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RESEARCH ARTICLE

Enhanced Antenna Positioning Control System Using Adapted DC Servo Motor and Fuzzy-PI Controller

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ABSTRACT Control systems for Ground Data Receiving Stations (GDRS) play a crucial role in accurately pointing antennas to receive data from satellites. This study focuses on designing and simulating a closed-loop control system using PID, LQR, and Fuzzy-PI controllers for precise antenna positioning and establishing reliable communication links during data receiving sessions. The proposed model incorporates a DC servo motor-based controller and antenna positioning system, implemented through MATLAB/SIMULINK software. Comparative analysis of the controllers is performed based on various performance metrics. The findings indicate that the Fuzzy-PI controller exhibits the most responsive and robust operation, outperforming the PID and LQR controllers. It effectively manages time delays in antenna control within the GDRS and supersedes the current controller with enhanced bypass, rise time, and tracking antenna calibration values. The study demonstrates the significance of optimizing control systems for ground stations, particularly when dealing with large motors, offering potential advancements in motor control and system stability. The proposed Fuzzy-PI controller presents a valuable solution for improving the overall efficiency of GDRS and enhancing its data reception capabilities.

INDEX TERMS Ground data receiving stations, control systems, antenna positioning, PID controller, LQR controller, fuzzy-PI controller, DC servo motor, closed-loop control, satellite communication.

I. INTRODUCTION

The control systems utilized in Ground Data Receiving Stations (GDRS) are of paramount importance in ensuring precise alignment of antennas for the reception of satellite data. The antenna needs to provide sufficient signal gain to produce noise-free reception [1], [2]. Wallach, in 1997 [3] was provide a Parabolic antennas used in ground-based data receiving stations, which are frequently employed for remote sensing and satellite tracking activities, are susceptible to environmental disturbances. Aloo, in 2018 [4] was explained the disturbance causes a pointing error and disrupts the communication between the receiving station's antenna and the satellite. A DC servomotor is an automatic device that corrects the antenna performance of a mechanism using error detecting feedback [5], [6]. In fact, directional antennas with narrow beams and high gain must track the satellite in elevation and azimuth directions [7], [8]. The determination of the earth station antenna's location and coordinates (latitude and longitude) is necessary for the process of aligning the GDRS antenna with a satellite from which data is being downloaded. This determination is achieved by the transmission of a command to the satellite. Several control models have been developed over time to handle the antenna pointing problem when using a servo mechanism to monitor moving objects and satellites [9], [10], [11]. Consider the case of satellite communications overseas, where the control system of the earth station antenna directs the motorized antenna toward a specific satellite [12], [13]. Describe the fault tolerance control (FTC) system, which was created using a ship simulation facility to preserve tracking functionality in an aircraft [14], [15]. However, estimating the error has proven

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to be a very difficult task with satellite tracking. Active and passive DFTCs are the two primary classifications that can be made. The FTC (AFTC) can detect any type of error by monitoring the system's performance and comparing the normal state to the faulty state.

An important point that researchers have paid attention to in the past decade is the development of control and tracking systems to avoid signal loss from satellites and their impact on the received data [16]. The important point in this field was the study and calibration of control and tracking strategies. The integration and relative derivative (PID) algorithm are the most often used control technique in the business sector [7], [17], [18], [19].

An antenna stabilizers, which is commonly employed in dynamic fields such as: ships, automobiles, military vehicles, etc., helps to stabilize the antenna [20]. A servo motor controller is required for antenna stabilisation using PID as speed control [21], [22]. The Linear-Quadratic-Regulator (LQR) console's fuzzy logic helps to eliminate mistake and automatically controls the servo motor [23]. Our GDRS motors for the third axis, elevation and azimuth, are DC "BPMDC" motors with polished permanent magnets. Simulation and experimental validation of controllers using a user-developed data acquisition and control (DAC) system [24]. Digital signal processing (DSP) [25], [26], Overview of speed control based on the most common servo motor, Permanent magnet setup on a brushed DC motor (LQR), Controllers based on Linear-Quadratic-Gaussian (LQG) and fuzzy logic [27]. Utilizing the Particle Swarm Optimization (PSO) algorithm due to its ease of use and rapid convergence to optimal values, the design and tuning of the PID controller for brushed DC motors has been used to develop low-cost robotic applications [6], [28], [29]. The beginning was in laboratory experiments, choosing a DC servo motor, and building a control system on an antenna [30], [31]. Targeting a reduction in sprocket torque and an increase in generated torque, it is used to improve the permanent magnet motor, a critical technology Thus, data availability is highly dependent on the operation of the ground station control unit, which will be simulated and annotated [31].

The emphasis of the paper is on enhancing the permanent magnet motor by decreasing sprocket torque and increasing generated torque. The availability of data is contingent on the simulation and annotation of the ground station control unit's operation. The following are the primary topics covered in the paper:

- A controller is proposed in order to reduce antenna tracking disturbance during satellite data reception. This will increase the integrity of received data and decrease transmission errors.
- Three control types, namely PID, LQR, and Fuzzy_PI, will be utilized and contrasted to determine the most suitable control type for the system. This will aid in selecting the most efficient control method to enhance the system's overall performance.
- The paper proposes a controller that provides more reliable measurements and has a significant impact on the overall efficacy of the system. This incorporates the Egyptian Ground Data Receiver Station's (EGDRS) time-delay management of antenna control. This controller will supplant the current controller, resulting in improved system performance and utilization.

For the real problem solution Future studies may optimize the tuning procedure, evaluate system robustness under different operating situations, and integrate other artificial intelligence approaches for better control performance [4].

II. DATA RECEIVING STATION SYSTEM SETUP

A. EGDRS SYSTEM DESCRIPTION

A Ground Data Receiving Station, also known as a GDRS, has been set up in the Egyptian city of Aswan in order to receive images from European radar satellites (ERS), Landsat, and Spot. The satellite's downlink from (Egyptsat-1) can now be received at the station thanks to recent upgrades. Because it is located in Aswan, which is in upper Egypt, the station is able to cover the all of Egypt, the Nile basin, the majority of Arabian countries, the majority of African countries, and south European countries [32], [33].

The block diagram of GDRS antenna is explained in *Figure 1*. There is a common type of servomotors for antenna movement in the satellite ground receiving stations; brush DC motor (BDCM). Due to the brush and commutator, there is a risk of sparking with the BDCM's starting performance. The brushless DC motor has good dynamic performance, but its driver's electronic circuit is complex, and its size, weight, and power consumption are all high. for these reasons, GDRS designed with a brush DC motor and Digital Electronic Unit (DEU). Researchers in the aerospace and ground station domains have recognized the significance of incorporating Units controller and printed circuit board (DEU/PCB) design into the PWM antenna position servo system. This integration enables the achievement of accurate control, facilitated by the advancements in digital technology. In this paper, the

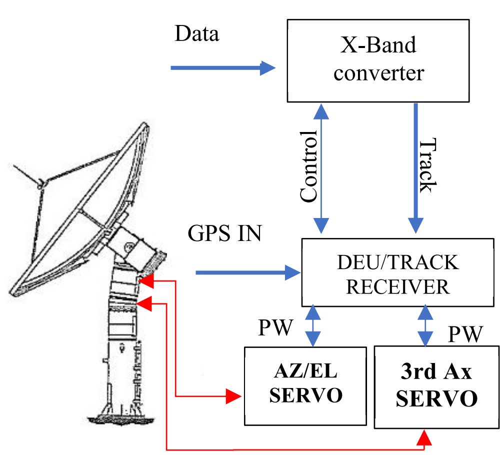

FIGURE 1. Simple block diagram of GDRS antenna.

goal is to construct PID, LQR, and fuzzy-PI controllers for the studied system to meet tracking system requirements. In addition, a comparison was made between them and the appropriate type of control was determined. We conducted laboratory tests on a DC servo motor suited for automatic reflector antenna positioning in the event that the system required it.

B. DC SERVO MOTOR CONTROL SYSTEMS

The experiment's servo motor is a structural component of a servo system and is utilised in conjunction with a servo motor [18], [26]. The servo motor consists of the motor that drives the load as well as a position detecting component, such as an encoder. To precisely regulate the functioning of the machine, the servo system modifies the controlled quantity, such as position, speed, or torque, based on the goal value (command value) that has been specified [34], [35].

The following interpretation is a mathematical description of a compacted servo motor based on the diagram of Figure 2, which shows Block diagram of individually excited DC servo motor and the motor circuit diagram is shown in Figure 3. The Mathematical modeling DC Servo motor system describe in the following:

$$V_a(t) = R_a I_a(t) + L_a \frac{dI_a(t)}{dt} + E_b(t) \tag{1}$$

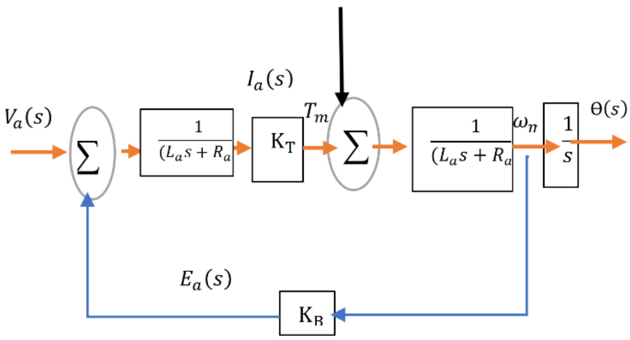

FIGURE 2. Block schematic of a DC servo motor with separate excitation.

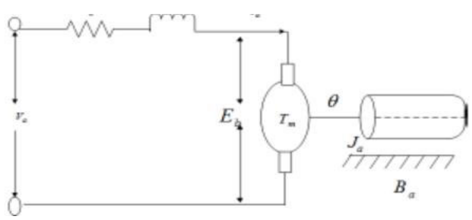

FIGURE 3. DC motor circuit diagram.

The relationship between motor torque $T_a(t)$ and armature current $I_a(t)$ is constant. K_T is given in (2):

$$T_a(t) = K_T I_a(t) \tag{2}$$

In addition, the relationship between the back electromotive force (e.m.f.) $E_b(t)$ and the rotational velocity is given by (3):

$$E_b(t) = K_T \omega_m(t) = K_T \frac{d\Theta}{dt} \tag{3}$$

According to Newton's and Kirchhoff's Laws, (4) and (5) are obtained:

$$J_a \frac{d^2O}{dt^2} + B_a \frac{d\Theta}{dt} = K_T I_a(t) \tag{4}$$

$$L_a \frac{dI_a(t)}{dt} + R_a I_a(t) = V_a(t) - K_b \frac{d\Theta}{dt} \tag{5}$$

where V_a: Armature voltage, R_a: resistor, L_a: inductance, I: current, E_b: Back electromotor force.

Laplace transform applied to (4) and (5) with zero initial conditions yields (6) and (7):

$$J_a s^2 O(s) + B_a s O(s) = K_T I_a(s) \tag{6}$$

$$L_a s I_a(s) + R_a I_a(s) = V_a(s) - K_T s O(s) \tag{7}$$

Making the subject of (7) current and substituting (6) yields (8):

$$J_a s^2 O(s) + B_a s O(s) = k_T \frac{V_a(s) - k_b O(s)}{R + L - s} \tag{8}$$

where, $V_a(s)$: ArmatureVoltage; $T_m(s)$: Torque; $\omega_m(s)$: Velocity; $\Theta(s)$: the output azimuth elevation angle.

For uncontrolled system calculated from equation. (8) to get angular displacement in equation. (9) as the following:

$$G_a(S) = \frac{\Theta O(S)}{V_a(S)} = \frac{K_T}{S[(R_a + L_a S)(J_m S + B_{m)} + K_T K_B]} \tag{9}$$

C. THE PROPOSED MOTOR PARAMETERS

In this section, we will continue the analysis of the motor control-supported antenna's parameters. Now we will employ our prior knowledge of Servo motors in our antenna application (Satellite Ground Receiving Station) to determine the appropriate Servo motor. We will clarify the information necessary to size the motor based on antenna weight, speed, acceleration, and other application-specific requirements. The following Table 1 show parameters of the proposed motor supported by the antenna reflector 6.1-meter diameter, KOLLMORGEN (T-36001) DC Servo motor [36].

TABLE 1. The parameters of T-36001 DC Servo motor.

SCHEMATIC PARAMETERS		
PARAMETER	**DEFINITION**	**AZ/ELE**
Bm	Bm Equivalent viscous friction coeff. [Nms /rad]	**13.558**
Ja	Motor Inertial Constant[Kg.m2]	**3.5946**
Jm	Equivalent moment of inertia[Kg.m2]	**51.386**
KB	Back emf Constant[Vs/rad]	**187**
KT	Motor Torque Constant[Nm/A]	**138**
La	Motor Armature Inductance[H]	**29**
Ra	Motor Armature Resistance[Ω]	**13.3**

Reduction mechanism (refer for this method and number for equations), Applying momentum conservation in the equation to the analysis and processing of real-world cases is the primary contribution of our study.

$$T_1\theta_1 = T_2\theta_2; \quad \frac{\theta_1}{\theta_2} = \frac{T_2}{T_1} = \frac{N_1}{N_2} = \frac{D_1}{D_2} > 1$$
$$T_2 = m * g * r * \cos\theta_2$$

where: θ_1 : motor angle θ_2 : antenna angle T_2: motor torque N_2 : Gear Teeth N_1 : turns of motor $\frac{D_1}{D_2}{}_1$ diameter ratio r : distace between C.G and pivot joint T_2 : antenna torqe

$$\theta_2 (s) = G (s)\, \theta_1 \frac{N_2}{N_1} \tag{10}$$

III. CONTROLLERS DESIGN

This section focuses on the design of the PID, LQR, and Fuzzy_PI controllers, which have been developed with the aim of improving the performance of the antenna control system in the Satellite Ground Station. The controller is designed based on the system's dynamic modeling, beginning with the derivation of an appropriate mathematical model to characterize the antenna motion.

A. PID-CONTROLLER

Proportional-Integral-Derivative (PID) Controllers are employed due to their inexpensive cost, their ability to often give strong closed-loop response characteristics, their tuning using relatively simple rules, and their relative ease of construction. Control signal is the sum of proportional, integral, and derivative gain scaling factors [7], [11]. Figure 4 depicts the PID controller's construction. Where PID controllers drive a closed-loop system, they are simple to implement but require a great deal of time to reach setpoint and have degraded performance in the presence of system nonlinearities [18]. PID controller is represented by Equation 11.

$$u(t) = K_P e(t) + K_I \int e(t)\, dt + K_D \frac{d}{dt} e(t) \tag{11}$$

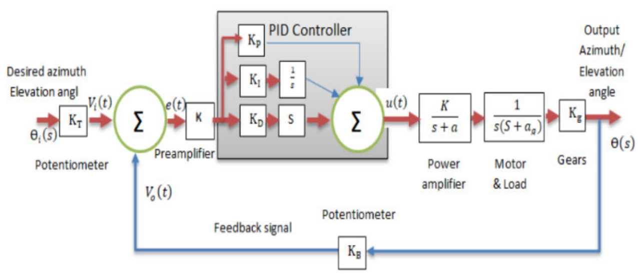

FIGURE 4. Block diagram of antenna azimuth PID controller.

where *kp* represents the proportional gain, ki represents the integral gain, and kd represents the derivative gain. There are numerous tuning methods for determining the correct *kp*, *ki*, and *kd* values to provide the desired response.

A proportional-integral-derivative (PID) controller is a type of control system that adjusts the output of a system based on the error between a setpoint and the actual output. The controller uses three components, namely proportional, integral, and derivative, to adjust the output and maintain a stable response. The proportional gain adjusts the output in proportion to the current error, such that the larger the error, the larger the output. The integral gain adjusts the output based on the accumulated error over time, thereby reducing steady-state error. The derivative gain adjusts the output based on the rate of change of the error, such that it can predict and counteract any sudden changes in the system. The PID controller is widely used in various industrial applications, such as robotics, process control, and automation. However, the PID controller's performance can be affected by factors such as the system's complexity, nonlinearity, and time-varying behavior. Therefore, engineers and researchers must design and optimize PID controllers to ensure stable and reliable control of complex systems, by carefully selecting and tuning the proportional, integral, and derivative gains to suit the specific application.

B. LINEAR QUADRATIC REGULATOR (LQR)

Standard LQR control generates an optimal controller for disturbance-free systems [5]. However, the majority of systems are affected by disturbances that impact optimal control. In this section, the LQR control design for disturbance-excited linear systems will be discussed.

In general, it is difficult to create an appropriate non-linear model of an actual DC motor [12]. This system uses a state space technique to evaluate and regulate the system. Figure 5 clarify the Linear Quadratic control system [21].

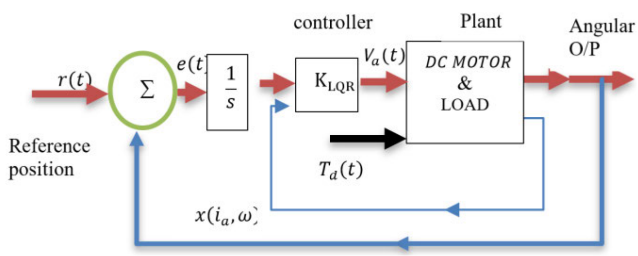

FIGURE 5. Linear quadratic regulator control system.

The design assumptions, Plant DC Servomotor-based antenna positioning control system design using LQR Controller model defined by equation (14), and All states are directly measurable and are all well-known (available for feedback) [13]. Selecting the inputs to be error in angle and the output voltage: rotating speed with Linear-Time-Invariant (LTI) system.

State-space form

$$\boldsymbol{X}(t) = \boldsymbol{A}x(t) + \boldsymbol{B}u(t) \tag{12}$$
$$\boldsymbol{Y}(t) = \boldsymbol{C}x(t) + \boldsymbol{D}u(t) \tag{13}$$

where A is the ***nxn*** state matrix, B is the ***nxr*** input matrix, C is the ***mxn*** output matrix, D is the ***mxr*** matrix, X(t) is the n-state vector, and Y(t) is the r-control vector. Using values from Table 1 we will obtain equations 14,15:

$$\begin{bmatrix} \frac{di_a}{dt} \\ \frac{d\omega_r}{dt} \\ \frac{d\Theta}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{R}{L} & \frac{K_B}{L} & 0 \\ \frac{K_m}{J} & -\frac{B}{J} & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} i_a \\ \omega_r \\ O \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0.0 \\ 0.0 \end{bmatrix} V_a \tag{14}$$

$$y = \begin{bmatrix} 0 & 0 & 180/\pi \end{bmatrix} \begin{bmatrix} i_a \\ \omega_r \\ O \end{bmatrix} + [0.0]Va$$

$$A = \begin{bmatrix} -0.4483 & 6.4483 & 0 \\ 2.6855 & -0.2837 & 0 \\ 0 & 1 & 0 \end{bmatrix};$$

$$B = \begin{bmatrix} 0.0345 \\ 0 \\ 0 \end{bmatrix};$$

$$C = \begin{bmatrix} 0 \; 0 \; 180/\pi \end{bmatrix}; \quad D = [0.0] \tag{15}$$

LQR is used in modern optimal control theory. To enhance the design and fine-tune the response, numerous Q matrices and R values were tested. LQR parameter design steps are as follows:

- Select the weighting matrices Q.
- Select the weighting matrices R.
- The constant feedback gain vector K is computed using the 'LQR' instruction provided in a fully parameterized code.

The closed-loop system step responses are found by simulation. It is necessary to achieve proper choice of the two parameters, R and Q, to balance the relative importance of the control effort and error respectively, in the cost function. For instance, LQR matrices were used for R, 25000000 was applied. Furthermore, it has been established that augmenting the values of the elements in Q would potentially improve the response by mitigating tracking errors. However, this method of action would need a greater exertion of control, hence incurring higher costs.

C. FUZZY - PI CONTROLLER

The structure of the proposed Fuzzy- PI controller has two inputs: the error e(t), which depends on the set point and the current state, and the error's derivative Δe, which determines when the change occurs [37]. see figure 5. In which, the fuzzy controls the PI gains ***Kp*** and Ki with time. In this fuzzy control structure, the controller outputs are the proportional and integral controller gains ***KP*** and ***KI***, respectively. The error is supplied to the PI controller, and the PI gains are derived from the Fuzzy controller output. The advantage of this topology is that it combines FUZZY and PI controller qualities [38]. This controller's PI gains are dynamic and vary according to the current e and Δe. The gains Ge, GΔe are scaling factors for e and Δe to fuzzy logic. The gains

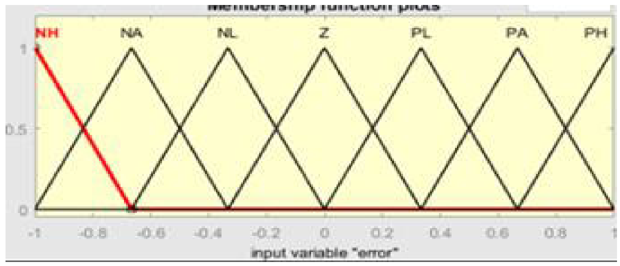

FIGURE 6. Error (e) and Δe membership function (input).

GKP and ***GKi*** are the ***KP*** and ***KI*** scaling factors following defuzzification shown in Figure 6.

1) DESIGN OF FUZZY LOGIC BASED CONTROLLERS

For each variable, a Gaussian membership function is created and utilised to randomise the inputs and outputs of the Suspension system. These fuzzy sets contain the linguistic variables NH, NA, NL, Z, PL, PA, and PH. Total of 49 rules are shown Figure 6. Utilized are the Mamdani type inference method and the centroid defuzzification method. Result of fuzzy controller output, Fuzzy logic-based controllers include four fundamental components: fuzzification, rule base, decision logic, and defuzzification. The language terminology for fuzzification are N, P, or Negative and Positive, respectively. H, A and L are High, Average, and Low, respectively. Thus, NH stands for Negative High, PA for Positive Average, etc. The Fuzzy- PI speed controller features two PI gain output variables. The fuzzy output variables KP and KI are seen in Figure 7.

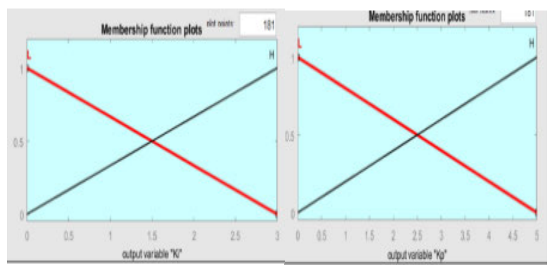

FIGURE 7. Output variables for Fuzzy- PI Controller (KP membership function& KI membership function).

2) RULE BASE

The Fuzzy controllers utilised in this work are those developed by Mamdani. In terms of membership functions, the 'IF ...THEN' rules for e and Δe determine the relationship between output variables [39]. The Fuzzy speed controller rule base is shown in Table 2.

IV. PROPOSED SIMULINK MODEL

The simulation model for a DC servo mechanism with a graphical user interface, as shown in Figure 8, consists of auxiliary details using SIMULINK components for open loop simulation in mathematical modeling, experiments with

TABLE 2. Rule base for fuzzy PI speed controller (Kp)& rule base for fuzzy PI speed controller (KI).

E/Δe	NH	NA	NL	Z	PL	PA	PH
NH	Kp H Ki L	Kp H Ki L	Kp H Ki L	Kp H Ki L	Kp H Ki L	Kp H Ki L	Kp H Ki L
NA	Kp L Ki H	Kp H Ki L	Kp H Ki L	Kp H Ki L	Kp H Ki L	Kp H Ki L	Kp L Ki H
NL	Kp L Ki H	Kp L Ki H	Kp H Ki L	Kp H Ki L	Kp H Ki L	Kp L Ki H	Kp L Ki H
Z	Kp L Ki H	Kp L Ki H	Kp L Ki H	Kp H Ki L	Kp L Ki H	Kp L Ki H	Kp L Ki H
PL	Kp L Ki H	Kp L Ki H	Kp H Ki L	Kp H Ki L	Kp H Ki L	Kp L Ki H	Kp L Ki H
PA	Kp L Ki H	Kp H Ki L	Kp H Ki L	Kp H Ki L	Kp H Ki L	Kp H Ki L	Kp L Ki H
PH	Kp H Ki L	Kp H Ki L	Kp H Ki L	Kp H Ki L	Kp H Ki L	Kp H Ki L	Kp H Ki L

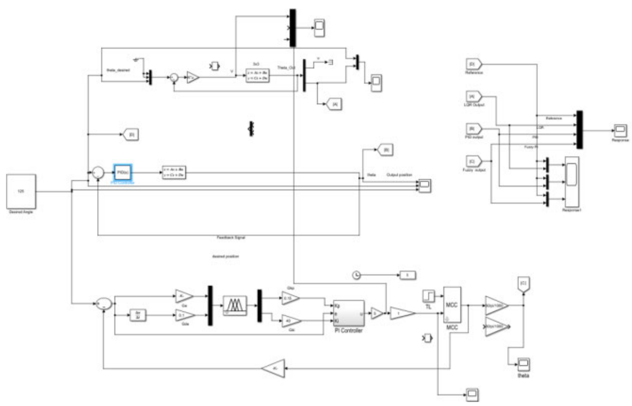

FIGURE 8. Simulink model of PID, LQR and Fuzzy -PI.

closed loop, PID control, frequency response, and system time constant in armature and field-controlled modes. Figure 8 depicts the MATLAB-created SIMULINK model for the intended PID, fuzzy- PI, and LQR controller system used to conduct simulations. In one scenario, the controller is interpreted as a PID controller, and in another, as a LQR, fuzzy- PI controller. As a reference, a step input signal was applied to the plant transfer function and state-space system.

Where, θ_i : Input Desired angle; θ_o : System output angle; $G(s)$: Transfare Function; MCC : disturbance.

V. RESULTS AND DISCUSSION

In the carried-out simulation, an experiment was conducted to assess and compare the efficacy of several controllers in regulating the motor angle towards a predetermined goal value of 100 degrees. In this experimental study, the DC servo motor employed was identified as Model T-36001 with weight (1360 LB). The aim of this study was to conduct an analysis and comparison of the responses exhibited by several controllers when applied to the same motor, using a specific target angle as the reference.

A. PID CONTROLLER

The PID parameters in the MATLAB/SIMULINK environment were obtained through the utilization of the autotune feature inside the Simulink environment. The resulting values for the proportional gain (K_p), integral gain (K_i), and derivative gain (K_d) were determined to be 15.5291817, 1.2905841, and -41.517558326, respectively.

B. LQR CONTROLLER

Using MATLAB programming language, we have acquired the following values: The value of K that successfully attained the desired outcome. The performance optimization was eventually established by finding the value of K that satisfied the transitory design criteria, which was calculated as K = [(220.1899 & 348.0243&3.6237)]. The system's reaction is derived from the Linear Quadratic Regulator (LQR) algorithm.

$$Q = \begin{bmatrix} 1000000 & 0 & 0 \\ 0 & 1000000 & 0 \\ 0 & 0 & 1000000 \end{bmatrix}$$

$$L = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

$$R = 2500000$$

C. FUZZY CONTROLLER

Figure 9 shows the fuzzy surface for the specified controller by using the Gaussian membership function.

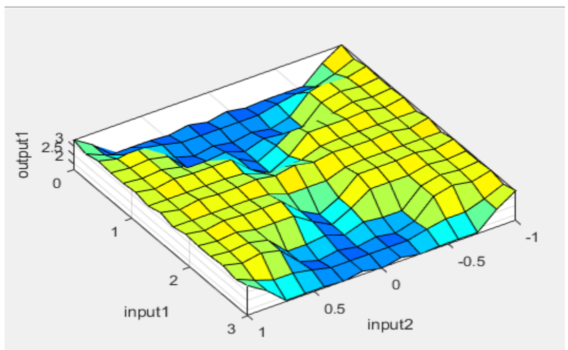

FIGURE 9. Fuzzy surface of the proposed controller with 49 rules.

The next section is design and simulation have been utilized to examine the proposed model control system. The LQR, PID and fuzzy- PI are controllers that have been modeled for the same motor in which the better response.

VI. SYSTEM RESPONSE

This study's findings have major significance for heavy motor control system design and optimization. The Fuzzy PI controller shows that fuzzy logic-based control systems can perform well in dynamic and complicated contexts. These insights can help researchers and engineers design and optimize control systems for heavy industrial motors. This study also improves heavy motor system performance and safety, lowering maintenance costs, extending motor lives, and increasing production

Figure 10 represents the system response at elevation 100 degree., we obtained the results that recorded in Table 3. In general high slew rates are expected to reduce the lifetime [40].

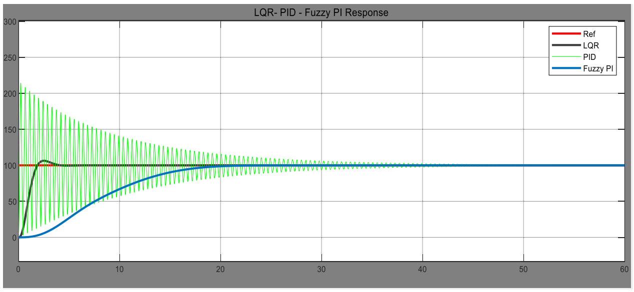

FIGURE 10. System responses at 100 DEG (three controllers).

TABLE 3. Response of controllers at different angles.

controller	Slew rate /sec	Rise time (Sec.)	Overshoot (%)
PID	502.726	2.109	155.581%
LQR	68.351	1.170	5.85%
Fuzzy-PI	**6.839**	**11.581**	**0.505%**

Heavy motors are essential in industry, transportation, and robotics. Heavy motors need reliable control systems to manage speed and torque for safe and effective operation. In general, high slew rates are expected to reduce the lifetime This study tested PID, LQR, and Fuzzy PI for managing a hefty motor. The PID controller overshot, causing mechanical stress, wear, and vibration, according to the results. However, the LQR controller had a slight overshoot and was unreliable. The Fuzzy PI controller outperformed the other two because of its consistent response without excess.

Fuzzy logic-based feedback helps the Fuzzy PI controller function better. The error signal and rate of change affect the Fuzzy PI controller's proportional and integral gains. This lets the controller adjust to changing conditions, avoid high overshoot and lowest slew rate. Fuzzy logic-based control systems may be superior at controlling large motors than PID and LQR. The studies also stress optimizing control systems for robust and reliable motor control.

VII. CONCLUSION

The primary purpose of this study article was to investigate the design and simulation of closed-loop control systems for Ground Data Receiving Stations (GDRS). The focus was on properly positioning antennas to facilitate the reception of data from satellites. The study conducted a comparative analysis of the performance of three distinct controllers, specifically PID, LQR, and Fuzzy-PI. This analysis was carried out using a DC servo motor-based controller and an antenna positioning system, which were constructed using the MATLAB/SIMULINK software. The findings of the comparison analysis revealed that the Fuzzy-PI controller had superior performance in terms of responsiveness and robustness when compared to the PID and LQR controllers. The management of time delays in antenna control inside the GDRS was conducted effectively, resulting in improvements in bypass, rising time, and tracking antenna calibration values. This discovery underscores the importance of improving control systems for ground stations, particularly in the context of managing big motors. Additionally, it presents significant opportunities for breakthroughs in motor control and enhancing system stability. Furthermore, the research study provided evidence of the detrimental consequences associated with an overshoot in PID and LQR control methodologies. These consequences encompass motor deterioration and heightened mechanical strain, which can result in escalated maintenance expenses and diminished operational longevity. On the other hand, the Fuzzy-PI controller that was suggested demonstrated its effectiveness in mitigating overshoot, hence enhancing the safety and reliability of motor control. The study highlights the significance of carefully choosing control strategies to attain the most favorable system response and stability during ground data-receiving operations. The Fuzzy-PI controller that has been proposed offers a significant contribution in terms of strengthening the overall efficiency of the Ground Data Reception System (GDRS) and expanding its capabilities for receiving data. It is generally expected that higher slew rates have a negative impact on the lifetime. To address the issue of excessive overshoot, it is advisable to prioritize the utilization of the lowest possible slew rate.

The objective of cutting-edge future studies is to enhance the efficiency of tuning operations, evaluate the resilience of systems under different circumstances, and integrate a range of artificial intelligence techniques to enhance control performance. Additionally, the use of supplemental control methodologies, such as adaptive and model-based control, exhibits promise in augmenting system performance and mitigating overshoot. Filters such as the Kalman filter have the potential to enhance control accuracy in antenna placement systems. This study makes a substantial contribution to the field of ground station control systems by improving the reliability, efficiency, and security of motor operations in many sectors. The ramifications of this technology support engineers and researchers in the development of efficient control systems, as well as the progress of satellite data receipt and communication.

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