Volume-3-Issue-11-November,2025 **International Journal of Modern Science and Research Technology**
ISSN NO-2584-2706

Antenna Position Control based on Smell Agent Optimization Algorithm

Abdulazeez Abdulazeez N[1;] Abel. E.Airoboman[2;] Isah Usman Yusuf [3]
[1,2]Department of Electrical/Electronic Engineering, Nigerian
Defence Academy, Kaduna, Nigeria
[3]Department of Electrical & Electronic Engineering, Abdullahi Fodiyo
University of Science and
Technology, Aliero-Kebbi State-Nigeria.

Abstract

This paper presents an antenna azimuth position control system based on a Smell Agent Optimization (SAO) algorithm. Antenna positioning performance is often affected by external disturbances such as wind, which introduce uncertainties and result in communication signal loss. Conventional nonlinear Proportional–Integral–Derivative (PID) controllers enhanced with Smell Agent Optimization (SAO) have been widely used to regulate antenna azimuth systems; however, PID controllers are often unable to fully suppress external disturbances, leading to longer settling times during satellite signal acquisition. To overcome these limitations, this work develops a SAO-based PID control scheme for enhanced antenna position regulation. The antenna azimuth position model was implemented in MATLAB/Simulink, and SAO-NPID and PSO-PID controllers were designed and evaluated. Simulation results show that the proposed SAO-NPID controller achieves a settling time of 1.13s and a root mean square error (RMSE) of 0.034, compared to 1.20 s and 0.051 obtained with the SAO-NPID controller. This corresponds to an improvement of 5.83% in settling time and 33.33% in RMSE. The results demonstrate that the proposed SAO-NPID controller exhibits superior tracking performance and robustness in stabilizing antenna azimuth angles under disturbance conditions. All simulations were performed using MATLAB 2022b.

Keywords-Antenna position control, Smell Agent Optimization (SAO), PID, azimuth angle, satellite communication

1. Introduction

Satellite communication plays a vital role in enabling reliable connectivity for a wide range of users with line-of-sight access to the sky. It remains a crucial backbone for remote communication, emergency services, and the Internet of Things (IoT) applications involving ground-based sensors and secure links (Kodheli et al., 2021). Compared to terrestrial communication systems, satellite links provide broader coverage and resilience in geographically challenging regions. However, the increasing demand for high data rates driven by applications such as video streaming, online gaming, and telemedicine has created the need for more advanced techniques to enhance communication performance. One of the simplest yet effective approaches to address these demands is adjusting the Effective Isotropic Radiated Power (EIRP) through the use of high-gain antennas, which has spurred developments in antenna design, control, and optimization (Aljuhani et al., 2021).

DOI: https://doi.org/10.5281/zenodo.17580797

Parabolic antennas serve as essential mechanicalcomponentsintelecommunications and broadcasting systems, enabling the transmission and reception of satellite signals between ground stations and satellites. These antennas are typically installed at earth stations and are susceptible to environmental disturbances such as wind, which can adversely affect the azimuth positioning control and, consequently, the system's communication efficiency (Kumar et al., 2018). Accurate azimuth positioning is therefore critical to maintaining stable communication links and ensuring optimal signal tracking performance. Numerous control techniques—such as Proportional–Integral–Derivative (PID), Linear Quadratic Regulator (LQR), and Fuzzy Logic Control (FLC)—have been proposed to enhance antenna position control (Uthman et al., 2022). Among these, the PID controller remains one of the most widely used methods due to its simplicity, robustness, and effectiveness in handling linear control problems (Aravind et al., 2022).

Nevertheless, the nonlinear dynamics of antenna azimuth systems, combined with external disturbances, often limit the performance of conventional PID controllers. Nonlinear PID (NPID) controllers enhanced with Particle Smell Agent Optimization (SAO) have been introduced to address this limitation. Although the SAO-NPID approach improves adaptability, it frequently results in extended settling times for antenna stabilization, which degrades tracking efficiency and signal quality. Therefore, there is a growing need for an enhanced optimization strategy capable of refining controller parameters for improved dynamic response and robustness against disturbances.

To overcome these challenges, this research proposes a Smell Agent Optimization-based Nonlinear PID (IPSO-NPID) controller for efficient azimuth position control of satellite parabolic antennas. The proposed method aims to minimize the settling time and enhance disturbance rejection performance compared to conventional SAO-NPID techniques. The control algorithm is implemented and validated in MATLAB/Simulink, using a benchmark antenna model derived from Rasheed et al. (2023). Comparative analysis is conducted between the proposed SAO-NPID and the standard SAO-NPID in terms of key performance metrics, including settling time, steady-state error, overshoot, and root mean square error (RMSE).

The main contribution of this work lies in the development of an optimized antenna position control system based on the SAO technique, which significantly enhances the dynamic performance of satellite communication antennas. The research further demonstrates the feasibility of integrating intelligent optimization methods into control systems to improve reliability, precision, and overall communication efficiency in real-world satellite applications.

2. Mathematical Model

Satellite communication antennas are critical components that enable efficient transmission and reception of electromagnetic signals between ground stations and satellites. These antennas, often designed as parabolic reflectors, offer high gain and directivity, making them suitable for applications in satellite links, radio relays, and radar systems (Ahmed et al., 2014). The performance of such antennas, however, depends largely on the precision of their azimuth and elevation positioning mechanisms, which are commonly affected by environmental disturbances such as wind or mechanical vibration. Hence, developing robust control strategies for antenna

DOI: https://doi.org/10.5281/zenodo.17580797

positioning has become a significant research area (Kumar et al., 2018).

The antenna azimuth system is a servo-based mechanism composed of key subsystems such as power amplifiers, gearboxes, feedback potentiometers, and motor-load assemblies. The system's dynamics can be represented mathematically by combining electrical and mechanical equations that describe torque generation, damping, and inertia (Rasheed et al., 2023). In general, the transfer function of the antenna azimuth model is expressed as:

$$\frac{\emptyset_o(s)}{V_p(s)} = \frac{20.83}{S^3+101.71s^2+171s} \quad (1)$$

where $\emptyset_o(s)$ is the azimuth output and $V_p(s)$ is the amplifier input. This model provides a foundation for analyzing and designing appropriate control schemes for stabilizing antenna movement and tracking signals under dynamic conditions.

2.1 Control Techniques for Antenna Positioning

Proportional–Integral–Derivative (PID) controllers remain the most widely adopted technique for antenna azimuth position control due to their simplicity, robustness, and effectiveness in linear systems. The PID control law is generally expressed as:

$$u(t) = K_p e(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt} \quad (2)$$

where K_p, K_i, and K_d are the proportional, integral, and derivative gains, respectively, and e(t) represents the error signal. For systems exhibiting nonlinear characteristics, a Nonlinear PID (NPID) structure can be formulated by replacing the integral of the error with an arctangent function to improve convergence and reduce oscillations (Rasheed et al., 2023). The control law is given as:

$$u(t) = K_p e(t) + K_i \int tan^{-1}\big(\gamma e(t)\big)dt + K_d \frac{de(t)}{dt} \quad (3)$$

where γ is a design constant that modulates nonlinearity.

Despite the widespread application of PID-based schemes, traditional controllers often struggle with long settling times and poor adaptability to disturbances. Consequently, optimization algorithms such as Smell Agent Optimization (SAO), Genetic Algorithms (GA), and Fuzzy Logic have been employed to fine-tune controller parameters for improved system response (Mahmood et al., 2021; Nguyen et al., 2024). Among these, SAO has gained popularity for its ease of implementation and ability to balance exploration and exploitation during parameter search.

2.2 Smell Agent Optimization (SAO)

Although SAO enhances the tuning of PID parameters, the standard algorithm suffers from premature convergence due to static velocity and position update equations. As a result, particles tend to become trapped in local minima, particularly in complex or multimodal search spaces. To mitigate this issue, several SAO variants have been introduced, integrating adaptive inertia weights, time-varying acceleration coefficients, and simulated annealing concepts (Khan et al., 2021). The Smell Agent Optimization (SAO) algorithm, adopted in this study, employs a convergence factor (CF) to dynamically adjust the particles' search space and enhance the balance between exploration and exploitation. This modification enables the ISAO to maintain population diversity and achieve more accurate global optimization.

2.3 Performance Evaluation Metrics

The performance of a control system is typically assessed using both transient and steady-state responses. The transient response characterizes how quickly and smoothly the system reaches equilibrium,

DOI: https://doi.org/10.5281/zenodo.17580797

with key parameters including rise time, overshoot, and settling time (Tanga et al., 2022). Settling time indicates how long the system output remains within a specified tolerance band, while overshoot measures the extent to which the response exceeds the desired steady-state value. The steady-state error (SSE) quantifies the long-term deviation between the system output and input, serving as a measure of accuracy (Hansen et al., 2020). Additionally, the root mean square error (RMSE) provides a numerical indicator of overall system performance by accounting for the magnitude of residual deviations.

2.4 Review of Related Works

Several studies have investigated antenna azimuth position control using various optimization and control schemes. Eze et al. (2021) developed a PID–Sliding Mode Controller (SMC) tuned compensator for DC servomotor-based antenna systems. Although their controller improved rise time and overshoot, chattering effects led to increased settling times. Similarly, Ekengwu et al. (2021) implemented a digitally tuned PID compensator for ground station antennas using MATLAB's Control and From the reviewed literature, it is evident that while many optimization techniques—such as SAO, GA, DE, and fuzzy logic—have improved antenna control accuracy, the problem of prolonged settling time remains largely unresolved. This issue directly impacts the ability of antenna dishes to rapidly stabilize and track incoming satellite signals, leading to potential communication delays or signal loss. To address this limitation, the present study introduces an optimized Nonlinear PID controller enhanced with a Smell Agent Optimization (SAO) algorithm, aiming to achieve faster settling time, reduced RMSE, and superior robustness against environmental Estimation Tools, achieving faster stabilization but limited adaptability under nonlinear conditions.

Muoghalu and Achebe (2021) employed a Two-Phase Hybrid Stepping Motor (TPHSM) with a PSO-tuned PID controller, which improved transient and steady-state responses compared to open-loop configurations. Mahmood et al. (2021) designed a Fractional-Order PID (FOPID) optimized via a Genetic Algorithm, demonstrating better accuracy but longer settling times. Iliya et al. (2023) proposed a Differential Evolution (DE)-based PID control scheme that enhanced tuning efficiency; however, the system still exhibited extended stabilization periods. Rasheed et al. (2023) introduced a SAO-optimized PID for antenna azimuth control, achieving improvements in RMSE and overshoot but leaving the issue of long settling times unresolved. More recently, Mahmood et al. (2024) and Nguyen et al. (2024) explored fuzzy logic and GA-based PID control, respectively, yielding improved steady-state performance yet persistent delays in stabilization.

2.5 Research Gap and Motivation

disturbances in satellite antenna azimuth positioning systems.

3. Materials and Methods

3.1 Overview

This section describes the modeling, design, and simulation of the antenna azimuth position control system based on the Smell Agent (SAO) algorithm. The performance of the proposed SAO–NPID controller was evaluated in MATLAB/Simulink and benchmarked against the PSO–PID scheme using transient response and Root Mean Square Error (RMSE) as performance metrics.

DOI: https://doi.org/10.5281/zenodo.17580797

3.2 Simulation Setup

All simulations were executed on an HP personal computer equipped with an Intel Core i5 processor (2.13 GHz), 8 GB RAM, and Windows 11 Pro (64-bit). MATLAB/Simulink R2023b was used for all modeling and optimization tasks due to its robust control design and numerical analysis capabilities.

3.3 Antenna Azimuth Model Development

The open-loop system was modeled in Simulink using standard blocks such as the Transfer Function, Step Input, and Scope, as depicted in Figure 3.1.

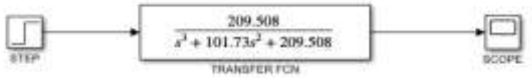
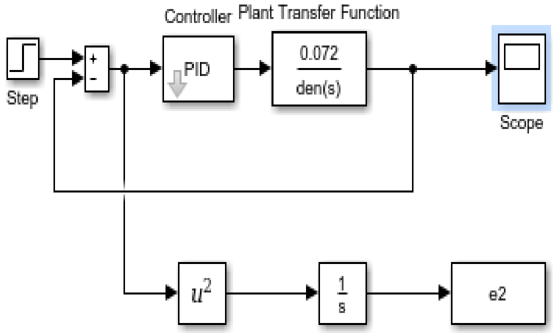


Figure 3.1. Simulink model of the antenna azimuth position system.

The model consists of the step input, the antenna azimuth transfer function block, and the output scope for system response visualization.

3.4 SAO–NPID Controller Design

3.4.1 Controller Structure



3.5 Implementation of SAO–NPID

Control Scheme 29 $< k_p <$ 28.9, 0.0005 $<$ $k_i <$ 0.0003, 7 $< k_d <$ 7.5

The SAO algorithm modifies the standard PSO by introducing a convergence factor to balance global and local search capabilities. The Simulink setup for ITAE-based optimization is shown in Figure 3.2.

The antenna azimuth system dynamics are represented by a third-order transfer function (Rasheed et al., 2023):

$$G(s) = \frac{\emptyset_o(s)}{V_p(s)} = \frac{K_1 K_m}{S^3 + 101.71s^2 + a_{mK_1}s}$$

(4)

where $\emptyset_o(s)$ is the azimuth output angle, $V_p(s)$ is the control input voltage, and the constants are as in the work Rasheed *et al.,* 2023.

The nonlinear PID controller is governed by:

$$u(t) = K_p e(t) + K_i \int tan^{-1}(\gamma e(t))dt + K_d \frac{de(t)}{dt} \quad (5)$$

where K_p, K_i, K_d, and γ represent proportional, integral, derivative, and nonlinear coefficients, respectively.

3.4.2 Optimization Process Using SAO

The SAO algorithm was applied to determine the optimal controller gains (K_p, K_i, K_d, and γ) that minimize the Integral of Time-weighted Absolute Error (ITAE) defined as:

$$J = \int_0^T t|e(t)|dt$$

The block diagram integrates the ITAE performance criterion, SAO algorithm block, PID tuner, and feedback comparator for optimal controller gain tuning.

The optimized gains obtained from the SAO algorithm were integrated into the antenna azimuth system model for closed-loop control. The complete Simulink configuration of the SAO–NPID control systemis illustrated in Figure 3.3. The system incorporates optimized gain values from SAO tuning into the closed-loop antenna azimuth plant for simulation and performance evaluation.

DOI: https://doi.org/10.5281/zenodo.17580797

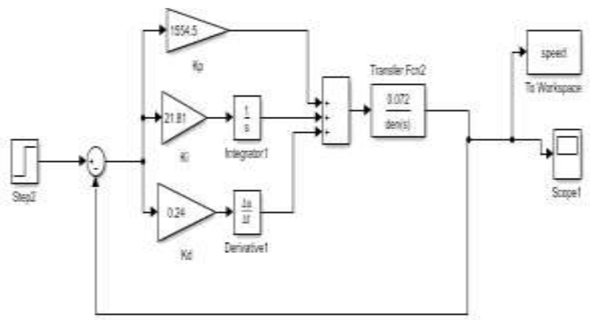


Figure 3.3. Simulink model of the SAO–NPID-based antenna azimuth position control system.

3.6 Performance Evaluation

The SAO–NPID controller performance was compared with that of the conventional PSO–PID controller using step response analysis. The evaluation metrics included rise time, settling time, steady-state error, and Root Mean Square Error (RMSE).

The percentage improvement of the SAO–NPID controller over the PSO–PID scheme was computed using:

$$\eta = \frac{\text{PSO\_PID} - \text{SAO\_PID}}{\text{PSO\_NPID}} \times 100\% \quad (6)$$

where η represents the percentage improvement in system response

4. Results and Discussion

4.1 Overview

This section presents the simulation results and analyses of the antenna azimuth position control system before and after the implementation of the Improved Smell Agent Optimization–Nonlinear PID (SAO–NPID) control algorithm. The system performance was evaluated using convergence behavior, time-domain responses, angular velocity, and control signal characteristics.

4.2 Convergence of PSO–NPID and SAO–NPID Based on RMSE

The convergence performance of the conventional SAO–NPID and the proposed Improved SAO–NPID controllers was analyzed using the Root Mean Square Error (RMSE) as the objective (cost) function.

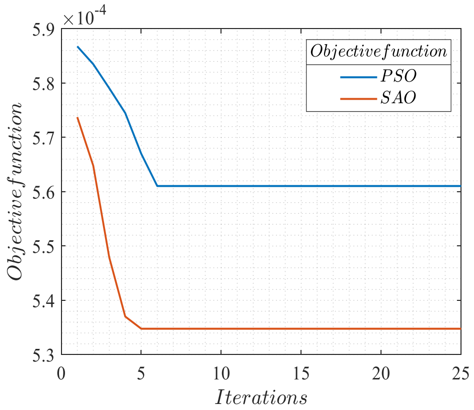


Figure 4.1 illustrates the convergence behavior of both controllers.

The SAO–NPID achieved convergence at approximately the 5.2th iteration with a minimum RMSE of 5.88 x 10^{-4}, whereas the Improved SAO–NPID converged faster, around the 4.8th iteration, with a lower RMSE of 5.72 x 10^{-4}.

This demonstrates the improved convergence efficiency and enhanced search capability of the proposed SAO algorithm.

DOI: https://doi.org/10.5281/zenodo.17580797

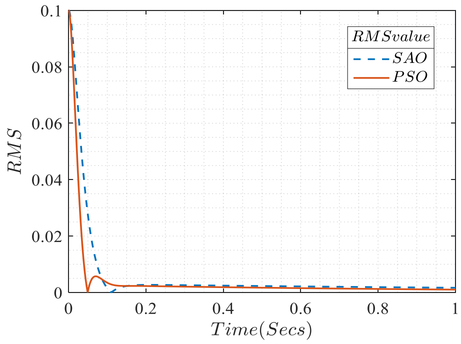


Figure 4.1. Convergence behavior of PSO–NPID and SAO–NPID controllers based on RMSE.

4.3 Step Response of PSO–NPID and SAO–NPID Controllers

The time-domain step responses of the PSO–NPID and SAO–NPID controllers for the antenna azimuth position system are shown in Figure 4.2. The responses were obtained from the Simulink implementation presented in Figure 3.3, using an ideal unit-step input.

The optimized controller parameters were determined as follows:

- PSO–NPID: $K_p = 28.87$, $K_i = 0.00018$, $K_d = 6.67$, $\gamma = 10.05$
- SAO–NPID: $K_p = 25.00$, $K_i = 0.00012$, $K_d = 3.25$

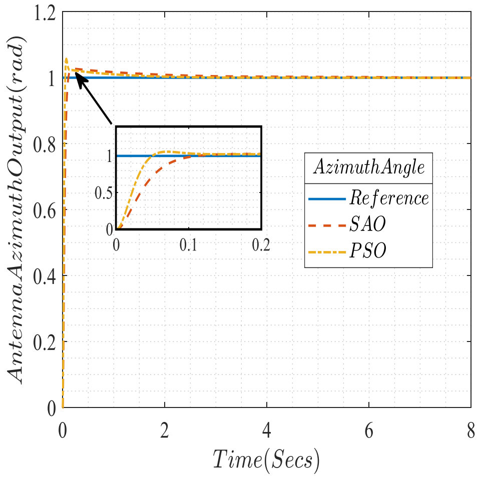


Figure 4.2 shows that the SAO–NPID controller achieved a settling time of 1.2 s with an overshoot of approximately 14%.

In contrast, the SAO–NPID controller reached steady-state faster (0.85 s) with a negligible overshoot of 0.001%.

This result confirms that the improved optimization mechanism provided smoother control action, faster convergence, and better transient performance.

4.4 Angular Velocity Response

The angular velocity of the controlled system during antenna azimuth tracking is depicted in Figure 4.3.

The SAO–NPID controller exhibited a minimal amplitude rise, signifying a smooth transition and reduced oscillation. Conversely, the conventional PSO–NPID controller displayed a higher velocity amplitude, which may lead to mechanical stress and instability in practical applications.

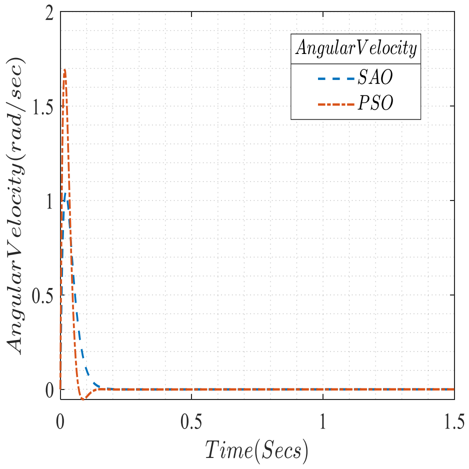


Figure 4.3. Angular velocity response of the antenna azimuth position system.

4.5 Control Signal Behavior

The control voltage signals of both controllers are presented in Figure 4.4.

Both controllers maintained voltage levels within the allowable ±48 V range of the DC servomotor, with no evidence of abrupt spikes or oscillations.

DOI: https://doi.org/10.5281/zenodo.17580797

The SAO–NPID controller demonstrated a more stable and efficient control effort, enhancing the overall reliability of the system.

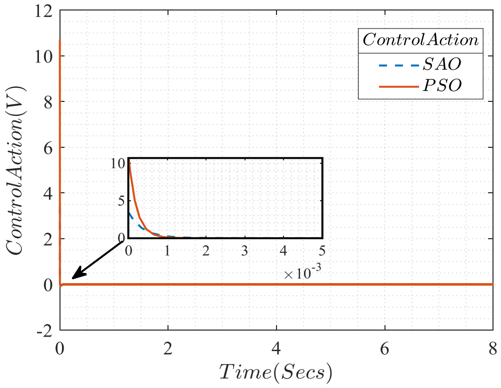


Figure 4.4. Control voltage signals of PSO–NPID and SAO–NPID controllers.

The results show that both controllers satisfied the required design specifications (settling time < 2 s, overshoot < 2 %). However, the SAO–NPID controller demonstrated better dynamic performance with a 5.83 % reduction in settling time and a 33.33 % reduction in RMSE compared to the conventional PSO–NPID design. These improvements validate the robustness and enhanced adaptability of the proposed optimization scheme

4.6 Performance Comparison

Table 4.1 compares the performance metrics of the PSO–NPID and SAO–NPID controllers based on settling time, overshoot, and RMSE.

Performance Specification	**Design Specification**	**Controller**		**Percentage Improvement (%)**
		SAO-NPID	**PSO-NPID**	
Settling Time(s)	**Less than 2s**	**1.13** **0**	**1.2** **0**	**5.83**
Overshoot (%) **Steady State Error** **RMSE**		**0.** **0.34**	**0** **0.05**	**_** **_** **33.33**

Table 4.1. Performance comparison between PSO–NPID and SAO–NPID controllers. The results show that both controllers satisfied the required design specifications (settling time < 2 s, overshoot < 2 %). However, the SAO–PID controller demonstrated better dynamic performance with a 5.83 % reduction in settling time and a 33.33 % reduction in RMSE compared to the conventional PSO–PID design. These improvements validate the robustness and enhanced adaptability of the proposed optimization scheme.

5. Conclusion

In this work SAO-NPID controller based position control of antenna was developed. The system has reduced the settling time in the antenna azimuth position model response in order to avoid the problem of signal losses during antenna satellite communication.

The SAO-NPID controller outperformed the PSO-NPID controller for settling time as compared with the work of (Rasheed *et al*., 2023).

Reference

Ahmed, M., Noor, S. B. B. M., Hassan, M. K. B., & Soh, A. B. C. (2014). A Review of Strategies for Parabolic Antenna Control, Australian Journal of Basic and Applied Sciences, 8(7), pp. 135-148.

Ali Mahmood, Karrar Y.A. Al-bayati2, Róbert Szabolcsi, "Optimizing Antenna

Azimuth Position Control using Fuzzy PD, Fuzzy PD-I, and Fuzzy PD-plus-I Controllers," 2024 15th International Conference on Electronics, Computer and Computation (ICECCO), IEEE, 2024, pp. 1–6

Aravind M. A., Niranjan Saikumar, Dinesh N. S. (2022).Optimal Position Control of Antenna Azimuth Position System Using LQG with EKF. International Conference on Mechanical System and Control Engineering.IEEE Trans. 978-1-5090-6530

Binh-Hau Nguyen, Hoang-Thanh-Tuan Cao, Thai-Toan Nguyen and Minh-Duc Pham, "Application of Genetic Algorithm for Optimizing Continuous and Discrete PID to Control Antenna Azimuth Position," 2024 18th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology(ECTICON),pp.858-861,2024.

Deniz, B. B., Alagoz, F. N., Keles, C., and Tan, N. (2021). Disturbance rejection performance analyses of closed loop control systems by reference to disturbance ratio. ISA transactions, 55, 63-71.

Ekengwu.B.O, Eze P.C, Nwawelu U.N. (2021). Effect of PID Tuned Digital Compensator on Servo-based Ground Station Satellite Antenna Positioning Control System. Journal of Engineering Sciences, 8(1): 9-16. https://doi.org/10.21272/jes.2021.8(1).

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): 9-16. https://doi.org/10.21272/jes.2021.8(1).

Hansen, R. A., Alphinas, H. H., and Tambo, T. (2020). Comparison of conventional closed-loop controller with an adaptive controller for a disturbed thermodynamic system. Paper presented at the 2020 Evolving and Adaptive Intelligent Systems (EAIS).

Kumar, E.G., Prakash, R., Rishivanth, S., Anburaja, S.A., Gopi Krishna, A. (2018). Control of antenna azimuth position using fractional order lead compensator. International Journal of Engineering & Technology, 7(2): 166-171. https://doi.org/10.14419/ijet.v7i2.24.12023

L. T. Rasheed, N. Q. Yousif, and S. Al-Wais, "Performance of the Optimal Nonlinear PID Controller for Position Control of Antenna Azimuth Position System.," Math. Model. Eng. Probl., vol. 10, no. 1, 2023.

Mahmood, A., Almaged, M., Abdulla, A.I. (2021). Antenna azimuth position control using fractional order PID controller based on genetic algorithm. 1st International Ninevah Conference on Engineering and Technology (INCET), IOP Conference Series: Materials Science and Engineering, 1152: 012016. http://doi.org/10.1088/1757-899X/1152/1/012016

Muoghalu .C. N and Achebe P. N. Two-Phase Hybrid Stepping Motor Based Antenna Positioning Control System Using Proportional Integral and Derivative Controller. Proceeding of the 26th Conference of FRUCT Association, 473-477

Rehan Ali Khan, Shiyou Yang, Shah Fahad, and Shafi Ullah Khan, "Research on intrusion detection based on particle swarm optimization in IoT," IEEE Access, vol. 9, pp. 38254–38268, 2021.

R. C. Johnson, H. A. Ecker, and J. S. Hollis, "Determination of Far-Field Antenna Patterns from Near-Field Measurements," Proc. IEEE, Vol. 61, No. 12, pp. 1668–1694, December 2023.

S. Iliya, F. Egbuojo, O. O. Awodiji, and P. Omolaye, "Differential Evolution Based PID Antenna Position Control System," Int. Journal. Science. Engineering. Res. July 2017, 2023.

Tanga, R.E., Hassan,F.N., and Anas, R.S. (2022). Optimal PID Control of a DC motor using PSO and BF techniques" proceedings of the IEEE, Vol. 33,No. 5, pp. 54-77, 2022.

DOI: https://doi.org/10.5281/zenodo.17580797

Uthman, A., Sudin, S. (2022). Antenna azimuth position control system using PID controller & state-feedback controller approach. International Journal of Electrical and computer Engineering (IJECE), 8(3): 1539-1550. http://doi.org/10.11591/ijece.v8i3.pp1539-1550