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Enhancing the Performance of a Telemedicine Node Using Intelligent-Based Adaptive Mechanism

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Abstract

Reliable dish-antenna positioning is essential for satellite communication between healthcare personnel and patients through distributed mobile telemedicine nodes. However, the conventional Proportional–Integral–Derivative (PID)-based positioning system used on mobile telemedicine vehicles communicating via NigComSat-1R in Nigeria experiences performance degradation as communication delays increase and cannot adapt effectively to parameter variations, changing operating conditions, and nonlinear uncertainties. This study aims to enhance the performance of satellite dish-antenna positioning for distributed mobile telemedicine nodes using an intelligent adaptive control mechanism. A dynamic model of the antenna positioning system was developed, followed by the design of a Model Reference Adaptive Control (MRAC) method augmented with a Fuzzy Logic Control (FLC) algorithm, hereafter termed MRAC–FLC. The proposed controller was integrated into the positioning system and evaluated in a MATLAB/Simulink simulation environment. The conventional PID-controlled system exhibited a rise time of 85.9896 s and a settling time of 153.6396 s under communication delay. By comparison, the MRAC–FLC system achieved a rise time of 8.2215 s and a settling time of 16.1065 s. The proposed system also provided a smoother control response and improved overshoot performance compared with the conventional PID controller. These findings demonstrate that integrating MRAC with FLC substantially improves the transient response of the antenna positioning system. The enhanced response can facilitate faster antenna tracking and stabilization during satellite communication, thereby supporting more efficient information exchange in distributed mobile telemedicine services.

Keywords: Antenna Positioning Control; Distributed Mobile Telemedicine; Fuzzy Logic Control; Model Reference Adaptive Control; Satellite Dish Antenna

INTRODUCTION

Healthcare services leveraging Information and Computer Technology (ICT) is becoming more affordable, and available and has made quality delivery in rural area to be the same as obtainable in urban cities (Ibiyemi and Ajiboye, 2012b). Therefore, in developing countries such as Nigeria where there is heightened lack of medical personnel and prevailing healthcare delivery that seems to be at a low level, the integration and appropriate implementation of ICT as part of the health system can alleviate these challenges. One of the technologies that have been deployed as part of healthcare system to provide wide reaching effect in terms of providing quality healthcare delivery for rural areas or remote places is the telemedicine.

Telemedicine is one aspect of technology being increasingly deploy in healthcare services globally. Its introduction in healthcare delivery system in developing countries such as Nigeria can be a solution to a number of problems facing the healthcare sector. As result of distribution and mobility nature of telemedicine system including the large land mass of Nigerian geographical space, large propagation delay occurs during satellite communication between dish antenna nodes and this can lead to poor quality or instability in system performance if not compensated.

Many control methods have been developed in literature to enhance positioning system, such as in Muoghalu and Achebe (2025), Okafor *et al.* (2025), Onyekwelu, *et al.* (2023), and Eze *et al.* (2017). In antenna position control system several approaches have been used. For instance, Onyeka *et al.* (2018) used model predictive controller (MPC) to enhance the tracking response performance of parabolic antenna and achieved required specifications for different prediction horizon. The cost performance of a ground station satellite antenna was improved cascade compensator (Achebe, 2018). The use of PID controller compensated system to provide better performance than the uncompensated system in terms of reduction in dynamic response time domain parameters such as rise time, settling time, and peak time was demonstrated by Ajiboye *et al.* (2019). Eze *et al.* (2021) studied the use of PID tuned compensator for positioning control of direct current servomotor-based antenna. The study seeks to design a control scheme that will provide robustness and effective tracking for efficient azimuth positioning operation of a satellite antenna. The simulation results obtained showed that the proposed PID tuned compensator (PIDTC) was able to provide effective tracking and robust in the presence of disturbance. PID controller was designed to facilitate setpoint the tracking azimuth/elevation of satellite antenna for efficient line of sight operation in Muoghalu and Achebe (2021). Discrete time linear quadratic regulator (LQR)-based optimal control system was used to improve the positioning system of satellite antenna by Anyanwu *et al.* (2024). The effect of delay in position control of satellite dish antenna was reduced by improving the transient and steady-state response performance using full state feedback (FSFB) algorithm in Ekengwu *et al.* (2022). The performance response of mobile satellite dish antenna network was improved using PID plus pre-filter by Eze *et al.* (2020). Ekengwu *et al.* (2021) presented effect of Proportional Integral Derivative Tuned Digital Compensator (PIDTDC) on servo-based ground station satellite antenna positioning control system. High speed response performance was achieved in satellite antenna positioning system using back propagation neural network (BPNN) based proportional integral and derivative (PID) controller (Eze *et al.*, 2024a).

Considering the control systems reviewed, PID controller and its augmented form have been the most frequently used technique used in motorized parabolic dish satellite tracking application including other servo based control systems such as in chopper fed DC motor speed control (Muoghalu *et al.*, 2021), industrial belt conveyor system (Muoghalu *et al.,* 2025), and positioning and trajectory tracking in robot manipulator (Okafor *et al.*, 2025). Also, implemented in combination of other control algorithm such as LQR (Ekengwu *et al.*, 2024) to achieve optimal method. However, the issue of parameter variation and susceptibility to distortion has been largely reported with PID in literature. This is largely due to its low cost and the ease of implementation. Hence, this paper proposes intelligent based adaptive controller that will be able to adapt or adjust the parameters of dish antenna positioning control system so as to force the antenna position to follow or behave like an ideal positioning (reference) model.

METHODS

System Modelling and Configuration

The dynamic characteristics of the dish antenna considered in this work are represented by mathematical equations in the following subsections.

Determination of Time Delay

The overall travelled distance of the signal divided by the electromagnetic wave speed (speed of light) is equal to the estimated round trip. The distance, d_{sr} between an earth station and geostationary satellite is given by (Ajiboye *et al.*, 2019; Ibiyemi and Ajiboye, 2012a and 2012b):

$$d_{sr} = \sqrt{D^2 + R^2 - 2DR\cos(\alpha_{sn})\cos(\Delta_{sn} - \Delta_s)} + \sqrt{D^2 + R^2 - 2DR\cos(\alpha_{rn})\cos(\Delta_{rn} - \Delta_s)} \quad (1)$$

where Rstands for the radius of the earth in Km, D is sum of the radius of the earth and altitude of the satellite in Km, $\Delta_s$is the angle of longitude of the sub-satellite point, α_{sn} is the latitude of the sending node location on the earth surface in degree, α_{rn} is the latitude receiving node location on the earth surface in degree, and Δ_{sn}, Δ_{rn} are the longitudes of the sending node and receiving on the earth surface in degrees respectively.

In order to determine the time delay resulting in transmitting signal from the sending node (antenna) to receiving node, the distance between the transmit node and receive node is divided by signal speed and is given by Ibiyemi and Ajiboye (2012a):

$$T = \frac{2d_{sr}}{v} \quad (2)$$

where $v = 3 \times 10^8$ms^{-1}speed of light.

The determined minimum and maximum time delay range was between 0.2461 s at latitude 4.3°N and longitude 2.73°E of the Gulf of Guinea and 0.2496 s at latitude 13.91°N and longitude 14.94°E of the Lake Chad (Ibiyemi and Ajiboye, 2012a) respectively.

Dish Antenna Dynamic

The mathematical expression representing the dynamic characteristics of the dish assembly is given by Eze *et al.* (2020) and Eze *et al.* (2024a):

$$I_A \frac{d^2\theta_A}{dt^2} + B_A \frac{d\theta_A}{dt} + \tau_A \theta_g \quad (3)$$

The Laplace transform of Equation (3) assuming the initial conditions are zero, which represents the model of the dish structure in transfer function is given by Eze *et al.* (2020) and Eze *et al.* (2024a):

$$\frac{\theta_A(s)}{\theta_g(s)} = \frac{\tau_A/I_A}{s^2+(B_A/I_A)s+(\tau_A/I_A)} \quad (4)$$

where $\theta_A$stands for angular displacement of dish in radian, $\theta_g$is the gear output shaft angular displacement in radian, $I_A$is the moment of inertia of the dish about an axis of value 140.60 Kgm^2, $B_A$is the damping coefficient of value 126.78 $Nmsrad^{-1}$, $\tau_A$is the torsional spring stiffness of value 317.5 $Nmrad^{-1}$. Putting these figures into Equation (4) gives:

$$G_A(s) = \frac{2.2578}{s^2+0.9016s+2.2578} \quad (5)$$

The transfer function of actuator motor and gear ratio is given in Eze *et al.* (2020) and Ibiyemi and Ajboye (2012a) by:

$$G_m(s) = \frac{0.075}{s(0.015s+1)} \quad (6)$$

$$K_g = 0.033 \quad (7)$$

Time Delay Model

The time delay is expressed as transfer function for both forward and feedback paths expressed by:

$$\left.\begin{array}{l} G_{d1}(s) = e^{-T_1 s} \\ G_{d2}(s) = e^{-T_2 s} \end{array}\right\} \quad (8)$$

where T_1forward path time delay from base station to the dish antenna (or mobile node) in seconds and $T_2$is the feedback time delay from the dish antenna to the base station.

Taking the forward path time delay to be equal to feedback time delay then Equation (8) can be rewritten by:

$$G_{d1}(s) = e^{-T_1 s} = G_{d2}(s) = e^{-T_2 s} = G_d(s) = e^{-Ts} \quad (9)$$

For the simulation, the maximum time delay 0.2496 s was used since it is the worst case delay (Ajiboye *et al.,* 2019). Thus, the system model in MATLAB/Simulink environment is shown in Figure 1 and the closed loop transfer function is given by Equation (10).

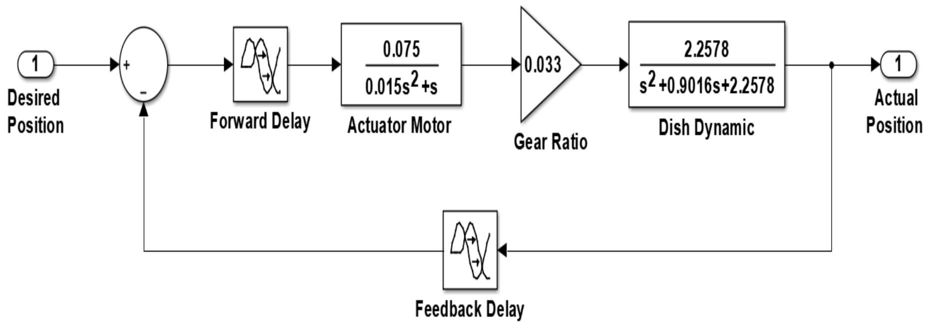

Figure 1: Closed loop Simulink model of dish antenna system

$$G_p(s) = \frac{\theta_A(s)}{\theta_r(s)} = \frac{3.76e^{-Ts}}{s^5+67.56s^4+62.36s^3+150.52s^2+3.76e^{-Ts}} \quad (10)$$

Controller Design

In this section, a model reference adaptive controller (MRAC) is designed. Many approaches are used in the design such as Lyapunov theory, augmented error theory and Massachusetts Institute of Technology (MIT) rule. In this work, a MRAC is developed using the MIT technique.

Designing the MRAC using MIT requires that the error and cost function be established as follows:

Adjustment Mechanism

Let the difference between actual output of the process and the reference model $\theta_m$output be defined as the error, e given by:

$$e = \theta_A - \theta_m \quad (11)$$

The cost function $\theta_c$is expressed in terms of the error in Equation (11) and is given by:

$$J(\theta_c) = \frac{1}{2}e^2 \quad (12)$$

Minimizing the cost function such that the change in the parameter $\theta_c$can be maintained in the direction of the negative gradient of J given in Eze *et al.* (2017) and Eze *et al.* (2024b) as:

$$\frac{d\theta_c}{dt} = -\gamma \frac{\partial J}{\partial \theta_c} = -\gamma e \frac{\partial e}{\partial \theta_c} \tag{13}$$

Equation (13) is an expression of the change in $\theta_c$with respect to time in order to able to minimize the cost function to zero. The expression $\partial e/\partial \theta_c$is called the sensitivity derivative, which depicts the change in error *e* with respect to the cost function J**.** The quantity γ is a positive value that represents the gain of the adaptation mechanism of the controller.

Now the objective is to design a reference model defined characteristic performance that the dished antenna position system will automatically followed or tracked irrespective of the variations in system or environment parameters.

Let the transfer function of the dish antenna system be equal to $KG_p(s)$ where K is a parameter whose value is unknown. Also, let the reference model be approximated to a second order transfer function considering the dish antenna structure in Equation (5). Thus the reference model is defined by:

$$G_m(s) = K_o G_p(s) \tag{14}$$

where K_o is a parameter, whose value is defined, thus the error, Equation (11) can be expressed by:

$$E(s) = KG_p(s)U(s) - K_o G_p(s)U_c(s) \tag{15}$$

where $KG_p(s)U(s) = \theta_A$ such that the control input to the plant is $U(s)$ and $K_o G_p(s)U_c(s) = \theta_{mod\,el}$ such that $U_c(s)$ is the control input to the reference model.

Therefore, control law is state as given by:

$$U(s) = \theta_c \times U_c(s) \tag{16}$$

Substituting Equation (16) into Equation (15) and taking the partial derivative gives:

$$\frac{\partial E(s)}{\partial \theta_c} = KG_p(s)U_c(s) = \frac{K}{K_o}\theta_{mod\,el} \tag{17}$$

Equating Equation (13) and Equation (17) gives:

$$\frac{d\theta_c}{dt} = -\gamma e \frac{K}{K_o} \theta_{model} = -\gamma^1 e \theta_{model} \quad (18)$$

where $\gamma^1 = \gamma K/K_o$ and the Equation (18) is the law for parameter θ_c adjustment and represents the adjustment mechanism of the adaptive controller.

Reference Model

It is required that reference model $G_m(s)$ be designed approximately as a second order system similar to the dynamics of the dish antenna dynamic characteristics such that its transient and steady state performance meets that of industrial standard stated as follows (Aloo *et al.*, 2016):

i. Rise time of less than or equal to 4 s.
ii. Settling time of less than or equal to 5 s.
iii. Overshoot of less than or equal to 10%.

The second order reference model is defined by:

$$G_m(s) = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2} \quad (19)$$

where ω_n, ζ stands for the natural frequency and damping ratio. These quantities are determined as follows:

$$M_p = e^{-\pi\zeta/\sqrt{1-\zeta^2}} \quad (20)$$

where M_p is the maximum percentage overshoot of value 5%. Solving Equation (20) given by:

$$\log_e\left(\frac{5}{100}\right) = -\frac{\pi\zeta}{\sqrt{1-\zeta^2}} \log_e^e \quad (21)$$

Results in $\zeta = 0.69$ and taking a settling time of $T_s = 1$ s, the natural frequency of the system is computed using:

$$T_s = \frac{4}{\zeta\omega_n} \quad (22)$$

Thus $\omega_n = 5.77 \text{rads}^{-1}$. Substituting these values into Equation (19) gives:

$$G_m(s) = \frac{33.29}{s^2 + 7.95s + 33.29} \quad (23)$$

Intelligent Control System Design

The algorithm designed in this work and to enhance the performance of the telemedicine (that is the antenna positioning system) is the Fuzzy Logic Controller (FLC). The Mamdani model is used for the developed FLC in MATLAB/Simulink environment. Centroid is used for the defuzzification method. Figure 2 is the block diagram of the fuzzy logic controlled antenna positioning system.

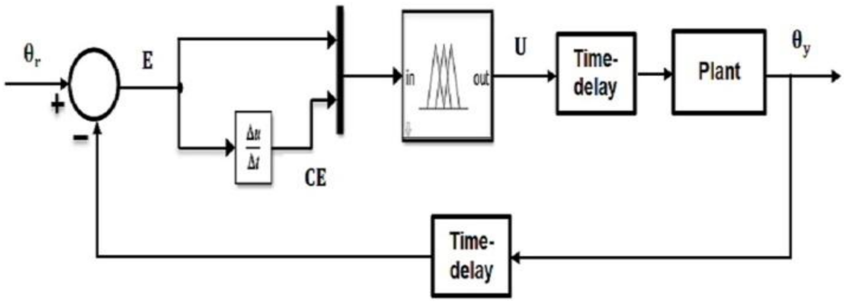

Figure 2: Fuzzy logic controlled antenna positioning system

As shown in Figure 2, the error E and change in error CE are the two input variables for the FLC, while the control variable (output of the controller) is U that changes in accordance to changes in inputs. This is shown Table 1, which is the representation of the linguistic variables that determine the behaviour of the FLC in accordance to the transformed crisp fuzzy input set (or variables) by fuzzification. The linguistic variables are defined as: negative large (NL), negative medium (NM), negative (NE), zero (ZE), positive (PO), positive medium (PM), and positive large (PL). Then each input has 3 membership functions (MFs), while the output has 5 MFs. There are 9 rules formulated for the designed FLC.

Table 1. Rule table of designed FLC

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

The grade value of each input MF is defined as: NE = [-2 -1 0], ZE = [-1 0 1], and PO = [0 1 2]. Each MF of the output is defined as follows: NL = [-1 -07.5 -0.5], NM = [-0.75 -0.5 -0.25], ZE = [-0.25 0 0.25], PM = [0.25 0.5 0.75], and PL = [0.5 0.75 1]. It should be noted that triangular MFs have been used for modelling the inputs and the output. Figures 3a-c show the shapes of the MFs.

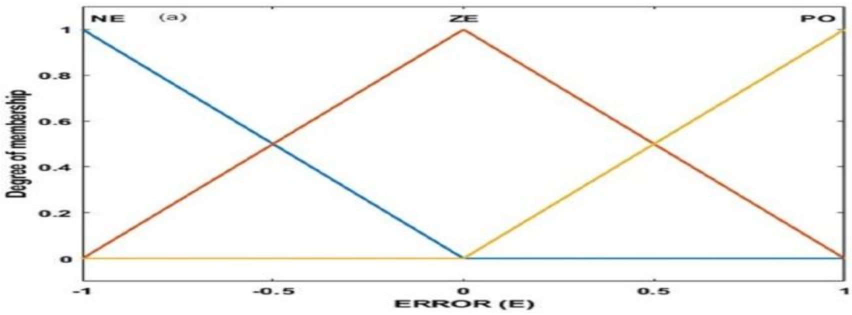

Figure 3(a): Error input membership shape

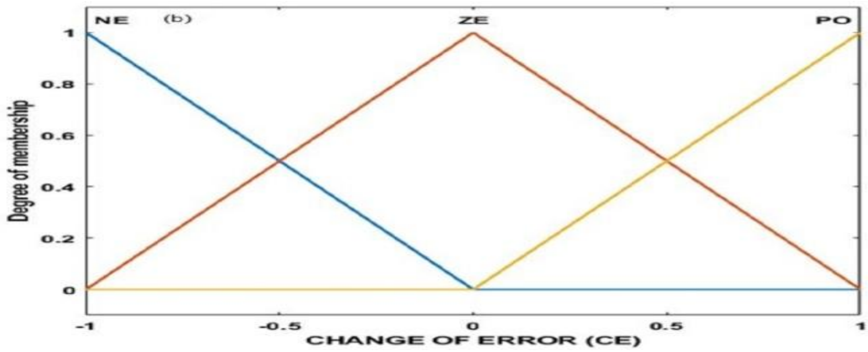

Figure 3(b): Change in error membership shape

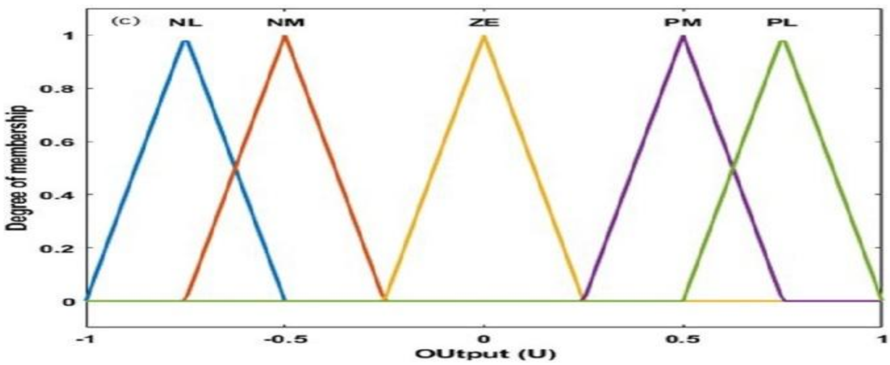

Figure 3(c): Output membership shape

The configuration of the proposed automatic control for dish antenna positioning system in this work is shown in Figure 4.

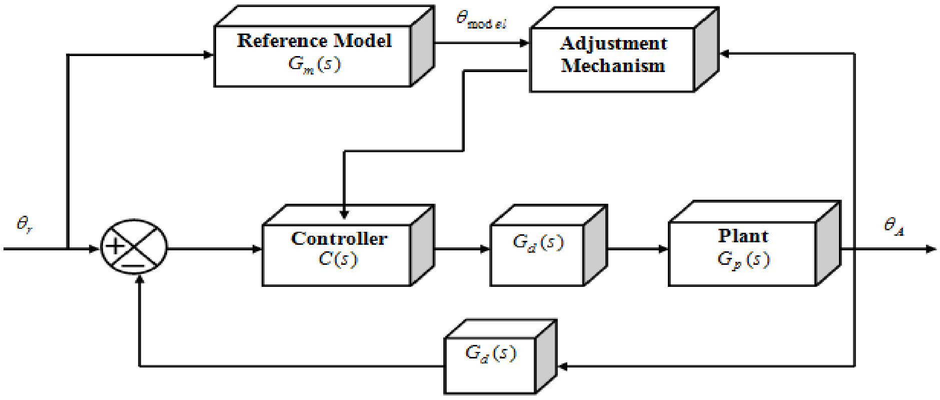

Figure 4: Proposed system configuration

Implementation Flowchart

The system parameters are listed in Table 2 for simulation in MATLAB/Simulink environment.

Table 1: Plant parameter (Ibiyemi & Ajiboye, 2012c)

Definition of parameter	Symbol	Unit	Value
Dish angular displacement	θ_A	radian	-
Gear output shaft angular displacement	θ_g	radian	-
Moment of inertia of the dish	I_A	Kgm^2	140.60
Damping coefficient	B_A	Nms/rad	126.78
Torsional spring stiffness	τ_A	Nm/rad	317.5
Mass of dish	m	kg	250
Modulus of rigidity	G	Pa	77×10^9
Dish radius	r_A	m	1.2
Polar moment of area for a material circular sectional area	J	m^4	2.8040×10^{-9}
Circular section diameter	D	m	0.013
Length of material	L	m	0.68
Jack gear rasio	K_g	-	30
Time delay	T	s	0.25

RESULTS AND DISCUSSION

Step Response of Conventional System

The initial performance of the dish antenna position control system without incorporating a controller called the conventional system, was tested by simulating the closed loop transfer function given by Equation (10), using MATLAB/Simulink software. A step response plot of the result is shown in Figure 5.

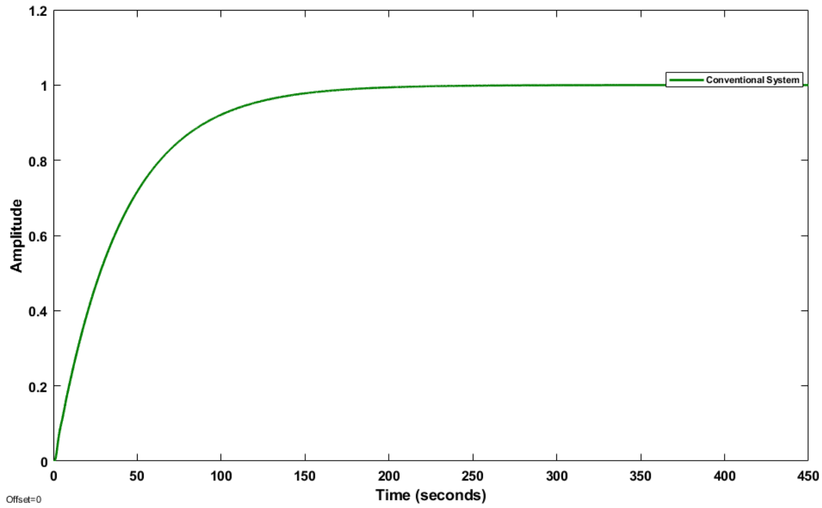

Figure 5: Step response of the conventional system

The response parameters of the conventional system are characterized as follows: rise time of 85.9896 s, settling time of 153.6396 s, overshoot of 0, and steady-state error 0. These parameters indicated that the system response to unit step input is very slow resulting in prolonged rise (or response) time and settling time of above 60 s (or 1 minute). Though the step response showed that the conventional system was able to track the desired position defined in terms of unit step input, it was largely sluggish. This is not desirable for satellite tracking system considering the efficiency or effectiveness required of it. Such antenna for telemedicine communication needs to provide urgency or promptness in data or information sharing for efficient and reliable healthcare delivery. Hence, there is need to compensate for this weakness by introducing a technique that will improve the response performance of the control system.

Step Response of Fuzzy Logic Control System

This section presents the result of the step response performance characteristics of the fuzzy logic (or intelligent) control dish antenna positioning system. The obtained step response curve to unit step input for FLC system is shown in Figure 6. The numerical evaluation of the system response with the FLC is listed in Table 3 together with that of the conventional system.

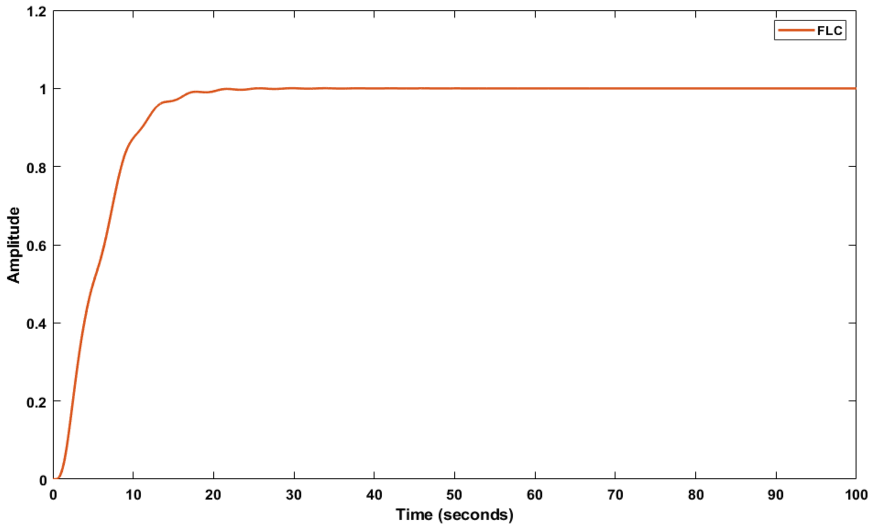

Figure 6: Step response of the FLC system

Table 3 Dynamic response parameters of FLC system

Parameter	Control condition	
	Conventional system	FLC system
Rise time	85. 9896 s	9.2438 s
Settling time	153.6396s	16.1792 s
Peak time	350 s	29.7405 s
Peak percentage overshoot	0	0.05%

It is clear from Table 3 that the introduction of FLC into the closed loop control system for the telemedicine antenna positioning improved its dynamic response performance parameters. This is based on the largely reduced response (rise) time, settling (convergence) time, peak time, and peak percentage overshoot achieved. From the obtained results, the addition of FLC algorithm will make the antenna to respond faster, settles at desired referenced level to unit telemedicine signal received via satellite and this will ensure improve communication during healthcare delivery services. The achieved improved is statistically presented as follows: the FLC system provided 89.3%, 89.5%, and 91.5% improvement in rise time, settling time, and peak time over the conventional system. However, in both control conditions, the system offered the same overshoot of zero.

Step Response of MRAC Augmented FLC System

Despite the fact that the FLC was able to improve the dynamic response of the telemedicine antenna compared to what was obtainable in the conventional state, the dynamic or transient response parameters can be further improved. Thus, an adaptive control algorithm was used to augment the FLC called MRAC-FLC as proposed in this work and the simulation results are presented in this section.

The proposed MRAC-FLC is multi-loop control scheme that uses an adaptive (or adjustment) mechanism, which is implemented in the outer loop of the controller. The adjustment mechanism measures and updates the adjustable parameter in accordance to the error or deviation between the actual position (antenna response) and the reference model response as in Equation (11). The adjustable or updated signal (or parameter) θ_c is applied to the inner loop fuzzy logic controller (FLC) to adjust or tune its control torque and then antenna position is adjusted according to the ensuing optimized adaptive fuzzy logic control commander signal (Eze *et al.* 2026).

The simulation curves obtained for varied adaption gain (γ = 1, 2, 3, 4, and 5) are shown in Figures 7 and 8 in terms of the optimized control torque (input) of the proposed controller and the position response of the antenna unit step input. The numerical values of dynamic response parameters and the analysis performed in terms of integral square error (ISE) are listed in Table 4.

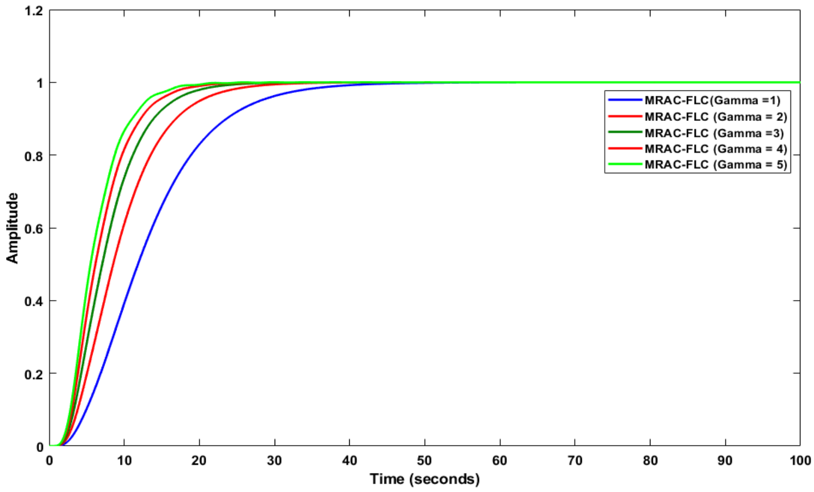

Figure 7: Step response of the MRAC-FLC system

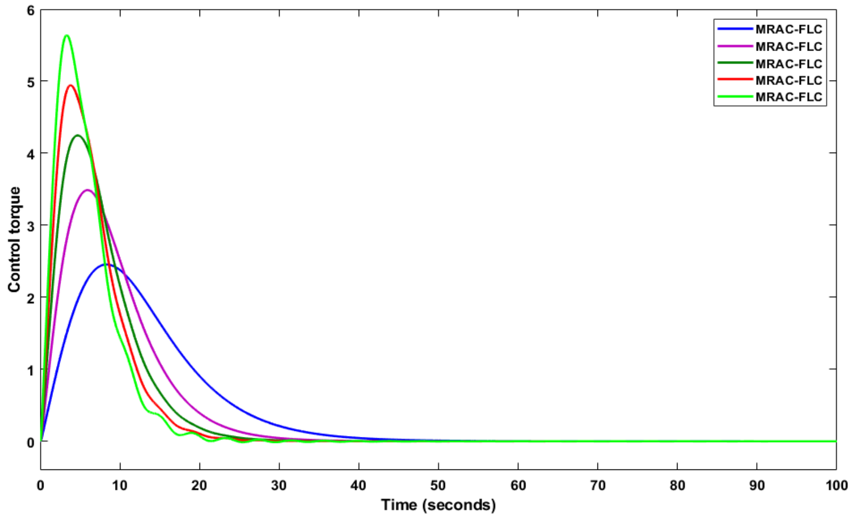

Figure 8: Control torque response of the MRAC-FLC system

Table 4: Dynamic response parameters of MRAC- FLC system

Parameter	Control condition				
	γ = 1	γ = 2	γ = 3	γ = 4	γ = 5
Rise time (s)	18.6681	13.0934	10.5943	9.1647	8.2215
Settling time (s)	34.0626	24.3558	20.1219	17.4915	16.1065
Peak time (s)	100	100	80.6329	42.6575	29.9472
Peak percentage overshoot (%)	0	0	0	0.0011	0.0295
Integral square error (ISE)	9.431	6.957	5.863	5.213	4.770
Control torque magnitude	2.4544	3.4844	4.2473	4.9448	5.6371

In selecting the adaptation gain,γ the values were chosen by tuning from low value to high value range. It can be seen looking at Table 4 that high adaptation gain value reduces the rise time, settling time, and peak time. On the other hand, the system overshoot and the control torque magnitude gradually deteriorate. The ISE performance revealed that the system offers minimum deviation or error between actual position and referenced position when the adaptation gain increases. ISE is critical in analysis the effective of controller in terms of its potential to offer optimal control performance. Therefore, the MRAC-FLC with adaption gain 5 is considered and selected as the most efficient state for the controller to offer the finest performance. Also, with adaption gain 5, the proposed MRAC-FLC outperformed the FLC such that the rise time was reduced from 9.2438 s to 8.2215 s, which is 11% improvement in response time to received satellite signal. In settling the system at the reference position, the MRAC-FLC improved the settling time of FLC from 16.1792 s to 16.1065, which is 0.45% improvement. It also achieved better smooth response and stability by providing reducing the overshoot from 0.05% to 0.0295%, which is an improvement of 41%.

Performance Comparison

In this section the effectiveness of the designed MRAC-FLC validated via comparison with the previous studies carried out by Eze *et al.* (2020) and Ajiboye *et al.* (2019) wherein pre-filter enhanced PID were implemented and PID. Figure 9 shows the step response performance of the comparison curves for the various control systems. The numerical analysis of the control systems are presented in Table 5 in terms of dynamic response parameters.

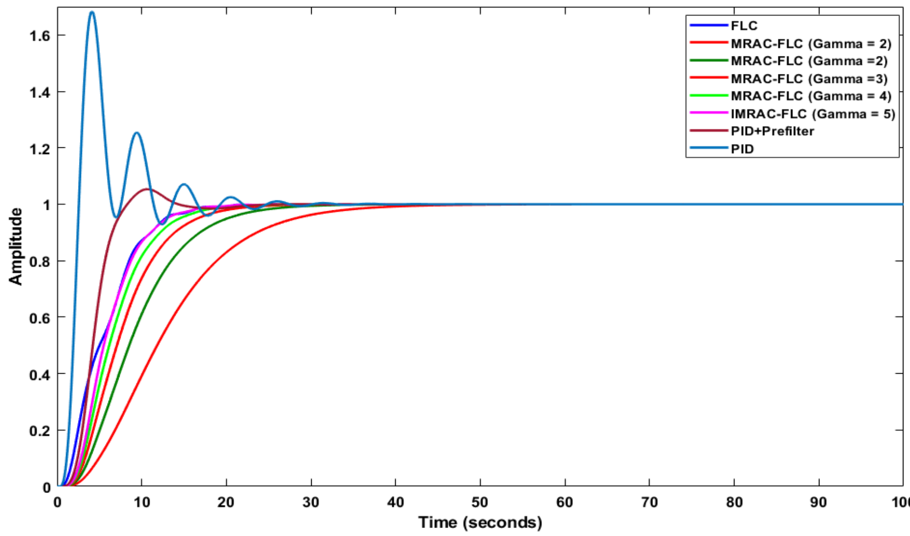

Figure 9: Step response of different control systems

Table 5 Performance analysis of dynamic response parameter for different controllers

Control condition	Rise time (s)	Settling time (s)	Peak time (s)	Overshoot (%)
Conventional system	85. 9896	153.6396	350	0
FLC	9.2438	16.1792	29.7405	0.05
MRAC-FLC (γ = 1)	18.6681	34.0626	100	0
MRAC-FLC (γ = 2)	13.0934	24.3558	100	0
MRAC-FLC (γ = 3)	10.5943	20.1219	80.6329	0
MRAC-FLC (γ = 4)	9.1647	17.4915	42.6575	0.0011
MRAC-FLC (γ = 5)	8.2215	16.1065	29.9472	0.0295
PID (Ajiboye *et al.,* 2019*)*	1.34201	21.3121	3.9422	50.5101
PID-prefilter (Eze *et al.*, 2020)	4.0913	12.9213	10.6712	5.3201

It can be seen looking at the comparison plot in Figure 9 that the only control system that exhibit high oscillation or cycling with possibility of introducing high instability during the positioning of the antenna for satellite communication is the PID presented in Ajiboye *et al* .(2019). This because it outrageously shoots (or peaks) above the desired referenced position by 50.5% at peak time of at 3.9422 s and subsequently cycles before settling at a quite prolong settling time of 21.3121 s. Though it offers the most promising performance in terms of rise time and peak time, the associated high peaking effect introduced by the controller into the system defeats it supposed advantage of very much reduced rise time. In the case of the PID-prefilter implemented in Eze *et al.* (2020), it is obvious that a great deal of improvement was achieved compared with the PID especially in terms of overshoot and settling time. This makes PID-prefilter more efficient and of better performance potential in practice system than the PID. However, it introduced significant level of oscillation as it shoots by 5.32% above the referenced position. For the initially designed FLC and the MRAC algorithms, the system overshoot is near zero or zero. Thus, both FLC and MRAC-FLC controllers offered smooth response and more stability to the closed loop control system. However, with either fuzzy only or with MRAC optimized fuzzy, the system show deteriorating performance in terms of rise time, settling time and peak time as in Table 5. Since the basic objective of this work is to design a system that will address the associated rise time and settling time of the system with causing the system stability and smooth dynamic response measured in terms of overshoot to deteriorate, the FLC and MRAC-FLC controllers are the appropriate choice of control system. Considering the fact that the MRAC algorithm has successfully be used together with FLC to achieve multi-loop control strategy, MRAC-FLC at adaptation gain of 5 is selected as the state in which the proposed system offer the finest performance.

CONCLUSION

This work has implemented a multi-loop control strategy that use model reference adaptive control (MRAC) augmented fuzzy logic controller (FLC) in dish antenna positioning for distributed mobile telemedicine nodes. The dynamic equations of a dish antenna position control system used in distributed mobile telemedicine nodes were obtained in the form of a transfer function models in continuous time domain. An MRAC algorithm was developed followed by fuzzy logic control model, which is based on human reasoning and knowledge. Both MRAC and FLC were combined in multi-loop arrangement to provide more stable positioning control for the antenna system. The performance of the system was studied in terms of rise time, settling time, peak time, overshoot, and minimum error performance based on integration of square error (ISE). A multi-loop control system with MRAC-FLC algorithm was designed and implemented in MATLAB/Simulink environment. The system performance was evaluated considering the conventional state, the fuzzy logic control state, the MRAC control state with five adaptation gain scenarios, and the comparison test to validate the advantage of the designed multi-loop control system over other schemes. The simulation analysis revealed that the MRAC-FLC yielded the best when the adaptation gain was five and offered the finest value for control system performance measured in terms minimum integral square error.

REFERENCES

Achebe, P. N. (2018). Design of digital cascade compensator for ground station satellite antenna servo control system. *International Journal of Latest Engineering Science, 1*(3), 26–31. https://ijlesjournal.org/2018/volume-1%20issue-3/ijles-v1i3p104.pdf

Ajiboye, A. T., Ajayi, A. R., & Ayinla, S. L. (2019). Effects of PID controller on performance of dish antenna position control for distributed mobile telemedicine nodes. *Arid Zone Journal of Engineering, Technology and Environment, 15*(2), 304–313. https://www.azojete.com.ng/index.php/azojete/article/view/72

Aloo, L. A., Kihato, P. K., & Kamau, S. I. (2016). DC servomotor-based antenna positioning control system design using hybrid PID-LQR controller. *European International Journal of Science and Technology, 5*(2), 17–31. https://eijst.org.uk/vol-5-no-2-march-2016/

Anyanwu, K. U., Muoghalu, C. N., Ozumba, E. C., & Onuoha, M. K. (2024). Design of discrete-time LQR for optimal positioning control of deep space satellite antenna. *International Journal of Academic Engineering Research, 8*(8), 56–61. https://ijeais.org/wp-content/uploads/2024/8/IJAER240808.pdf

Ekengwu, B. O., Eze, P. C., Asiegbu, C. N., Olisa, S. C., & Udechukwu, C. F. (2022). Satellite dish antenna control for distributed mobile telemedicine nodes. *International Journal of Informatics and Communication Technology, 11*(3), 206–217. https://doi.org/10.11591/ijict.v11i3.pp206-217

Ekengwu, B. O., Eze, P. C., Muoghalu, C. N., Asiegbu, C. N., & Achebe, P. N. (2024). Design of robust centralized PID optimized LQR controller for temperature control in single-stage refrigeration system. *Indonesian Journal of Electrical Engineering and Informatics, 12*(3), 726–738. https://doi.org/10.52549/ijeei.v12i3.5629

Ekengwu, B. O., Eze, P. C., Nwawelu, U. N., & Udechukwu, F. C. (2021). Effect of PID tuned digital compensator on servo-based ground station satellite antenna positioning control system. In *Proceedings of the 2nd International Conference on Electrical Power Engineering (ICEPENG 2021)* (pp. 97–101). Department of Electrical Engineering, University of Nigeria, Nsukka. https://sites.google.com/unn.edu.ng/eeunnconference/presented-papers

Ekengwu, B. O., Muoghalu, C., & Achebe, P. N. (2018). Performance improvement of antenna positioning control system using model predictive controller. *European Journal of Advances in Engineering and Technology, 5*(9), 722–729. https://doi.org/10.5281/zenodo.10722808

Eze, P. C., Ekengwu, B. O., Muoghalu, C. N., Aigbodioh, F., & Chukwuma, O. B. (2017). Positioning control of electrical discharge machining device for improved transient response performance. *Science Journal of Circuits, Systems and Signal Processing, 6*(3), 29–34. https://doi.org/10.11648/j.cssp.20170603.11

Eze, P. C., Jonathan, A. E., Agwah, B. C., & Okoronkwo, E. A. (2020). Improving the performance response of mobile satellite dish antenna network within Nigeria. *Journal of Electrical Engineering, Electronics, Control and Computer Science, 6*(21), 25–30. https://jeeeccs.net/index.php/journal/article/download/151/132

Eze, P. C., Njoku, D. O., Nwokonkwo, O. C., Onukwugha, C. G., Odii, J. N., & Jibiri, J. E. (2024). Wheel slip equilibrium point model reference adaptive control based PID controller for antilock braking system: A new approach. *International Journal of Automotive and Mechanical Engineering, 21*(3), 11581–11595. https://doi.org/10.15282/ijame.21.3.2024.10.0893

Eze, P. C., Obichere, J. K., Mbonu, E. S., & Onojo, O. J. (2024). Positioning control of satellite antenna for high speed response performance. *IPTEK The Journal of Engineering, 10*(2), 119–136. https://doi.org/10.12962/j23378557.v10i2.a20670

Eze, P. C., Onojo, O. J., Obichere, K. J., & Mbonu, E. S. (2026). Design of direct ITAE based MRAC augmented fuzzy and fuzzy-PD plus integral controller for position control system. *Journal of Advanced Science and Optimization Research, 10*(9), 87–107. https://doi.org/10.70382/sjasor.v10i9.035

Eze, P. C., Ugoh, C. A., Ezeabasili, C. P., Ekengwu, B. O., & Aghoghovbia, L. E. (2017). Servo position control in hard disk drive of a computer using MRAC integrating PID algorithm. *American Journal of Science, Engineering and Technology, 2*(4), 97–105. https://www.sciencepublishinggroup.com/article/10.11648/j.ajset.20170204.11

Eze, P. C., Ugoh, C. A., & Inaibo, D. S. (2021). Positioning control of DC servomotor-based antenna using PID tuned compensator. *Journal of Engineering Sciences, 8*(1), E9–E16. https://doi.org/10.21272/jes.2021.8(1).e2

Ibiyemi, T. S., & Ajiboye, A. T. (2012a). Automatic tracking of NigComSat-1R satellite by dish network mounted on mobile tele-medicine vehicles. *International Journal of Engineering Research & Technology, 1*(4), 1–4. https://www.ijert.org/automatic-tracking-of-nigcomsat-1r-satellite-by-dish-network-mounted-on-mobile-tele-medicine-vehicles

Ibiyemi, T. S., & Ajiboye, A. T. (2012b). On PID controller design for mobile node network with variable delays. *International Journal of Science and Advanced Technology, 2*(4), 176–180.

Ibiyemi, T. S., & Ajiboye, A. T. (2012c). Robust PID control of mobile satellite dish network within Nigeria. *International Journal of Computer Applications, 41*(21), 37–42. https://doi.org/10.5120/5828-8154

Muoghalu, C. N., & Achebe, P. N. (2021). Two-phase hybrid stepping motor based antenna positioning control system using proportional integral and derivative controller. *Iconic Research and Engineering Journals, 4*(10), 152–157. https://www.irejournals.com/paper-details/1702637

Muoghalu, C. N., & Achebe, P. N. (2025). Enhancing the dynamic response servo positioning system using internal model control based compensator: A case study of HDD. *International Journal of Progressive Research in Engineering Management and Science, 5*(3), 236–242. https://www.ijprems.com/uploadedfiles/paper/issue_3_march_2025/38786/final/fin_ijprems1741408882.pdf

Muoghalu, C. N., Achebe, P. N., & Oyeka, D. O. (2025). Investigating the essence of compensators in engineering systems: A case study of industrial belt conveyor system. *International Journal of Research Publication and Reviews, 6*(5), 353–358. https://ijrpr.com/uploads/V6ISSUE5/IJRPR44556.pdf

Muoghalu, C. N., Ndefo, M. I., & Ugwu, H. I. (2021). Performance enhancement of chopper fed DC motor speed control system using PID controller. *Multidisciplinary International Journal of Research and Development, 1*(2), 1–8. https://www.mijrd.com/papers/v1/i2/MIJRDV1I20001.pdf

Okafor, S., Mbachu, C. B., Muoghalu, C. N., & Ekengwu, B. O. (2025). Positioning and trajectory tracking with deflection suppression in flexible link robotic manipulator using PID-LQR controller. *Asian Journal of Science, Technology, Engineering, and Art, 3*(4), 1131–1146. https://doi.org/10.58578/ajstea.v3i4.6278

Onyekwelu, C. I., Nwabueze, C. A., Muoghalu, C. N., & Ekengwu, B. O. (2023). Model reference adaptive control based PID controller for hard disk drive read/write head servo posistioning system. *International Journal of Academic Multidisciplinary Research, 7*(8), 135–144. https://ijeais.org/wp-content/uploads/2023/8/abs/IJAMR230816.html