



Microsatellite Yaw-axis Attitude Control Using Fuzzy Logic Controller

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Abstract

Original Research Article

This paper presents microsatellite yaw-axis attitude control using Fuzzy Logic Control system. The mathematical models of amplifier, actuator, and satellite structure for determining the transfer function a microsatellite yaw-axis attitude were obtained. A FLC algorithm was developed. A MATLAB/Simulink model, which was computer-based model, was developed using the mathematical models of the closed control system. The FLC was introduced into the system, which resulted in settling time 4.29 s and zero overshoot, indicating the capacity to offer smooth transient response.

Keywords: Fuzzy logic control, Attitude control system, Microsatellite, yaw-axis.

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1. INTRODUCTION

Attitude in relation to spacecraft communication means to satellite's orientation in space. Attitude control can be defined as the control of the orientation axis of an on-orbit flight satellite. An on-orbit flight satellite is one that is orbiting in space. Therefore, ACS consists of set of components forming a system (with controller inclusive, which is a subsystem) that aids in analysing and control of satellite orientation in space. The main task involve in attitude control is to enable the accurate pointing of satellite antenna at a particular region of interest on the ground-based stations and solar panels towards the direction of the sun.

Generally, the description for attitude is presented from the perspective of angle instead of

distance. For satellite, attitude means angular rotation about the satellite's centred coordinate frame. There are three axes that are used to describe the attitude of satellite. These are: pitch, roll, and yaw. The angle corresponding to each axis is called roll angle, pitch angle, and yaw angle respectively. The roll angle is formed from the rotation about the x-axis, while the pitch angle and the yaw angle are formed from the rotation in y-axis and z-axis respectively.

The rotation of the satellite about the x-axis (roll axis) leads to North and South track motion considering an equatorial orbit. For rotation of satellite about y-axis (pitch axis), the track movement occurs East and West. In the case of rotation due to antenna tracking, the satellite movement is about the z-axis (yaw-axis). Important



parameters to determining the attitude control requirements are the accuracy and the rate with which the attitude is changing. The ability of a satellite to properly point or focus the emitted radiation towards an earth station (or desired target on the ground) is corresponds to its accuracy. This implies that regardless of the slight shift experienced by the satellite, it must be able to focus or centre the beam on the target. The emitted beam towards the target makes a cone. Thus, the accuracy of the attitude is measured by the angular size of the coned formed and this is called attitude accuracy. Therefore, the control objective is that the control system ensures that satellite properly operates so that the emitted beam is focused toward the target.

Considering the fact that attitude angles of a satellite can be put out of place due to various sources of natural disturbance such as the radiation pressure from solar, gravity gradient of the earth, and the magnetic field of the Earth; and because successful mission of a satellite depends on its ability to maintain a predetermined orientation with respect to the Earth (Nobari, 2013), several control schemes have been developed for stabilizing attitude motion. Jonathan and Emmanuel (2024) designed a classical continuous time compensator for microsatellite yaw-axis attitude control system (ACS) to meet the performance specification of a microsatellite with respect to its yaw-axis attitude (or angle) dynamics using a suitable control unit. Genetic algorithm (GA) optimized fuzzy logic control system was used for attitude control in nanosatellite by delCastañedo, et al. (2019). Eze and Ezenugu (2024) developed a Model Reference Adaptive Control (MRAC) based Proportional Integral and Derivative (PID) controller for microsatellite yaw-axis Attitude Control System (ACS). Achebe and Muoghalu (2025) designed an adaptive Proportional and Derivative (APD) controller for microsatellite y-axis attitude control system (ACS). The transfer function models of amplifier, actuator, and satellite structure for microsatellite yaw-axis attitude were obtained.

The most popularly used controller is the PID. These controllers have been largely employed in many studies relating to control system because of its associated simple structure and design simplicity including the ability to provide control effort for

system with complex dynamics. It has been used in the control of many processes such as pitch control (Okeya *et al.*, 2024), in improving the response of power electronics converter (Idam *et al.*, 2026), using Cascade Controllers for hard disk drive (HDD) positioning system (Onyekwelu *et al.*, 2023), in turning of compensator for robust transient response in engine's idle speed control (Eze *et al.*, 2017), to improve the response of two-phase hybrid stepper motor based control system (Onyeka *et al.*, 2019; Muoghalu & Achebe, 2021), enhancing the performance of chopper fed DC motor speed control (Muoghalu *et al.*, 2021), in human heart stabilisation system (Muoghalu *et al.*, 2024), combined with LQR in temperature control system, and positioning and tracking in robot manipulator (Ekengwu *et al.*, 2024; Okafor *et al.*, 2025), linear wheel slip control in antilock braking system (ABS) (Eze *et al.*, 2018; Ekengwu *et al.*, 2018), and for positioning control in electrical discharge machine (Eze *et al.*, 2017). Similarly, in satellite attitude control system, the classical PD control algorithm is widely implemented in satellite Attitude Determination Control System (ADCS) (Benzeniar and Fellah, 2014). For instance, PID has been advantageously considered for satellite yaw-axis ACS because of its rapid transient response and zero steady-state error (Hassan, 2009). Despite the advantages of classical PID controllers, their performances are largely affected by mismatch or parameter variation (Agwah & Eze, 2022). A Fuzzy Logic Control (FLC) system is developed in this paper.

2. METHODS

This section details the mathematical modelling of the microsatellite and the development of the FLC system.

2.1 Mathematical Modelling of the System

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):

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

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

$$G_{amp}(s) = \frac{240}{0.1 s + 1} \quad (3)$$

Where $G_{sat}(s)$ is the satellite structure (plant) is dynamic, $G_a(s)$ is the actuator dynamic, and $G_{amp}(s)$ is the amplifier dynamic. The cascade combination of Equations (1) to (3) gives the forward path gain expressed in Equation (4). Substituting the numerical values of the transfer functions gives Equation (5).

$$G(s) = G_{amp}(s) \times G_a(s) \times G_{sat}(s) \quad (4)$$

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

Thus, using the classical definition for transfer function of a negative-feedback closed-loop control system (without the controller) in Equation (6), the numerical uncontrolled closed loop transfer

function of the system is computed using MATLAB and it is given by Equation (7).

$$\frac{\theta_o(s)}{\theta_d(s)} = \frac{G_{amp}(s) \times G_a(s) \times G_{sat}(s)}{1 + [G_{amp}(s) \times G_a(s) \times G_{sat}(s)] \times H(s)} \quad (6)$$

$$\frac{\theta_o(s)}{\theta_d(s)} = \frac{18792 s}{0.08 s^5 + 146 s^4 + 3410 s^3 + 1.957 \times 10^4 s^2 + 18792 s} \quad (7)$$

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.

2.2 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.

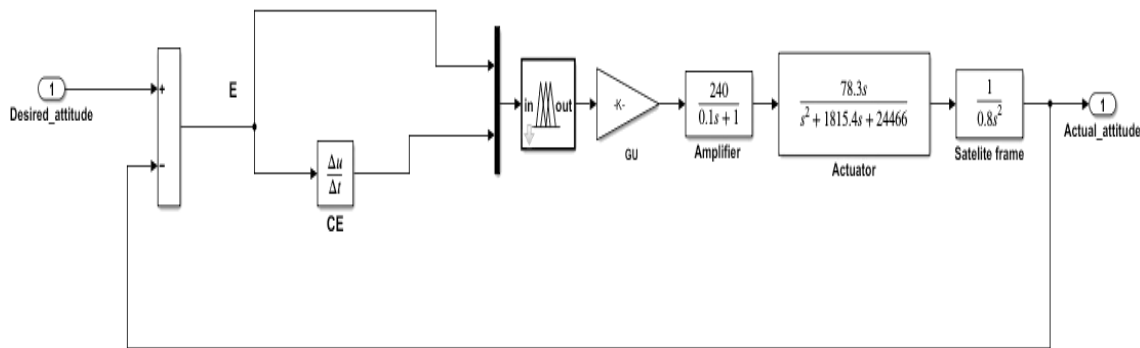


Figure 1: FLC system microsatellite yaw-axis attitude

The system consisted of fuzzy logic algorithm with two input variables, 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 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: 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 2 to 5.

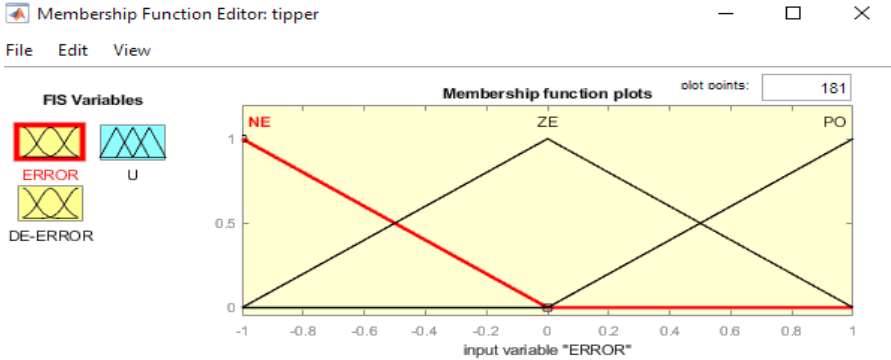


Figure 2: Membership function for error (E) input

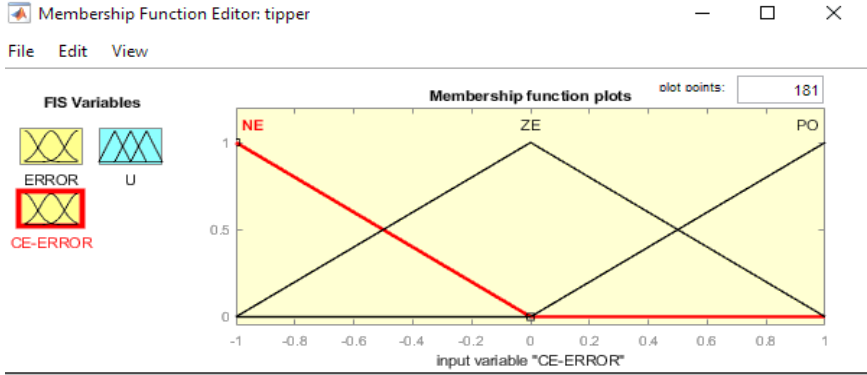


Figure 3: Membership function for change in error (CE) input

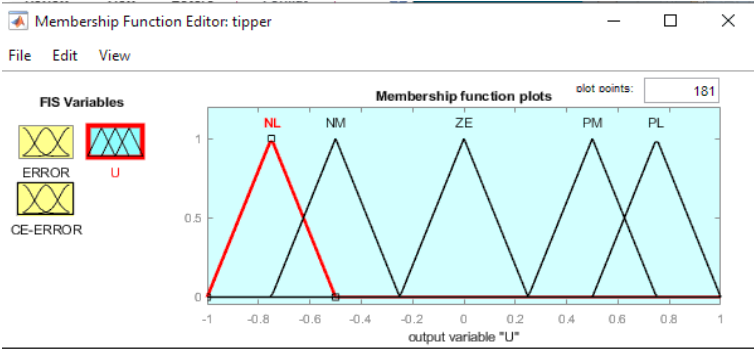


Figure 4: Membership function for control variable (u) output of FLC

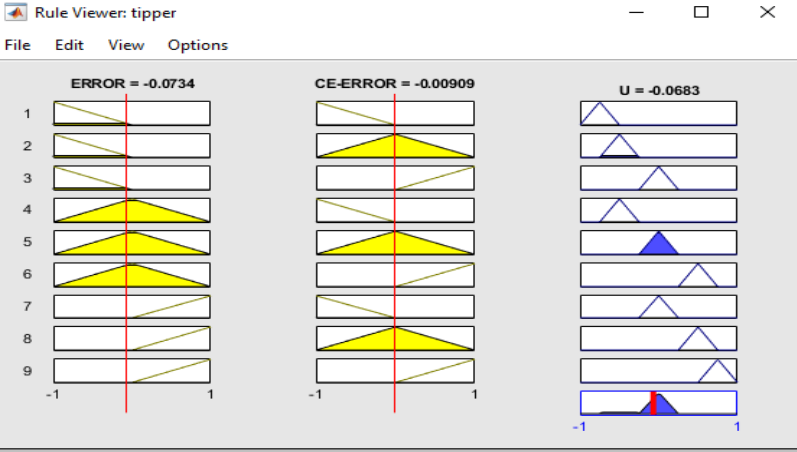


Figure 5: Rule viewer of the designed viewer

3. RESULTS

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 6 and the numerical analysis is shown in Table 2.

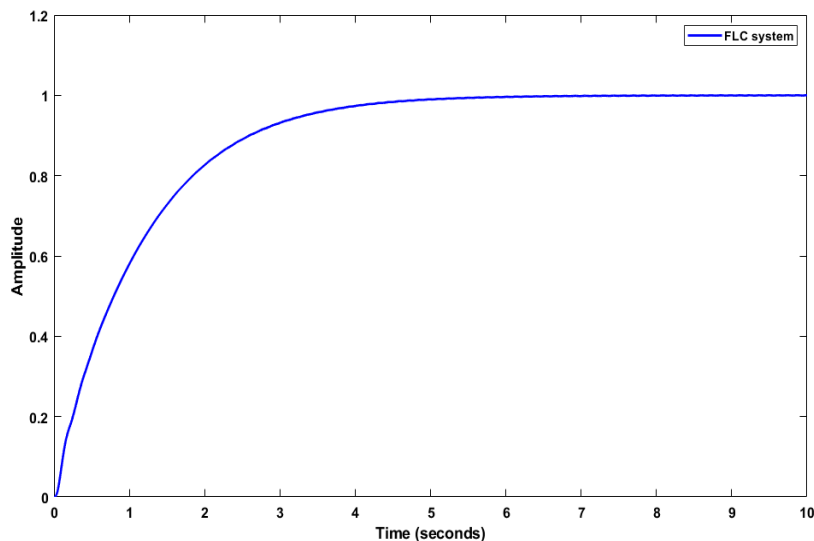


Figure 6: Step response of system with FLC system

Table 2 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 6, it can be observed that step response of the FLC system achieve smooth response with overshoot of 0% as shown in Table 2. 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.

4. CONCLUSION

This work has presented enhancing the dynamic response and stability of microsatellite yaw-axis attitude using FLC 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. A FLC system was developed using the Mandani fuzzy logic design method for microsatellite yaw-axis ACS. The proposed control system was modelled and simulated in MATLAB/Simulink environment. The developed fuzzy controller offered efficient and smooth control process for yaw-axis ACS.

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