Design of PID Tuned Digital Compensator for Improved Positioning Performance of Satellite Dish Antenna for Distributed Mobile Telemedicine Nodes within Nigeria

B.O Ekengwu, D.O Oyeka[1], C.B Mbachu, and C.A Nwabueze[2]

[1]*Department of Electronic Engineering, University of Nigeria, Nsukka.*

[2]*Dept. of Electrical/Electronic Engineering Chukwuemeka Odumegwu Ojukwu University, Uli*

Email: bonaventure.ekengwu@unn.edu.ng; oyeka.dumtochukwu@unn.edu.ng; cbmbachu@yahoo.com; canwabueze@gmail.com

Abstract: This paper has presented design of proportional integral and derivative (PID) tuned digital compensator for improved positioning performance of satellite dish antenna for distributed mobile telemedicine nodes within Nigeria. The objective was to design a compensator that will ensure satellite dish antenna for distributed mobile telemedicine nodes within Nigeria, maintains desired line of sight for effective communication and improved propagation time delay handling. In order to achieve this, mathematical model of dish antenna was obtained and expressed in continuous time including, the dynamic models of motor actuator, gear ratio, and propagation time delay in both forward path and feedback. The continuous time system was then transformed into discrete time form. A PID tuned lead compensator was designed using robust response time tuning method with interactive (adjustable performance and robustness) design mode in continuous time and then converted to digital form using Tustin method with frequency prewarping. Simulations were conducted considering four different cases, which are uncompensated control loop, compensated control loop with continuous time compensator, digital compensator control loop, and existing PID control loop using MATLAB programme (m-file). The results obtained showed that the developed digital compensator improved the performance of the system, which was analyzed in terms of time domain parameters, yielding a rise time of 4.68 seconds, peak time of 6.5 seconds, peak percentage overshoot of 8%, and settling time of 10.2 seconds. Generally, the results obtained revealed that the proposed system outperforms the uncompensated system and existing PID compensated system especially in terms of settling time, tracking and stability performances.

Keywords: *Antenna, Compensator, Mobile Telemedicine, Nigeria, PID*

1. Introduction

Satellite antennas are essential part of communication systems. Satellites carry large amount of data representing telephone traffic, radio signals, and television signals. The application of satellite has been increasing common and has become an integral part of everyday life as can be seen in many homes and offices with various forms of antennas which are employed for signal reception from satellites located far distance away from the earth (Sowah et al., 2017). Satellite communications certainly provide the most important technology that makes communication possible without selecting location and time (Fandakh, 2016).

In communication systems, antennas aid the interaction between observers on the earth and satellites. The majority of parabolic antennas used in radio communication have over the years, used direct current (DC) servomotor based controllers that have been developed and implemented using different control algorithms (Onyeka et al., 2018). There are various control models and algorithms such as conventional Proportional Integral (PI) controller, Proportional Integral and Derivative (PID) controller, Linear Quadratic Gaussian (LQG), Fault Tolerant Control (FTC), and Hybrid PID and Linear Quadratic Regulator (hybrid PID-

LQR) that have been implemented to solve the problem of antenna positioning for different areas of radio/telecommunications.

The performance of a satellite dish antenna position mounted on distributed mobile telemedicine nodes within Nigeria when the link is via Nigcomsat-1R (Ajiboye et al., 2019) is examined in this paper using a discrete time control compensator. For the system under consideration, the link between the base station and the distributed mobile nod of dish antenna is via Nigerian's communication satellite (Nigcomsat-1R) that is located in International Telecommunication Union (ITU) region1 at 42.5^{o} East (Ajiboye et al., 2019).

Maintaining communication over long distances exceeding 550km in space for moving objects and satellites is a major concern in mobile satellite communication (Eze et al., 2020; Aloo, 2017). The mobile satellite dish network considered in this paper can be located within Nigeria anywhere in the region and it is desired to operate with maximum speed of 240km/h (Ibiyemi and Ajiboye, 2012). Consequently, the goal is to design a digital compensator that will provide improved positioning performance as a way of ensuring effective tracking and line of sight operation of the antenna, while also providing better delay handling performance.

2. System Overview

A description of communication link between the base station and the mobile dish antenna is shown in Fig. 1. The figure illustrates the wireless communication structure for transmit and receive operation between the system controller and the plant. The system controller represents the base station while the plant represents the satellite dish antenna, and both ends keeps communicating via Nigerian's communication satellite (Eze et al., 2020; Ajiboye et al., 2019). A wireless communication is established between the base station and the antenna, which suffers from the effect of propagation time delay as a result of dish antenna relative position to the base station, which give rise to forward path delay. Another cause of delay is the speed of the mobile vehicle, which is responsible for the feedback delay. A block diagram representation of the system simplifying s the control loop arrangement of the base station and the dish antenna is shown in Fig. 2.

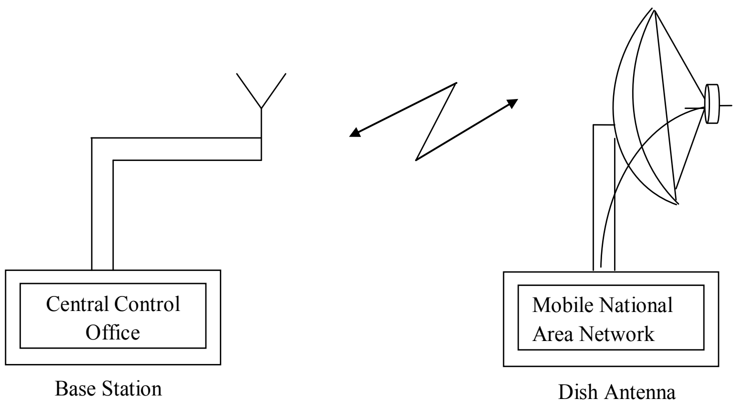

Fig. 1 Link arrangement between base station and mobile dish antenna (Eze et al., 2020)

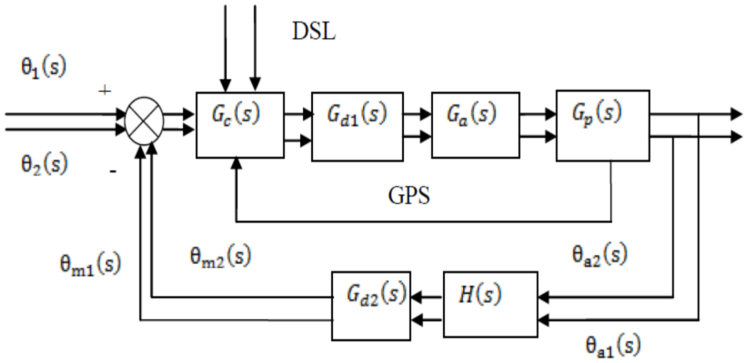

Fig. 2 Control loop analogy of the system (Ibiyemi and Ajiboye, 2012)

where $G_c(s)$, $G_{d1}(s)$, $G_{d2}(s)$ are the transfer function models of the controller, forward path and feedback propagation time delays. Similarly, the actuator transfer function, the dish antenna transfer function, and the feedback gain transfer function are given by $G_a(s)$, $G_p(s)$, and $H(s)$.

3. System Design

This section provides the mathematical description of the system in terms of time delay model, dish antenna model, time delay transfer function, and proposed system.

a) Time Delay Model

Dividing the overall distance travelled by signal with the speed of light gives the estimated round trip. The distance, d_{sr}, between an earth station and geostationary satellite is given by Ibiyemi and Ajiboye (2012), Ajiboye et al. (2019), Ibiyemi and Ajiboye (2012) as:

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

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

Hence, the propagation time delay as a result of the transmitting signal between sending and receiving nodes is obtained using the expression (Ajiboye eta l., 2019):

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

where T is the time delay in seconds and v is the signal speed, which is taken as $v = 3\times10^9 m/s$. In order to solve the problem of a given propagation time delay in of the communication link, a minimum and a maximum time delay of 0.2502 s and 0.2469 s were used by Ajiboye et al. (2019).

b) Dish Antenna Equation

The mathematical description of the dish antenna is represented in the form of a second order differential equation given by:

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

Taking the Laplace transform of Eq. (3) assuming zero initial conditions, the transfer function of the dish antenna in terms of angular displacement and gear displacement 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 $\theta_A, \theta_g, I_A, B_A, \tau_A$ are the dish angular displacement in radian, the angular displacement of the gear output shaft in radian, the moment of inertial about a given axis of the dish with a value of $140.60 kgm^2$, the damping coefficient of value $126.78 Nms/rad$, the torsional spring stiffness of value $317.5 Nm/rad$. Putting these values into Eq. (4) yields (Ibiyemi and Ajiboye, 2012):

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

The transfer function of the motor actuator, $G_m(s)$, and the jack actuator gear ratio, K_g, are given by Ibiyemi and Ajiboye (2012):

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

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

The overall transfer function combining Eq. (5), (6) and (7) is given by:

$$\mathrm{G_p(s)} = \frac{3.76}{\mathrm{s^4 + 67.56s^3 + 62.36s^2 + 150.52s}} \tag{8}$$

c) Time Delay Transfer Function

The propagation time delays for the forward path and feedback are given by Ajiboye et al. (2019) as:

$$\left.\begin{array}{l} G_{d1}(s) = e^{-T_1 s} \\ G_{d2}(s) = e^{-T_2 s} \end{array}\right\} \tag{9}$$

d) Proposed System

It is necessary to briefly present the control loop structure of the existing system before the proposed digital system is presented. The existing system is a block diagram arrangement with continuous time dynamic characteristics as shown in Fig. 3.

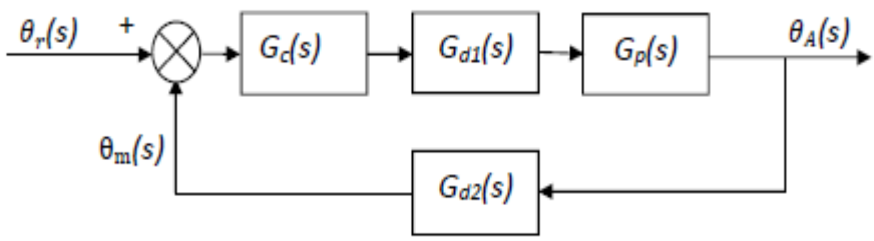

Fig. 3 Block diagram of the existing system (Ajiboye et al., 2019)

The proposed system in this paper is a digital control loop structure with a sampling time, $T_s = 0.5s$, as shown in Fig. 4. The control objective is achieved by discretization of the process using sample and hold circuitry and zero order holder (ZOH).

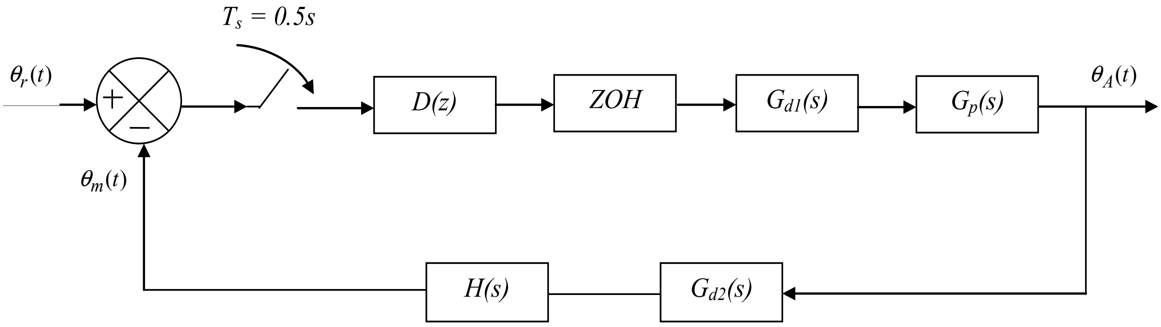

Fig. 4 Block diagram of the proposed digital structure

The discrete time equivalent of the transfer function of the plant $G_p(s)$ in continuous time is given by:

$$G_p(z) = \frac{0.0009427z^3 + 0.003575z^2 + 0.0008963z + 1.229e-07}{z^4 - 2.204z^3 + 1.841z^2 - 0.6371z + 2.135e-15} \quad (10)$$

The propagation time delay in discrete time is given by:

$$G_{d1} = G_{d2} = z^{-1} \quad (11)$$

The feedback gain $H(s)$ is equal to 1.

In order to design the discrete time compensator, $D(z)$, the continuous time equivalent, $G_c(s)$ was initially designed using the PID tuning method of the control and estimation tool manager. The tuning method used is the robust response time while the design mode was interactive (adjustable performance and robustness). The developed continuous time compensator is giving by:

$$G_c(s) = \frac{s(13 + 3.25s)}{s(1 + s)} \quad (12)$$

Then to convert $G_c(s)$ to $D(z)$, the Tustin method with frequency prewarping was used because it gives a better-matching frequency than just using only Tustin without prewarping. Thus, the implemented discrete time compensator is given by:

$$D(z) = \frac{5.56z^2 - 4.96z - 0.6005}{z^2 - 1.526z + 0.5261} \quad (13)$$

Generally, simulation was conducted using MATLAB programme developed as m-files for the various simulations conducted as follows.

(ii) Results and Discussion

3.1 Results

This section presents the various simulation results obtained in terms of unit step response including, the performance analysis shown in Table 1and the discussion.

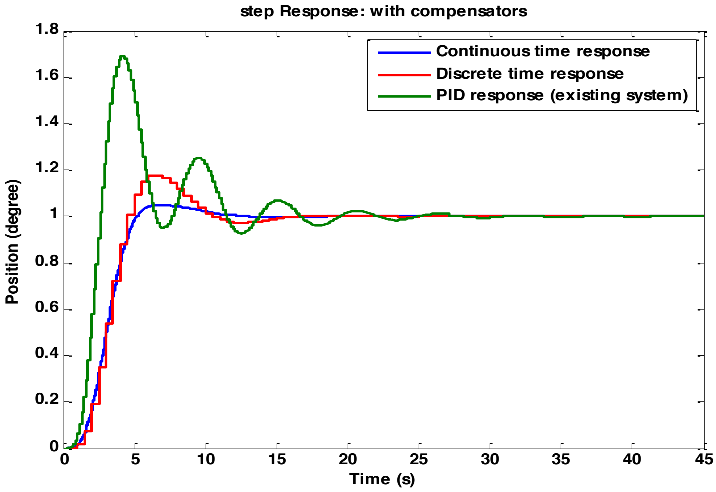

Fig. 5 Step response performance comparison

Table 1: Time Domain Performance Analysis

System	Rise time (s)	Peak time (s)	Peak overshoot (%)	Settling time (s)
Uncompensated	86	300	0	155
Continuous time compensated	2.75	6.75	4.86	10.1
Discrete time compensated	4.68	6.5	8	10.2
PID compensated (Existing)	1.34	3.94	50.5	21.3

3.2 Discussion

Generally, the discrete time compensated system outperforms the uncompensated system in terms of rise time, peak time, and settling time. The only time domain parameter in which the uncompensated system provided better performance was the peak percentage overshoot. However, this will not adversely affect the performance of the compensated system because system would have settled even before the uncompensated system rises. This holds for other compensated system. Also, in terms of stability and robust tracking for effective line of sight operation, the proposed system performs creditably well compare with the existing PID loop.

4. **Conclusion**

This paper has presented the design of PID tuned digital compensator for improving step response performance of satellite dish antenna for distributed mobile telemedicine nodes within Nigeria. The dynamic equations of a dish antenna position control system used in distributed mobile telemedicine nodes were obtained in the form of a transfer function models in continuous time domain. The transfer function models were transformed into equivalent discrete models. MATLAB programmes developed as m-files were used to conduct simulations, and the results obtained revealed that the proposed system outperforms the uncompensated system and existing PID compensated system especially in terms of settling time, tracking and stability performances. This way, the system offers improved step response tracking to unit input, which is considered in this study as line of sight operation.

References

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

Aloo, L.A. (2017). 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.

Eze, P.C. Jonathan, A.E., Agwah, B.C., & Okoronkwo, E.A. (2020). Improving the Performance Response of Mobile Satellite Dish Antenna Network within Nigeria. Journal of Electrical Engineering, Electronics, Control and Computer Science, 6(21), 25-30.

Fandakl, S. A. (2016). Antenna Azimuth Position Control with PID , Fuzzy Logic and Sliding Mode Controllers. https://doi.org/10.1109/INISTA.2016.7571821

Ibiyemi, T.S. and Ajiboye, A.T. (2012). Automatic Tracking of NigComSat-1R Satellite by Dish Network Mounted on Mobile Tele-Medicine Vehicles. International Journal of Engineering Research and Technology, 1(4), 1-4.

Ibiyemi, & Ajiboye (2012). Robust PID Control of Mobile Satellite Dish Network within Nigeria. International Journal of Computer Application,41(21), 32-36.

Onyeka, E. B., Chidiebere, M., & 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.

Sowah, A.R. Mills, A.G., Nortey, Y.J., Armoo, K.S. et al. (2017). Automatic Satellite Dish Positioning for Line of Sight Communication using Bluetooth Technology. Science and Development, 1(2), 85-98.