Antenna Position Control Systems, Review and New Perception

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Abstract*-This paper attempts to provide brief overview of different antenna pointing mechanisms modeled and implemented for different Space Applications. Traditionally servo systems with DC motors or hydraulic actuators are used for antenna driving and different control algorithms PI, LQG (Linear Quadratic Gaussian) are used to improve performance of the pointing systems. PI controllers are easy to implement but having low sensitivity to noise and degraded performance with nonlinearities in the system. LQG controllers are well suited for traditional Antenna Pointing Mechanisms which are using servos as actuators. LQG controllers are noise sensitive, so it provides better system performance in case of wind gusts' noise.*

Keywords-Control System, Antenna Positioning, Fine pointing, Monopulse

1. INTRODUCTION

A position control systems consist of a position error sensing module and position error correcting module. Position error sensing is carried out by different tracking mechanisms: Conical scanning, Sequential scanning, Monopulse Tracking etc.

Conical scanning and sequential scanning are multipulse techniques. So as time instant changes, error may change and hence it leads to less accurate error sensing. In monopulse tracking error signal is generated using single pulse, so accuracy improves. Also, The monopulse Tracking mechanism provides more accurate position sensing as it is based on the null tracing rather than peak tracking.[2]. Position error correcting module is servo loop controlling antenna position using actuators.Geo Stationary Satellites are nowadays using Ku and Ka band providing narrow beam coverage. A more accurate position control system of the order of 0.005 deg is required to limit the antenna de-pointing losses within 1 dB at end of coverage at Ka and Kuband .

2. REQUIREMENTFOR FINE POINTING

Aurele Vuilleumier and Max Eigenmann have presented paper on fine pointing and trim mechanism to be used for future Geo Stationary Satellites operating with narrow beam coverage. He has introduced Piezo actuators to control the position which removes backlash introduced in conventional pointing mechanisms.But mass, power supply requirements, stiffness and cost of developments are issues with this concept. In comparison stepper motor based systems are easy to implement as drives for it are commercially available.[3]

3. ANTENNA POSITION CONTROL SYSTEM AND CONTROLLER IMPLEMENTATION

Here I have briefed different papers for antenna position control and their results.

3.1 Liu Xuan has modeled and designed azimuth position control system and analyzed controllerimplementation.[4]

- Their team implemented the DC motor based system in open loop and closed loop and determined most stable controller.
- They have modeled available position control system with servo actuators (DC motor) and gears with feedback potentiometer and implemented discrete controller for stability.

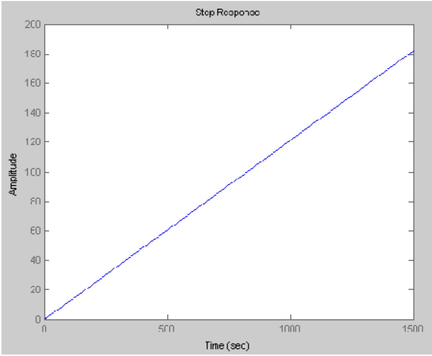

Fig.1 Step Response to Open Loop System[4]

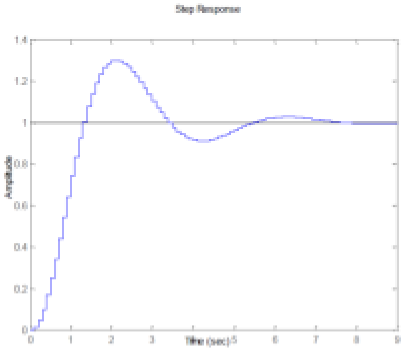

Fig.2 Step Response to Closed Loop System with PID controller[4]

- They found step response of open loop system as ramp (Fig. 1) which saturates the system components. They used PID controller for achieving stability (Fig. 2).

3.2 Wodek Gawronski has major contribution in the field of antenna pointing mechanisms. His paper discusses the compensation of antenna-pointing errors following the analysis and retrofit of the NASA Deep Space Network antenna-control systems.The desired high-frequency communications with spacecraft (at Ka-band) require improved pointing precision over lower-frequency communications (at X-band). The quality of the antenna drives (hardware), the control algorithm (software), and the physical structure of the antenna (in terms of thermal deformations, gravity distortions, encoder mounting, and wind gusts) all influence pointing precision, and create the challenging task of remaining within the required pointing-error budget. [5]

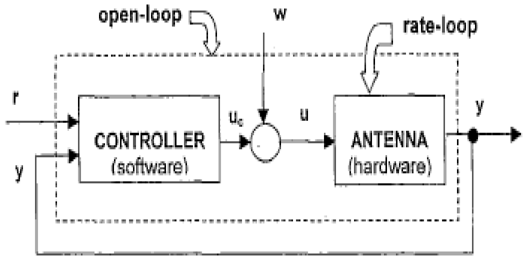

Fig. 3 Antenna Position Control System- Open Loop and Closed Loop[5]

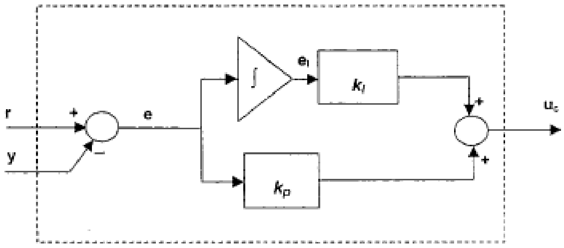

Fig. 4 Block Diagram of PI controller[5]

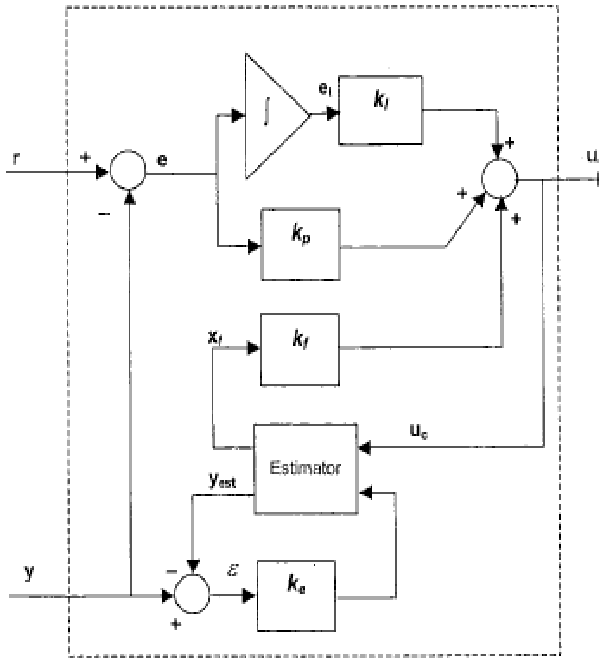

Fig. 5 Block Diagram of LQG Controller[5]

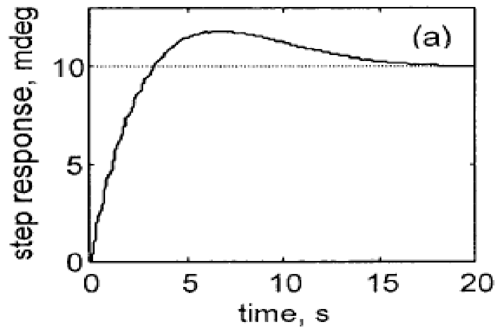

Fig. 6(a)

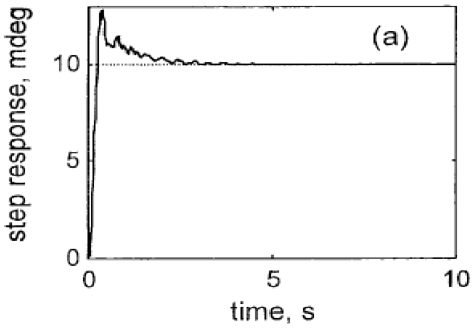

Fig. 6(b)

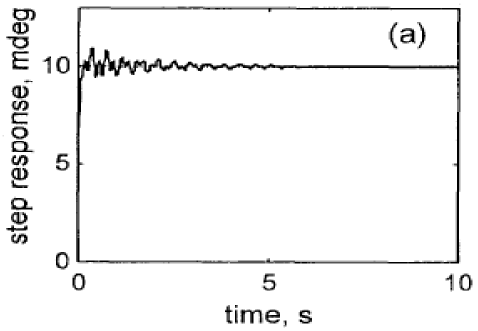

Fig.6(c)

10mdeg step response with PI controller (Fig 6(a)), LQG Controller (Fig. 6(b)), H∞ Controller (Fig. 6(c))[5]

- Increasing Proportional gain in PI controller improves settling time and bandwidth so speed of the response increases, so it gives good performance in disturbance, but it adds vibrations. LQG controller helps to sense and control the vibrations during increase in proportional gain.
- Three control algorithms - PI (proportional-and-integral), LQG (linear-quadratic-Gaussian), and H∞ are discussed, and their basic properties, tracking precision, and limitations as applied to antenna tracking are addressed. His paper shows that the PI algorithm is simple and reliable, but its performance is limited. It also explains how significant improvements in tracking precision are achieved when implementing the LQG control algorithm or the H∞ control algorithm. Still, pointing precision attributable to software modification is limited. It is pointed out that an additional increase of tracking precision requires concurrent improvements in the antenna drives. To upgrade from PI to LQG controller requires just software to update and provides better settling time and overshoot. Upgrading from LQG to H∞ requires hardware to update and mostly the motors to drive the antenna.

3.3 He also has presented paper to tune PI and LQG controller for the antenna pointing system. He also carried out the simulation and practical experiment to find performance of both controllers in wind disturbances andconcluded that LQG controllers are best suited as it is the estimation based algorithm.[6]

3.4Wodek Gawronski also has worked on Design and performance of Monopulse control system. Ka-band (32 GHz) monopulse tracking was chosen. This required an increased pointing accuracy for the Deep Space Network antenna servo systems that can be maintained in a noisy environment. The noise sources include wind gusts, encoder imperfections, and receiver noise. This article describes the selection of the position and monopulse controllers for the improved tracking accuracy, and presents the results of linear and non-linear simulations to confirm that servo performance will meet the requirements.[7]

- He has modeled the monopulse controller, RF front end and position controlling loop with rate loop.
- Then he implemented PI and LQG controller for monopulse tracking system for both azimuth and elevation axis and found radial error for different SNR values and calculated mean radial error.
- He concluded that PI controller can work for low bandwidth. Any effort to improve its bandwidth leads to instability.

3.5 WodekGawronski has also worked on performance of the system under different error conditions. Also he has modeled the wind gust and disturbance as Davenport filter and other pointing challenges like backlash, encoder error, and friction simulated it with PI, LQG and H∞ controller to check its performance. [8]

Table 1 Variants of Position Correction Subsystems

Antenna system for Monopulse tracking	Motor	Drives	Controllers	Sensing mechanism
- Corrugated horn - classical four horn monopulse antenna	- Servo - Stepper Motor	- Transistor - PWM - PFM	- PI - LQG	- Monopulse - Sequential lobing - Conical scanning

Table 2 Parameters need to be modeled for position control system

Antenna system for Monopulse tracking	Motor	Drives	Controllers	Sensing mechanism
- Inertia with Az and El axis - Friction - Wind gust load	- Motor shaft inertia - Friction - Torque constant - Resistance - Inductance - Voltage constant	- Type of signal required for motor - Resolution	- Response time - Overshoot - Bandwidth - Gains	- Mathematical representation-relating position error with error voltage

4. FUTURE SCOPE

Actuators like DC motor and Servos adds backlash and friction heat, so now stepper motors are accepted for actuators to antenna. Hybrid stepper motors are suited as it provides good torque. The tracking system for multibeam Geo Stationary Satellite is going to use monopulse tracking mechanism.We can model the tracking system with stepper motor and check its performance in wind gust and structural deformations with PID, LQG and H∞ controller.

Also, the above mentioned future scope can be extended to make the model generalized for different variants of each subparts. This can make designer to simulate the system by selecting according to its system variants and understand the system behavior.

5. DISCUSSION

From the literature survey we can brief the system variants and modelling parameters as in Table 1 and Table 2.

Corrugated horn or four horn feed antenna are suited for monopulse signal generation. Servo motors are used for ground based systems while stepper motor based systems are used for onboard systems. Different servo motor and stepper motor speed or position control system requires better performance so PI or LQG controllers are implemented to improve bandwidth, settling time and to reduce overshoot. As LQG controller is based on Kalman estimation, it provides better accuracy in case of uncertainties. To drive motor at different speed and to position the antenna at particular location, different drive mechanism are used like PWM, PFM or transistor based linear systems. To model antenna system, its inertia and friction should be considered. Also as the antenna is outdoor element for satellite communication, wind gust acts as uncertain load torque, so it also must be considered for exact modeling. Motor model consist of its electrical and mechanical performance modeling so motor shaft inertia, friction, motor torque constant are modeled as mechanical parameters and resistance, inductance and maximum winding current are modeled as electrical parameters.

6. CONCLUSION

There are many approaches to model antenna pointing systems. Tracking mechanisms, antenna system, its drive, gear boxes, controlling algorithms are having different variants and sub variants. Also modeling each of this can be carried out in many ways. For higher frequency band operation, to achieve higher pointing accuracy monopulse tracking is best suited. Above mentioned literature and its thorough understanding helps to model the control system for given specifications.

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