UJEAS

UNIZIK JOURNAL OF ENGINEERING AND APPLIED SCIENCES

UNIZIK Journal of Engineering and Applied Sciences 6(2), June (2026), 3447-3457
Journal homepage: https://journals.unizik.edu.ng/index.php/ujeas
PRINT ISSN: 2992-4383 || ONLINE ISSN: 2992-4391

Enhancing the Performance of DC Servomotor Based Antenna Position Control System in Satellite Communication Using PID-LQR

[An Application of PID Optimized Discrete-time LQR]

Kingsley Ugochukwu Anyanwu[1*], Chidiebere Nnaedozie Muoghalu[2], Patience Nkiruka Achebe[2], Ikenna Uzoma Ajere[3], and Matthew Chinedu Okechi[4]

[1]Department of Electronic and Computer Engineering, Nnamdi Azikiwe University Awka, Anambra State, Nigeria.

[2]Department of Electrical and Electronic Engineering, Chukwuemeka Odumegwu Ojukwu University, Uli Campus, Anambra State, Nigeria.

[3]Department of Information Technology, Federal University of Technology Owerri, Imo State, Nigeria.

[4]Department of Electrical and Electronic Engineering, Institute of Management and Technology (IMT) Enugu, Enugu State, Nigeria.

[*]Corresponding Author's E-mail: ku.anyanwu@unizik.edu.ng

Abstract

In this work, a control system has been designed based on Proportional Integral Derivative (PID) optimized discrete-time Linear Quadratic Regulator (LQR) called PID-LQR and implemented with a DC servomotor-based antenna positioning control system in MATLAB/Simulink environment. The system response was analyzed considering the uncompensated state, the results obtained were presented in terms of steady-state transient response characteristics, which were rise time, peak time, settling time, overshoot, and steady-state error. In the uncompensated state, the rise time was 0.52s, peak time was 1.30s, settling time was 4.35s, overshoot was 34.7%, and steady-state error was 0. Considering the high value of overshoot, a LQR was designed and incorporated into the system to form a closed-loop control system, and simulation conducted revealed that the cycling associated with the uncompensated because of high overshoot (34.7%) was greatly reduced to 6.43% and steady-state error of 0 was achieved. The performance of LQR was further optimized by integrating PID parameter. PID-LQR reduced the rise time from 2.02s to 1.98s, peak time from 4.20s to 3.49s, settling time from 6.11s to 3.94s, and overshoot from 6.43% to 3.80%. These reductions in transient response parameters revealed that the designed PID-LQR yielded the most effective response in terms of stability. This is because the PID-LQR provided most smooth and most stable response compare to other control systems measured against the uncompensated system. Therefore, the use of the PID-LQR provided more stable and reliable tracking for antenna positioning system in satellite dish antenna for deep space application.

Keywords: Antenna, Communication, PID, Discrete-time PID-LQR, DC servomotor, Position control system, Satellite

1. Introduction

Communication systems require an antenna to convey transmitted and received signals between the space satellite and the earth-based station. Satellites carry large amount of data representing telephone traffic, radio signals, and television signals (Ekengwu *et al.*, 2022). The use of satellite in recent times has made it to be an important part of everyday life as can be seen in many homes and offices with different forms of antenna that are connected for signal reception from the satellites located far distance away from the earth (Sowah *et al*., 2017). Communication via satellites offers communication without selecting location and time (Fandakh & Okumuş, 2016). Satellite antenna is designed in such a way as to focus on a given broadcast source that receives information by reflecting signal beams and focusing them into a relatively narrow beam that hits its parabolic surface and subsequently passes the signal on to the feed horn, at which point it is further transmitted to the receiving equipment (Nice & Harris, 2002).

The major problem with satellite antenna used in communication is positioning, which involves aligning the dish in order to aim at the correct satellite location for proper communication. Since every antenna is dedicated to a specific satellite, it is not easy to point it (Sugandhi *et al*., 2016). It is therefore, essential for an automated system to be incorporated with the satellite antenna so as to achieve the optimum positioning for quality signal transmission and reception (Chishti *et al.*, 2014). In positioning of a satellite antenna, effective process can be achieved regarding the anticipated link margin necessary to receive most of the satellite transmission data from certain angle of elevation (azimuth) position (Mahmood *et al.*, 2024). In order to achieve this, a controller is included as a subsystem and it is linked to the existing antenna system in order to improve its performance (Fkirin & Khira, 2023). One of the most common techniques that have been implemented for positioning control systems are classical controllers such as Proportional Integral and Derivative (PID), Proportional Derivative (PD), and analogue compensators (Muoghalu *et al.*, 2021; David *et al*., 2024; Achebe *et al.*, 2025; Muoghalu *et al.*, 2025; Eze *et al.*, 2021; Achebe, 2018). However, optimal techniques have been implemented in modern control systems to provide more cost effectiveness and timeliness in transient response that applied Linear Quadratic Regulator (LQR) (Anyanwu *et al.*, 2024; Muoghalu *et al*., 2020; Aloo *et al.*, 2016; Eze *et al.*, 2025) including full state feedback state control method (Eze *et al*., 2022).
In this work, an optimal control based on hybrid PID-LQR is implemented for deep space antenna positioning system to provide optimal control system with pointing or tracking accuracy. The developed PID-LQR is implemented as a discrete time-based optimal controller rather than as a continuous time control system commonly obtained in previous literature (Aloo *et al*., 2016; Eze *et al.*, 2025; Ekengwu *et al*., 2024) so as to ensure more flexibility to control loop performance compared to continuous time method (Achebe, 2018).

Some of the recent techniques applied in satellite antenna positioning system are reviewed in this section. The parameters of PID controller were optimized by weighted Cultural Artificial Fish Swarm Algorithm (wCAFSA) to enhance positioning system of deep space antenna (Salawudeen *et al.*, 2017). Model Predictive Controller (MPC) was implemented to achieve tracking specification of rise time of less than or equal to 4 s, settling time of less than or equal to 5 s and overshoot of less than or equal to 10% considering different prediction horizon (Ekengwu *et al.*, 2018). Model Reference Adaptive Control (MRAC) and its modified form with fuzzy logic model have been implemented to achieve position control system for servomotor-based antenna (Uthman, 2019; Eze *et al*., 2026). Pointing accuracy of deep space antenna position control system was improved using fuzzy-PID (Yakubu *et al*., 2020). Back Propagation Neural Network (BPNN) was used to optimize classical PID parameters for faster response speed and improved transient behaviour in (Eze *et al.*, 2024). Discrete-time and continuous time LQR have been separately applied by Anyanwu *et al*. (2024) and Aloo *et al.* (2016) in DC servomotor-based antenna positioning system. Nonlinear PID (NPID) formulated by adding an arc tan function to integral component rather than the direct error was used together with Particle Swarm Optimization (PSO) method to improve the performance antenna azimuth positioning system subject to external disturbance (Rasheed *et al.*, 2023). Model Following Control-based PID (MFC-PID) controller was used to address the weakness in transient response of classical PID controller (Akwukwaegbu *et al.*, 2023).

Regarding the related surveyed works the use of optimal control for DC servomotor based deep space antenna using discrete time hybrid LQR-PID. Therefore, this paper attempts to fill this gap by implementing a discrete time (digital) optimal controller based on LQR with PID to replace the continuous time LQR implemented in Anyanwu *et al*. (2024) and improve system stability in terms of reduced overshoot associated with system as in Akwukwaegbu *et al*. (2023).

2. Methodology

The section presents a hybrid control system based on discrete-time PID-LQR model as shown in Figure 1. The error signal due to the difference between the desire position and the actual position is manipulated by the PID controller using complex computation algorithm and subsequently produce a control command that optimizes the LQR. The resulting command from the LQR is used to adjust the antenna to a new position according to the error signal.

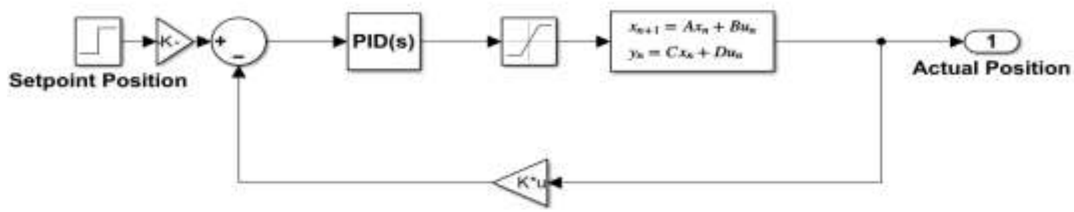

Figure 1: Block diagram of discrete-time PID-LQR control system

The variables in the discrete –time block for the plant model in Figures 1 are the state-space parameters. These variables define or represent the dynamic characteristics of the plant, which is a DC servomotor-based antenna positioning system. Where A, B, C, and D, are the state matrix, the input matrix, the output matrix, and the transition matrix. The state space model of a LTI system can be defined by:

$$\left.\begin{aligned} \dot{x} &= Ax + Bu \\ y &= Cx + Du \end{aligned}\right\} \tag{1}$$

The constants A, B, C, and D represent the state matrix, input matrix, output matrix, and direct transition matrix respectively. The state-space description of the DC servomotor position control for deep space antenna is defined in Equations (2) and (3). Table 1 defines the parameters of the deep space DC servomotor-based antenna system

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & -\frac{B_a}{J_a} & \frac{K_T}{J_a} \\ 0 & -\frac{K_B}{L_a} & -\frac{R_a}{L_a} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \frac{1}{L_a} \end{bmatrix} V_a \tag{2}$$

$$y = \begin{bmatrix} 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + [0]\, V_a \tag{3}$$

Table 1. **Parameters of deep space DC servomotor-based antenna system (Eze *et al.*, 2021)**

Physical Quantity	Definition of Quantity	Numerical Value
a	Power Amplifier Pole	100
a_m	Motor and Load Pole	1.71
B_a	Motor Dampening Constant [Nm/rad]	0.01
B_L	Load Dampening Constant [Nms/rad]	1
B_m	Equivalent Viscous Friction Coefficient [Nms/rad]	0.02
J_a	Motor Inertia constant [kgm^2]	0.02
J_L	Load Inertia constant [kgm^2]	1
J_m	Equivalent moment of Inertia [kgm^2]	0.03
K	Preamplifier Gain	-
K_1	Power Amplifier Gain	100
K_B	Back emf Constant [Vs/rad]	0.5
K_g	Gear Ratio	0.1
K_m	Motor and Load Gain	2.083
K_{pot}	Potentiometer Gain	0.318
K_T	Motor Torque Constant [Nm/A]	0.5
L_a	Motor Armature Inductance [H]	0.45
N	Turns on Potentiometer	10
N_1, N_2, N_3	Gear Teeth (Respectively	25,250,250
R_a	Motor Armature resistance [Ω]	8
V	Voltage Across Potentiometer [V]	10

Substitution of the numerical values of DC servomotor for antenna positioning system from Table 1 into Equation (2) gives:

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\\ \dot{x}_3\end{bmatrix}=\begin{bmatrix}0 & 1 & 0\\ 0 & -0.5 & 25\\ 0 & -1.111 & -17.78\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ x_3\end{bmatrix}+\begin{bmatrix}0\\ 0\\ 2.22\end{bmatrix}u \tag{4}$$

where,

$$A=\begin{bmatrix}0 & 1 & 0\\ 0 & -0.5 & 25\\ 0 & -1.111 & -17.78\end{bmatrix}, B=\begin{bmatrix}0\\ 0\\ 2.22\end{bmatrix}, C=[0 \quad 1 \quad 0], D=[0]$$

where $x_1=\theta(t)$, $x_2=\omega(t)$, and $x_3=i_a(t)$. the first order derivative of position, angular speed, and current is given by $\dot{x}_1$, $\dot{x}_2$, and $\dot{x}_3$ respectively.
The state-space model of the overall transfer function of the closed loop system is given by:

$$\begin{cases}\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\\ \dot{x}_3\end{bmatrix}=\begin{bmatrix}0 & 1 & 0\\ 0 & 0 & 1\\ -663 & -171 & -101.71\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ x_3\end{bmatrix}+\begin{bmatrix}0\\ 0\\ 1\end{bmatrix}u\\ y=[663 \quad 0 \quad 0]\begin{bmatrix}x_1\\ x_2\\ x_3\end{bmatrix}\end{cases} \tag{5}$$

Equations (4) and (5) are the continuous time state space model of the system

2.1 State-Space Model in Discrete Time

The discrete-time state space for *nth* order linear time invariant system is expressed by:

$$\begin{cases}x(k+1)=Ax(k)+Bu(k)\\ y(k)=Cx(k)+Du(k)\end{cases} \tag{6}$$

In this paper, the sampling time chosen for the conversion from continuous time to discrete time is 0.01 s based on zero order hold (ZOH) sampling technique.

The discrete-time state space model of the DC servomotor-based antenna positioning system is given in Equations (7) and (8), while the controllability and observability matrices are presented in Equations (9) and (10).

$$\begin{bmatrix}x_1(k+1)\\ x_2(k+1)\\ x_3(k+1)\end{bmatrix}=\begin{bmatrix}0.9999 & 0.009977 & 3.656e-05\\ -0.02424 & 0.9937 & 0.006258\\ -4.149 & -1.094 & 0.3571\end{bmatrix}\begin{bmatrix}x_1(k)\\ x_2(k)\\ x_3(k)\end{bmatrix}+\begin{bmatrix}1.315e-07\\ 3.656e-05\\ 0.006258\end{bmatrix}u(k) \tag{7}$$

$$y(k)=[0 \quad 0 \quad 663]\begin{bmatrix}x_1(k)\\ x_2(k)\\ x_3(k)\end{bmatrix}+[0]\,u(k) \tag{8}$$

$$Con_{matrix}=\begin{bmatrix}0.0000 & 0.0000 & 0.0000\\ 0.0000 & 0.0001 & 0.0001\\ 0.0063 & 0.0022 & 0.0007\end{bmatrix} \tag{9}$$

The rank of the controllability matrix is 3.

$$Observ_{matrix}=\begin{bmatrix}0 & 0 & 663\\ -2.510 & -725.6 & 236.8\\ -3715.6 & -1007.6 & 79.9\end{bmatrix} \tag{10}$$

The rank of the observability matrix is 3. Hence, the discrete-time system of the antenna positioning loop is completely controllable and observable.

2.2 Design of Discrete Linear Quadratic Regulator

The design of discrete-time linear quadratic regulator (LQR) is carried out using the MATLAB command given by Equation (11):

$$\begin{cases} A = sys\_d.a; \\ B = sys\_d.b; \\ C = sys\_d.c; \\ D = sys\_d.d; \\ Q = C' * C \\ R = 1; \\ [K] = dlqr(A, B, Q, R) \end{cases} \tag{11}$$

$$\begin{cases} Q = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 439569 \end{bmatrix} \\ K = [K_1 \quad K_2 \quad K_3] = [-509.1512 \quad 32.6613 \quad 54.8124] \end{cases} \tag{12}$$

In Equation (12), the symmetric matrix Q and the gain matrix K for the entire dish antenna positioning arrangement including the DC motor is captured. Thus, Equation (12) defines the designed discrete-time LQR designed for the antenna position control system.

2.3 PID Optimized LQR Control System

The proposed control system for deep space satellite antenna positioning is shown in Figure 1. The control algorithm of LQR is optimized using the PID controller. The objective is to achieve a position control system with reduced rise (response) time, settling time, overshoot, steady state error, and improved tracking performance. The measurement device is assumed to be a unity feedback gain sensor. This is achieved as follows:

Assuming the error, the rate of error and the integral of the error signal e(t) are state variables, the optimal feedback gains of the LQR in Equation (12) i.e. $K = [-509.1512 \quad 32.6613 \quad 54.8124]$, are considered the parameters of the PID controller. Thus, the state variables are defined by:

$$\left. \begin{aligned} x_1 &= \int e(t)dt \\ x_2 &= e(t) \\ x_3 &= \frac{de(t)}{dt} \end{aligned} \right\} \tag{13}$$

Considering the block diagram of the proposed system in Figure 1, the optimal control law $u(t)$ of the PID-LQR is defined by:

$$u(t) = K_o x(t) \tag{14}$$

where K_o is the gain of the designed PID-LQR controller, which is the product of the PID gains and the gains of the K matrix of LQR. It is given by:

$$K_o = K \begin{bmatrix} k_i \\ k_p \\ k_d \end{bmatrix} = [K_1 \quad K_2 \quad K_3] \times \begin{bmatrix} k_i \\ k_p \\ k_d \end{bmatrix} = [K_I \quad K_P \quad K_D] \tag{15}$$

where $K_I = K_1 k_i$, $K_P = K_2 k_p$, and $K_D = K_3 k_d$ respectively.

Where:

$$x(t) = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} \tag{16}$$

Equation (13) is substituted into Equation (16). Then substituting the resulting equation together with Equation (15) into Equation (14) gives:

$$u(t) = \begin{bmatrix} K_I & K_P & K_D \end{bmatrix} \begin{bmatrix} \int e(t)dt \\ e(t) \\ \frac{de(t)}{dt} \end{bmatrix} = K_I \int e(t)dt + K_P e(t) + K_D \frac{de(t)}{dt} \quad (17)$$

PID controller is mathematically defined for a bounded control by:

$$u_{pid}(t) = k_p e(t) + k_i \int_{t_0}^{t_f} e(t)dt + k_d \frac{de(t)}{dt} \quad (18)$$

The PID is designed using the MATLAB/Simulink tuner. The designed PID controller and its parameters are defined in Laplace transform given by:

$$C(s) = 1.002 + \frac{5\times 10^{-11}}{s} + 1 \times 10^{-8} s \quad (19)$$

where $k_p = 1.002$, $k_i = 5 \times 10^{-11}$, and $k_d = 1 \times 10^{-8}$ and substituted into Equation (17) to optimize the gains of the optimal control law of the designed LQR.

3. Result and Discussion

The designed discrete-time LQR control technique for antenna positioning servomotor control system has been implemented by simulation in MATLAB/Simulink environment. Simulations have been carried out considering uncompensated scenario and compensated scenario (closed-loop) antenna positioning servomotor control system. The simulation was based on step response of uncompensated antenna positioning servomotor control system shown in Figure 2. In the same vein, the positioning servomotor control system compensated with a LQR controller is presented Figure 3.

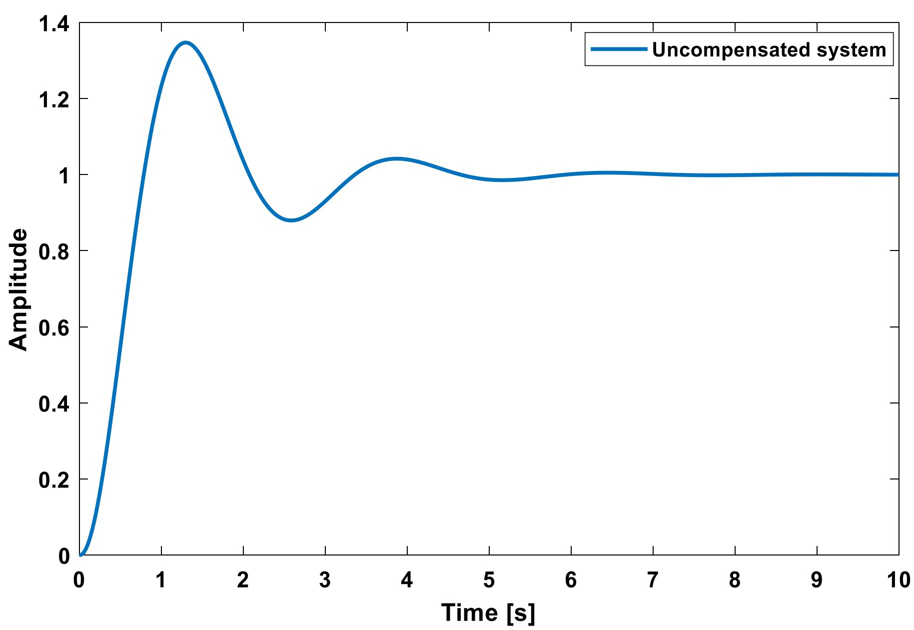

Figure 2: Step response of uncompensated system

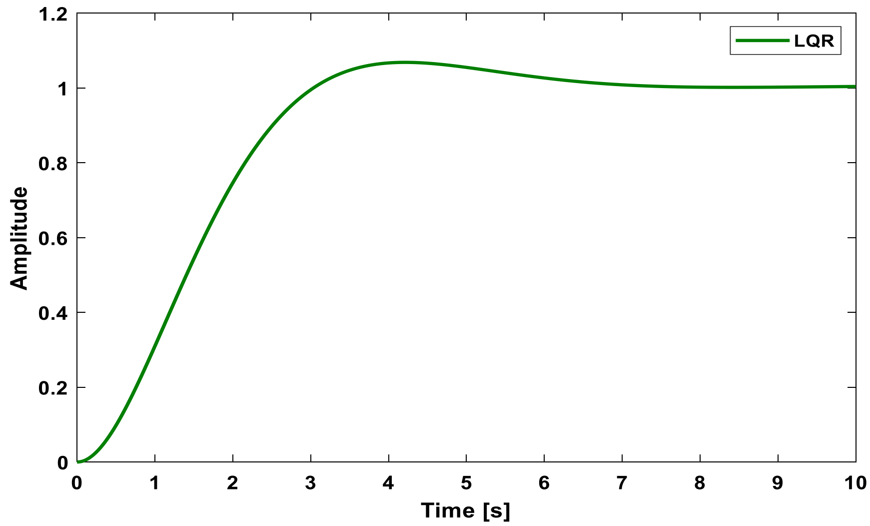

Figure 3: Step response of LQR control system

Figure 2 represents the step response of antenna positioning servomotor control system model in the open loop when no controller is integrated into the system to realize the feedback closed loop control system. That is the condition of the system without a controller (uncompensated). The simulation curve reveals that the system has high degree of cycling considering the overshoot which is 34.7% prior to the system settling. The simulation plot for unit step response of antenna positioning servomotor control system model with an LQR controller as shown in Figure 3 reveals that that its introduction caused the overshoot value to reduce to 6.43% with zero steady-state error as listed in Table 2.

Table 2. **Numerical analysis of time domain performance of uncompensated system and LQR**

Control System	**Rise time (s)**	**Peak time (s)**	**Settling time (s)**	**Overshoot (%)**	**Steady-state error**
Uncompensated	0.52 s	1.30s	4.35 s	34.7%	0.181
LQR	2.02 s	4.2 s	6.11 s	6.43%	0

Looking at Table 2, it can be deduced in terms of the rise time that uncompensated system outperformed the LQR system, which is 0.52s against 2.02s. The same holds in terms of peak time and settling time where the values were peak time of 1.30s against peak time of 4.2s and settling time of 4.35s against 6.11s respectively. However, in terms of overshoot and steady-state error, the LQR system outperformed the uncompensated system such that when the overshoot was 34.7 % in the case of uncompensated system, the overshoot was 6.43% for the LQR system. For steady state error, the uncompensated system yields 0.181 whereas LQR system gives 0. Since the objective is to design a system to ensure improved stability by reducing error or deviation with improved tracking for effective positioning, The LQR compensated will offer better antenna positioning for improved line of sight operation (considered in this case as the ability to track unit step input). Thus, with LQR the antenna tracked the satellite signal with zero error (steady state error of 0) with improved stability (overshoot of 6.43%).

Figure 4 shows the simulated step responses of LQR and PID-LQR. The graphical plot of the response of the PID-LQR control system when a set point input is applied to the system at t = 0. The PID-LQR system was able to track the setpoint input within the bounded time simulation interval as shown in the figure. The numerical values of the transient response parameters are listed in Table 3.

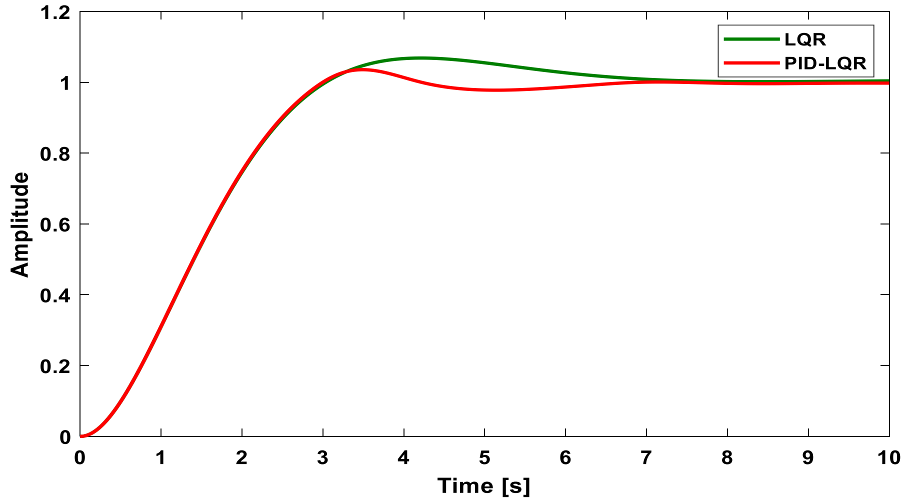

Figure 4: Step response comparison of LQR and PID-LQR

Table 3. Numerical comparison of PID and LQR control system

Control System	**Rise time** (s)	**Peak time** (s)	**Settling time** (s)	**Overshoot** (%)	**Steady-state error**
LQR	2.02 s	4.21 s	6.11 s	6.43%	0
PID-LQR	1.98 s	3.49 s	3.94 s	3.80%	0

From Figure 4 and Table 3, the performance characteristics of the PID-LQR revealed that the integration of PID to optimize the LQR control system performance yielded better position control system response. Hence, PID-LQR reduced the rise time from 2.02 s to 1.98 s, peak time from 4.21 s to 3.49 s, settling time from 6.11 s to 3.94 s, and overshoot from 6.43% to 3.80%. These reduction in transient response parameters indicated improvement in system's response behaviour.

The step responses of the uncompensated system (marked Sys1), PID, PIDD, MFC-PID (Akwukwegbu et al., 2023), LQR, and developed discrete-time hybrid PID-LQR are presented in Figure 5 to compare various control techniques in order to validated the proposed system. Table 4 shows the numerical performance of the various control systems.

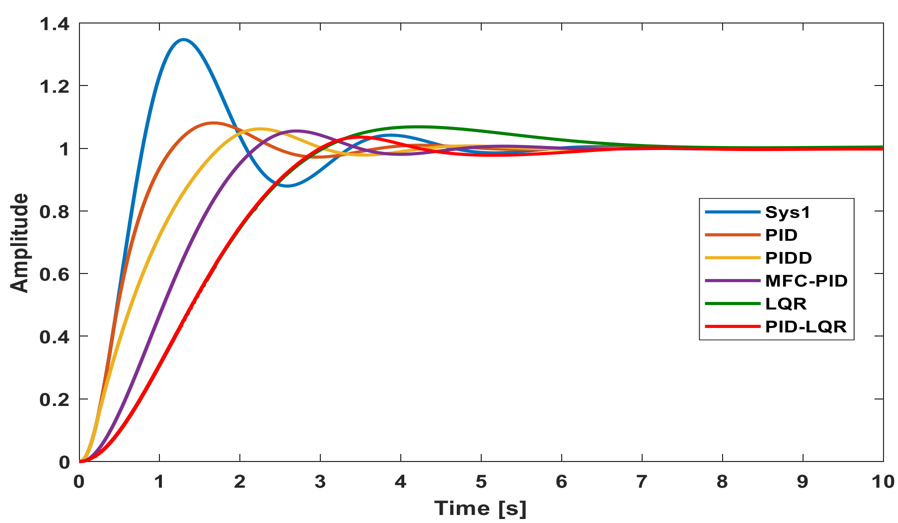

Figure 5: Step response of different control system

Table 4. Numerical analysis of time domain performance parameters

Control System	Rise time (s)	Peak time (s)	Settling time (s)	Overshoot (%)	Steady-state error
Sys1	0.52	1.30	4.35	34.7	0
PID	0.73	1.67	3.29	8.09	0
PIDD	1.21	2.25	3.70	6.17	0
LQR	2.02	4.20	6.11	6.43	0
MFC-PID	1.45	1.06	3.25	5.52	0
PID-LQR	1.98	3.49	3.94	3.80	0

Looking at the simulation curves and the numerical performances of each control system in Table 4, it is obvious that when no controller was introduced, the system shows high level overshoot. Therefore, without controller the system is unstable and not reliable considering the high overshoot (34.7%). The introduction of the controllers largely improved the system performance in this regard (i.e. stability of system). Each controller ensured that the system achieved pointing accuracy and efficient tracking of setpoint value with reliable link performance during satellite communication and improved system in system dynamic. The controller that offered most efficient tracking in terms of smoothest response and best stability compared to the uncompensated system is the discrete-time PID-LQR.

4. Conclusion

A control system based on PID-Linear Quadratic Regulator (LQR) controller has been designed for Direct Current (D.C.) servomotor-based deep space antenna positioning system has been effectively achieved. This was established through simulation conducted in MATLAB/Simulink environment for Simulated output responses of antenna positioning servo control system to step input signal which met the design specifications. Also, the simulation results obtained showed that PID-LQR control technique could be set up in driving the azimuth/elevation of D.C. servomotors so as to direct a parabolic dish antenna and ensures that it is always kept within the referenced line of sight with a particular satellite. The effectiveness of the developed discrete-time PID-LQR was compared with different control systems for position control of satellite antenna. Each control system was modelled and introduced into the control of a DC servomotor-based antenna positioning system. The simulation results indicated that the introduction of each controller guaranteed better performance than the original system without a controller. Hence, all the control system provided enhanced pointing accuracy and tracking performance. However, comparison of the controllers indicated that PID-LQR yielded the best performance with most smooth and stable response in terms of reduced overshoot.

5. Recommendation

Despite the fact that the discrete PID-LQR was able to improve system tracking performance by offering improved stability, it lagged behind PID, PIDD, and MFC-PID in terms of rise time and settling time. Thus, future study will incorporate swarm intelligent algorithm to tune the PID prior to optimizing the LQR. Also, prototyping the developed system will facilitate practical application and further validates its effectiveness.

Acknowledgements

Nomenclature

B_a = Motor damping constant, Nm/rad;
J_a = Motor inertia constant, kgm^2;
K_B = Back emf constant, Vs/rad;
K_T = Motor torque constant, Nm/A
L_a = Motor armature inductance; H;
R_a = Motor armature resistance; Ω
V_a = Applied voltage;

Declaration of Generative AI and AI-assisted technologies in the writing process

No AI tool was used in this research.

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.

Achebe, P. N., Muoghalu, C. N. 2025. Design of Adaptive PD controller for microsatellite yaw-axis attitude control system. *International Journal of Engineering Research and Development,* 2(21): 225-232

Akwukwaegbu, I.O., Nosiri, O., Olubiwe, M., Paulinus Nwammuo, C.F., Okonkwo, E. 2023. Design of model following control integrating PID controller for DC servomotor-based antenna positioning system. *SSRG International Journal of Electrical and Electronics Engineering,* 10(6): 33-42.

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.

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.

Chishti, A. R., Bukhari, S.F., Khaliq, H.S., Khan, M.H., Zulfiqar, S., Bukhari, H. (2014). Radio Telescope Antenna Azimuth Position Control System Design and Analysis in MATLAB/ SIMULINK Using PID & LQR Controller, (Lxiv).

David, C.C., Mbachu, C.B., Muoghalu, C.N., Ekengwu, B.O. 2024. Enhancing the pitch control of an unmanned aircraft using PSO based intelligent PID controller. *International Journal of Research Publication and Reviews*. 5(3): 55-63.

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.

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.

Ekengwu B.O., Muoghalu C.N., 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.

Eze, P.C., Muoghalu, C.N., Uebari, B. Egbunugha, C.A. 2022. State variable feedback control of data centre temperature. *International Journal of Advanced Networking and Applications*, 14(1): 5250-5257.

Eze, P.C., Nwadike, S.U., Oyiogu, D.C., Iroegbu, M.C. 2025. Hybrid PID-LQR controller for dynamic response and stability enhancement of synchronous generator's AVR system. *Asian Journal of Science, Technology, Engineering, and Art, 3*(3): 866-879.

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.

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.

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):12-21.

Fandakh, S.A., Okumuş, H.I. (2016). Antenna Azimuth Position Control with PID , Fuzzy Logic and Sliding Mode Controllers, (December 2017).

Fkirin, M.A., Khira, M. A –E. 2023. Enhanced antenna positioning control System using adapted DC servo motor and fuzzy-PI controller. *IEEE Access, 11*, 102661-102668.

Mahmood, A., Al-bayati, K.Y.A., Szabolcsi, R. 2024. Optimizing antenna azimuth position control using fuzzy PD, fuzzy PD-I, and fuzzy PD-plus-I controllers. *Nanotechnology Perceptions, 20* (3):18–32.

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*, 10(4): 2456-8880.

Muoghalu, C.N., Achebe, P.N., Onyeka, 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*, 5(6):353-358.

Muoghalu, C.N., Uju, I.U., Mbachu, C.B. 2020. Performance response improvement of automatic voltage regulator using linear quadratic gaussian tuned controller. *International Journal of Latest Technology in Engineering, Management & Applied Science,*11(9): 2278-2540.

Nice, K., Harris, T. 2002. How Satellite TV Works. HowStuffWoorks. Available from: http://electronics.howstuffworks.com/satellitetv.htm. [20 October 2025]

Rasheed, L.T., Yousif, N.Q., Al-Wais, S. 2023. Performance of the optimal PID controller for position control of antenna azimuth position system. *Mathematical Modelling of Engineering Problem, 10*(1): 366 – 375.

Salawudeen, A.T., Mu'azu, B.M., Sha'aban, Y.A., Chan, C.J. 2017. Optimal design of PID controller for deep space antenna positioning using weighted cultural artificial fish swarm algorithm. *Journal of Electrical & Electronic Systems*, 6(4):1-8.

Sowah, R.A., Mills, G.A., Nortey, J.Y., Armoo, S.K., Fiawoo, S.Y. 2017. Automatic satellite dish positioning for line of sight communication using Bluetooth technology. *Automatic Satellite Dish Positioning for Line of Sight Communication,* 1(5): 85-98.

Sugandhi, P., Sanganwar, M., Pai, A., Gayatri, P. 2016. Automatic Antenna Positioning System, 4(3):372–374.

Uthman, A. 2019. Antenna azimuth position control system using model reference adaptive control method gradient approach and stability approach. *Journal of Engineering and Applied Science, 14*(16): 5657-5664.

Yakubu, H.S., Hussein, S.U., Koyunlu, G. 2020. Fuzzy-PID controller for azimuth position control of deep spaceantenna. *Covenant Journal of Informatics & Communication Technology, 8*(1): 1-7.