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Antenna Positioning Control System for Effective Satellite Communication

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Abstract- This paper has presented antenna positioning control for effective communication. The system uses Two-Phase Hybrid Stepping Motor (TPHSM) to position an antenna in azimuth/elevation for effective satellite communication and quality signal reception. The ability to track a step input signal has been taken as efficient line of sight operation. The dynamic of a TPHSM was obtained in form of a transfer function and then transformed into an equivalent state space model. The stability of the system was determined. An open-loop simulation of the system was carried out in MATLAB/Simulink to check the ability of the system to communicate effectively without a controller. The result obtained indicated that a line-of-sight operation could not be achieved. A feedback gain was developed and added but the response was not satisfactory. A forward path gain was included such that response was able to track a step input indicating effective line of sight operation. In order to further provide more robust operation with efficient output measurement or estimation, an observer loop was designed and added to the system, the simulation result showed that the proposed full state feedback controller provided good tracking performance for efficient line of sight communication for the TPHSM based antenna positioning control system.

Indexed Terms- Antenna, Controller, Full State Feedback, Observer, Satellite

I. INTRODUCTION

Satellite antennas are important component of communication systems. Large amount of data representing telephone traffic, radio signals, and television signals are carried by satellites. The application of satellite has become increasingly common and has turn out to be an essential part of everyday life as can be seen in several homes and offices with different forms of antennas which are used for signal reception from satellites located far distance away from the earth [1]. Satellite communications definitely offer the most vital technology that makes communication possible without selecting location and time [2].

Receive antennas used in satellite communication are mounted on movable devices like ship, train, car or aeroplane [3, 4]. Therefore, for quality signal reception, the antenna system mounted in the network must be turned in the appropriate position of elevation and azimuth angles to track a given object or satellite [5]-[8].

The remaining part of this paper is divided into: description of stepping motor, antenna control system design, simulation result and discussion, conclusion.

II. DESCRIPTION OF STEPPING MOTOR

The system that is considered in this paper is a satellite tracking antenna, whose parabolic dish is being positioned in terms of azimuth and elevation by Two-Phase Hybrid Stepping Motor (TPHSM). Figure 1 is the block diagram of a TPHSM based antenna positioning control system for satellite signal tracking.

Stepping motors are a sort of electromagnetic mechanical devices that can convert discrete electric impulses, typically of square wave pulses, into linear or angular displacement [9]. These motors are unique type of synchronous motors designed to rotate through predetermined angle called a step for each electrical pulse received from control unit [10]. They are typically used in control and measurement purpose due to the advantage of easy open loop control and no error buildup which they provide [9.11]. Stepping motors are perfect choice for applications with small power (< 100 watts) while maintaining fast and efficient positioning control such as in robotics, machine tools, servos, aerospace applications, printers, and scanners [9,12].

There are a variety of benefits provided by stepping motors like small inertia, large output torque, and high frequency response [9]. These characteristics have made the application of stepping motors to be wide in the industry currently, especially in control applications and measurement [9,13]. Also, other advantages like compatibility with digital system and no feedback sensor requirement for position and speed sensing [10, 14] have made their use valuable in control systems engineering. Nevertheless, some disadvantages of stepping motor includes relatively long settling time and overshoot for a given step response [9]. There are different types of stepping motors. One of them is the hybrid stepping motor.

TPHSM is stepping motor that contains the permanent magnet rotor and many teeth both on the rotor and the stator poles [9]. These devices are most commonly employed in the industry as this ensures that the power electronic circuits are relatively simple because of higher efficiencies over the variable reluctance permanent magnet stepping motors.

III. ANTENNA CONTROL SYSTEM DESIGN

Figure 1 is a block diagram of a TPHSM based antenna positioning control system. The system parameters are defined and presented in Table 1.

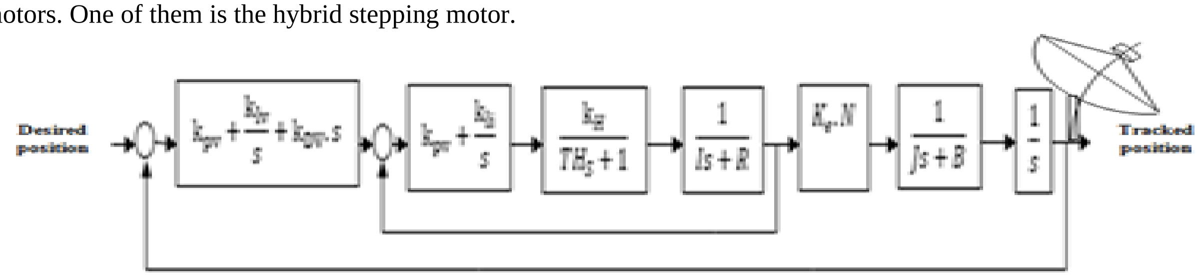

Fig. 1 Block diagram of TPHSM based antenna position control system

Table 1 System parameters [3]

Parameter	Description	Value
R	Armature resistant	2.96Ω
L	Armature inductance	150mH
J	Moment of initial	42.3×10^{-6} kgm^2
B	Viscous friction coefficient	48.6×10^{-6} Nms
K_e	Torque constant	13.5×10^{-3}Nm/A
K_b	Back EMV constant	13.5×10^{-3}Vs/rad
N	Number of teeth	180
β	Beta gain	1
K_H		15
K_{PV}	Voltage gain	500
K_{IV}	Voltage integrator parameter	0
K_{DV}	Voltage differentiator parameter	100
K_{Ii}	Current integrator parameter	500
K_{Pi}	Current Gain	5

A. System Dynamic Equation

The open-loop transfer function G(s) of two-phase hybrid stepping motor-based antenna positioning control system is given by [3]:

The open-loop transfer function G(s) of two-phase hybrid stepping motor-based antenna positioning control system is given by [3]:

$$G(s) = \frac{A(s)}{B1(s) + B2(s)} \qquad (1)$$

where

$$A(s) = \left(K_{PV} + \frac{K_{IV}}{s} + K_{DV}s\right)\left(K_{Pi}s + K_{Ii}\right)K_e N K_H$$

$$B1(s) = JLs^4 + \left(JR + \beta L + JK_{Pi}K_H\right)s^3$$

$$B2(s) = \beta K_{Pi}K_H s + \left(JK_{Pi}K_H + \beta R + \beta K_{Pi}K_H\right)s^2$$

Substituting the parameters in Table 1 into Eq. (1) gives the transfer function of the control system as follows (Al-Yasiri et al., 20):

$$G(s) = \frac{13500}{6.345s^2 + 132.498s + 326.106} \qquad (2)$$

Equation (2) is transformed into state space equation given by:

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -51.4 & -20.88 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 2127.66 \end{bmatrix} u(t) \qquad (3)$$

$$y = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \qquad (4)$$

Equations (3) and (4) conform to the canonical form given by:

$$\dot{x} = Ax + Bu(t) \qquad (5)$$

$$y = Cx + Du(t) \qquad (6)$$

where:

$$A = \begin{bmatrix} 0 & 1 \\ -51.4 & -20.88 \end{bmatrix}, \; B = \begin{bmatrix} 0 \\ 1 \end{bmatrix}, \; C = \begin{bmatrix} 1 & 0 \end{bmatrix}, \; D = 0.$$

The open-loop model of system in Simulink is shown in Fig.2

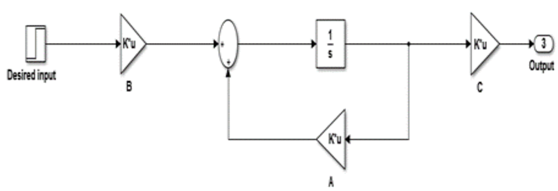

Fig. 2 Open-loop model in Simulink

B. System Stability

In this subsection, the stability of the open-loop system is analysed. If by computing the eigenvalues of matrix A (which is equal to the poles of the transfer function), it is observed that all are negative then the system is stable. A (which is equal to the poles of the transfer function), it is observed that all are negative then the system is stable. Hence, the calculated eigenvalues of matrix A are: $p_1 = -2.8510, \; p_2 = -18.0290$. Since the poles (eigenvalues) are negative, it means that the system is stable.

C. Controllability and Observability

A system is controllable when there is always a control input, u(t), that transfers any state of the system to any other state in finite time. For linear time invariant (LTI) system, the system will be controllable if the controllability matrix C_o given by Eq. (7) is of rank n (where n is the number of states variables).

$$C_o = \begin{bmatrix} B & AB & \cdots & A^{n-1}B \end{bmatrix} \qquad (7)$$

The controllability matrix and its rank calculated for the system is:

$$C_o = \begin{bmatrix} 0 & 2128 \\ 2128 & -44426 \end{bmatrix}, \text{rank} = 2.$$

Also a system is observable if the initial state, $x(t_0)$, can be determined based on what is known about the system input, u(t), and the system output, y(t), over some finite time interval, $t_0 < t < t_f$. For LTI system, this can be achieved using observability matrix O_b, which must be of rank n and is given by:

$$O_b = \begin{bmatrix} C \\ CA \\ \vdots \\ CA^{n-1} \end{bmatrix} \qquad (8)$$

The observability matrix and its rank calculated for the system is:

$$C_o = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}, \text{rank} = 2.$$

D. Full State Variable Feedback

A full state variable feedback is a pole placement design approach such that all desired poles are selected at the beginning of the design. In order to demonstrate that this strategy can place the pole in any desired location, it is initially assumed that the reference is zero, and is simply expressed by:

$$u = -Kx \qquad (9)$$

where u is the control input, K is the feedback gain, and x is a state variable. Substituting Equation (9) into Equation (5) gives:

$$\dot{x} = (A - BK)x \qquad (10)$$

One strategy for calculating the state feedback gains K, so as to place the closed loop poles. The closed loop system of the state space system given by Eq. (5) and whose input is given by Eq. (11) can be expressed as in Eq. (12):

$$u = K_f r - Kx \qquad (11)$$

$$\dot{x} = (A - BK)x + BK_f r \qquad (12)$$

The gains of the state feedback gain K necessary to move the poles to the desired positions can be determined from the eigenvalues of (A-BK). Given the state variable feedback matrix K, such that:

$$K = [K_1 \quad K_2] \qquad (13)$$

$$(A - BK) = \begin{bmatrix} 0 & 1 \\ -51.4 - 2127.66K_1 & -20.88 - 2127.66K_2 \end{bmatrix}$$

… (14)

In order to determine the eigenvalues, the expression below is used:

$$\det[\lambda I - (A - BK)] = 0 \qquad (15)$$

Hence,

$$\det[\lambda I - (A - BK)] =$$

$$\begin{vmatrix} \lambda & -1 \\ 51.4 + 2127.66K_1 & \lambda + 20.88 + 2127.66K_2 \end{vmatrix} \qquad (16)$$

Solving Eq. (14) gives the characteristics equation:

$$\lambda^2 + (20.88 + 2127.66K_2)\lambda + 51.44 + 2127.66K_1 = 0$$

….. (17)

Since the system is of second order, it conforms to general characteristics equation of a second order system given by:

$$\lambda^2 + 2\zeta\omega_n\lambda + \omega_n^2 = 0 \qquad (18)$$

Choosing overshoot value of M_p = 5% and substituting this value into the expression $M_p = e^{-\pi\zeta/\sqrt{1-\zeta^2}}$ gives the damping ratio ζ as 0.69. Using the relationship ($T_s = 4/\zeta\omega_n$ between settling time T_s, the damping ratio ζ, and the natural frequency response, ω_n, such that T_s = 1, gives ω_n as 5.77. Also, comparing equivalent values in Eq. (17) and (18) gives:

$51.44+2127.66K_1 = 33.293$; hence, $K_1 = -0.00853$.

$20.88+2127.66K_2 = 7.963$; hence, $K_2 = -0.00607$.

Therefore, $K = [-0.00853 \quad -0.00607]$.

The Simulink block diagram of the full state feedback control loop with the calculated feedback gain is shown in Fig. 3.

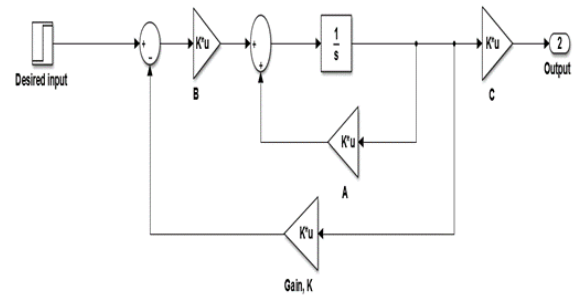

Fig.3 Simulink model of full state feedback control

E. Forward Path Gain

The setback of using full state feedback only is that the chance of tracking a step input is not assured. To address this setback, a forward path gain is implemented in Simulink as shown in Fig. 4 and with a value, K_f = 0.0156.

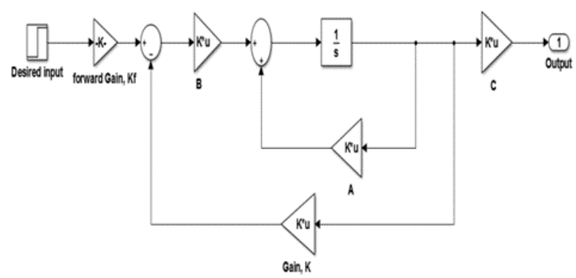

Fig. 4 Simulink model of full state feedback control with forward gain

F. Observer Design

The reason for implementing the observer is to estimate the actual plant so that even if the actual states are in no way measured, the ones estimated by the observer can be used in the state feedback control. Below is the mathematical theory of calculating and selecting observer gains.

From Fig. 5, the observer state equation is given by:

$$\left.\begin{aligned} \dot{\hat{x}} &= A\hat{x} + Bu + L(y - \hat{y}) \\ \hat{y} &= C\hat{x} \end{aligned}\right\} \qquad (19)$$

where $u = K_f r - K\hat{x}$ and L is the observer gain given by:

$$L = [L_1 \quad L_2 \quad L_3 \quad L_4] \qquad (20)$$

For an observer, the target is to reduce the error between the actual and the estimate states to zero.

$$\text{error}, e = x - \hat{x} \to 0 \qquad (21)$$

$$\begin{aligned}\dot{e} &= \dot{x} - \dot{\hat{x}} = Ax + Bu - \left(A\hat{x} + Bu + L(y - \hat{y})\right) \\ &= (A - LC)(x - \hat{x}) \end{aligned} \qquad (22)$$

$$\dot{e} = (A - LC)e \qquad (23)$$

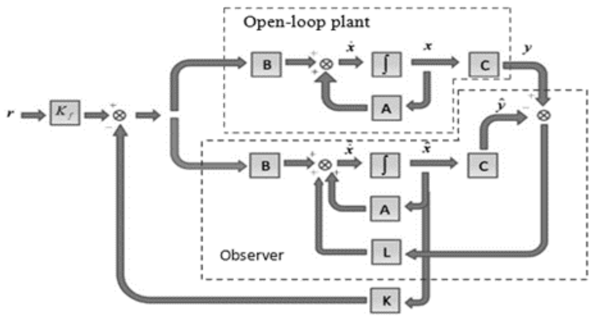

Fig. 5 Full state feedback with an observer loop

The values of the feedback gains, $K = [K_1 \quad K_2]$, were substituted into the characteristics equation in given by Eq. (17) so as to obtain the eigenvalues which represent the desired closed loop poles, p. The characteristics equation for obtaining the eigenvalues is given by:

$$\lambda^2 + 7.965\lambda + 33.29 = 0 \qquad (24)$$

Solving Eq. (24) the values of the poles, p, of the closed loop system are obtained as presented below.

$$\lambda_1 = p_1 = -3.98 + 34.85j$$

$$\lambda_2 = p_2 = -3.98 - 34.85j$$

The observer gain L was determined using MATLAB to be:

$$L = \begin{bmatrix} 60 \\ 121760 \end{bmatrix}$$

The Simulink block diagram of the antenna positioning control system for effective satellite communication using a full state feedback technique is shown in Fig. 6.

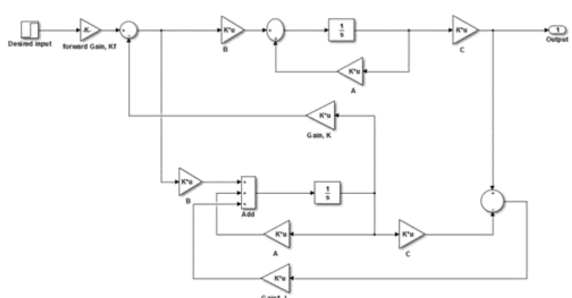

Fig. 6 Proposed antenna position control system in Simulink

IV. RESULTS AND DISCUSSION

In this section, the simulation results obtained using the MATLAB software are presented. Figure 7 is the simulation plot of the system in open-loop state to unit step input. With the feedback gain designed and added to form full state feedback loop, simulation was conducted and the step response plot is shown in Fig. 8. A forward gain was implemented and simulation conducted gives a response plot to unit step input as shown in Fig. 9. Finally, with a full state observer added to full state feedback loop with forward path gain, simulation carried out in terms of step input gives the step response in Fig. 10. In order to further show the effectiveness of the observer estimation capacity, simulation plot of the difference between the actual output and estimated output (that is $y - \hat{y}$) is presented in Fig. 11. Table 2 is the performance analysis table with respect to various simulation results obtained. All analysis has been done it terms of continuous term domain response parameters: rise time, peak time, overshoot, settling time and final value.

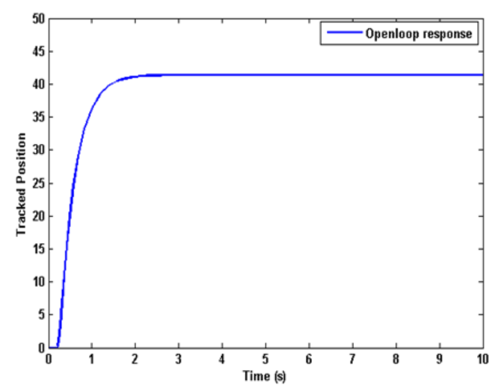

Fig. 7 Open-loop step response

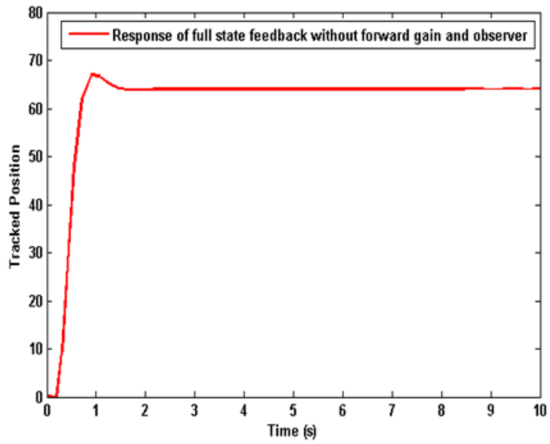

Fig. 8 Step response with feedback gain

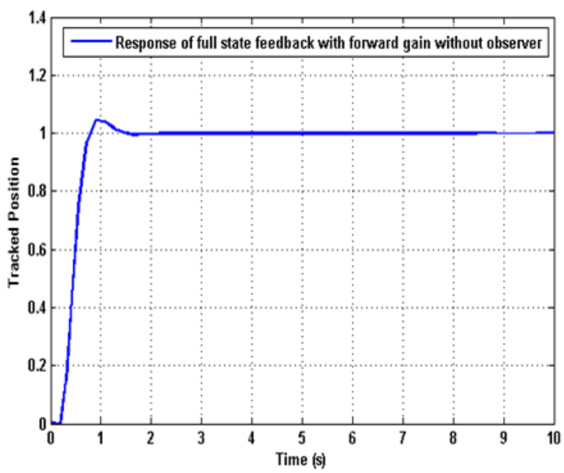

Fig. 9 Step response with forward path gain

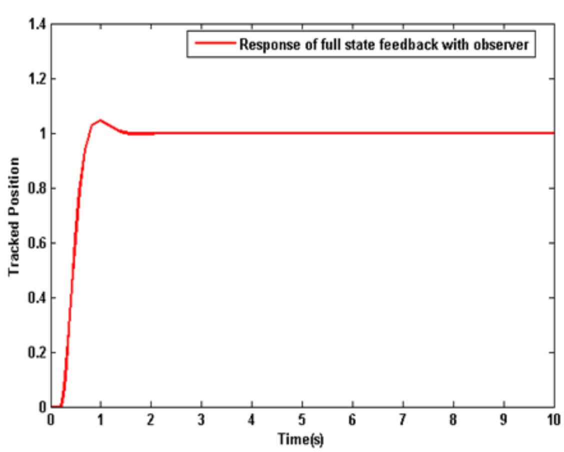

Fig. 10 Step response with observer in the loop

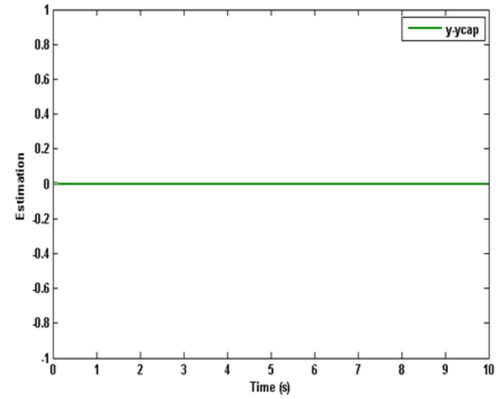

Fig. 11 Estimation error

Table 2 Performance response analysis to unit step input

Parameter	Open-loop	Feedback gain loop	Forward path gain loop	With observer loop
Rise time (s)	0.7990	0.3937	0.3937	0.3714
Peak time (s)	8.2303	0.8944	0.8944	09992
Overshoot (%)	0.0059	4.6549	4.6549	4.8298
Settling time (s)	1.6437	1.2415	1.2415	1.2518
Final Value	41.3969	66.9663	1.0447	1.0464
Steady State Error	-40.3969	-65.9663	-0.0447	-0.0464

Figure 7 shows the open-loop simulation result for the performance of two-phase hybrid stepping motor (TPHSM) based antenna positioning control system. It is obvious from the unit step response plot that the open-loop system was unable to track the desired azimuth/elevation (taken as unit step input). Rather a final value of 41.3969 was achieved which is far off the desired value. Hence, steady state error of -40.3969 (margin of error between desired value and actual value) was achieved. Though the domain performance response seems promising looking at Table 2, the general remark about the system is that is unsatisfactory because the antenna in this case will not be able to track the position of a satellite for quality signal reception. This also holds for the state of the closed loop control when feedbacks gain was added (Fig. 8) considering the error margin of -65.9663.

With the addition of a forward path gain, the time domain performance parameters of the full state feedback compensated system are enhanced as shown in Fig. 9. A rise time of 0.3937 seconds, settling time of 1.2415 seconds and overshoot of 4.6549 % at 0.8944 seconds is achieved in this case as shown in Table 2. It is obvious from the simulation plot that the desired step input is perfectly tracked by the controller with the forward path gain added in the loop and provide a near zero steady state error (-0.0447). Also, the addition of observer improved the system response performance to a step input giving a rise time of 0.3714 seconds, settling time of 1.2518 seconds and overshoot of 4.8298% at 0.9992 seconds as well as providing a perfect tracking with steady state error of near zero (-0.0464).

In order to validate the effectiveness of the observer, simulation plot was obtained for the difference between the actual output and estimated output. The result shows that a perfect estimation of the output was provided by the observer since the difference between the actual position and the estimated antenna position was zero as shown in Fig. 11.

CONCLUSION

The paper has presented antenna positioning control system for effective satellite communication. The dynamic equations of a Two-Phase hybrid Stepping Motor (TPHSM) based antenna positioning control system used in the tracking of satellite signal. The transfer function models were transformed into equivalent state space models. The state space equations were represented by different features of Simulink used to model the system in MATLAB/Simulink environment. The performance of the system was studied in terms of stability, controllability, and observability. A state feedback controller was designed and implemented in MATLAB/Simulink environment considering three steps namely, full state feedback with no forward gain, full state feedback with forward path gain, and full state feedback with an observer loop. Simulation results generally indicated that proposed control was capable of achieving perfect tracking.

REFERENCES

[1] 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.

[2] Fandakl, S. A., and Okumuş, H.I. (2016). Antenna Azimuth Position Control with PID , Fuzzy Logic and Sliding Mode Controllers, (December 2017). https://doi.org/10.1109/INISTA.2016.7571821

[3] Al-Yasiri, M., Saad, M., and Hassan, M. M. Satellite Control System Tuned by Particle Swarm Optimization. Proceeding of the 26th Conference of FRUCT Association, 473-477.

[4] 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 –JEEECCS, 6(21), 25-30.

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

[6] Kyaw, M.M., New, C.M. and Tun, H.M. (2012). Satellite dish positioning control by DC Motor using infrared remote control. International Journal of Electronics and Computer Science Engineering, 3(3) 199-207.

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

[8] Hoi, T.V., Xuan, N.T. and Duong, B.G. (2015). Satellite tracking control system using Fuzzy PID controller. VNU Journal of Science: Mathematics and Physics, 31(1), 36-46.

[9] Attiya, A. J., Shneen, S. W., Abbas, B. A., Wenyu, Y. (2016). Variable Speed Control Using Fuzzy-PID Controller for Two-phase Hybrid Stepping Motor in Robotic Grinding. Indonesian Journal of Electrical Engineering and

Computer Science, 3(1), 102–118. DOI:10.11591/ijeecs.v3.i1.

[10] Nagrath, I. J., and Gopal, M. (2005). Control Systems Engineering, 4th Edition, New Age International Publishers.

[11] Zhan, R., Wang, X., Yang, Y., Qiao, D. (2008). Design of two-phase hybrid stepping motor driver with current closed-loop control based on PIC 18F2331. Electrical Machines and Systems, ICEM 2008. International Conference on IEEE.

[12] Bellini, A., Concari, C., Franceschini, G., Toscani, A. (2004). Mixed mode PWM for high performance stepping motors. Conference of IEEE Industrial Electronics Society, IECON.

[13] Zhaojin, W., Weihai C., Zhiyue, X., Jianhua, W. (2006). Analysis of Two-Phase Stepper Motor Driver Based on FPGA. IEEE International Conference on Industrial Informatics.

[14] Zhang, S., and Wang, X. (2013). Study of Fuzzy-PID Control in MATLAB for Two-phase Hybrid Stepping Motor. Proceeding of the 2nd International Conference on Systems Engineering and Modeling (ICSEM-13). Atlantis Press, Paris, Francis, 1011-1014.