Comparison of Lead-Controller and Pid-Lead Controller to Control InnoSAT Attitude System

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Abstract
Space technology advancement is gaining popularity as it is one of the measures used to gauge a nation's level of development. One of the countries that is starting to develop into a nation involved in the exploration of satellite technology is Malaysia. Finding all appropriate prospective solutions is crucial. One of the problems that may occur in space is a satellite's position being altered by various events. The stability and orientation of a satellite can be controlled and maintained using an attitude control system (ACS). The Malaysian Innovative Satellite (InnoSAT) nano-satellite system can be stabilized by focusing on the control method. Therefore, the purpose of this study is to improve the three axes of the control system-Roll, Pitch and Yaw. Next, two control strategies for the InnoSAT system ACS have been proposed by this study: Lead Controller and PID-Lead Controller. The simulation was done using reference inputs composed of unit step functions. In comparison to the PID-Lead Controller, research has demonstrated that the Lead Controller successfully produces lower tracking performance. The key result of the study is that a PID-Lead controller

is more suitable for managing satellite attitude.

Keywords: InnoSAT, attitude control system, Lead Control, PID-Lead Control

1.0 Introduction

This document contains the guidelines for manuscript preparation and submission. Please adhere strictly to these instructions to assure smooth production of journal article. Please use this template in preparing your manuscript. Small satellites have gained popularity for study in recent years because of their affordability in terms of design, development, power use, and size. Because of this, the cost is minimal in every way. Technology has advanced so quickly that it is now possible to manufacture miniature satellites for use in daily life as well as for study. The smallest mini satellites are called Nano and Pico satellites. Mini satellites are classified into various tiers. The size and weight of these satellites are used to distinguish them from one another. The Innovative Satellite (InnoSAT), a type of nano satellite, was developed by the National Space Agency (ANGKASA) to pique Malaysian universities' interest in the field of satellite construction [1]. Attitude control systems (ACS) are essential for satellite operation as well as the achievement of mission goals. Years of continuous research into the satellite attitude control problem have resulted in the development of numerous potential solutions [2-3]. The attitude of satellites can be controlled using a variety of techniques, such as PID, Linear Quadratic Regulator (LQR) [3], Linear Matrix Inequality (LMI), gain scheduling/linear parameter change, and more. To enhance attitude control performance, artificial intelligence techniques like fuzzy logic [4-5] and neural networks [6-7] are also used. The Lead controller and PID controller have been chosen for this investigation for several reasons. A Lead Controller is a major and reliable way for creating traditional frequency-domain controls for continuous-time systems. The Lead Controller concept for laser missiles employing Bode plots was created to satisfy the required performance standards [8]. A PID controller can also output its input with the least amount of error feasible when it receives full state data. The usage of this control method with multivariable systems is also simpler and more user-friendly. In addition, by selecting a few parameters, the controller can be generated automatically. Researchers have created a simulation to examine the use of Lead controllers alone and in combination with PID controllers after researching the efficacy of Lead and PID Controllers. Following that, the PID Controller and Lead Controller combination to form PID-Lead Controller was used to ensure the output response's stability when considering perturbations [9-10].

2.0 Methodology

This research used Lead Controller and PID-Lead Controller as the control scheme. The transfer function needs to be converted into state space. This transfer function is represented by Roll (ϕ), Pitch (θ) and Yaw (ψ) such as in (1), (2) and (3) (Hashim et al., 2015).

$$\phi_{(s)}=\frac{s^2+0.3051s+0.2040}{s^4+1.1050s^2+0.1650} \quad (1)$$

$$\theta_{(s)}=\frac{1}{s^2-7.1138\times10^{-3}} \quad (2)$$

$$\psi_{(s)}=\frac{s^2-0.3051s+0.8088}{s^4+1.1050s^2+0.1650} \quad (3)$$

By (4) and (5) below, the general form of state-space is presented.

$$x_{k+1}=Ax_k+Bu_k+w_k \quad (4)$$

$$y_k=Cx_k+Du_k+v_k \quad (5)$$

A is the "state (or system) matrix," B is the "input matrix," C is the "output matrix," D is the "feedforward matrix," where x is the "state vector," y is the "output vector," u is the "input (or control) vector," and (in cases where the system model does not have a direct feedforward, D is the zero matrix). The equations (4) and (5) are also amended to include the state noise, w_k and measurement noise, v_k.

2.1 Lead Controller

The Lead controller is written in polynomial form:

$$C_L(s) = K_c \frac{s-z_o}{s-p_o} \quad (6)$$

Lead controller is when the magnitude of p_0 is greater than the magnitude of z_0. The Lead controller can move the root locus to the left in the complex s-plane. Therefore, this controller will be tuned to select the best performance of the output, the value of the Lead Controller where the denominator and denominator are set to 0.5 and 5 respectively.

$$C_L(s) = K_c \frac{s\mp 0.5}{s+5} \quad (7)$$

Hence, there is an increase in the stability of the ACS system and an increase in the response speed of InnoSAT.

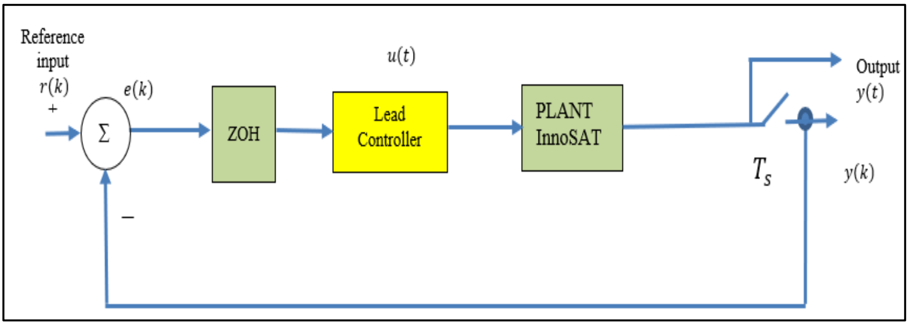

Figure 1: Block Diagram of a Lead Controller for InnoSAT Plant

2.2 PID-Lead Controller

The PID controller, which combines the benefits of each style of control, is the most widely utilized. This includes the advantage of the proportional controller's faster response time, which minimized offsets caused using both integral and derivative controllers. By adding using the integral control, this offset was eliminated. Because a derivative controller forecasts system disruption by analyzing the change in error, it improves the controller's reaction when used in tandem. The term PID describes its three main components, a proportional control term (KP), an integral control term (T_i), and a differential control term (T_{dd}).

$$G_{cPID}(s)=K_p\left(1+T_i s+\frac{T_{dd}s}{1+(T_{dd}/N')\,s}\right) \quad (8)$$

In this case, $\frac{T_{dd}s}{1+(T_{dd}/N')\,s}$ is set to T_d'. Hence, Equation (8) can be written as:

$$G_{cPID}(s)=K_p(1+T_i s+T_d') \quad (9)$$

The transfer equation can only be determined after tuning the PID controller using rule of thumb [2] [8]. Furthermore, the Lead Controller is also set to 0.5 and 5 respectively. The combination of PD and Lead (PD+Lead) Controller is then combined in series with the InnoSAT plant can be expressed as in Equation (10) where the value of Lead Controller is set the same as in previous controller:

$$G_{c_{PD}}(s) = K_p\left(1+T_i s+T_d'\right)\left(\frac{s+0.5}{s+5}\right) \quad (10)$$

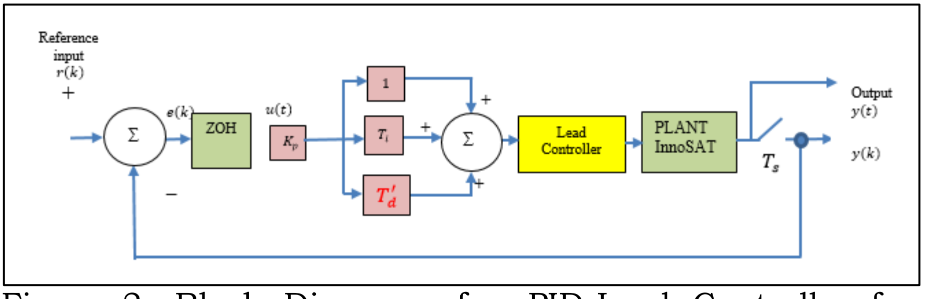

Figure 2: Block Diagram of a PID-Lead Controller for InnoSAT Plant

3.0 Results and Discussion

The step input was used to test the polynomial equations in equations (1), (2), and (3) resulted in the response outputs seen in Figures 3, 4, and 5. The response outputs for the three Roll, Pitch and Yaw axes show that the longer the time tested, the greater the error generated. This proves that the InnoSAT plant is unstable and requires a certain controller to stabilize its output.

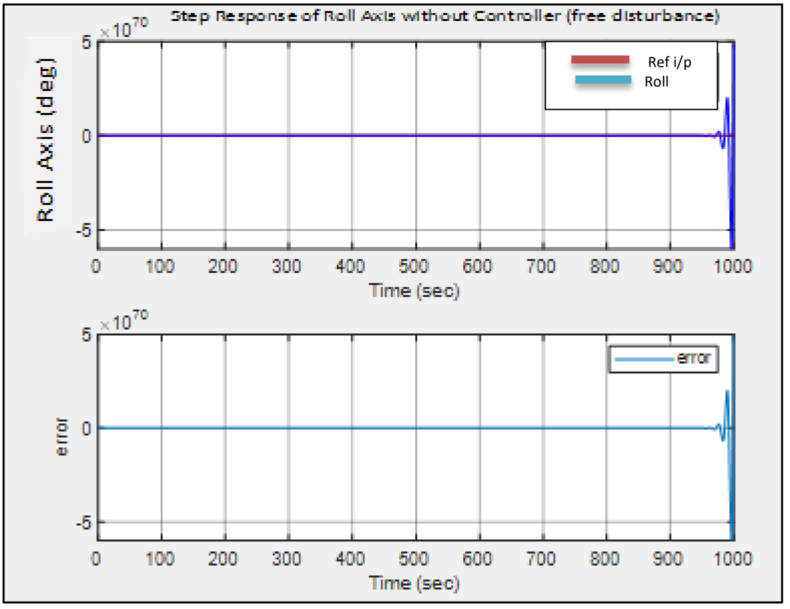

Figure 3: Step response for Roll axis of InnoSAT plant

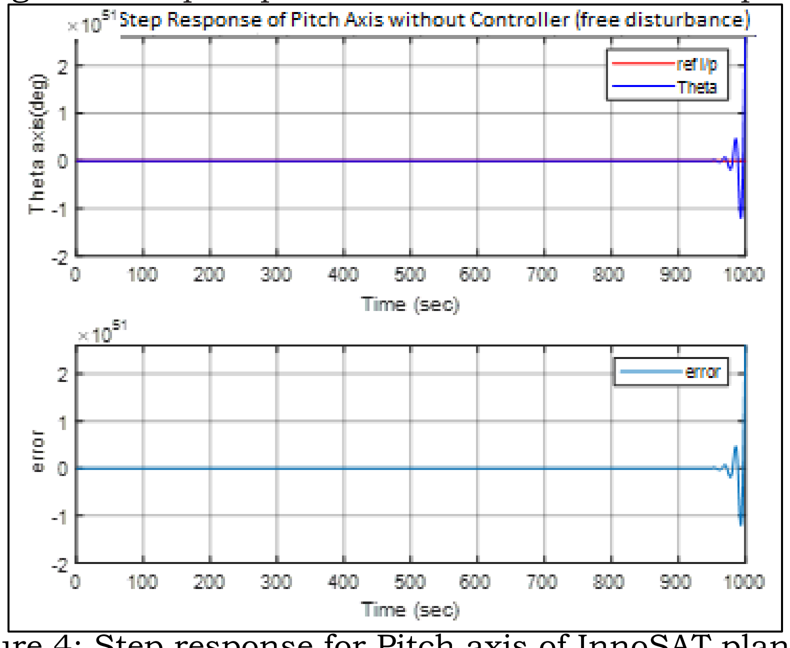

Figure 4: Step response for Pitch axis of InnoSAT plant

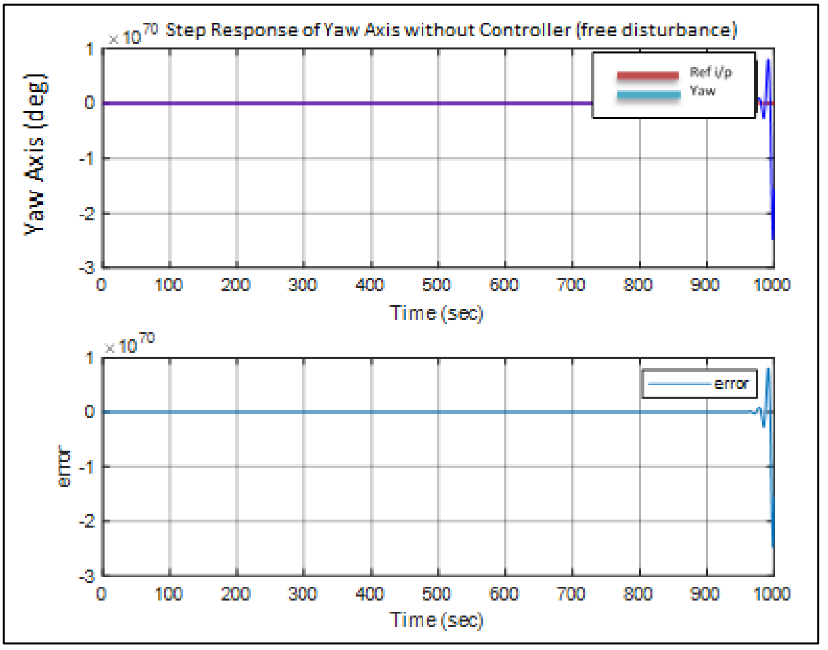

Figure 5: Step response for Yaw axis of InnoSAT plant

Based on the equations in the methodology section, a set of Matlab codes have been developed. Figures 6, 7 and 8 show the response output, $\hat{y}_{k|k-1}$ plots produced by Lead Controller and PID-Lead Controller for InnoSAT with no consideration on perturbation of Roll, Pitch and Yaw axes respectively. As shown in Figures 6, 7 and 8, the output response for both controllers tends to converge to zero. However, the actual value for the lead controller to converge to zero should not be determined because it takes too long to produce a steady-state condition as stated in Ogata (2002). The figures show that all three output responses can produce stable output over a relatively long period of time. It is concluded here that, although the Lead Controller has succeeded in producing a stable output, a controller still needs to be added to speed up the time for the output to converge to zero. Figure 6 shows the output response for the Roll axis which can produce a stable output over a relatively long period of time. There is still vibration at the beginning of the response period, but as the time increases, the error becomes less and more stable.

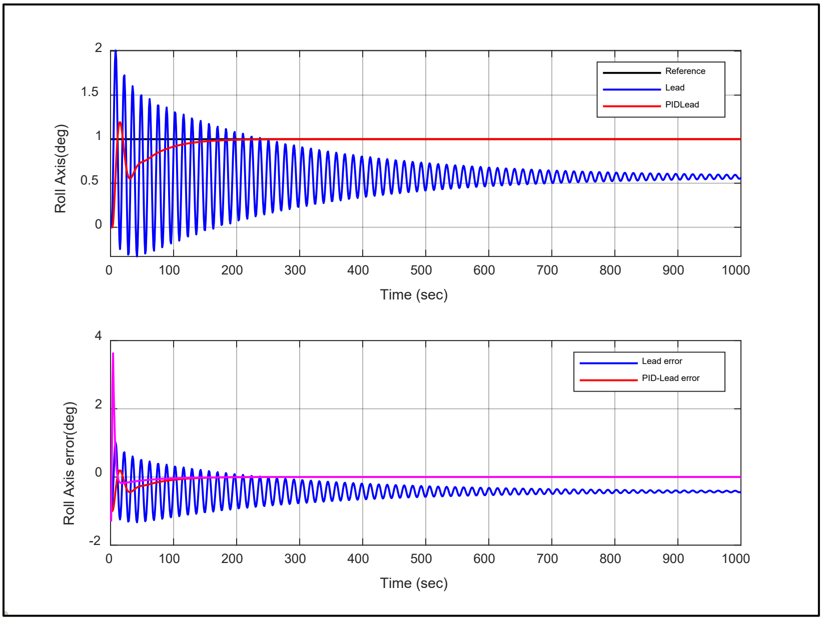

Figure 6: Comparison performance of Step Response for Roll axis with Lead Controller vs PID-Lead Controller

Figure 7 shows the output response for the Pitch axis which can produce a stable output in a faster period for both Lead Controller and PID-Lead Controller. Vibration only occurs at the beginning of the time and before the 100 second period, the output after that time has reached a stable state. Figure 8 shows the output response for the Yaw axis which is almost identical to the situation for the Roll axis. Output response can produce stable output but over a relatively long period of time. There is vibration at the beginning of the response period up to a relatively long period. However, it was found that there was an increase in the stability rate until the 400th second of the testing period. The output response becomes stable until the end of the testing period.

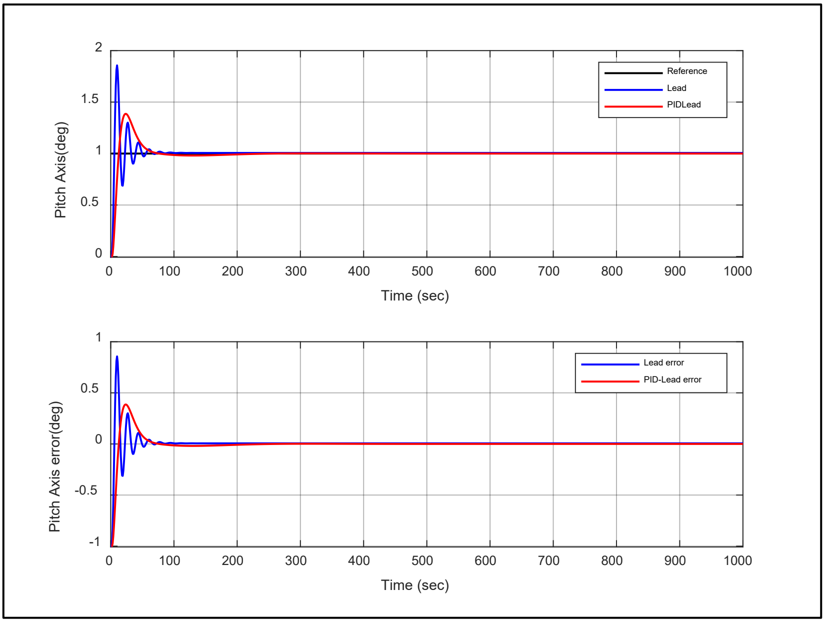

Figure 7: Comparison performance of Step Response for Pitch axis with Lead Controller vs PID-Lead Controller

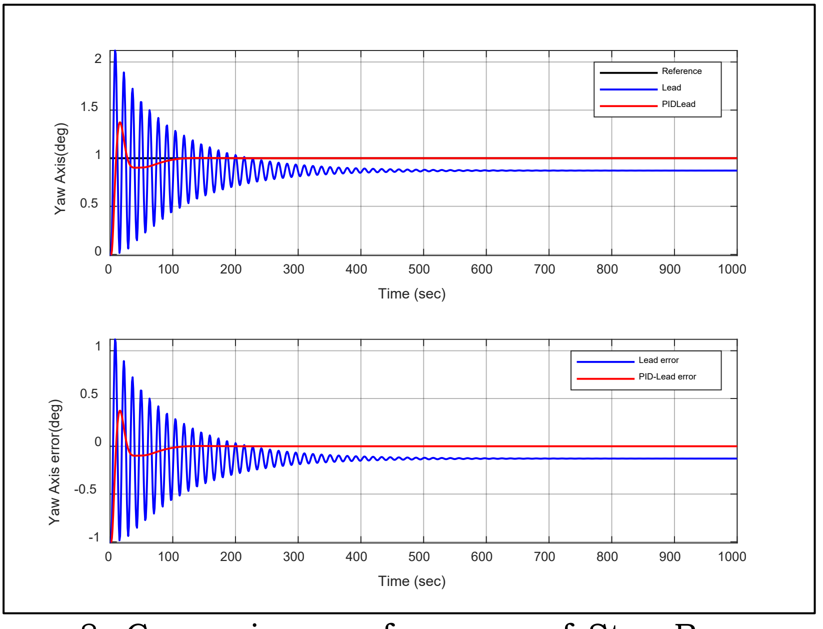

Figure 8: Comparison performance of Step Response for Yaw axis with Lead Controller vs PID-Lead Controller

After conducting tests on all three axes using the PID-Lead Controller, it was observed that the characteristics of the plant have improved as shown in Table 1. The rise time (tr) and delay time (td) have shown that the Yaw axis is the fastest while the percent of overshoot, the Roll Axis is the lowest while all axes show zero values for the undershoot condition. Based on Table 1, Pitch axis has reached the fastest Settling Time (ts).

Table 1: The Step Response Analysis of Roll, Pitch and Yaw Axes using a PID-Lead Controller

Characteristics of the System	Roll Axis	Pitch Axis	Yaw Axis
Rise Time (tr)	5.492s	7.444s	5.317s
Delay Time (td)	7.405s	7.804s	6.402s
% Overshoot	19.39	38.52	37.34
% Undershoot	0	0	0
Settling Time (ts)	158s	63.65s	96.46s

4.0 Conclusion

A simulation study for InnoSAT has been conducted to explore and illustrate the practical viability and performance of the proposed controller as well as the stability qualities achieved in this paper. The two types of controllers that have been built are Lead Controller and PID-Lead Controller. The PID-Lead Controller was determined to have a greater value when all three axes were inspected. Additionally, the output performance stability of the system during launch is good when the maximum overshoot value is less than 20%. For this controller, the shorter settling time is also clearly audible. As a conclusion, InnoSAT's attitude control system can be controlled by the PID-Lead Controller because its output performance has improved significantly for all three axes.

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Author Contributions
F. Hashim: Introduction, Methodology, Writing- Original Draft Preparation; **M. Y. Mashor:** Software; Supervision; **Z. Osman:** Introduction, Methodology; **N. H. Zainol:** Writing-Reviewing and Editing.

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