Australian Journal of Science and Technology

ISSN Number (2208-6404)
Volume 7; Issue 1; March 2023

Original Article

UAV gimbal position control using PID compensator

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ABSTRACT

In this paper, the authors developed a proportional-integral-derivative (PID) controller for unmanned aerial vehicle gimbal stability. During aerial flights, the gimbal instability as a result of actuator fluctuation leads to the capture of blurred images and joggled videos. This poses a post-flight data analysis problem. Viewing the gimbal as a robotic manipulator, independent joint control method is employed in obtaining the gimbal transfer function. Employing Matlab's control systems analysis toolbox, the results obtained showed a stable convergence as seen from the bode plot. The PID controller parameters showed that the percentage required for the system value was 8.63%. The time taken for the system response to reach the target value from an initial state of zero was 0.496 s. The time taken for the system to reach steady state after the initial rise was 1.54 s.

Keywords: Gimbal, modulation, proportional-integral-derivative controller, unmanned aerial vehicle

Submitted: 02-01-2023, **Accepted:** 03-02-2023, **Published:** 30-03-2023

INTRODUCTION

The unmanned aerial vehicle (UAV)[1,2] is an aerial robotic system that serves a variety of purpose. Such purposes could be civilian or military, of which operations, surveillance, disaster management, and aerial photography may be mentioned as examples.[1] Such applications require live video recording and transmission. Thus, image stabilization is a primary requirement for the success of such applications. How best can a stable image be achieved? Image stabilization can be achieved when the visual sensor payload is compensated for vibration, wind gust, and vehicle attitude transients.[3] An object developed for maintaining and keeping the visual sensor in a steady and desired orientation despite the UAV's motion is needed. Such an object is termed a stabilized platform.[4]

A stabilized platform is an object used to isolate payloads such as sensors, cameras, telescopes, and antennas from the motion of the carrier (in this instance, the UAV), on which the payload is mounted.[5] It enables the camera mounted on the platform to aim and track objects rapidly and exactly. Thus, the basic requirements of the platform are to maintain stability during operation even when changes occur in the dynamics of the system and also to have a very good disturbance rejection capability.[6]

The gimbal is a typical example of a stabilized platform. It is a robotic manipulator that positions the visual sensor during aerial flights. It is a mechanical system consisting of a servo, position encoder, and an inertia measurement unit. However, the gimbal being a mechanical system is susceptible to vibrations which lead to blurred images. This mechanical instability can be compensated for using control algorithms to effectively control the camera position.[7,8] This control mechanism is known as gimbal control.

In control theory, various control algorithms have been proposed. With specific application to control theory, algorithms developed for gimbal control include; coulomb Friction control algorithms,[9] command filtered back stepping algorithms,[10] PD controllers,[11] and genetic algorithms[7].

In this paper, the design scheme of a proportional-integral-derivative (PID) controller is presented. The gimbal system is modeled using Simulink. The proposed controller is built around the mathematical model and the controller behavior is analyzed and tested for stability by employing bode plots techniques.

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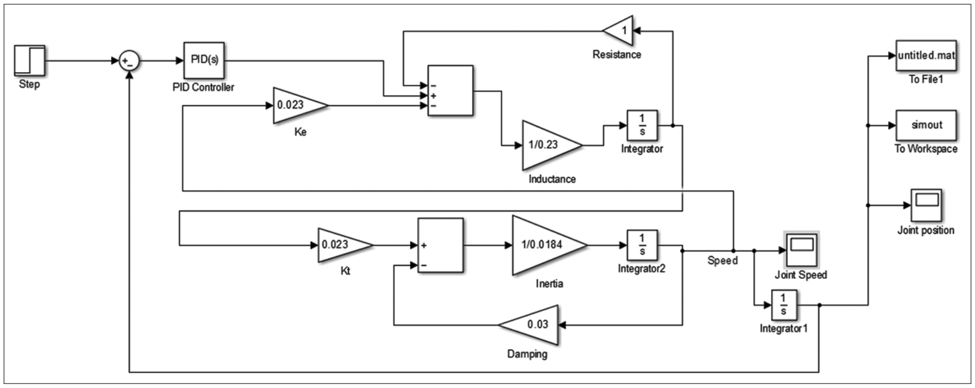

Figure 1: Simulink model of PID gimbal control system[9]

METHODOLOGY

In developing the controller algorithm, the model of the gimbal device and its actuator system is presented.

Gimbal Modeling

In modeling the gimbal device, it is viewed as a robotic manipulator.[12] Thus, using the Euler –Lagrange equation, the dynamic equation of the gimbal is developed. The LaGrange equation of motion provides a systematic approach to obtain the dynamic equation of a robot manipulator.[13] Defining the LaGrangean (L), it is defined as the difference between the kinetic and potential energies. That is;

$$K_i = \frac{1}{2}{}^{o} v_i^T m_i {}^{o} v_i + \frac{1}{2}{}_{o}\, \omega_i^{T\,i} I_{io}\, \omega_i \qquad (1)$$

$$= \frac{1}{2} q_i^T \left(\sum_{i=1}^{n} \left(J_{Di}^T m_i J_{Di} + \frac{1}{2} J_{Ri}^{T\,o} I_i J_{Ri}\right)\right) \dot{q}_i \qquad (2)$$

$$K = \frac{1}{2} \dot{q}_i^T D \dot{q}_i \qquad (3)$$

Where D is a n*n matrix known as the manipulator inertia matrix. Thus

$$D = \sum_{i=1}^{n} J_{Di}^T m_i J_{Di} + \frac{1}{2} J_{Ri}^{T\,o} I_i J_{Ri} \qquad (4)$$

The equation of motion for a robot manipulator can be shown in the concise form

$$D(q)\dot{q} + H(q,\dot{q}) + G(q) = Q \qquad (5)$$

Actuator Dynamics

Actuators are devices which translate power into motion. Manipulators are actuated using electrical, hydraulic, and pneumatic piezoelectric means. Electrically actuated manipulators are powered by Dc motors due to their clean, quiet, and precision qualities.

$$\frac{di}{dt} = \frac{1}{L}(u - R_m i - k_e a_w) \qquad (6)$$

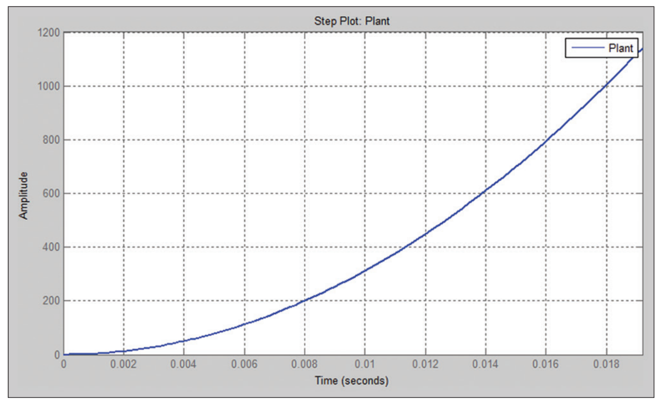

Figure 2: Step response Plot of Gimbal system

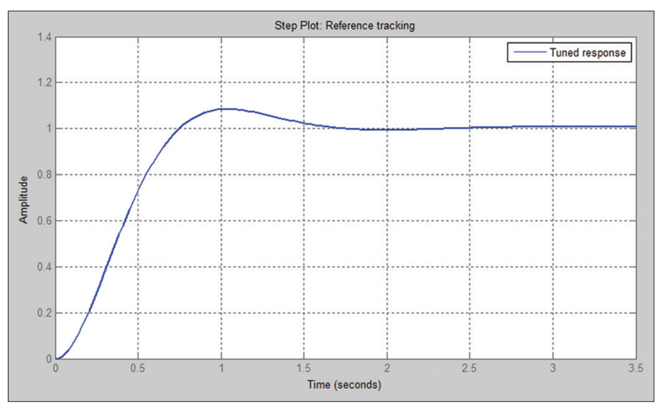

Figure 3: Reference tracking Plot of PID Controlled Gimbal system

Controller Design

A PID controller is a control feedback loop mechanism commonly employed in control systems. In describing the

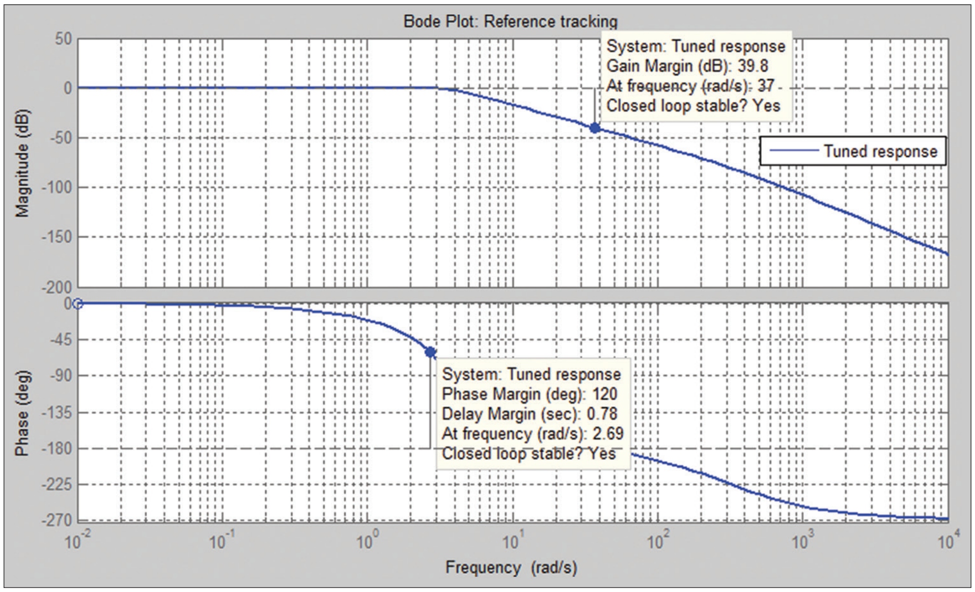

Figure 4: Bode Plot response of PID Controlled Gimbal system

PID controller, the existing relationship between the controller output (u(t)) and the error $e(t)$ is considered. The relationship is expressed in the continuous form as

$$u(t) = K_p e(t) + K_i \int_0^t e(T)\,dT + K_d \frac{de(t)}{dt} \quad (7)$$

Where the terms *kp*, *ki,* and *kd* are the gains of the proportional integral and derivative parameters of the controller. E is the error signal, and it is represented as

$$e = SP - PV \quad (8)$$

Developing the controller within the Simulink design environment, we obtain our controller parameters to be used in controlling the gimbal model. PID gain values obtained that gave a stable operation to the system are; *Kp* = 3.9072, *Ki* = 0.090406, *Kd* = 2.5714, and a filter coefficient (N) = 306.9477. The Simulink model of the closed loop feedback pid gimbal control system is shown in Figure 1.[9]

The Pid controller model is thus given as

$$\frac{793.1s^2 + 1119s + 27.75}{s^2 + 306.9s} \quad (9)$$

RESULTS AND DISCUSSION

In analyzing the controller results, the initial system response is considered. Figure 2 shows the response of the gimbal system to a unit step input.

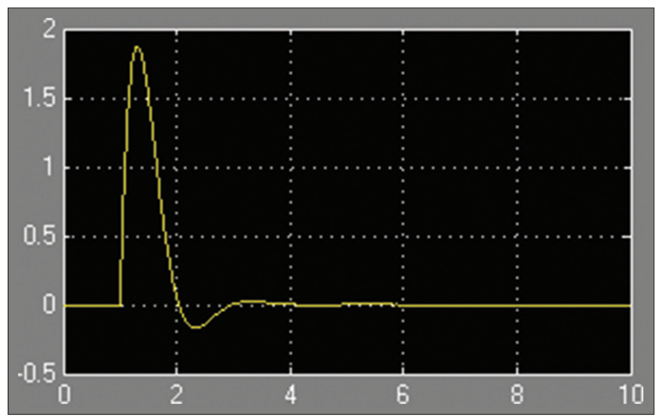

Figure 5: Joint Angular velocity output plot of PID gimbal control system

Due to the non-linear nature of the system, it was necessary to add a compensator. Figure 3 shows the response of the system to a unit step input when a PID controller is tuned alongside the plant. It is observed that stability was achieved as a result of the auto tuning technique employed.

The control performance and robustness parameters obtained are a rise time of 0.496 s, settling time of 1.54 s, a percentage overshoot of 8.63%. Figure 4 shows the Bode plot response of the PID controlled system.

From the plot in Figure 4, a phase margin of 60° with a gain margin of 39.8 decibels was obtained. The overall performance of the system showed a system with a stable performance. The system output showing the angular velocity and position of the gimbal is shown in Figures 5, respectively. From the plots, it is seen that the response of the velocity plot exhibited a drop in overshoot before settling.

CONCLUSION AND FUTURE WORK

In trying to develop an adaptive controller for the gimbal model, which is a non-linear system, an auto tuned PID controller is developed and implemented on a Simulink model. The results obtained show that while stability was achieved, the disturbance rejection capability of the developed controller was not ideal.

Hence, it is recommended that other control system development techniques be looked into so as to achieve a more robust and performance enhancing controller for stabilizing and control of gimbal systems.

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