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Automatic Tracking of NigComSat-1R Satellite by Dish Network Mounted on Mobile Tele-Medicine Vehicles

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Abstract

Tele-medicine will rely on effective real-time multimedia communication via global area network such as geostationary satellite. This work is concerned with commanding and controlling centrally, network of satellite dishes mounted on mobile tele-medicine vehicles. The vehicle carrying satellite dish can be in a fixed position or cruising at a maximum speed of 240 km/hr within Nigeria with its dish always pointing and locking to NigComSat-1R satellite quickly and precisely. However, the effectiveness of the PID controller used is largely determined by the amount of delay between formulation of PID control law and its delivery to the controller's actuator. The time delay incurred can be colossal considering the fact that Nigeria has a vast land area of 923,766 sq km and extensive geographical coordinates between longitude 2°43.207'E and 14°54.685'E and latitude 4°17.825'N and 13°52.837'N. The minimum and maximum time delay between Abuja and the tele-medicine vehicle being at any location within Nigeria was determined. The performance of the formulated control law was then tested for robustness for these given time delays using system response settling time as a principal performance index. The result analysis confirmed remarkable improvement in the performance index of the compensated system over the uncompensated system.

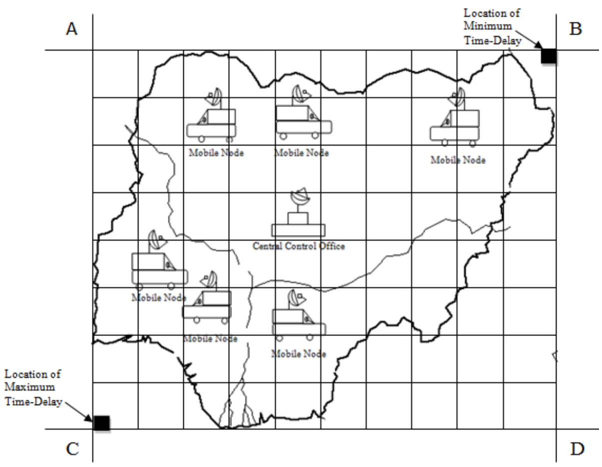
1. Introduction

Information technology, IT, is making healthcare delivery more affordable and available even in rural areas at the same quality of delivery as obtainable in urban cities. Hence, the acute shortage of medical personnel and the low level of healthcare delivery prevailing in developing countries such as Nigeria can be alleviated by appropriate implementation of IT. Tele-medicine, that is remote healthcare delivery, will rely on effective real-time multimedia communication via global area network such as geostationary satellite. A geostationary satellite placed at a distance of 35768 km directly above the equator suspends a solid angle of about 17.4^o with the earth. This translates into about 11000 km of land visibility which is about one third of the earth, hence only three satellites are required to cover the entire earth simultaneously [1]. ITU has, therefore, divided the world into three regions. Region1 covering Europe, Africa, and Middle East with longitudes ranging from 40^{o}W to 45^{o}E. Nigerian's geostationary communication satellite named NigComSat-1R is located in ITU's region1 at 42.5^{o}E.

This work is concerned with commanding and controlling centrally network of satellite dishes mounted on mobile tele-medicine vehicles cruising within Nigeria at a maximum speed of 240 km/hr to point and lock onto NigComSat-1R quickly and precisely. The command and control is based on Proportional-Integral-Derivative, PID, and controller algorithm. However, the effectiveness of Proportional-Integral-Derivative, PID, controller is largely determined by the amount of delay between formulation of PID control law and its delivery to the controller's actuator. It well established that the performance of a PID controller degrades with increase in time delay. This is because the formulated corrective action is based on the past output and not the current output being corrected. Hence, the problem of design of robust PID controller in supervisory control configuration involving large and variable time delays is still a very active area of research. In this work, the design of a robust and effective PID controller in a supervisory control configuration of network of mobile satellite dishes incurring large and variable time delays is presented. The two major sources of time delay are the position within Nigeria of a tele-medicine vehicle with a satellite dish mounted on it ; and the vehicle moving at a speed of up to 240 km/hr.

The time delay incurred can be colossal considering the fact that Nigeria has a vast land area of 923,677 sq km and extensive geographical coordinates between longitude 2°43.207'E and 14°54.685'E and latitude 4°17.825'N and 13°52.837'N. It is assumed that the central control office is at Abuja (7.18°E, 9.2°N), and the NigComSat-1R satellite is at 42.5^0E. The parameters needed to formulate the control law are the round trip delay, and the plant's *transfer function*. This round trip time delay is the sum total of delays from the plant to the satellite, the satellite to the control office in Abuja, Abuja to the satellite, and the satellite back to the node; or vice versa. Plant means the satellite dish unit under control. Therefore, a model for predicting the end-to-end delays was developed; and the plant's transfer function was empirically determined. The plant consists of a satellite dish, BUC/LNB, and a jack actuator. The round trip delay model is based on calculating the round trip distance divided by the speed of light at $30 * 10^9$ m/s. The transfer function is determined from the plant total mass, spring constant, and damping coefficient. Ordinarily these parameters should be read off the plant, however, these information are not available on the nodes used in this work. Therefore, the parameters were empirically determined by experimentation [2].

The minimum and maximum time delays incurred by any tele-medicine vehicle mounted satellite dish unit located within Nigeria and pointing to NigComSat-1R are 0.2491 seconds at Gulf of Guinea (2°43.207'E, 4°17.825'N) and 0.2469 seconds at Lake Chad (14°54.685'E, 13°52.837'N) respectively as indicated in Fig.1.



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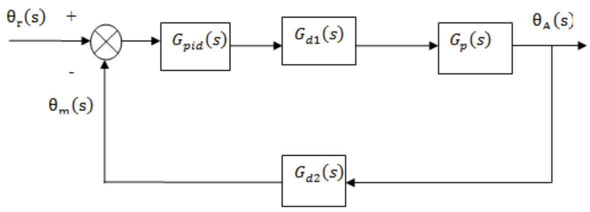
2. System Design

The composite system as shown in the block diagram of Fig.2. has the transfer function given in eqn(1) [2,3,4,5,6].



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$$\frac{\theta_A(s)}{\theta_r(s)} = \frac{G_{pid}(s)G_p(s)G_{d1}(s)}{1+G_{pid}(s)G_p(s)G_{d1}(s)G_{d2}(s)} \quad (1)$$

where:

$G_{pid}(s) \Rightarrow$ *PID controller transfer function given in eqn*(2)

$G_p(s) \Rightarrow$ *Plant transfer function given in eqn*(3)

$G_{d1}(s) \Rightarrow$ *Forward path delay transfer function given in eqn*(4)

$G_{d2}(s) \Rightarrow$ *Feedback path delay transfer function given in eqn*(4)

Transfer function of a PID controller is as defined in eqn(2):

$$G_{pid}(s) = \frac{K_d s^2 + k_p s + k_i}{s}$$

where:

$k_p \Rightarrow$ Pr*oportional gain* (2)

$k_i \Rightarrow$ *Integral gain*

$k_d \Rightarrow$ *Derivative gain*

The plant, that is the satellite dish unit, transfer function is made up of the transfer function of the dish structure, the drive and the gear as compositely expressed in eqn(3):

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

The round trip delay is made up of the forward path and the feedback path delays as expressed in eqn(4):

$$G_d(s) = e^{-T_{rt}S} \quad (4)$$

where:

$$G_d(s) = G_{d1}(s).G_{d2}(s)$$

$$T_{rt} = \frac{2d_{sr}}{v}$$

$$d_{sr} = \sqrt{D^2 + R^2 - 2DRcos(\alpha_{sn})cos(\Delta_1)} + \cdots$$

$$\ldots \sqrt{D^2 + R^2 - 2DRcos(\alpha_{rn})cos(\Delta_2)}$$

$$\Delta_1 = \Delta_{sn} - \Delta_s$$

$$\Delta_2 = \Delta_{rn} - \Delta_s$$

$d_{sr} \Rightarrow$ distance between the source and the receiving node

R = radius of the earth in km

D = sum of the radius of the earth and satellite altitude in km

Δ_s = angle of longitude of the satellite location in space in degrees

α_{sn} = latitude of the sending node location on the earth surface in degrees.

α_{rn} = latitude of the receiving node location on the earth surface in degrees.

Δ_{sn} = angle of longitude of the sending node location on the earth surface in degrees.

Δ_{rn} = angle of longitude of the receiving node location on the earth surface in degrees

v = signal speed in km/sec

Inserting the individual transfer function's parameters in eqn(1) gives the system composite transfer function of eqn(5).

$$\frac{\theta_A(s)}{\theta_r(s)} = \frac{X}{Y} \qquad (5)$$

$$X = 3.76K_d e^{-\frac{T_{rt}}{2}s} s^2 + 3.76K_p e^{-\frac{T_{rt}}{2}s} s + 3.76K_i e^{-\frac{T_{rt}}{2}s}$$

$$Y = s^5 + 67.56s^4 + 62.36s^3 + \ldots$$

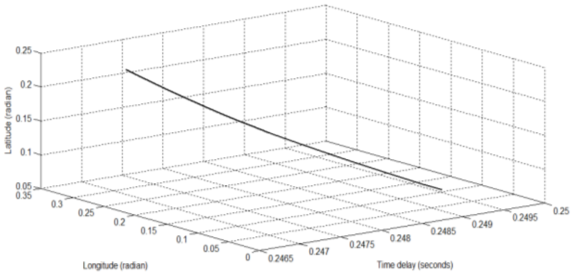
$$\ldots\left(5052 + 3.76K_d e^{-T_{rt}s}\right)s^2 + \ldots$$

$$\ldots 3.76K_p e^{-T_{rt}s} s + 3.76K_i e^{-T_{rt}s}$$

In order to evaluate the effectiveness of the formulated PID control action, the system settling time, t_s, after excitation by a step input is used as the principal performance index. Therefore, the worst case settling time is first obtained by subjecting the uncompensated composite system, that is the system without the PID controller, to a step input forcing function [2,6,7,8,9]. This settling time forms the basis for the determination of PID controller's parameters. Then, the acceptable values of PID's parameters K_p , K_i and K_d which still maintain the composite system stable were determined.

3. Simulation and Analysis

Simulation experiment was carried out in MATLAB to determine the minimum and maximum time delay. It is assumed that the Control Office is at Abuja (7.18°E, 9.2°N) and the mobile tele-medicine vehicles carrying satellite dishes are distributed all over Nigeria with signal transmission via Nigcomsat-1R (42.5°E). The result of the simulation is given in Fig.3.



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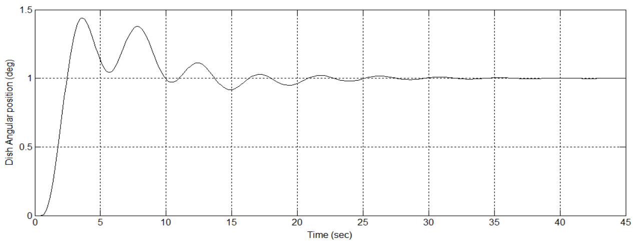
It can therefore be deduced from the simulation result that the minimum time-delay of 0.2469 second occurred at Lake Chad (14°54.685'E, 13°52.837'N) while the maximum time-delay of 0.2491 second occurred at Gulf of Guinea (2°43.207'E, 4°17.825'N). Another simulation experiment was carried out to determine the robustness of the performance indices over the entire time delay range by subjecting the composite system to a step input. Fig.4. shows the system response to a step input for K_p=20, K_i=5, and K_d=10.



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The system settling time of 158 seconds was obtained for the uncompensated system while the settling time for the compensated was 19.1 seconds. These results show an improvement in the steady state performance of the compensated system over the uncompensated system. Hence, of the compensated as a result of reduction in settling time.

6. Conclusion

A PID controller for commanding and controlling mobile tele-medicine vehicles carrying dish network to point and lock to NigComSat-1R satellite was developed. The vehicles could be at any fixed position or cruising with their roof mounted dishes at maximum of 240 km/hr within Nigeria. Simulation experiments showed that the performance indices remained constant over the range of time delay used. And the result analysis confirmed remarkable improvement in the performance index of the compensated system over the uncompensated system.

7. Acknowledgement

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