Effect of Different Controllers on Performance of Dish Antenna Positioning System for Distributed Mobile Telemedicine Nodes

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Abstract- The effect of different controllers on performance of dish antenna positioning system for distributed mobile telemedicine nodes has been examined. 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 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. Simulations were conducted for the designed full state feedback controller and existing schemes namely, proportional integral and Derivative (PID) controller and PID plus pre-filter method. The results revealed that the proposed system provided the best overall performance criteria compared to existing systems with rise time of 0.45 s, settling time of 1.22 s, peak time of 0.945 s, and peak percentage overshoot of 4.91%.

Indexed Terms- Antenna, Controller, Full state feedback, mobile telemedicine, positioning control

I. INTRODUCTION

In communication systems, the interaction between observers on the earth and satellites is aided by antennas. A satellite antenna is designed in such 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 passed the signal on to the feed horn, at which point it is further transmitted to the receiving equipment [1].

The most common problem with antenna employed in satellite communication is positioning, which is to align the dish so as to aim at the correct satellite location for proper communication. Since every antenna is dedicated to a specific satellite, it is difficult to point it [2]. It is necessary for an automated system to be integrated with the system so as to realize the optimum positioning for quality signal transmission and reception.

It is possible to achieve cost effectiveness with respect to the anticipated link margin necessary to receive most of the of the satellite transmission data from certain angle of elevation (or azimuth position). In order to achieve this, a compensator (controller) is added as a subsystem and it is connected to the existing antenna system so as to improve its performance. A compensator provides required command to the entire system to ensure that the desired performance response is achieved. This way, the control system ensures stability, steady state and improved transient responses, cost and robustness. These requirements are applicable to designing antenna servo control system for satellite ground station since the objective is to have a system with a robust tracking and reduced steady state error and improved transient response.

In this paper, the effect of various control approaches on the performance a satellite dish antenna positioning system for distributed mobile telemedicine nodes is evaluated. The system being considered is a dish antenna mounted on distributed mobile telemedicine nodes within Nigeria that communicates via NIGCOMSAT-1R.

II. NIGERIA'S COMMUNICATION SATELLITE AND TELEMEDICINE

The first Nigeria's Communication Satellite (NIGCOMSAT-1) was launched into the geosynchronous orbit by the National Space Research and Development Agency (NASRDA) the Federal Ministry of Science in collaboration with a Chinese organization. The launching of NIGCOMSAT-1 was aim to provide effective information communication technology (ICT) services for all the sectors of the Nigerian economy. One of the pilot areas of interest for this noble project is telemedicine. With the utilization of NIGCOMSAT-1, efficient medium for transmitting heavy streaming video and audio signals needed in telemedicine in addition to transmitting biological signals and patient images from telemedicine centres to base stations is created [3]. This way, an effective and fast healthcare service delivery is guaranteed. In general, telemedicine is aimed at offering expert-based healthcare to remote locations and give advance emergency care via modern ICTs. The basic components of NIGCOMSAT-1 with uplink and downlink communication with ground station antennas are shown in Fig. 1.

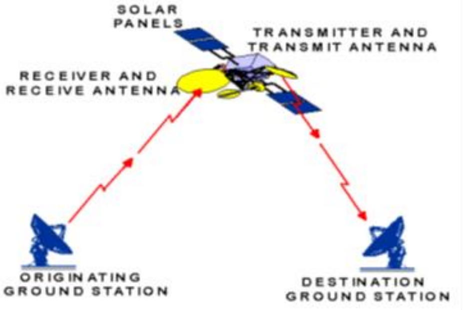

Fig. 1 NIGCOMSAT-1 communication components [3]

The application of telemedicine in NIGCOMSAT-1 has been implemented in multipurpose healthcare system as shown in Fig. 2 with the area of interest to this study indicated (the antenna positioning for effective satellite communication). It consists of base unit and telemedicine unit. The arrangement of telemedicine system as shown in Fig. 2 indicates that it is integrated among other units with a communication link via satellite.

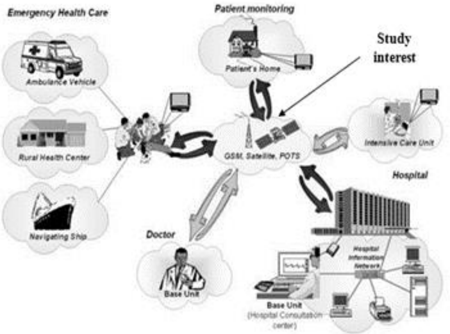

Fig. 2 Multipurpose telemedicine system configuration

The area of satellite dish antenna control in telemedicine with respect to application in NIGCOMSAT-1 has been studied. Ibiyemi and Ajiboye [4] has applied Proportional Integral and Derivative (PID) controller for mobile satellite dish antenna position control that communicates via NIGCOMSAT-1R within Nigeria. The objective was to develop a controller that will provide real-time optimal control action for satellite dish antenna network mounted on mobile vehicles spread across Nigeria. The PID controller was also to ensure that the large time delay associated with system is compensated for. The PID controller was able to provide performance response characteristics of 19.1 seconds settling time compared with the 158 seconds settling time of the system without the PID controller. Similar study involving the use of the effect of PID controller in the control loop of dish antenna mounted on distributed telemedicine nodes within Nigeria communicating via NIGCOMSAT-1R by Ajiboye et al. [5]. Eze et al. [6] developed a PID controller with a pre-filter to improve the performance of response of satellite dish antenna communicating via NIGCOMSAT-1R. A computer simulation using an analogue compensator to evaluate the performance of a compensated dish antenna was presented by Okolie et al. [7]. The Simulation results indicated that the addition of the compensation algorithm largely enhance the overall time domain response performance of the system in terms of rise time (2.75 s), peak time (6.73 s), overshoot (4.87%), settling time (10.1s) and steady state error (0 at 30 s).

In this paper, the performance a full state-feedback controlled dish antenna in telemedicine mobile nodes within Nigeria communicating via NIGCOMSAT-1R is compared with that of existing system using PID controller.

III. METHOD

A. System Transfer Function Determination

The transfer function of the plant was determined considering the dish and jack actuator dynamics model.

The dynamic equation describing the dish antenna structure is given by:

$$I_A \frac{d^2\theta_A}{dt^2} + B_A \frac{d\theta_A}{dt} + \tau_A \theta_A = \tau_A \theta_g \tag{1}$$

Taking the Laplace transform of Eq. (1) and assuming zero initial conditions and obtaining the transfer function gives:

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

$$G_A(s) = \frac{\theta_A(s)}{\theta_g(s)} = \frac{(\tau_A / I_A)}{s^2 + (B_A/I_A)s + (\tau_A / I_A)} \tag{3}$$

The definitions and the values of the parameters of the dish antenna are given below. Substituting these values into Eq. (3) gives [4]:

$$G_p(s) = \frac{2.2578}{s^2 + 0.9016s + 2.2578} \tag{4}$$

Definitions:

$\theta_A =$ Dish angular displacement in radian, $\theta_g =$ 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; 317.5Nm/ra d

The actuator motor dynamic transfer function and the actuator jack gear ratio, K_g are given by [4]:

$$G_M(s) = \frac{0.075}{s(1 + 0.015s)} \tag{5}$$

$$K_g = \frac{1}{30} \tag{6}$$

The time delay arising from sending signal between the sending node and the receiving node was obtained by dividing the distance by the signal speed and is given by [4]:

$$T = \frac{2d_{sr}}{v} \tag{7}$$

where: T is the time delay in seconds and 3×10^8 is the signal speed in m/s.

The maximum and minimum time delay was determined to be 0.2502s and 0.2469s. Thus, the overall transfer function considering the time delay and plant process model is given by [5]:

$$G_{dp}(s) = \frac{\theta_A(s)}{\theta_r(s)} = \frac{3.76e^{-Ts}}{s^5 + 67.56s^4 + 62.36s^3 + 150.52s^2 + 3.76e^{-Ts}} \tag{8}$$

B. *State Space Equation*

The dynamic characteristics of a physical system can be represented using the state variables equation. It serves as a very powerful scheme for the analysis and design of linear, and nonlinear, time-invariant or time varying multi-input-multi-output [MIMO] system [8]. A linear state space system can be represented in the form given by:

$$\begin{aligned} \dot{x} &= Ax + Bu \\ y &= Cx + Du \end{aligned} \tag{9}$$

where A, B, C and D are the constant matrices such that A is the state matrix, B is the input matrix, C is the output matrix, and D is the direct transition matrix.

The transfer function is further expressed to describe the internal variables of the system using state-space representation. This is obtained as follow:

$$\frac{Y(s)}{U(s)} = \frac{3.76}{s^4 + 67.56s^3 + 62.36s^2 + 150.52s} \tag{10}$$

where Y(s) and U(s) are the output and input of the plant. Assuming zero initial conditions, Eq. (10) can be expressed in the form:

$$\begin{aligned} & s^4 Y(s) + 67.56s^3 Y(s) + 62.36s^2 Y(s) \\ & + 150.52sX(s) = 3.76U(s) \end{aligned} \tag{11}$$

Let y = x_1 then Eq. (11) can be resolved as in Eq. (12).

$$\left.\begin{aligned} x &= x_1 \\ \dot{x}_1 &= x_2 \\ \dot{x}_2 &= x_3 \\ \dot{x}_3 &= x_4 \\ \dot{x}_4 &= -150.52x_2 - 62.36x_3 - 67.56x_4 + 3..76(t) \end{aligned}\right\} \tag{12}$$

Transforming Eq. (12) into state space form, gives:

$$\left.\begin{aligned} H = \begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \end{bmatrix} &= \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & -150.52 & -62.36 & -67.56 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} \\ &+ \begin{bmatrix} 0 \\ 0 \\ 0 \\ 3.76 \end{bmatrix} u(t) \\ y = \begin{bmatrix} 1 & 0 & 0 & 0 \end{bmatrix} &\begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} \end{aligned}\right\} \quad (13)$$

The state matrix A is given by:

$$A = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & -150.52 & -62.36 & -67.56 \end{bmatrix}$$

The input matrix B is given by: $B = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 3.76 \end{bmatrix}$

The output matrix C is given by: $C = \begin{bmatrix} 1 & 0 & 0 & 0 \end{bmatrix}$

The matrix D is given by: $D = 0$.

C. Design of Full State Feedback Controller

- Controllability

The first approach in the process of designing full state variable is to find out whether or not the control input, u, is capable of transferring every state to any desired location. In other words, can each state be affected by the control input. If all the states are not affected by the input, then it said that the system is uncontrollable and it is not possible to place the closed poles at any desire location. The first thing to do when determining the controllability of a system is to form the controllability matrix given by:

$$C_{matrix} = \begin{bmatrix} B & AB & A^2B & .... & A^{n-1}B \end{bmatrix} \quad (14)$$

If the controllability matrix is of full rank, a system is said to be controllable. For single input single output (SISO) systems, this is done so as to verify that the determinant of the controllability matrix is non-zero. For the dish antenna system, the controllability matrix is given by:

$$C_{matrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 4 & 300. \\ 0 & 3.76 & -254 & 16900 \\ 3.76 & -254.0256 & 16927 & 1128300 \end{bmatrix} \quad (15)$$

Rank = 4

Since the matrix of the 4th other model is of full rank, that is 4, the system is completely controllable.

- Observablity

The second step is to determine whether the system is observable. In order for a system to observable, its output must have an element with respect to each state. This means that a link must exist from each state to the output. A test on observability can be carried out to determine whether it is observable when there is no clear evidence. A simple test of observbility can be achieved by forming the observability matrix given by:

$$O_{matrix} = \begin{bmatrix} C & CA & CA^2 & .... & CA^{n-1} \end{bmatrix}^T \quad (16)$$

A system that is observable is one whose observability matrix is of full rank. For SISO systems, this is achieved by verifying the determinant of the matrix in order to ascertain if it is non-zero. If the determinant matrix is non-zero, the system is observable.

$$O_{matrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \text{Rank} = 4 \quad (17)$$

Since the rank of the observability matrix is 4, the system is observable.

- Full State Feedback Gain

A full state variable feedback is a pole placement design strategy in which all desired poles are selected at the beginning of the design process. Figure 3.8 shows the closed loop plant and control. 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:

$$u = -Kx \quad (18)$$

where u is the control input, K is the feedback gain, and x is a state variable. Substituting Eq. (18) into Eq. (9) gives:

$$\dot{x} = (A - BK)x \quad (19)$$

which has a solution of $x(t) = x(0)e^{-(A-BK)t}$ [9]. Therefore, by properly selecting the gains, K can adjust the response of the system as desired. The designed value of K representing the control law is given by:

$$K = \begin{bmatrix} 885.5 & 313.4 & 52.75 & -11.60 \end{bmatrix} \tag{20}$$

A forward path gain whose value is 885.5 is added to the loop to enhance the performance of the full state feedback controller. The Simulink model of the implemented system is shown in Fig. 3, and the simulation parameters are given in Table 1.

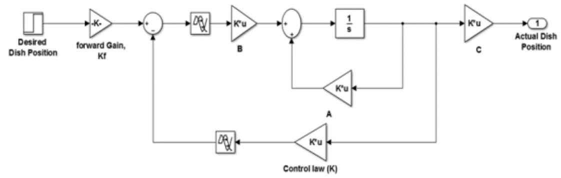

Fig. 3 Simulink model of proposed control system

Table 1 Simulation parameters

Quantity	Symbol	Value
Dish moment of inertial about a given axis	I_A	140.60kgm^2
Damping coefficient	B_A	126.78Nms/ rad
Torsional spring stiffness	τ_A	317.5Nm/rad
Signal speed	v	3×10^8 m/s
Feed forward time delay	T_1	0.2502 s
Feedback time delay	T_2	0.2469 s
Actuator jack gear ratio	K_g	0.033

IV. SIMULATION RESULTS

The response of dish antenna position control system was initially determined before the introduction of controller. The step response plot is shown in Fig. 4. The next simulation was carried out by comparing the step response performance of the system with the proposed full state feedback plus forward path gain with the step responses of existing PID controller only proposed by Ajiboye et al. [5] and existing PID controller plus pre-filter proposed by Eze et al. [6] as shown in Fig. 5. The time domain performance analysis of the simulation results of each step response plots is presented in Table 2.

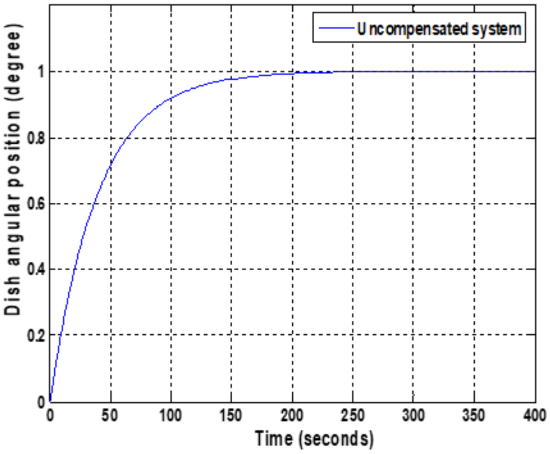

Fig. 4 Step response of system without controller

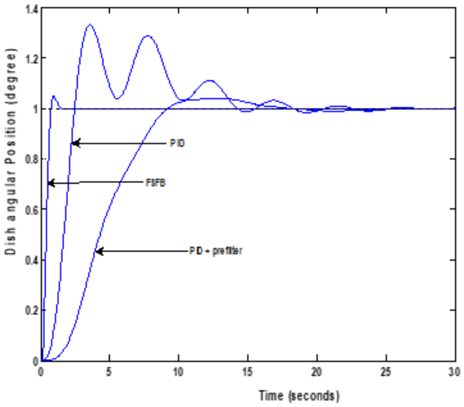

Fig. 5 Step response performance comparison of different

Figure 4 shows the simulation result for the performance of dish antenna position control system when it has not been compensated (that is when the controller has not been added in the loop). The system time domain performance parameters shown in Table 2 reveals that the uncompensated system has a rise time of 87.1 seconds, settling time of 155 seconds, time to peak 300 seconds and an overshoot of 0 %, which is an evident of system impacted by time delay as the response time (in terms of rise term) seems to be very high. That is takes more a minute for the system to position accurately for communication to take place.

Table 2 Summary of performance analysis for different control state

System condition	Rise time (s)	Settling time (s)	Time to peak overshoot (s)	Overshoot (%)	Response to a step input
Uncompensated (system without controller)	87.1	155	300	0	Able to track input but sluggish
Full state feedback (FSFB)	0.42	1.22	0.945	4.91	Able to track desired position
PID	1.4	17.6	3.57	33.1	Able to track desired position
PID + pre-filter	5.54	15.3	12.8	3.98	Able to track the desired position

The simulation results in Table 2 showed that the rise time was 1.4 seconds and 5.54 seconds with the introduction of PID and PID plus pre-filter controllers into the system respectively, but changed to 0.42 seconds when full state feedback plus observer controller was introduced. This signifies better improvement on system rise time as a result of incorporating full state feedback plus observer controller into the system. The time to peak overshoot was 3.57 seconds and 12.8 seconds when the system was with PID and PID plus pre-filter controllers respectively, but further reduced to 0.945 seconds when proposed controller was introduced which is also an indication of a better improvement with respect to time to peak overshoot. The overshoot was 33.1% and 3.98% percentage when the system was with PID controller and PID plus pre-filter controller but it changed to 4.91% due to the introduction of the full state feedback controller into the system, this shows that the performance of compensated system has been largely improved compared with that of the PID control system that has overshoot of 33.1%. The settling time for the PID control system was 17.6 seconds and that of PID plus pre-filter was 15.3 seconds as against the 1.22 seconds for the proposed system which is an indication of far better improvement in system performance with respect to settling time.

It can also be said from the simulation results of Table 2 that system with proposed full sate feedback controller has both better transient and steady states response than the system with PID controller and PID plus pre-filter system proposed by previous studies because of the lower value of system time domain performance response parameters it offers.

CONCLUSION

The performance of different control schemes for a dish antenna positioning system in distributed mobile telemedicine nodes has been studied. Since the dish antenna at the node is usually used to send or received medical information by the mobile telemedicine nodes, the quality of performance of such satellite tracking antenna will depend mainly on how effective the position of the antenna can be controlled. In respect to this, the full state feedback controller has been able to provide improved position control system in terms of effective antenna position tracking with improved transient response characteristics performance. It also ensures enhanced performance in terms of quality and timeliness in sending or receiving of healthcare information based on the fast (or better transient) response time achieved considering the improved rise time, settling time and percentage overshoot and zero steady state error provided by the proposed system.

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