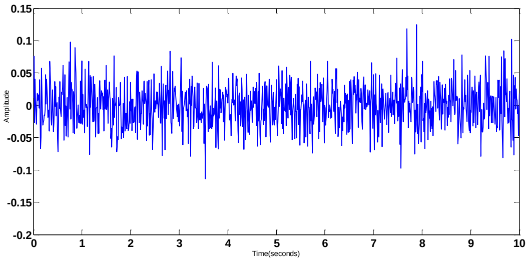

Fig. 14: Measurement white noise.

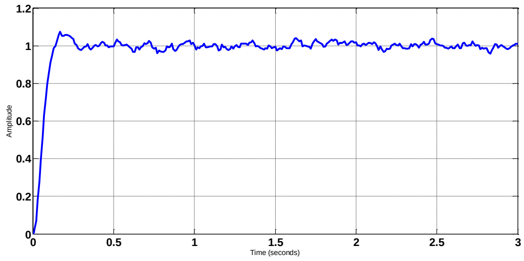

Fig. 15. PI controller step response when the measurement noise is considered.

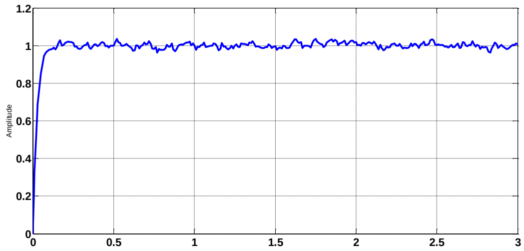

Fig. 16: GA-PI controller step response when the measurement noise is considered.

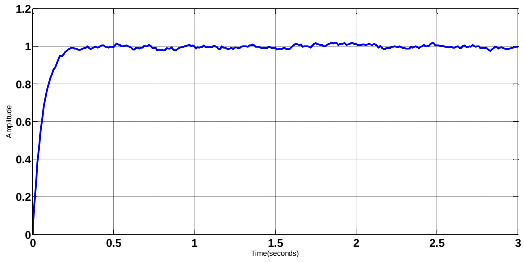

Fig. 17: LQR controller step response when the measurement noise is considered.

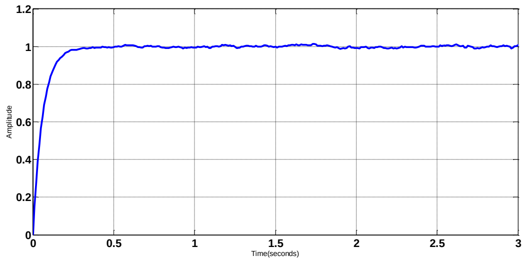

Fig. 18: LQG controller step response when the measurement noise is considered.

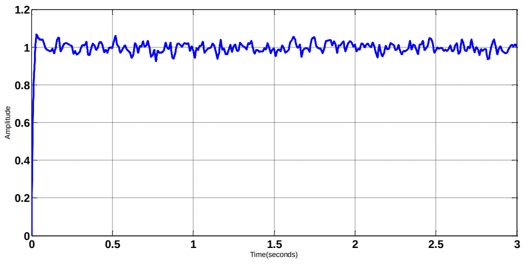

Fig. 19: H_∞ controller step response when the measurement noise is considered

With respect to the measurement noise on the ISP output sensors, the best performance achieved using LQG controller.

V. CONCLUSION

According to the previously designed controllers for LOS system, a comparative study -in normal operating conditions and when the system is subjected to model uncertainty- leads to choose H_∞ controller followed by GA-PI controller as they are the best in the used case study.

Taking in consideration two different kind of prospective outer disturbance, H_∞ controller achieve a noticeable ability to reject the outer disturbance. For the competence of either controller to attenuate the measurement noise, LQG controller remarkably attenuates the noise. As an overall assessment of the previously designed controllers for stabilized platform, considering the superiorities and the drawbacks of each controller in the case study, H_∞ can be chosen as the best controller for the ISP.

VI. REFERENCES

[1] A. Roshdy, Y. Z. Lin, C. Su, H. F. Mokbel, and T. Wang, "Design and performance of non-linear fuzzy logic PI controller for line of sight stabilized platform," in Optoelectronics and Microelectronics (ICOM), 2012 International Conference on, 2012, pp. 359-363.

[2] K. Tan, T. Lee, A. Mamun, M. Lee, and C. Khoh, "Composite control of a gyro mirror line-of-sight stabilization platform-design and auto-tuning," ISA transactions, vol. 40, pp. 155-171, 2001.

[3] Y. Han, Y. Lu, and H. Qiu, "An improved control scheme of gyro stabilization electro-optical platform," in Control and Automation, 2007. ICCA 2007. IEEE International Conference on, 2007, pp. 346-351.

[4]T. Zhiyong, P. Zhongcai, and W. Baolin, "Research on Image-Stabilizing System Based on Gyro-Stabilized Platform with Reflector," in Proceeding of SPIE, 2008, pp. 71281A1-71281A6.

[5]J. Hilkert and S. Cohen, "Development of mirror stabilization line-of-sight rate equations for an unconventional sensor-to-gimbal orientation," in SPIE Defense, Security, and Sensing, 2009, pp. 733803-733803-12.

[6]L. Said, L. Sheng, N. Farouk, and B. Latifa, "Modeling, Design and Control of a Ship Carried 3 DOF Stabilized Platform," 2012.

[7]J. Basilio and S. Matos, "Design of PI and PID controllers with transient performance specification," *Education, IEEE Transactions on*, vol. 45, pp. 364-370, 2002.

[8]R. C. Dorf and R. H. Bishop, "Modern control systems," 1998.

[9]K. Ogata, "Modern control engineering."

[10] Q. Guo, G. Liu, B. Xiang, H. Liu, and T. Wen, "The disturbance rejection of magnetically suspended inertially stabilized platform," *Transactions of the Institute of Measurement and Control*, 2016.

[11] A. Habashi, M. Ashry, M. Mabrouk, and G. Elnashar, "Controller Design for Line of Sight Stabilization System," in *International Journal of Engineering Research and Technology*, 2015.

[12] M. Juhlin, "Assessment of crosswind performance of buses," 2009.

[13] K. J. Aström and R. M. Murray, *Feedback systems: an introduction for scientists and engineers*: Princeton university press, 2010.