
A NOVEL INTELLIGENT-BASED CONTROL SYSTEM AND HYBRID CONTROL STRATEGIES FOR ENHANCED STABILITY OF MICROSATELLITE ATTITUDE

Adaobi Sochima Emekaoranebo*¹, Mbachu C.B², Iroh C.U.³

¹Department of Electrical Electronics Engineering, Federal Polytechnic, Oko, Anambra State.

²Department of Electrical Electronics Engineering. Chukwuemeka Odemegwu Ojukwu University, Uli. Anambra state.

³Department of Electrical Electronics Engineering, Abia State University, Uturu, Abia State.

Article Received: 22 January 2026

Article Revised: 11 February 2026

Published on: 03 March 2026

***Corresponding Author: Adaobi Sochima Emekaoranebo**

Department of Electrical Electronics Engineering, Federal Polytechnic, Oko, Anambra State.

DOI: <https://doi-doi.org/101555/ijrpa.7291>

ABSTRACT:

This study presents an innovative approach to enhancing the stability of microsatellite yaw-axis attitude control through the design and implementation of an intelligent-based control system. The research begins with an examination of the satellite attitude, emphasizing its importance in maintaining optimal performance amid various external disturbances. A mathematical model of the microsatellite's yaw-axis attitude control system is established, followed by the design of a fuzzy logic and proportional-derivative (Fuzzy-PD) controller. The system's performance is simulated using MATLAB/Simulink to assess transient and steady-state characteristics. Results indicate that the Fuzzy-PD controller significantly improves response time, maintaining a settling time below 2 seconds and achieving zero steady-state error, while preventing overshoot. Comparative analyses with existing control techniques demonstrate the proposed controller's superior reliability and robustness in meeting performance specifications. Consequently, this work contributes to advancing satellite attitude control systems by integrating intelligent algorithms, paving the way for further research in multidimensional satellite dynamics and other adaptive control techniques.

KEYWORDS: Microsatellite, stability, performance, fuzzy-PID, attitude, controllers, overshoot.

I. INTRODUCTION

Background to the Study

The satellite attitude is regarded as the orientation in space considering the different coordinate system (Mbaocha et al., 2016; Sullivan et al., 2007). The flight attitude of the satellite changes to different degrees during the on-orbit flight of a satellite because of external disturbances of and gravitational perturbation (Shan et al., 2022). These disturbances acting on the satellite can cause it to shift over time and the resulting effect can be angular (or degree) variation in pitch, yaw, and roll (Travis, 2020; Shan et al., 2022). Considering the fact that a satellite is exposed to varying disturbances, it is important to keep it at a preset position and a specified attitude so as to achieve desired function and performance criteria. Hence, for satellite to accomplish its task, it is very important to examine its control subsystem and then choose the control technique that provides improved transient or dynamic characteristics and steady-state performance for attitude adjustment and stability. This is because the performance of the satellite regarding meeting its expected tasks is directly determined by the effect of Satellite Attitude Control (SAC) (Shan et al., 2022).

Statement of the Problem

The flight attitude of a satellite will change due to varying angular variations in pitch, yaw, and roll caused by gravitational perturbation and external disturbance during the on-orbit flight of the satellite. Considering, most specifically, the fact that some satellites have defined observation tasks, the slight change of attitude angle of satellite through the orbit radius enlargement with respect to the displacement deviation cannot be neglected.

Aim and Objectives of the Study

The aim of this work is to enhance the stability of a microsatellite yaw-axis attitude using intelligent based control system. The specific objectives are to:

- 1.establish the mathematical model of a microsatellite yaw-axis attitude control system.
- 2.design an intelligent based controller for satellite yaw-axis attitude control system.
- 3.develop a model for the system and simulate it in MATLAB/Simulink environment.

Scope of Study

In this work, the mathematical model representing the dynamics of satellite yaw-axis will be presented. An adaptive control scheme will be designed. MATLAB/Simulink model of the satellite yaw-axis control system will be designed

II LITERATURE REVIEW

In this chapter, the environment in which satellites must operate in and energy conservation will be discussed in this chapter. Useful orbits such as Low Earth Orbit (LEO), Medium Earth Orbit (MEO) and Geosynchronous Earth Orbit (GEO) will be presented. Satellite attitudes are discussed. Empirical review of related work is presented including research gap.

Satellite Environment and Energy Conservation

Generally, the conditions existing above the earth's atmosphere is regarded as space environment. There is no predetermined condition to describe the edge of space given that the atmosphere gradually dissipates with increase in altitude (*Travis, 2020*). A classical definition for the edge of atmosphere marks the beginning of space to be 100 km above the surface of the earth (*Travis, 2020*). here is need for satellites to leave the relatively comfort or safety of the atmosphere so as to reach their missions' required altitude. The structure of a spacecraft or satellite with reference body coordinate frames with respect to pitch, roll and yaw-axis is shown in Figure 2.1.

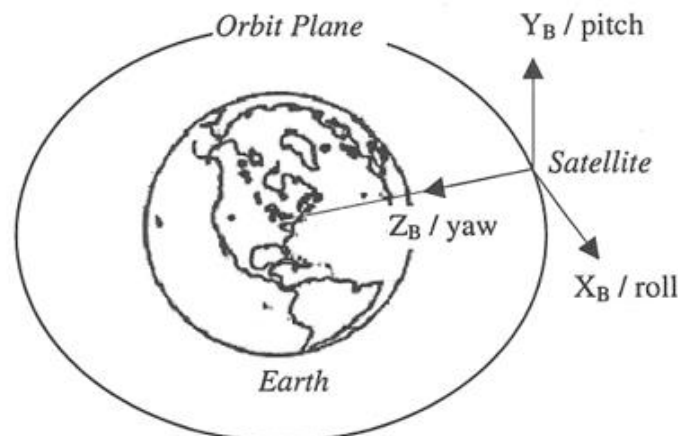


Figure 1.1 Satellite reference coordinate frames. (*Ouhocine et al., 2004*)

The greatest effect in the space environment is considered to be gravity (*Travis, 2020*). For the satellite, there other forces apart from gravity, acting on it such as drag, thrust, and force due to celestial bodies. The drag force is felt by satellite as it passes through the atmosphere. The rockets on the satellite generate thrust. Gravitational force can be imparted on the satellite by other celestial bodies such as moon and Jupiter.

Satellite Orbits

The various earth's orbits associated with satellite operation are described in this section. These orbits have been successfully used for space mission. Each of the orbits has its own peculiar advantages and disadvantages. Hence, choosing any of these orbits for space mission depends on the advantages that are critical and the disadvantages that can be overlooked. The inclined orbit representation of on-board satellite called OBITO and its open view are shown in Figures 1.2 And 1.3

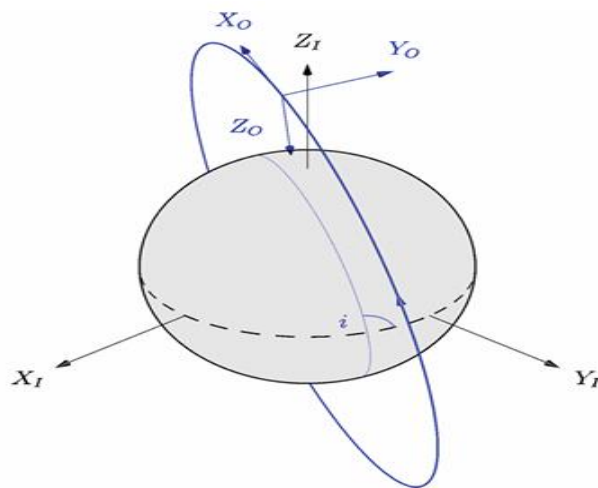


Figure 1.2 Inclined orbit representation of QBITO satellite together with orbit (X_o , Y_o , Z_o) (*del Castañedo et al. (2019)*)

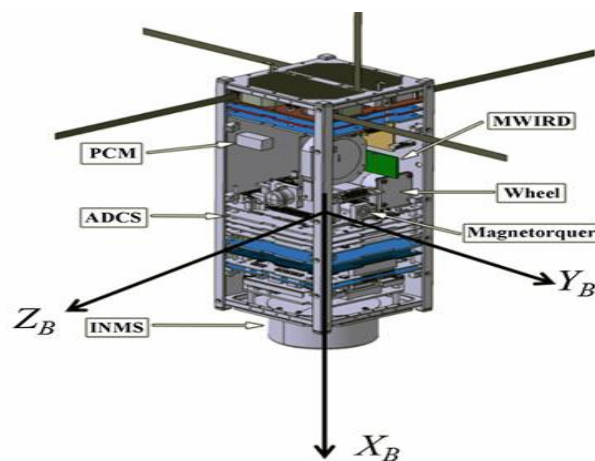


Figure 1.3 Open view QBITO with all payloads. (*Castañedo et al. (2019)*)

Low Earth Orbit

Low Earth Orbit (LEO) can be elliptical or circular orbits with an altitude between 160 and 6000 km. This orbit is useful for several reasons because of its relative closeness to the earth's surface (*Travis, 2020*). Compare to other orbits, the LEO orbit requires the least

amount of energy (smaller rocket) to put the satellite into orbit because it has the smallest size. In staying in LEO orbit, there are some compromises required.

Medium Earth Orbit

The Medium Earth Orbit (MEO) tends to be circular and with an altitude of nearly 20,000 km. Over a given area of the earth, the revisit times of the satellite are consistent and predictable because the altitude equates to a period of 12 hours (*Travis, 2020*). Putting satellites in this orbit, which is a higher altitude than LEO, provides larger footprint or coverage across the earth surface. This means that unlike in LEO where 60 + satellites may be required to cover the entirety of the earth's surface, few satellites (say 24) can be used to offer continuous coverage such as in Global Positioning System satellites (*Travis, 2020*).

Geosynchronous Earth Orbit

The entire earth surface can be seen by satellite at GEO. Hence, unlike the LEO and the MEO, only four satellites are required to give continuous coverage to the entire surface of the earth (*Travis, 2020*). The main drawback of GEO is problem of square radius losses of signals. This is due to the fact that the signals have to cross the vast distance to the surface.

Satellite Actuators

The requirement for actuators in satellite positioning depends on the mission. High pointing precision are required by satellites with optical payloads for a short-term time frame to meet the objectives of mission.

Reaction Wheel

The reaction wheel being accelerated by a flywheel produces torque. The direction of spin is dependent on the disturbance torque or the expected attitude. The flywheel angular acceleration is associated with the acceleration of the satellite body by angular momentum conservation and it is given by (*Moorthy 2019*):

$$I_{rw} \dot{\omega}_{rw} + I_s \dot{\omega}_s = \tau_d \quad (1)$$

where I_{rw} is the inertia of the reaction wheel, $\dot{\omega}_{rw}$ is the acceleration of the reaction wheel, I_s is the inertia of the satellite, $\dot{\omega}_s$ is the satellite acceleration, and τ_d is the disturbance torque. The design of the reaction wheels is such that during most of the mission operation, they rotate minimally and are able to predict disturbance torque. When active tracking of an

object is required by the satellite mission, the acceleration of the reaction wheels continues to change until the tracking maneuver is met. Figure 1.4 is cross-sectional view of a reaction wheel.

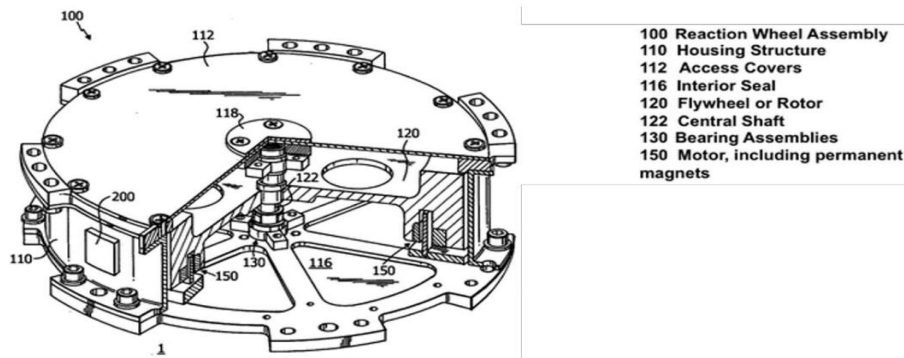


Figure 1.4: Illustration of cross-sectional view of a reaction wheel. (Leve et al., 2015)

The reaction wheel is gradually saturated by the incremental additional angular acceleration. When the reaction wheel is saturated, it will no longer be able to perform torque correction for the satellite attitude control since the current speed of the wheel surpasses the maximum predetermined value (Shen et al., 2015). According to this law, as a reaction wheel spins in one direction, the satellite rotates in the other direction. Therefore, an orthogonal arrangement of three reaction wheels provides 3-axis attitude control of satellite (Oland, 2018). Figure 2.5 is a typical reaction wheel design for CubeSats.

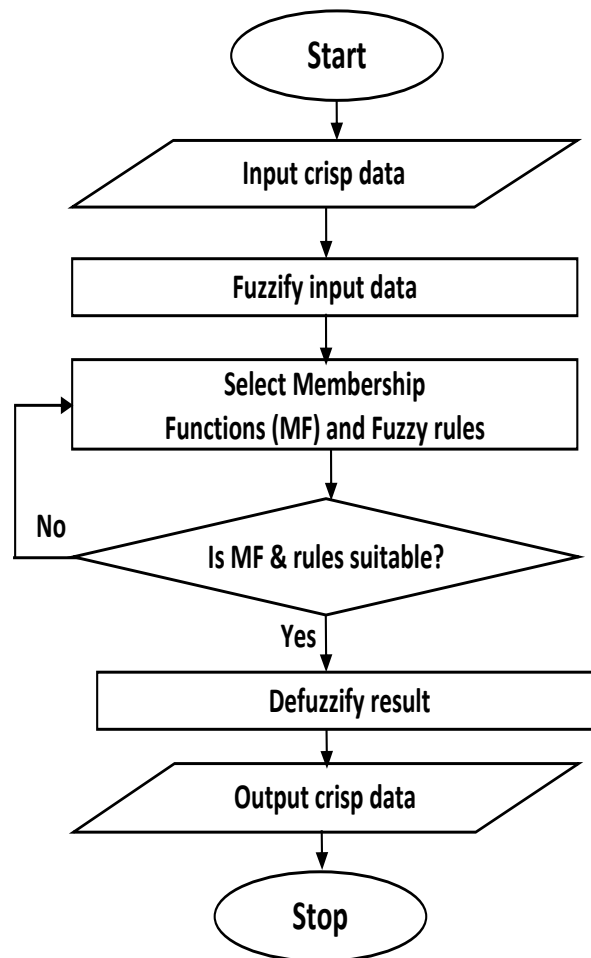


Figure 1.5 Flow Diagram of Fuzzy Logic Control Algorithm.

A typical fuzzy logic control system has at least two inputs and output. Fuzzy inference System (FIS) maps inputs-outputs using the member functions. A membership function (MF) is a shape that defines how each point in the input space is mapped to a membership values (or degree of membership) between 0 and 1.

Table 1.1: Comparison Between PD, Fuzzy PD, and Fuzzy Logic Controllers.

Feature Aspect /	PD Controller	Fuzzy PD Controller	Fuzzy Logic Controller (FLC)
Control Principle	Uses fixed mathematical relationship between error and derivative of error.	Combines conventional PD with fuzzy logic rules to handle nonlinearities.	Fully based on fuzzy logic using rule-based decision making.
Input Variables	Error (e) and rate of change of error (de/dt).	Error (e) and rate of change of error (de/dt).	Typically error (e) and change of error (Δe), but can include more inputs depending on design.

Output	A crisp control signal proportional to $K_p e + K_d(de/dt)$.	A fuzzy inference output adjusted using rule-based logic, producing a more adaptive control signal.	Fuzzy inference output based on a complete rule base; then defuzzified to yield the final control action.
Adaptability	Low – fixed gain values (K_p , K_d).	Medium – adapts using fuzzy rules while retaining PD structure.	High – fully adaptable to nonlinear systems and uncertainties.
Complexity	Simple implementation; easy tuning.	Moderate – requires defining membership functions and fuzzy rules.	High – requires full fuzzy inference system with fuzzification, rule base, and defuzzification.
Handling Nonlinearity	Poor; performance degrades with nonlinear or time-varying systems.	Better; fuzzy reasoning smooths transitions between control regions.	Excellent; designed specifically for nonlinear and uncertain environments.
Tuning Method	Manual or empirical (Ziegler–Nichols).	Fuzzy rule-based adjustment of K_p and K_d .	Based on fuzzy rule base and membership function optimization.
Robustness	Limited – sensitive to parameter changes and noise.	Improved robustness under parameter and disturbances.	Highly robust to disturbances and modeling uncertainties.
Computational Demand	Low – fast response.	Moderate – requires fuzzy inference calculations.	High – full fuzzy computation cycle per control step.
Typical Applications	Linear, predictable systems.	Semi-linear systems needing smooth transitions.	Highly nonlinear or uncertain systems (e.g., robotics, satellite attitude control).

II. Review of Related Works

There is critical demand for high-precision Satellite Attitude Control (SAC) and the need for satellite control technique that will ensure system reliability, stability and accuracy is becoming increasingly stringent considering the rapid development in aerospace industry (*Shan et al., 2022*); *Qi et al., 2022*). Linear control techniques that largely depend on feedback from output such as the classical Proportional Integral and Derivative (PID) controllers have been well implemented as subsystem for SAC. For instance, classical PID controller was used to meet performance specifications in yaw angle control of satellite system (*Mbaocha et al., 2016*). The PID controller was designed using the Ziegler-Nichols tuning method and it was introduced into the closed loop of satellite model for the determination and control of yaw-axis. The results of the simulation conducted in MATLAB

indicated that the PID controller provided settling time of 1.09 s and overshoot of 4.55% for the satellite attitude control system (SACS). Similarly, Hassan (2009) used PID controller in satellite attitude control system to achieve rapid settling time, reduced overshoot and zero steady-state error.

Integral Time Absolute Error (ITAE) based PID controller and Proportional and Derivative (PD) controller have been used for stabilizing attitude motion for microsatellite yaw-axis by Ajiboye et al. (2020). A fourth order microsatellite system was approximated by its second order version and used for design of ITAE based controller. This resulted in the design of reduced and higher-order pre-filter transfer functions. Four controllers were designed and are PID controller, PID with pre-filter (PIDf) controller, Proportional Derivative (PD) controller, and PD with pre-filter (PDf) controller. Simulation results revealed that the design specifications were met by the controllers except the PID controller. For the three controllers that met the design specifications, the PD control system outperformed the other controllers in terms of rise time (0.288 s against 0.365 s for PIDf and 0.332 for PDf), settling time (0.814 s against 1.17 s for PIDf and 0.887 s for PDf), and peak time (0.593 s against 0.761 s for PIDf and 0.706 s for PDf) respectively and it was recommended among the three by the authors because of its design and structural simplicity.

Shan et al. (2022) designed satellite attitude controller (SAC) based on PID control system and fuzzy-PID based control system. The kinematic model and dynamic model of satellite attitude were established. The PID controller and fuzzy-PID controller were used to carry out digital simulation of the SAC developed based on the mathematical model of satellite attitude. The results from the simulation analysis revealed that the system achieved steady state faster with PID than fuzzy-PID but with some torque oscillation whereas the Fuzzy-PID provided smoother and better stable transient and steady state response performance.). Classical PD controller was replaced with FLC for yaw-axis closed loop reaction wheel of LEO microsatellite attitude stabilization (Benzeniar and Fellah, 2014).

Portella et al. (2020) investigated the performance of a satellite in a circular orbit with four CMGs in pyramidal configuration either by employing Exponential Mapping Control (EMC) or Linear Quadratic Tracker (LQT) with integral compensator. The results indicated that the LQT has high settling time due to the use of only integral control algorithm without proportional and derivative schemes while the EMC showed faster but more oscillatory performance.

Bello et al. (2023) designed fuzzy Logic Controller (FLC), conventional PID controller, and adaptive PID controller that uses logic blocks that resets (or zeroes) the integral element

whenever change of sign in error function occurs were experimentally compared in a laboratory nanosatellite and its testing system with the results showing that using FLC rather than PID yielded significant improvement in energy consumption, convergence time and robustness in accordance to changes in environmental condition, which were the performance criteria including steady state error (accuracy). Thus, for 90-degree maneuver, the FLC yielded convergence time of 11.1 ± 2.4 s against 44.1 ± 12.2 s for PID and 17.9 ± 1.5 s for adaptive PID respectively. Also, for 179-degree maneuver, the FLC provided convergence time of 19.1 ± 1.7 s against 49.6 ± 21.0 s for PID and 30.8 ± 3.1 s for adaptive PID respectively.

Attitude stabilization was achieved using a reaction and two magnetic torquers with a multiple-input multiple-output (MIMO) fuzzy logic feedback algorithm for attitude control system (Shahmohamadi & Rezaeiha, 2012).

III. METHODOLOGY

System Design

In this section the description of a microsatellite is presented in terms of attitude closed loop control network.

Proposed System and Description

The proposed intelligent based control system for yaw-axis attitude is shown in Figure 1.5. The closed loop description of a microsatellite yaw-axis ACS studied in Ajiboye et al. (2020) is shown in Figure 1.5. It is a Single Input Single Output (SISO) linear time-invariant (LTI) system with unity feedback gain. With the block diagram arrangement, the microsatellite yaw-axis ACS can be vividly describe in very Simplified Manner.

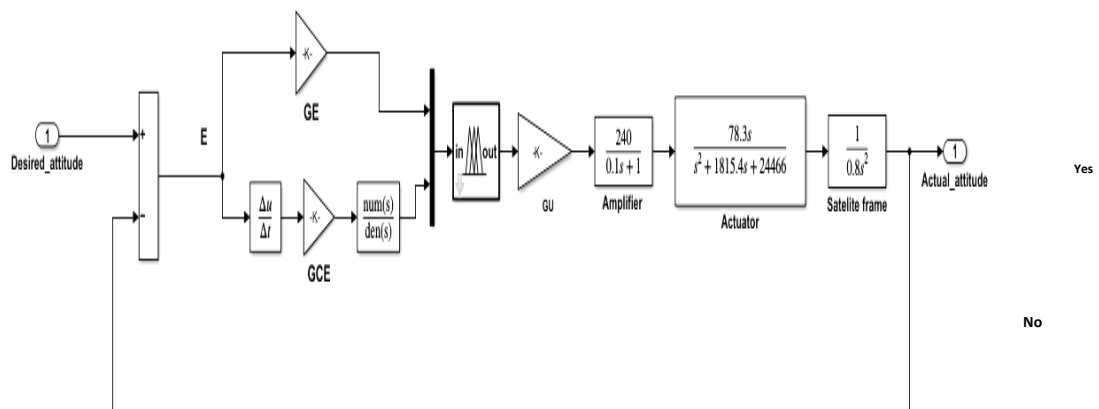


Figure 1.5 Proposed fuzzy-PD controller for microsatellite yaw-axis ACS.

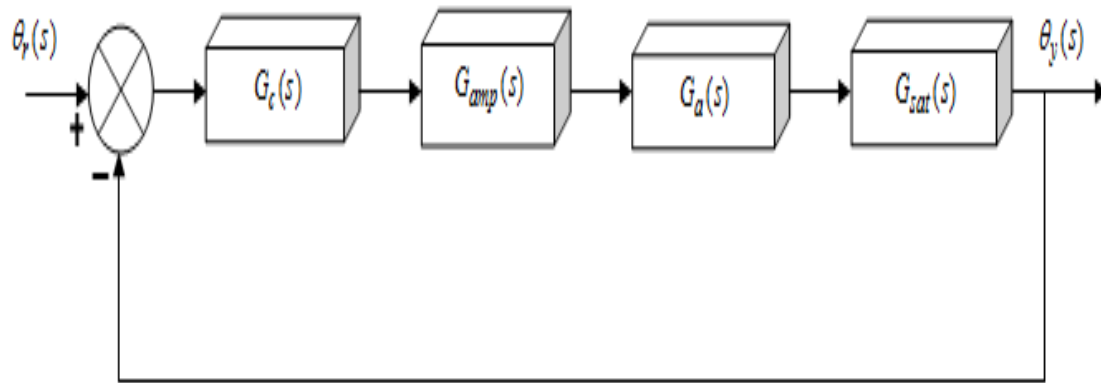


Figure 1.6 Block diagram of attitude control loop.

The dynamics of the amplifier, actuator and the satellite structure are determined in terms of transfer functions in Laplace form (s-domain) given by *Ajiboye et al. (2020)*:

$$G_{\text{sat}}(s) = \frac{1}{0.8s^2} \quad (3.1)$$

$$G_a(s) = \frac{78.3s}{s^2 + 1815.4s + 24466} \quad (3.2)$$

$$G_{\text{amp}}(s) = \frac{240}{0.1s + 1} \quad (2)$$

where $G_{\text{sat}}(s)$ is the satellite structure (plant) dynamic, $G_a(s)$ is the actuator dynamic, and $G_{\text{amp}}(s)$ is the amplifier dynamic. The MATLAB/Simulink model of the system (without controller) regarding Equations (3.1) to (3.3) is shown in Figure 3. 3.

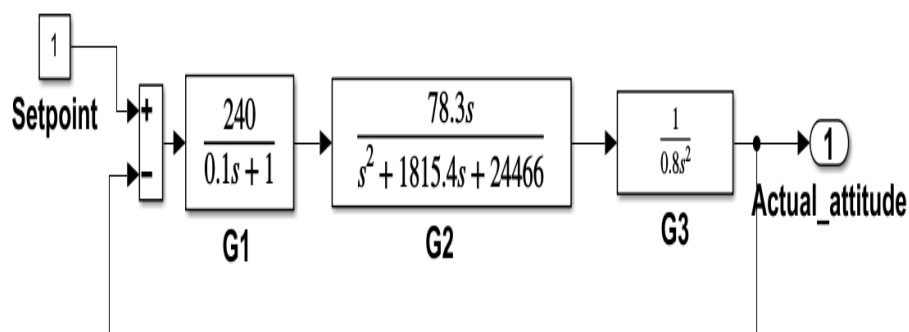


Fig. 1.7 System model without controller in MATLAB/ Simulink.

The cascade combination of Equations (1) to (3) gives the forward path gain expressed in Equation (for the closed loop system in Figure 3.2 neglecting the controller. Substituting the

numerical values of the transfer functions and using software (i.e., MATLAB) to compute Equation (3) gives Equation (4).

$$G(s) = G_{\text{amp}}(s) \times G_a(s) \times G_{\text{sat}}(s) \quad (3)$$

$$G(s) = \frac{18792s}{0.08s^5 + 146s^4 + 3410s^3 + 1.957 \times 10^4 s^2} \quad (4)$$

Equation (3.5) shows that the overall dynamic for yaw-axis attitude determination for the microsatellite is 5th order system considering the individual component (amplifier, actuator and satellite structure) transfer function. Thus, using the classical definition for transfer function of negative feedback closed loop control system (without the controller) in Equation (3.6), the numerical uncontrolled closed loop transfer function of the system is computed using MATLAB and it is given by Equation (5).

$$\frac{\theta_o(s)}{\theta_d(s)} = \frac{G_{\text{amp}}(s) \times G_a(s) \times G_{\text{sat}}(s)}{1 + [G_{\text{amp}}(s) \times G_a(s) \times G_{\text{sat}}(s)] \times H(s)} \quad (5)$$

$$\frac{\theta_o(s)}{\theta_d(s)} = \frac{18792s}{0.08s^5 + 146s^4 + 3410s^3 + 1.957 \times 10^4 s^2 + 18792s} \quad (6)$$

where $\theta_d(s)$ is the desired attitude (target yaw angle), $\theta_o(s)$ is the actual attitude (current yaw angle), and $H(s)$ is the unity feedback gain of the measurement sensor.

Performance Criteria

The objective is to design an adaptive controller with approximated second order reference model based PID controller to meet the following tracking specifications expressed as maximum overshoot ($M_p \leq 5\%$), settling time ($t_s \leq 2s$) with 2% criterion, zero steady-state error for a microsatellite yaw angle control system.

Controller Design

In this section, the approaches to design and subsequent implementation of the proposed intelligent based technique called Fuzzy Logic with Proportional and Derivative (Fuzzy-PD) controller are presented. Subsection 3.3.1 discussed the fuzzy logic control (FLC) design. The PD design is covered in subsection 3.3.2. Lastly, the proposed method, Fuzzy-PD is designed.

Fuzzy Logic Control Design

The structure of fuzzy logic control (FLC) system for the yaw-axis attitude of the microsatellite is shown in Figure 1.8.

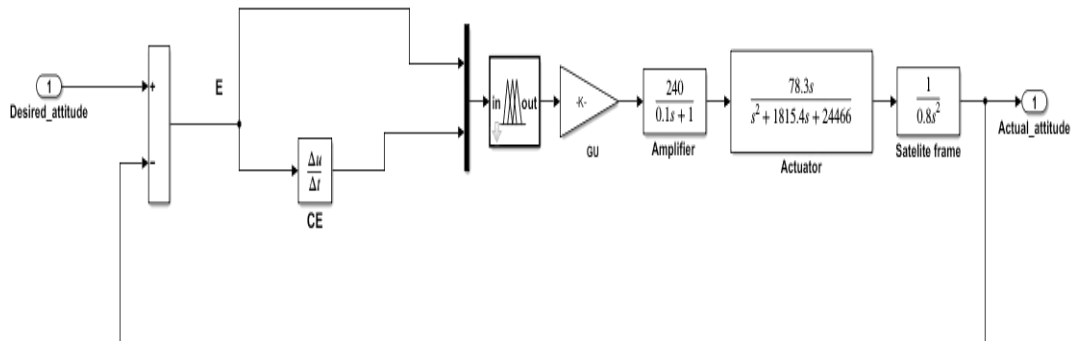


Figure 1.8 FLC system microsatellite yaw-axis attitude.

The system consisted of fuzzy logic algorithm with two input invariable, error (E) and change in error (CE), and an output U, which is the control variable that changes according to the changes in the inputs. The inputs-output relationship, represented by the linguistic variables that determine the control characteristics of the FLC according to the transformed crisp fuzzy input set by fuzzification. The linguistic variables-based relationship of inputs to output are listed in Table 3.1 and are defined as follows: Negative Large (NL), Negative Medium (NM), Negative (NE), Zero (ZE), Positive Large (PL), Positive Medium (PM), and Positive (PO). There are three Membership Functions (MFs) for each input and five MFs for the output. The total number of formulated rules for the designed FLC is nine.

Table 1.2 Rule table of fuzzy logic.

E/CE	NE	ZE	PO
NE	NL	NM	ZE
ZE	NM	ZE	PM
PO	ZE	PM	PL

Each input MF is graded as follows: NE = [-2 -1 0], ZE = [-1 0 1], and PO = [0 1 2]. For the output, each MF is sorted as: NB = [-1 -0.75 -0.5], NM = [-0.75 -0.5 -0.25], ZE = [-0.25 0 0.25], PM = [0.25 0.5 0.75], and PB = [0.5 0.75 1]. The inputs and the output were modelled by using triangular MFs. The shapes of the MFs and the rule viewer diagram representing the graphical illustrations of the algorithms of the designed FLC are shown in Figures 3.5 to 3.8.

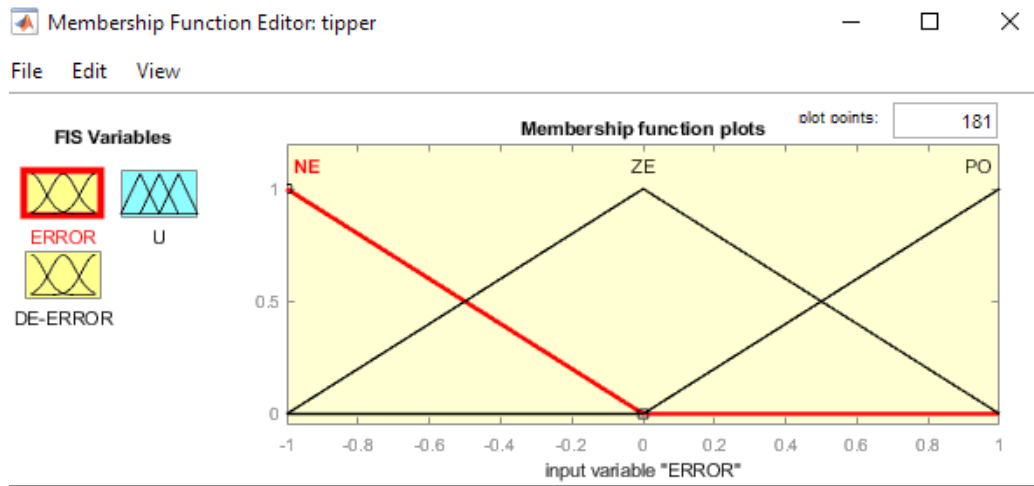


Figure 1.9 Membership function for error (E) input.

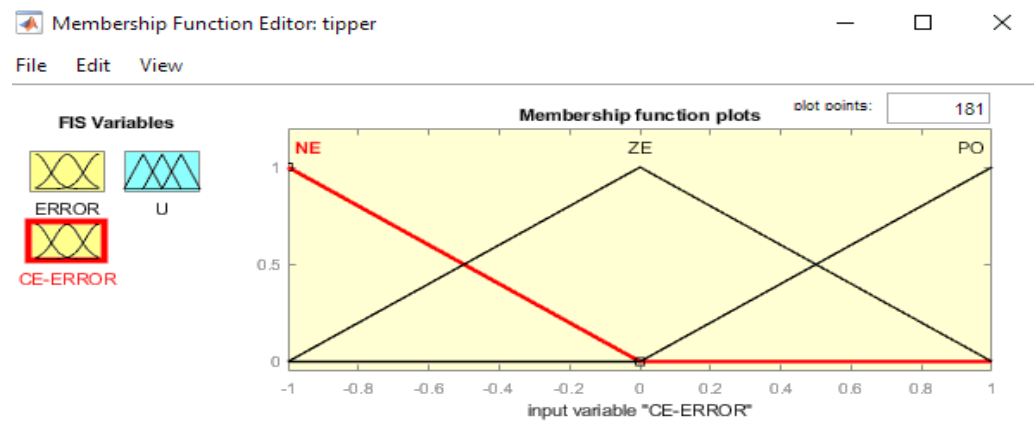


Figure 2.0 Membership function for change in error (CE) input.

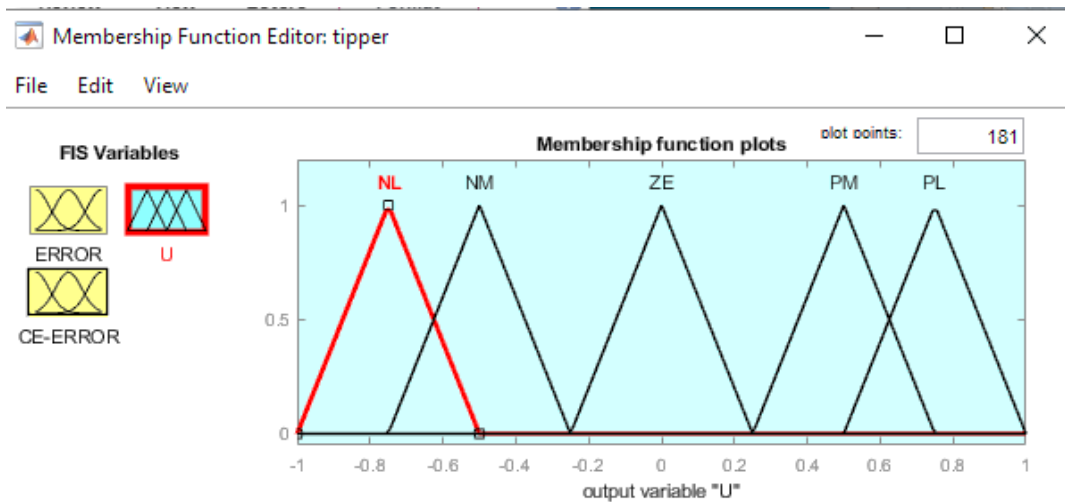


Figure 3.7 Membership function for control variable (u) output of FLC.

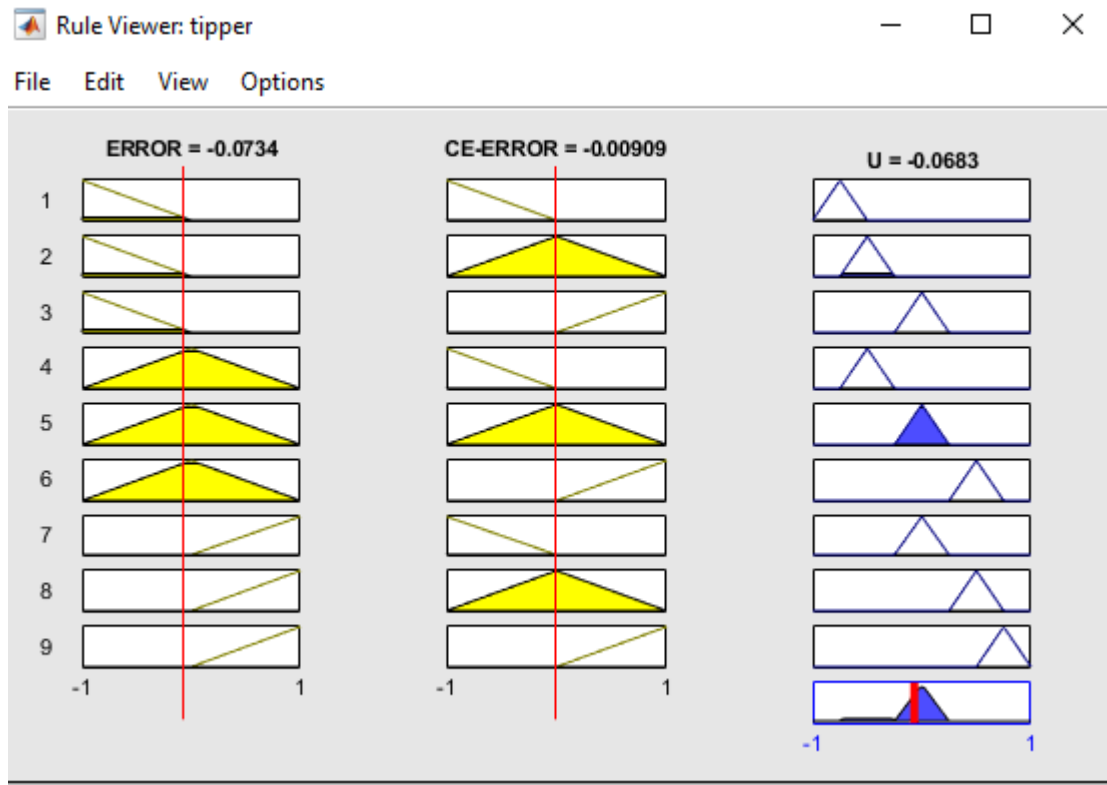


Figure 2.1 Rule viewer of the designed view.

Table 1.3 Tuned Parameters and Performance of the designed PID.

PID parameters	Value
Proportional gain, K_P	7.0716
Derivative gain, K_D	0.8041

Design of Fuzzy-PD

Now, the PD was introduced into the simplified closed loop structure of the FLC system in Figure 3.4. The tuned parameters of the designed PD were modified as in Equation (3.10) and combined with the FLC algorithm in Simulink.

$$\left. \begin{aligned} K'_P &= 1 \\ K'_D &= \frac{K_D}{K_P} = 0.1137 \end{aligned} \right\} (7)$$

The product of error E with the new proportional gain, K'_P , is represented by GE , and the product of the change or derivative of the error CE with the new derivative gain, K'_D , is represented by GCE . The product of the output U of the fuzzy with an optimally selected gain

corresponding to the initial proportional gain $K_P = 7.0716$, represents the GU as shown in the block diagram of the proposed system in Figure 1.1.

Simulation Parameters and Design Flowchart

The simulation parameters of the system are defined in Table 1.4. The values of these parameters are that of a microsatellite yaw-axis in *Ajiboye et al. (2021)*. Figure 3.10 shows the structure of the design flowchart.

Table 1.4 Dynamic parameters microsatellite yaw-axis attitude. (*Ajiboye et al., 2021*)

System	Parameter	Value
Satellite structure (frame)	Moment of inertial	0.800 kgm ²
Actuator	Actuator voltage	12 V
Amplifier	Amplifier gain and time constant	120, 0.25 s

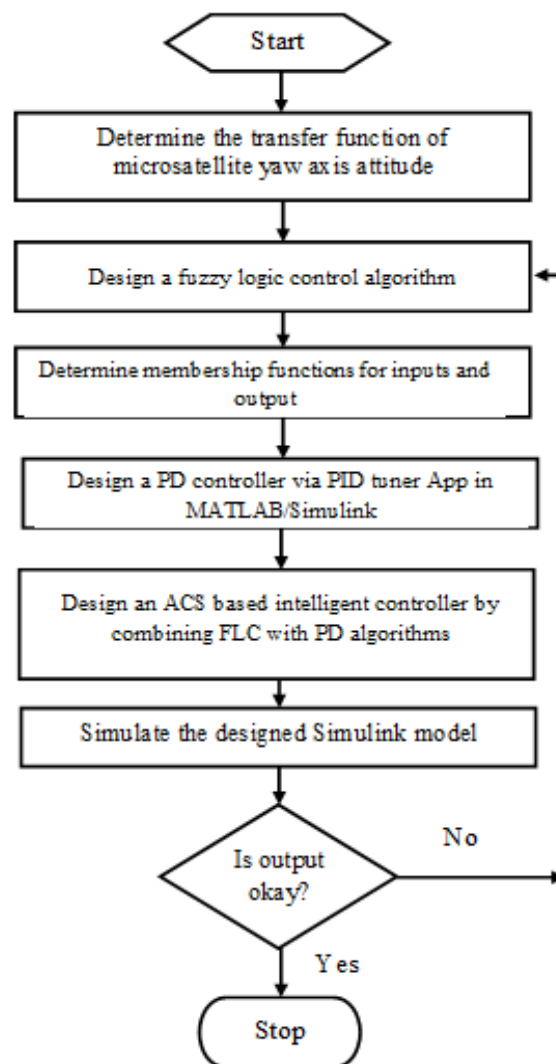


Figure 2.2 Design flowchart of the fuzzy-PD based yaw-axis ACS.

IV. RESULTS AND DISCUSSION

This chapter presents the results of the simulation analysis conducted in MATLAB/Simulink environment to investigate the performance of the designed Fuzzy-PD controller in terms of time domain transient response characteristics.

Simulation Analysis of System without Controller

In this scenario, simulation analysis was conducted to investigate the performance of the microsatellite yaw axis attitude in the absence of a controller. The resulting step response of the uncompensated satellite yaw-axis ACS is shown in Figure 2.2. The numerical analysis of the step response curve is shown in Table 1.5

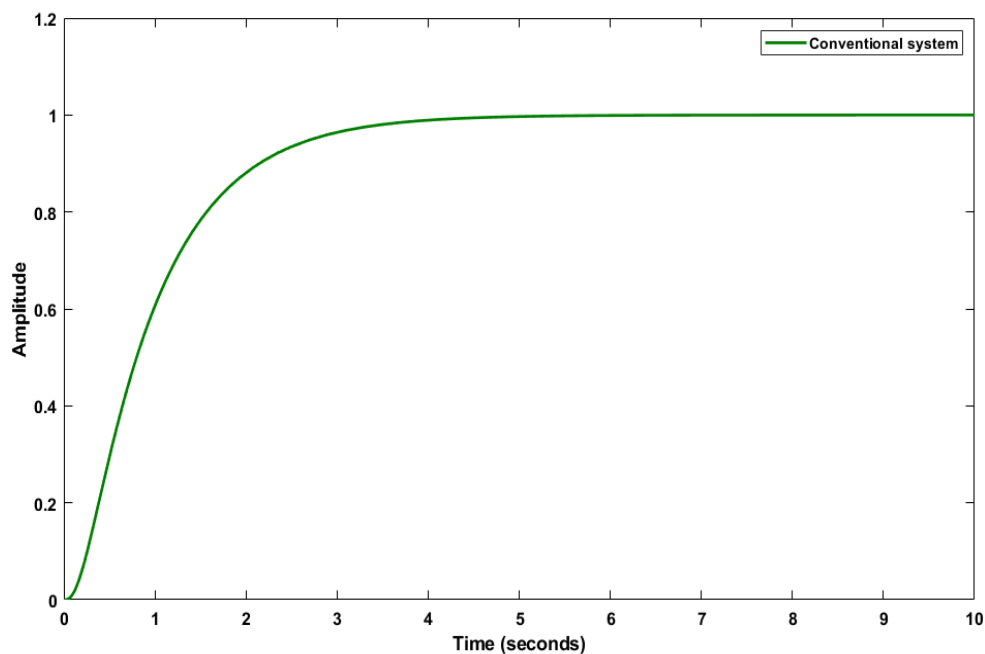


Figure 2.2 Step response of system without controller.

Table 1.5 Time domain characteristics of system without controller.

Step response parameter	Value
Rise time	1.89 s
Transient time	3.49 s
Settling time	3.49 s
Peak overshoot	0
Steady state error	0

Considering the step response shown in Figure 1.5, the numerical analysis as shown in Table 2.2 revealed that in the absence of a control algorithm, the system has a transient and steady-state that is characterized by rise time of 1.89 s, transient time and settling time 3.49 s respectively, peak overshoot of 0, peak time of 10 s, final value of 1 degree, and steady state

error of 0. As shown in Figure 4.1, the curve revealed that in the absence of a controller, the system response appears to be slow given the rise time and the fact that the system was not able to achieve the desired attitude at the predetermined convergence time (that is the stated settling time defined as the system performance criteria).

Simulation FLC System

This section presents the simulation scenario regarding the step response of the system when the fuzzy logic controller was introduced as a subsystem into the ACS. The simulation plot is shown in Figure 2.3 and the numerical analysis is shown in Table 1.6.

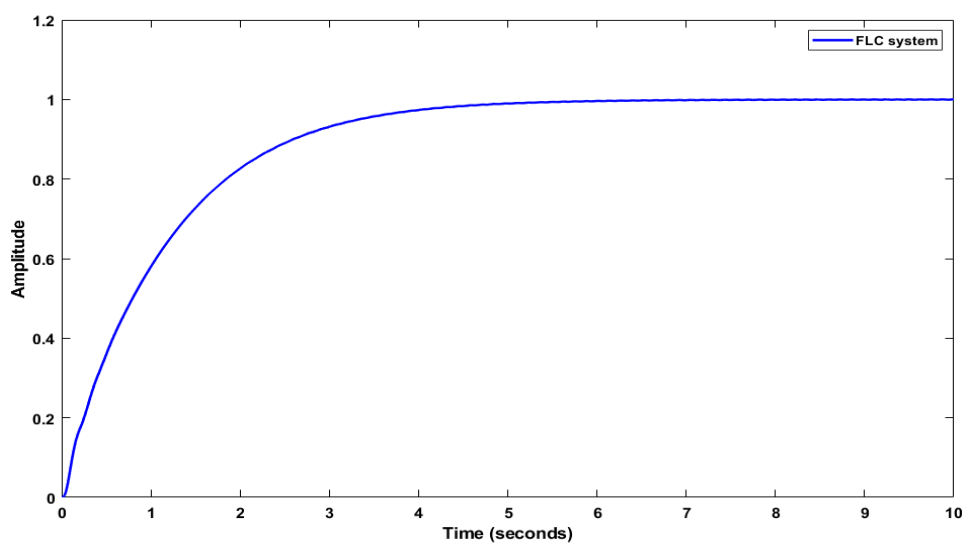


Figure 2.3 Step response of system with FLC system.

Table 1.6 Time domain characteristics of system with FLC controller.

Step response parameter	Value
Rise time	2.48 s
Transient time	4.29s
Settling time	4.29 s
Peak overshoot	0 %
Steady state error	0

Looking at Figure 2.3, it can be observed that step response of the FLC system achieve smooth response with overshoot of 0% as shown in Table 1.6. However, the settling is 4.29 and this is well above the required settling time in terms of the performance specifications. Hence, there is need to address the associated high-rise time with the FLC.

Simulation Analysis of PD Control System

This section presents the simulation scenario regarding the step response of the system when the PD controller was introduced as a subsystem into the ACS. The simulation plot is shown in Figure 2.4 and the numerical analysis is shown in Table 1.7.

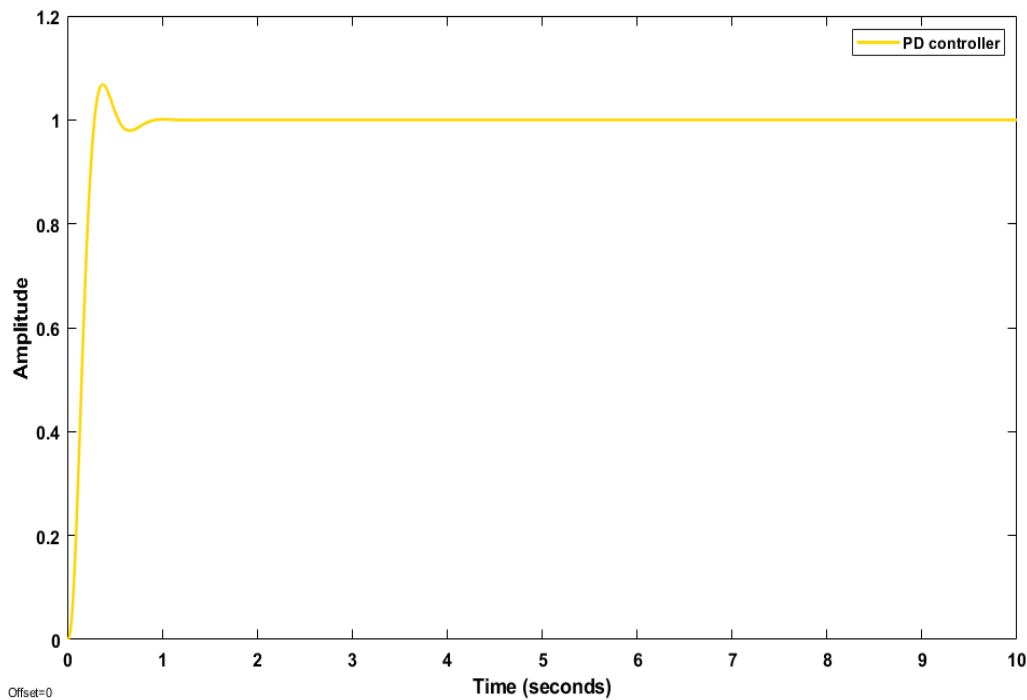


Figure 2.4 Step response of system with PD controller.

Table 1.7 Time domain characteristics of system with PD controller.

Step response parameter	Value
Rise time	0.18 s
Transient time	0.69s
Settling time	0.69 s
Peak overshoot	6.84%
Steady state error	0

Looking at Figure 2.4, it can be observed that step response of the PD control system overshoots the desired attitude by 6.84% as shown in Table 1.7. This is well above the required overshoot in terms of the performance specifications. However, except for the overshoot, the PD meets every other performance criteria required of the system. Thus, the the required peak percentage overshoot ($\geq 5\%$) was not achieved Hence, there is need to address the associated high overshoot with the PD controller

Simulation Analysis of Fuzzy-PD Control System

The simulation results are presented in this section in terms of the microsatellite yaw-axis attitude with the Fuzzy-PD controller in this work. The step response of the Fuzzy-PID control system is shown in Figure 2.5. The numerical analysis of the step response plots in terms of transient and steady state is listed in Table 1.8.

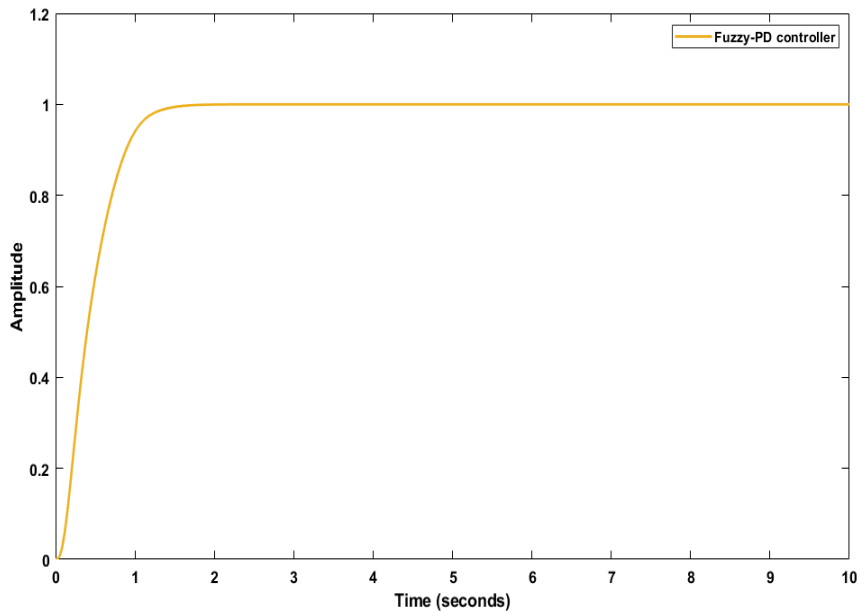


Figure 2.5 Step response of system with Fuzzy-PD control system.

Table 1.8 Time domain characteristics of system with Fuzzy-PD controller.

Step response parameter	Value
Rise time	0.7 s
Transient time	1.23s
Settling time	1.23 s
Peak overshoot	0%
Steady state error	0

Looking at Table 1.8, it can be observed that the Fuzzy-PD control system meets all the performance criteria of the design measured in terms of settling time of less than or equal to 2 s, peak overshoot of less than or equal to 5% with 2% criterion and zero steady state error. Thus, the designed intelligent based system, which was developed from the combination of FLC (intelligent algorithm) and conventional PD, met the stated performance or design specifications.

V. CONCLUSION AND RECOMMENDATIONS

Summary of Discussion

This work has presented enhancing the dynamic response and stability of microsatellite yaw-axis attitude using intelligent based control system. In order to realize the aim of this work, the dynamic equations representing the behaviour of a microsatellite yaw-axis in attitude control system were determined. The dynamic equations were then modelled using Simulink embedded blocks in MATLAB. An intelligent based control system was developed by hybrid combination of fuzzy logic and proportional and derivative algorithms to effectively provide command action for microsatellite yaw-axis ACS. The proposed control system was modelled and simulated in MATLAB/Simulink environment. The developed Fuzzy-PD controller offered provided efficient and smooth control process for yaw-axis ACS. The results from the simulation revealed that the proposed controller met the performance specifications of the microsatellite yaw-axis ACS.

Findings

The results have shown that classical control system based on PID control models such as the designed PD, can improve the dynamic response of system but their response are usually prone to high overshoot. Using fuzzy logic control alone can result in a system with slow response time and settling time, but is capable of eliminating overshoot. Thus, by exploiting the advantages of PID based model and fuzzy logic control, a hybrid controller such as the proposed Fuzzy-PD can eliminate the overshoot and enormously improved the response time and settling time of a control system.

Recommendations for Further Work

The proposed controller was developed and examined using MATLAB/Simulink. Since the pitch and the roll dynamics were not considered in this work, recommendations are made as follows for further work:

1. The effect of disturbance on the plant can be examined to further ascertain robustness of the Fuzzy-PD controller in providing effective control for the satellite structure in the presence environmental perturbation.
2. The Fuzzy-PD controller should be investigated with pitch, roll or both included as part of the microsatellite system to determine the ability of the technique to effectively provide complete control for microsatellite with respect to the three dimensions of the on-orbit flight dynamics.

3. It will be worthwhile to implement other control systems based on intelligent or machine learning algorithms to optimize the parameters of the PD controller.

Contribution to Knowledge

1. Control technique that uses combination of FLC and PD controller for microsatellite yaw-axis attitude control system (ACS) has been designed.
2. It has been shown by simulation analysis that hybrid model based on intelligent algorithm with classical system can be used to provide improved tracking performance of microsatellite yaw-axis ACS.

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