Journal of Electrical Engineering, Electronics, Control and Computer Science – JEEECCS, Volume 6, Issue 21, pages 25-30, 2020

Improving the Performance Response of Mobile Satellite Dish Antenna Network within Nigeria

Eze, P.C.
Department of Electrical and Electronic Engineering
Covenant Polytechnic, Owerrinta
Nigeria
Paulinuseze1@gmail.com

Jonathan, A.E.
Department of Electrical and Electronic Engineering
Federal University of Technology Owerri
Nigeria
Amajoe2002@yahoo.com

Agwah, B.C.
Department of Electrical and Electronic Engineering
Federal Polytechnic, Nekede, Owerri
Nigeria
agwa2748@gmail.com

Okoronkwo, E.A.
Department of Electrical and Electronic Engineering
Federal University of technology Owerri
Nigeria
okoronkwoea@hotmail.com

Abstract **– This paper has implemented improving the performance response of mobile satellite dish antenna network within Nigeria. As a result of the large geographical area of Nigeria, distance between base station and field antenna seems too long and this introduces time delay variableness. Hence a controller that would address this problem and at the same time ensured adequate positioning of the dish antenna for fast, accurate and precise line of sight operation in terms of robust tracking was required. In order to achieve this, the transfer functions representing the dynamics of a dish antenna position process and the time delay in transmit and receive paths were obtained. The system was modelled in MATLAB/Simulink and simulated without being compensated. The output response in terms of position in degree for unit constant input revealed that a compensator was needed to improve the transient and steady state performance of the system. A Proportional Integral and Derivative (PID) controller was designed using the manual tuning of PID tuner of the MATLAB/Simulink software. The Simulink model of the PID control for dish antenna position system was developed. The performance of the system was analyzed in terms of time domain performance parameters such as rise time, peak time, settling time, overshoot, steady state error, Integral Square Error (ISE), Integral Absolute Error (IAE) and Integral Time Absolute Error (ITAE). Simulations were conducted and results obtained were compared with the uncompensated system and existing system. The results showed that the proposed system provided stable, robust and improved tracking performance with more efficient time delay handling capacity than the uncompensated and existing system with respect to the settling time.**

Keywords-Antenna, Controller, PID, Time delay

I. INTRODUCTION

Control systems are either open loop or closed loop depending on the objective and economic or cost effectiveness required of the process. For instance, if it is required to just keep the system running with little or no effect on the system response due to load variation, an open loop system can be installed otherwise a closed loop system will be used instead. However, most of the industrial systems and processes in practice are subject to the effect of load variation and environmental perturbation. This has resulted to the use of closed loop control system virtually in all processes in practice –automatic control. In automatic control, it is expected that the control system automatically locks a load speed or position as quickly and precisely as possible.

There are various control strategies that have been proposed and implemental in theory and in practice. Several of which have been deployed in the industrial and process control plants to aid automation. Among these control strategies, the proportional Integral and Derivative (PID) controller is the most common control algorithm used in industry [1]. The popularity of the PID control algorithm lends credence to the fact that it is simple and easy to implement. The PID controller uses its proportional integral and derivative computing algorithm to manipulate the error signal arising from the difference between the setpoint value and measured output. The advantage of PID controller is better understood when it is applied to an industrial system. In this paper, a PID controller that will provide a more robust action and having far reaching effect on the general performance system including time delay management is proposed for control of mobile satellite dish antenna network within Nigeria to replace existing PID controller.

In mobile satellite communication, maintaining communication over long distances exceeding 550 km in space for moving objects and satellites is a major concern [2]. Communication in mobile satellite network requires that the receiver systems be mounted on movable device such as ship, train, car or aeroplane. Thus, for good signal receptions, the dish antenna system mounted in the network must be maneuvered in the appropriate position of elevation and azimuth angles to track a given object or satellite [3]-[6]. The mobile satellite dish network considered in this paper can be located anywhere within Nigeria and it is expected to operate in line with the maximum vehicle speed of 240 km/h [7]. Therefore, the objective is to design a controller that will provide improved robust tracking performance while compensating for the delays encountered between the locations of dishes mounted on vehicles either stationary or in motion and the base station within the communication network.

II. System Description

Figure 1 is a block diagram depicting communication arrangement of a mobile national area dish network. The figure shows the wireless network arrangement between the base station, which is the system controller, and the mobile node of satellite dish antenna, which is the plant, communicating via Nigerian's communication satellite [8]. A communication is established between the base station and the dish antenna nodes. The transmitted signal within this communication link suffers propagation time delay due to two major reasons: the dish antenna relative position to the base station (forward path delay) and the speed of the mobile vehicle (feedback delay). The network structure in Fig. 1 can be represented in more simplified control loop network shown in Fig. 2.

Figure. 1 Link between base station and mobile dish antenna

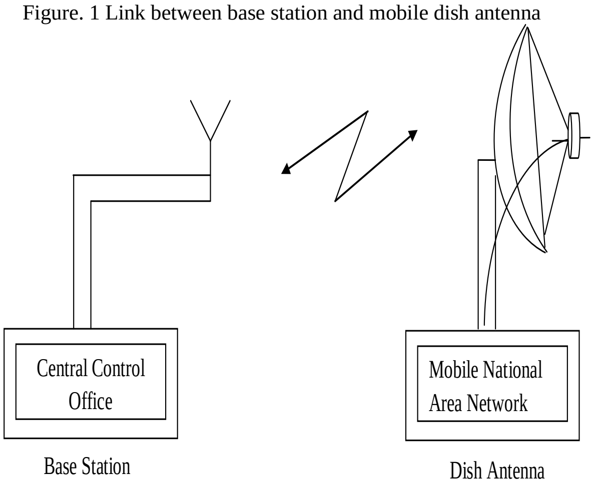
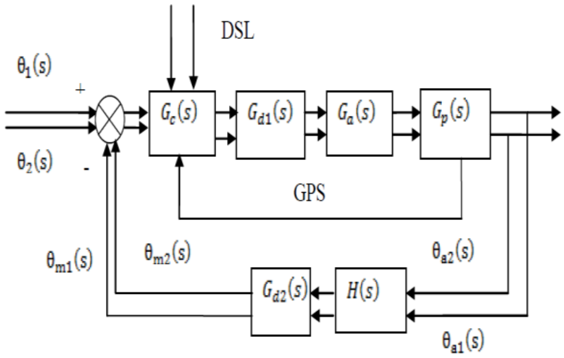


Figure. 2 Block diagram representation of system in form of control loop [7]



where $G_c(s)$ is the controller model in form of a transfer function, representing the typical action taking place at the central control room, G_{d1}, G_{d2} are the propagation time delay of transmitted signal for forward path and feedback path communications respectively, $G_a(s)$ is the actuator transfer function model, G_p the dish antenna transfer function model, $H(s)$ is the feedback transfer function model.

III. System Design and Configuration

The mobile satellite dish antenna network within Nigeria considered in this paper has the following mathematical equations describing the dynamic behavior of the system.

A. *Time Delay Model*

The estimated round trip is a measure of the total distance of signal travel divided by the speed of light. The distance, d_{sr}, between an earth station and geostationary satellite given by Ibiyemi and Ajiboye [7], Ajiboye et al. [8], Ibiyemi and Ajiboye [9]:

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

where, d_{sr} is the distance apart between the source and receiving node, R is the earth radius in km, D is aggregate of the earth's radius and the altitude of the satellite in km, Δ_s is the sub-satellite point angle of longitude, α_{sn} is the sending node location altitude on the earth surface in degree, α_{rn} is the receiving node location latitude on the earth surface in degrees, Δ_{sn} is the sending node longitude angle in degrees, and Δ_{rn} is the receiving node location longitude on the earth surface in degrees .

The time delay due to transmitting signal between the sending node and the receiving node was obtained by dividing the distance by the signal speed and is given by [8]:

$$T = \frac{d_{sr}}{v} \tag{2}$$

where: T is the time delay in seconds and v is the signal speed, which is taken as $v = 3 \times 10^9 m/s$. In addressing a given propagation time delay in the considered network, Ajiboye et al. [8] obtained a maximum and a minimum time delay of 0.2502 second and 0.2469 second respectively.

B. Dish Antenna Modelling

The equation of the dish antenna system is given by:

$$I_A \frac{d^2\theta_A}{dt^2} + B_A \frac{d\theta_A}{dt} + \tau_A \theta_A = \tau_A \theta_g \tag{3}$$

The Laplace transform and the equivalent transfer function in terms of dish angular displacement and gear displacement of Eq. (3) is given by:

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

where θ_A is dish angular displacement in radian, θ_g Angular displacement of the gear output shaft in radian, I_A Dish moment of inertial about a given axis; 140.60kgm^2, $B_A =$ Damping coefficient; 126.78Nms/rad , $\tau_A =$ Torsional spring stiffness; 317.5*Nm/rad*. Substituting these values into Eq. (4) gives Eq. (5) [7]:

$$G_p(s) = \frac{2.2578}{s^2 + 0.9016s + 2.2578} \tag{5}$$

The actuator motor transfer function and the actuator jack gear ratio, K_g are given by Ibiyemi and Ajiboye [7]:

$$G_M(s) = \frac{0.075}{s(1 + 0.015s)} \tag{6}$$

$$K_g = 0.033 \tag{7}$$

C. Time Delay Transfer Function

The transfer functions of the time delay for forward and feedback paths are given by Ajiboye et al. [8]:

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

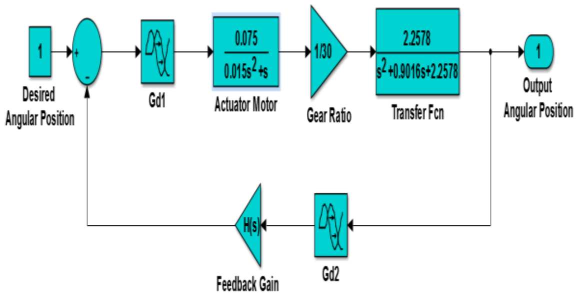
where: T_1 = Feed forward delay from base station to the node in seconds and, T_2 = Feedback delay from the node to base station in seconds. Now, assuming that the feed forward time delay is equal to feedback time delay, such that $T_1 = T_2 = T$. Equation (8) can be defined by Ajiboye et al. [8]:

$$G_{d1} = G_{d2} = G_d = e^{-Ts} \tag{9}$$

D. Simulink Model

The system is further modelled in Simulink. This is shown in Fig. 3. The model is a closed loop control structure of the dish antenna system without the controller (uncompensated). The feedback gain is taken as unity in this paper.

Figure. 3 Simulink model of the dish antenna system



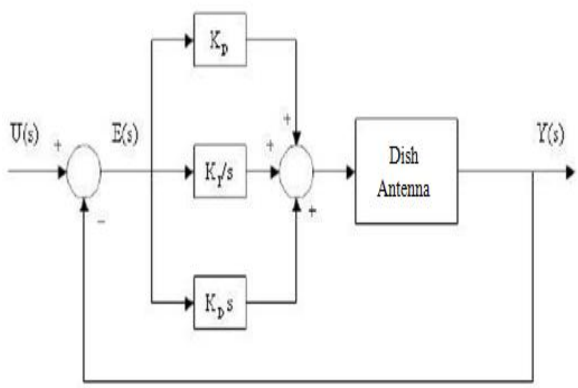
E. Design of PID Controller and System Configuration

A basic structure of a PID control system is shown in Fig. 4. A mathematical expression of the transfer function of the system is given by Eq. (10). In this equation, the required parameters of the controller (K_p, K_i and K_d) have to be determined.

The expression given by Eq. (10) presents the three parameters in-parallel‖ form and represents the resulting effect of the PID controller as the sum of the effects of the three individual components. Therefore, in determining the values of the gain parameters of the PID controller, the MATLAB/Simulink PID tuner is used in this subsection so as to achieve an overshoot of less than or equal to 10%, which conforms to that of a typical industrial system [10],[11].

$$G_{pid}(s) = K_p + K_i \frac{1}{s} + K_d s \tag{10}$$

Figure. 4 Block diagram of a PID controller

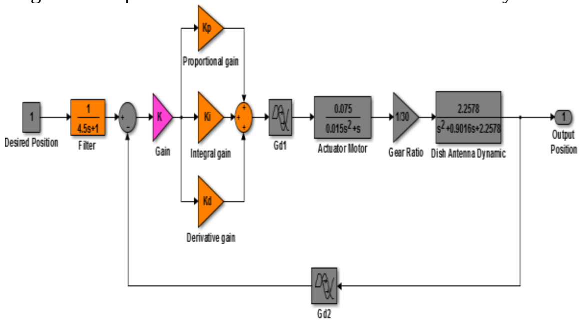


In Fig. 4, E(s) is represents the error between the setpoint V(s), which is a constant, and the measurement Y(s), which is the output of the plant, that is E(s) = V(s)-Y(s). The values of the parameters of the PID were gotten by employing the MATLAB software PID tuner. This tool combines slow and fast tuning as well as aggressive and robust tuning to effectively select the appropriate gains that will enhance the transient characteristics performance of a system. In this paper fast and robust tuning were used. The designed PID controller is given by: $K_p = 23.5078$, $K_i = 6.6177$, $K_d = 20.8765$. Substituting these gains into Eq. (10) gives:

$$G_{pid}(s) = 23..5078 + \frac{6.6177}{s} + 20.8765s \qquad (11)$$

The developed Simulink model for the mobile satellite dish antenna position control system is shown in Fig. 5. A look at the diagram shows a filter at the input and a gain (K = 0.7) on the forward path of the loop. Also, the feedback gain in Fig. 4 is taken as unity this work and as such it is not represented in the proposed system in Fig. 5.

Figure. 5 Proposed mobile satellite dish antenna control system



IV. SIMULATION RESULTS AND DISCUSSION

A. *Simulation Result*

This subsection presents the results of the simulation test conducted using MATLAB/Simulink software. Simulating to find out the performance of the developed PID controller on a mobile satellite dish antenna network, which includes the tracking performance, control effort (performance of the control input), and the error signal performance indices such as Integral Square Error (ISE), Integral Absolute Error (IAE) and Integral Time Absolute Error (ITAE). The expressions of the indices are given below:

a. Integral Square Error (ISE):

$$ISE = \int_0^{\infty} e^2(t)dt \qquad (10)$$

b. Integral Absolute Error (IAE):

$$IAE = \int_0^{\infty} |e(t)|\, dt \qquad (11)$$

c. Integral Time Absolute Error (ITAE):

$$ITAE = \int_0^{\infty} t\,|e(t)|\, dt \qquad (12)$$

Simulation plots are presented for: the time when the proposed PID controller was not in the closed loop (uncompensated system) in Fig. 6, the time when the proposed PID controller was in the closed loop in Fig. 7, and the comparison of the step response performance in Fig. 8, the error signal performance in Fig. 9 and the control variable performance in Fig. 10 for the proposed and the existing systems. Four tables are presented showing the performance analysis of the system from the simulation results. Table 1 is the time domain performance analysis of uncompensated system and the proposed system. Table 2 is the time domain performance of the performance analysis of proposed system and existing system in terms of step response. The existing system has a PID controller with parameter gains: $K_p = 20$, $K_i = 4$, and $K_d = 0$ [8]. Tables 3 and 4 are the time domain performance comparison in terms of error signal and control variable.

Figure. 6 Step response of uncompensated system

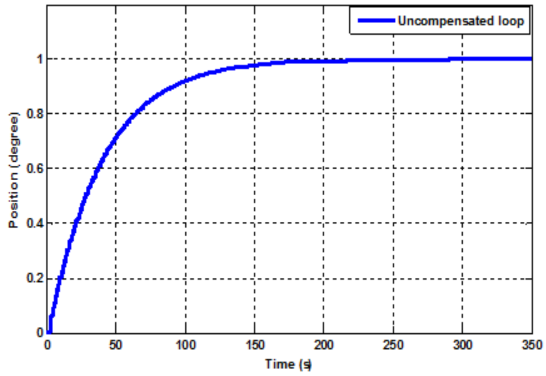


Figure. 7 Step response of proposed system

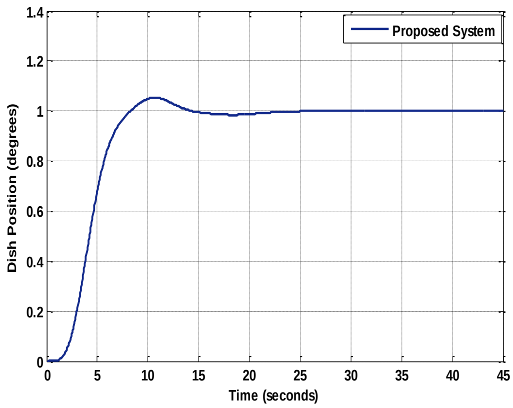


Figure. 8 Step response comparison of proposed and existing system

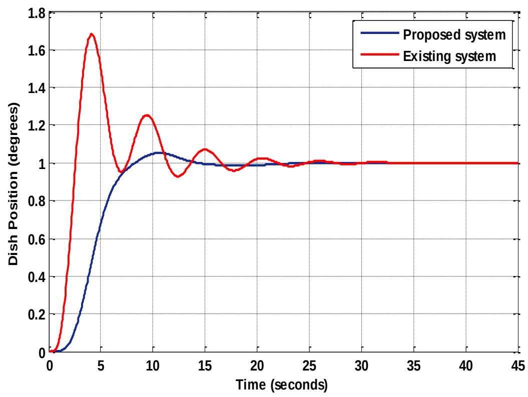


Figure. 9 Error signal performance comparison

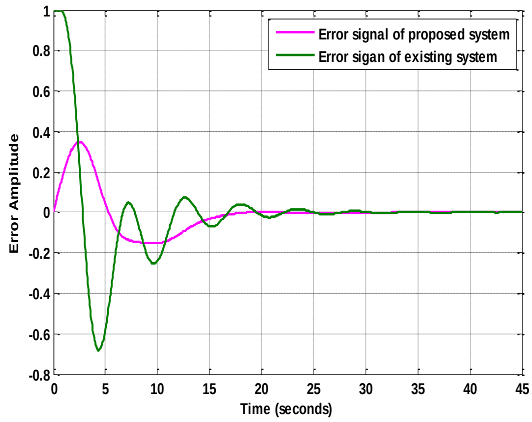


Figure. 10 Control variable performance comparison

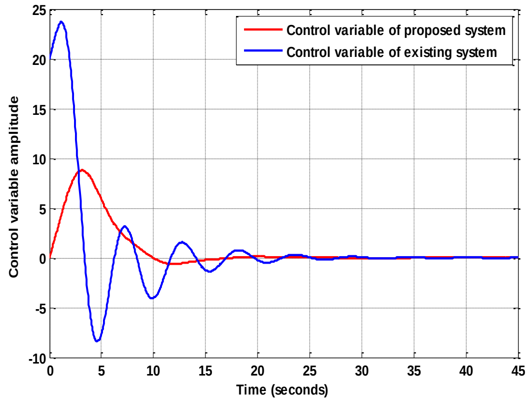


TABLE I. RESPONSE PERFORMANCE ANALYSIS OF UNCOMPENSATED AND PROPOSED SYSTEMS

System condition	RT (s)	PT (s)	OS (%)	ST (s)	***SSE***
Uncompensated system	86	300	0	154	0 at 300 s
Proposed System	4.09	10.67	5.32	12.92	0 at 30 s

RT = Rise time, PT = peak time, OS = overshoot, SSE = steady state error

TABLE II. RESPONSE PERFORMANCE ANALYSIS OF PROPOSED AND EXISTING SYSTEMS

Performance index	Proposed system	Existing system
Rise time (s)	4.09	1.34
Peak time (s)	10.67	3.94
Overshoot (%)	5.32	50.5
Settling time (s)	12.92	21.3
Steady state error	0	0
Integral Square Error (ISE)	0.435	2.753
Integral Absolute Error (IAE)	2.250	4.677
Integral Time Absolute Error (ITAE)	14.57	22.80

TABLE III. ERROR SIGNAL PERFORMANCE ANALYSIS OF PROPOSED AND EXISTING SYSTEMS

System Variable (Error signal)	RT (s)	PT (s)	OS (%)	ST (s)	***US (%)***
Proposed system	2.48e-04	2.49	3.75e +05	17.41	8.51e+05
Existing System	1.31	0	2.60e +05	21.34	1.78e+05

US = undershoot

TABLE IV. CONTROL VARIABLE PERFORMANCE ANALYSIS OF PROPOSED AND EXISTING SYSTEMS

System Variable (Control variable)	RT (s)	PT (s)	OS (%)	ST (s)	***US (%)***
Proposed system	2.07 e-05	3.16	9.30e +06	15.51	6.54e +05
Existing System	1.12	1.13	3.57e +05	21.19	1.27e +05

B. Discussion

In Table 1: the unit response of the system has been presented in terms of rise time, peak time, overshoot, settling time and steady state error. It can be seen that the rise time of the uncompensated system was 86 s but changed to 4.09 s for the proposed system. This signifies improvement on the rise time of the system because of the addition of the PID controller into the loop. The peak time of the system was 300 s when it has not been compensated but reduced to 10.67 s when compensated by the PID controller. This is also an improvement as regards peak time. The overshoot was 0% for the uncompensated state of the system but changed to 5.32% for the proposed system. In this case, the system performance seemed to have been degraded as far as overshoot is concern. The settling time of the uncompensated system was 154 s but reduced to 12.92 s for the proposed system, which in this case, signifies improvement in system performance with respect to settling time. The steady state error was 0 for both the uncompensated system and the proposed system. However, this took place at different time. With the proposed system offering a lesser time for the for the steady state error 30 s while the uncompensated system offers 300 s.

It can be said, looking at Table 1 that the proposed system outperformed the uncompensated system in terms of the transient and steady state response to unit input due to lower value of the time domain parameters of the system. Though the percentage overshoot of the proposed system seems to be the only time domain performance parameter that does not outperform that of uncompensated system, this will not impact negatively on overall performance of the proposed system because the system would have settled even before the uncompensated system rises. Also, the uncompensated system is very slow in response due to the negative effect of time delay.

In Table 2: the performance of the response to unit constant input is presented in terms of time domain parameter such as rise time, peak time, overshoot and steady state error, and in terms of performance indices such as ISE, IAE and ITAE. In the time domain performance parameters, the proposed system provides a rise time, peak time, settling time, overshoot and steady state error of 4.09 s, 10.67 s, 12.92 s, 5.32% and 0, while the existing system provides a rise time, peak time, settling time, overshoot and steady state error of 1.34 s, 3. 94 s, 21.3 s, 50.5%, and 0. In terms of ISE, IAE and ITAE, the proposed system offers 0.435, 2.250 and 14.57 while the existing system offers 2.753, 4.677 and 22.80. The proposed system offers lower values to ISE, IAE and ITAE performance measures compared with the existing system. This means that it provides better control in terms of error handling capacity than the existing system. Though the existing system gives a better rise time and peak time, it can be deduced that proposed system gives lower value of settling time, lower value of percentage overshoot, minimum value of errors and more improved robust tracking performance in comparison with the existing system. Hence, the proposed system is more stable and robust with improved tracking performance.

Tables 3 and 4 also showed that the error signal and control variable performances of the proposed system are better than that of the existing system. This is well revealed by the error signal and control variable performance plot in Fig. 9 and 10.

Looking at Fig. 6 to 10 and Tables 1 to 4, it can be said that the proposed system provides more improved performance compared with the uncompensated system and the existing system. It also provides a better line of sight operation. However, the rise time and the peak time are higher compared with the existing system.

V. CONCLUSION

This paper has exploited the advantage of PID controller in terms of ease of design and implementation to enhance the performance of industrial system such as dish antenna position control for optimal performance. A PID controller was designed using MATLAB/Simulink PID tool box. Manual tuning was carried out by means of the graphical user interface (GUI) of the PID tuner to select the appropriate values for the gain parameters that would yield the desired time domain response performance. The simulation results obtained showed that the proposed system was able to compensate for time delay variableness and provide improved time domain response compared to the uncompensated system and the existing system especially in the settling, tracking and stability performance.

REFERENCES

[1] L.T. Udeh, “Effect of a PID Controller in Closed Loop Feedback System,” Conference Paper, 1-5, 2013.

[2] L.A. Aloo, “Design of Neuro-Fuzzy System Controller for DC Servo Motor based Satellite Tracking System,” A Master Degree Thesis Submitted to Jomo Kenyetta University of Agriculture and Technology, 1-115, 2017.

[3] J.K. Kim, K.R. Cho and C. S. Jang, “Fuzzy control of data link antenna control system for moving vehicles," International Conference on Control, Automation, and Systems (ICCAS), June 2005.

[4] M.M. Kyaw, C.M. Nwe and H.M. Tun, “Satellite dish positioning control by DC Motor using infrared remote control," International Journal of Electronics and Computer Science Engineering, vol. 3, no. 3, pp. 199-207, 2012.

[5] M. N. Soltani, R .Zamanabadi and R. Wisniewski, “Reliable control of ship-mounted satellite tracking antenna," IEEE Transactions on Control Systems Technology, pp. 99, 2010.

[6] T.V. Hoi, N. T. Xuan and B. G. Duong, “Satellite tracking control system using Fuzzy PID controller," VNU Journal of Science: Mathematics and Physics, vol. 31, no. 1, pp. 36-46, 2015.

[7] T.S. Ibiyemi, & A.T. Ajiboye, “Robust PID Control of Mobile Satellite Dish Network within Nigeria,” International Journal of Computer Applications, 41(21), pp 32-36, 2012.

[8] A. T. Ajiboye, A. R. Ajayi, & S. L. Ayinla, “Effects of PID Controller on Performance of Dish Antenna Position Control for Distributed Mobile Telemedicine Nodes,” Arid Zone Journal of Engineering, Technology & Environment, 15(2), pp 304-313, 2019.

[9] T.S. Ibiyemi, & A.T. Ajiboye, “Automatic Tracking of NigComSat-1R Satellite by Dish Network Mounted on Mobile Telemedicine Vehicles,” International Journal of Engineering Research & Technology, 1(4), pp 1-4, 2012.

[10] L.A. Aloo, P. K. Kihato and S. I. Kamau, DC Servomotor-based Positioning Control System Design using Hybrid PID-LQR Controller, European International Journal of Science and Technology, 5 (2), pp 17-31, 2016.

[11] E.B. Onyeka, M. Chidiebere, and A.P. Achebe, “Performance Improvement of Antenna Positioning Control System Using Model Predictive Controller,” European Journal of Advances in Engineering and Technology, 5(9), pp 722-729, 2018.