STABILIZATION OF A GIMBAL SYSTEM USING PID CONTROL AND COMPENSATOR – A COMPARISON

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Abstract—Line-of-sight(LOS) stabilization systems form part of modern surveillance and fire control systems. Gimbal system is stabilized using PID controller and simple compensator. The performance of the two systems are compared. This paper shows which of the two design techniques is a better choice for the given gimbal system.

Index Terms— Compensator, Gimbal assembly, Line-of-sight (LOS), PID

I. INTRODUCTION

Line-of-sight (LOS) stabilization is an essential feature of modern fire control and surveillance systems [1]. These are sometimes referred to as pointing, tracking, stabilization, sightline control or LOS control systems [2]. In this paper, LOS stabilization of gimbal system is done using simple compensator and PID controller. The LOS is stabilized in azimuth against the angular disturbances. This paper attempts to develop compensator and conventional PID controller and the results of the two techniques are compared. The objective when designing a stabilization system is to build an electro-mechanical assembly that is capable of compensating for environmental effects, target maneuvers and disturbances so that the payload LOS is maintained in a given orientation [2]. The disturbances in the system can be due to bearing and motor friction, unbalanced aerodynamics, vibration forces, and spring torque forces. After a brief introduction, System dynamics are discussed in section II followed by problem statement in section III. In section IV, stabilization of the gimbal system using compensator and PID controller is given. The results of the two stabilization techniques are compared in section V. Finally, conclusions are drawn in section VI.

II. SYSTEM DYNAMICS

If gimbal design is not proper, the control algorithms may become complex and it may not be possible to meet the performance criteria [3]. The problems that are important to be considered are: resonance, friction and inertia. It is therefore necessary to capture all the dynamics of the plant and express the plant in analytical form. Thus in a control loop design cycle of any stabilized gimbal platform assembly, modeling of the plant dynamics is an important milestone [4]. A basic LOS stabilization loop of gimbal system is shown in fig. 1. Here, 1/Js is the gimbal, G0 is the gyro and G1 is the Drive motor.

A. Gimbal Modeling

A gimbal model is a combination of rigid model and model of flexible modes. In rigid model approach, gimbal assembly and pivots are considered to be rigid [3]. On the contrary, in modeling of flexible structure resonant modes are included which may limit the achievable bandwidth of control system design. Fig. 2 shows flexible azimuth base structure free body diagram whose transfer function for azimuth gimbal design having both rigid and flexible modes is given by [4],

\[
\frac{q + \delta \theta}{T}(s) = \frac{1}{s^2 + B} \left( s^2 + 2 \xi \omega_n s + \omega_n^2 \right)
\]

where,

- XYZ - inertial frame of reference
- X1,Y1,Z1 - azimuth gimbal frame
- \( \theta \) = azimuth servo angle
- \( T \) = torque of azimuth gimbal system
- \( I_1 \) = Motor of inertia of azimuth base structure
- \( B \) = viscous friction coefficient
- \( \xi \) = structural damping
- \( \omega_n \) = resonance frequency
- \( \omega_{n} \) = near-to resonance frequency
- \( \delta \theta \) = incremental angular deflection

The difference between the stiffness coefficients \( K_x \) and \( K_y \) of the azimuth gimbal determines the deviation of resonance frequency and near-to resonance frequency and hence the extent of coupling between the two modes.

B. Motor Modeling

Motors behave as actuators for driving the gimbal assembly. Fig. 3 shows diagram of a basic DC Motor with,

- \( L \) = armature inductance, \( R \) = armature resistance, \( V_a \) = armature voltage, \( i_a \) = armature current, \( e_b \) = back emf, \( \omega \) = angular speed, \( T \) = motor torque, \( J \) = load

Index Terms— Compensator, Gimbal assembly, Line-of-sight (LOS), PID
inertia, $K_t = \text{motor torque constant}$, $k_b = \text{back emf constant}$ and transfer function as [6]

$$T(s) = \frac{K_t}{L_s + R} \left( V_o(s) - k_b \omega(s) \right)$$  \hspace{1cm} (2)

$$w(s) = \frac{K_t}{sL + (R + K_b K_o)}$$ \hspace{1cm} (3)

II. PROBLEM STATEMENT

The stabilization of the given system is to be carried out for the given plant. In this paper, the plant under consideration consists of a gimbaled payload driven by a permanent magnet DC torque motor [8]. A servo power amplifier amplifies the controller output before being fed to the DC torque motor [1]. A dynamically tuned gyro is used to sense the inertial angular rate of the gimbal in azimuth. The random disturbance signal is simulated using a Band-limited white noise in conjunction with a low pass filter (LPF) with a cut-off frequency of 0.5 Hz [1]. The relevant parameters of the gimbal system are taken as $I_1 = 0.5 \text{ kgm}^2$, weight of payload = 35 kg, Load pole = 1 Hz, $\omega_n = 879.2$ rad/sec, torque rating = 3.5 nm (peak), $K_t = 0.786 \text{ Nm/A}$, $K_b = 0.786 \text{ V/rad s}^{-1}$, Gyro scale factor = 5.73 V/rad, $\omega = 628$ rad/sec, data acquisition resolution = 16 bits (maximum input = $\pm 10$ V), dead band due to friction = 10% of the peak torque, digital-to-analog converter resolution, 16 bits (maximum output = $\pm 10$ V), $L = 5 \text{ mH}$, $R = 12 \text{ ohm}$, $B = 3.14 \text{ N-m s/rad}$, servo Power Amplifier gain = 4.8 [8].

III. STABILIZATION OF THE GIMBAL SYSTEM

For LOS stabilization of gimbal system, Compensator and PID Controller are used.

A. Compensator

Fig. 5 shows the block diagram of LOS stabilization loop of the plant

**Step 1:** The first step in the stabilization loop
compensator design is to choose adequate gain so as to give a cut-off frequency of 315.50 Hz. The gain required is approximately 65.4 dB which translates to around 1949.844. Step 2: From the bode plot in fig. 6, it can be seen that the phase margin of the system is not adequate, leading to less than desirable damping ratio. Thus, a lead compensator with the transfer function given by (5) is designed. Overall system more accurate with transfer function given by (6). Nonlinearities and with nonlinearities is shown in fig. 7 and 8 respectively. The compensator output for disturbance attenuation is shown in fig. 9. The step response of the system without Step 3: A lag compensator is designed to make the

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B. PID Controller
Another technique used in this paper for LOS stabilization design is Proportional-Integral-Derivative (PID) control. The parameters are tuned using Zeigler-Nicholas tuning technique. The value of P, I and D used are P = 542.917, I = 11000, D = 0.7 with the filter coefficient, N = 15000.724. Figure 10 shows block diagram of LOS stabilization loop using PID. Figure 11(a) and (b) shows the step response of the system without nonlinearities and with nonlinearities. Figure 12 shows the PID controller output for disturbance attenuation.

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Table 1 shows the quantitative comparison of compensator and PID design based on LOS stabilization loops. Overall performance can be divided into two main categories, disturbance attenuation characteristics and dynamic time response [1]. PID control scores over Compensator Design. The disturbance attenuation of the system is better in the system with PID controller. In the absence of nonlinearities, plant clearly gives better characteristics when PID controller is used as compared to when compensator is used. In the presence of nonlinearities performance degrades remarkably for both the stabilization techniques. However, when the nonlinearities are present system slows down with large peak overshoot but settles down fast with zero steady state error with PID controller.

### Table 1 Results of compensator and PID controller

<table>
<thead>
<tr>
<th>Design Parameters</th>
<th>Without Nonlinearities</th>
<th>With Nonlinearities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Amplitude</strong></td>
<td><strong>Time (seconds)</strong></td>
<td><strong>Amplitude</strong></td>
</tr>
<tr>
<td>1. Percent Overshoot</td>
<td>20.8%</td>
<td>34.1%</td>
</tr>
<tr>
<td>2. Peak Error</td>
<td>0.25m</td>
<td>0.34m</td>
</tr>
<tr>
<td>3. Rise time</td>
<td>0.23m</td>
<td>0.34m</td>
</tr>
<tr>
<td>4. Setting time</td>
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<td>0.34m</td>
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<tr>
<td>5. Delay time</td>
<td>0.35m</td>
<td>0.34m</td>
</tr>
<tr>
<td>6. Steady state error</td>
<td>0.002</td>
<td>0.02</td>
</tr>
</tbody>
</table>

### CONCLUSION

LOS stabilization using lead-lag compensator and PID control is designed the gimbal system. Simulated results for both the designs are presented incorporating different nonlinearities in the system. The LOS stabilization using PID control gave better results when compared to lead-lag Compensator technique. The work can be extended for elevation gimbal assembly also. Controllers using modern design techniques like fuzzy, LQG/LQR can be used for better performance of the given system.

### REFERENCES