Design of Digital Cascade Compensator for Ground Station Satellite Antenna Servo Control System

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Abstract *–This paper has presented design of digital cascade compensator for ground station Satellite Antenna Servo Control System. It was desired to improve cost performance of a ground station satellite antenna. In order to realise the objective, the dynamic model of a ground station satellite antenna servo control system was obtained. An analogue compensator was initially designed using the Control and Estimation Tools Manager (CETM) of MATLAB GUI. The designed method is based on proportional integral and derivative (PID) tuning. The mode of the design is balanced performance and robustness using robust response time tuning of PID in combination with Nichols graphic tuning. The analogue compensator was then converted to its equivalent digital form with sampling time of 1 s. The designed compensator was added to the servo control loop and simulation performed in MATLAB environment. The simulation results indicated that the designed compensator achieved the object of the paper with improved elevation/azimuth tracking performance with a rise time of 0.8 s, overshoot of 0.022 %, and settling time of 0.98 s.*

Keywords —.*Elevation/Azimuth, Satellite Antenna, Digital compensator, Analogue compensator*

I. Introduction

There has been rapid growth in the use of digital (discrete) compensator (microprocessor) devices in recent times. This can be attributed to the growing demand of digital computer due to the improved price and reliability. A digital compensator provides more flexibility to the performance of control loop than the analogue. In fact, digital compensators offer the convenience of software reprogramming and unlike analogue compensator. Two possibilities of designing and implementing a discrete compensator presented in [3] are: by discretization of a continuous time plant model and then designing a discrete time compensator or by designing a continuous time compensator and then converting to discrete time equivalent.

Digital compensators receives and operates on signals in numerical codes (or discrete form) which is in contrast to continuous signals [4,5]. Two unique features characterizes discrete time control systems [3]. The signals in discrete time control systems are either in the form of pulse trains or are digitally coded, and the controlled processes usually contain analogue elements [6]. It is however possible to have a closed loop compensated system that uses discrete time compensator to control a continuous time plant model. Such system is a hybrid control system [7].

Data reception from remote sensing satellites is achieved currently using 7.5m size ground stations [1]. The cost effect of these stations on overall data reception systems is quite enormous [1,2]. This requires a cost effective ground stations. This paper is aimed at addressing the cost impact of a ground station satellite antenna system by the means of servo control to improve performance response using digital compensator implemented using MATLAB Graphical User Interface (GUI). The digital compensator will address the problem of elevation/azimuth performance response of antenna servo control system with improve tracking.

II. Digital cascade compensator

A digital compensator is often used in a closed loop feedback system as shown in Fig 1.The block diagram represents a typical single loop network for digital control system. The digital compensator takes error in discrete form to carry out computational algorithm so as to provide an output in discrete form.

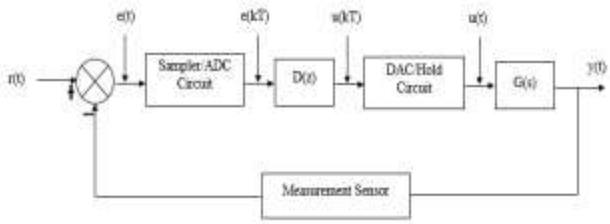

Fig. 1 Block diagram of digital compensated closed loop

Figure 1 shows that continuous time plant model can be controlled using digital compensator that output digital signal. The terms in the compensated closed loop are briefly defined.

A. Closed loop Variables

The input command $\mathrm{r(t)}$ is referred to as the setpoint or referenced input. It is the desired set target (or value) at which the response is required to run [8,9]. The feedback or measurement signal is the output $\mathrm{y(t)}$ which is measured by a sensor (output transducer) and fed to the summing point, where it is summed with setpoint signal. The result is an error $\mathrm{e(t)}$ expressed as $\mathrm{e(t)=r(t)-y(t)}$. The error signal in continuous time is converted to the discrete time equivalent, $\mathrm{e(kT)}$ by the sampler and analogue to digital converter (ADC) circuit. It is the discretized error that is fed into the digital compensator, $\mathrm{D(z)}$. The digital compensator manipulates the discretized error and execute a control command, $\mathrm{u(kT)}$. The control command is also known as manipulated variable in discrete form. It is fed into the digital to analogue converter (DAC) and hold circuit which acts on it and converted it to the equivalent continuous time form, $\mathrm{u(t)}$. The continuous time control command is fed to plant mode, $\mathrm{G(s)}$ and alters its performance to realize a response or output, $\mathrm{y(t)}$ that meets design specification.

B. Closed loop Elements

The components of the closed loop are the summing points, the sampler/ADC circuit, the digital compensator, the DAC/hold circuit, the plant model, and the measurement sensor. The sampler converts the continuous time error into sequence of pulses which are then expressed in numerical code [10]. The ADC carries out the encoding of the numerically coded error signal. The digital compensator receives the discretized error signal from the ADC and perform computational control algorithm and provide a discrete time manipulated variable. The discrete time manipulated variable is in binary coded form and is coded into continuous time signal by the DAC and hold circuit.

III. METHODOLOGY

A. Case Study

The developed discrete-time compensator is implemented in a position loop control of a ground station satellite antenna system. By manipulating changes of voltage requirement, the actual position is measured as the compensator ensures that the position is kept at the desired angle of elevation/azimuth while modulating voltage requirement. The block diagram of the system is shown in Fig.2.

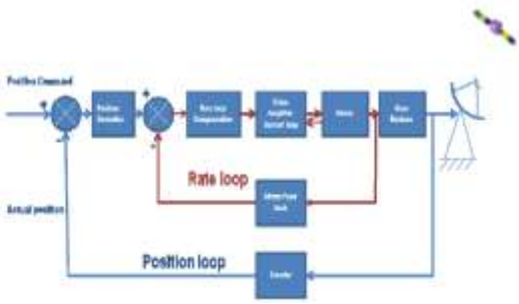

Fig. 2 Antenna Control loops for satellite tracking [1]

The rate (or speed) loop incorporate the current loop and forms an inner loop which improves the system damping [1]. However, the maximum performance of the servo is decided by the position control and hence the loo in Fig. 2 is reduced further as a single position control as shown in Fig. 3. Note that the position loop incorporates the rate loop transfer function dynamic model. The detailed dynamic modelling of the system can be find in [1].

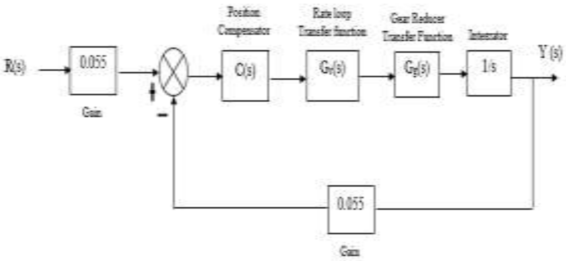

Fig. 3 position cotrol loop block diagram

The transfer functions of the speed loop, gear reducer and position loop are given by Eq. (1), (2), and (3). Equation (3) is the closed loop position transfer function without the compensator.

$$G_v(s) = \frac{0.01181\, s^2 + 39.38 s + 29.54}{0.0000059112\; s^3 + 0.01328\, s^2 + 39.38 s + 31.34} \quad \ldots (1)$$

$$G_g(s) = \frac{980}{515.655 s + 114.59} \quad (2)$$

$$G_\theta(s) = \frac{0.56688\, s^2 + 1890.24 s + 1417.92}{0.00307\, s^5 + 6.8486\, s^4 + 20308.02 s^3 + 20720.16 s^2 + 5491.80 + 1417.92} \quad (3)$$

The closed loop position transfer function in continuous time is the converted to its equivalent discrete time form, taking sampling time, T_s =1s, with zero order hold (ZOH) conversion, given by:

$$G_\theta(z) = \frac{0.04792 z^4 + 0.007588 z^3 - 0.01269 z^2 - 8.935e-06z + 1.488e-22}{z^5 - 2.17 z^4 + 1.573 z^3 - 0.3604 z^2 + 1.669e-17z - 1.245e-34} \quad (4)$$

C. *Compensator Design*

The compensator was initially designed in continuous time (analogue) form using the Control and Estimation Tools Manager (CETM) of MATLAB GUI. The designed method is based on proportional integral and derivative (PID) tuning. The mode of the design is balanced performance and robustness using robust response time tuning of PID in combination with Nichols graphic tuning shown in Fig. 4. The designed compensation is stated in Eq. (5).

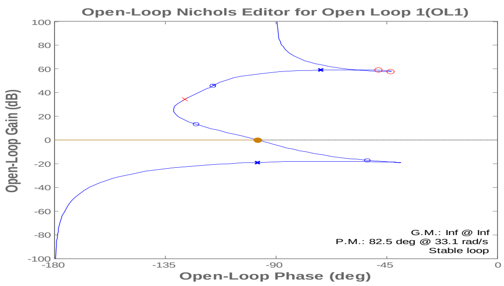

Fig. 4 Nichols graphic tuning

$$C(s) = \frac{3514.1(s + 0.3308)(s + 0.1589)}{s(s + 2.072)} \quad (5)$$

The discrete time (digital) compensator equivalent of the continous time compensator is given, taking a sampling time of T_s = 1s, by:

$$D(z) = \frac{3514.1(z^2 - 1.83z + 0.8448)}{(z-1)(z-0.126)} \quad (6)$$

The resulting closed loop configuration for the digital sevo control system for ground station satellite antenna is shown in Fig. 5

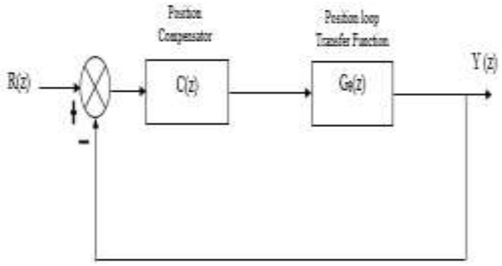

Fig. 5 A scheme for degital control servo system of ground station satellite antenna

IV. RESULTS AND DISCUSSION

The performance results of the ground station satellite antenna servo control system designed and implemented in MATLAB environment are presented in this section for open loop and closed loop conditions for both the continuous time form step response and discrete time form step response.

A. *Results for continuous time step response*

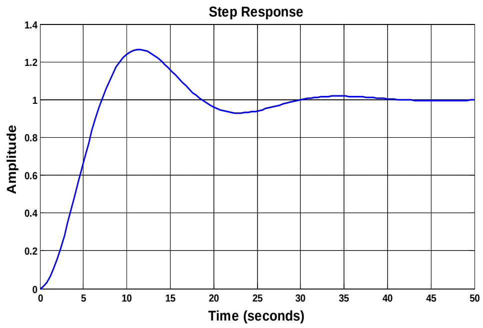

Fig. 6 Open loop step response in continous time form (uncompensated)

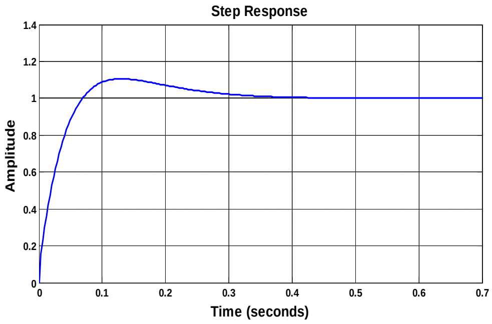

Fig. 7 Closed loop step response in continuous time form (compensated)

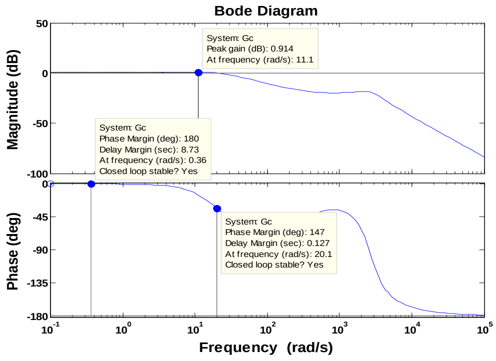

Fig.8 Stability performance in continous time form closed loop

B. ***Results for discrete time step response***

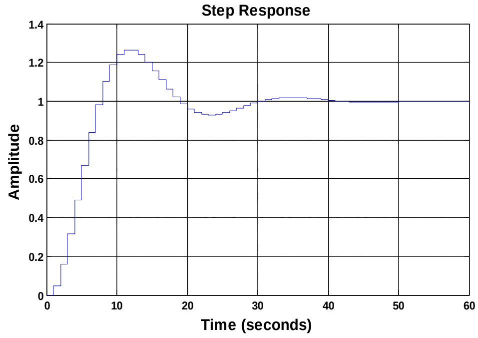

Fig. 9 Open loop step response in discrete time form (uncompensated)

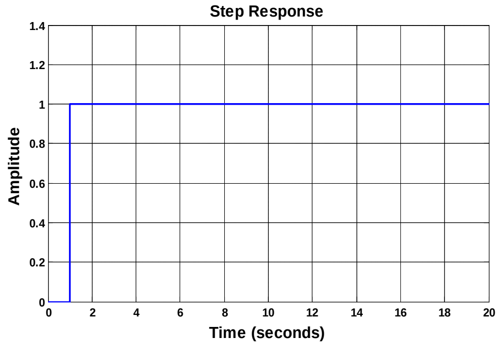

Fig. 10 Closed loop step response discrete time form (compensated)

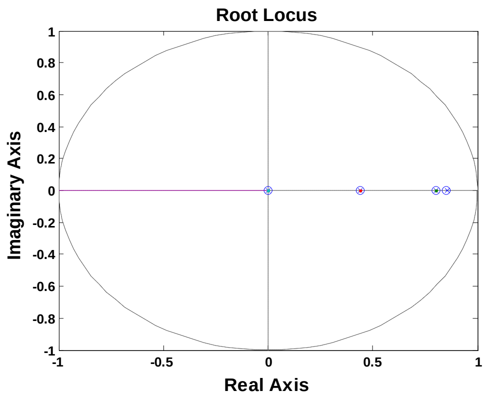

Fig. 11 Stability performance plot of the servo control system in discrete time

The performance results of the system in continuous time and discrete time for both open loop and closed loop conditions are presented in Table I.

Table I Performance Results Analysis

characteristics	Fig. 6	Fig. 7	Fig. 9	Fig. 10
Rise time	4.89 s	0.0502 s	4.96 s	0.8 s
Overshoot	26.5 %	10.5 %	26.4 %	0.022 %
Settling time	28.2 s	0.307	28.2 s	0.98 s

The simulation performance results are analysed in terms rise time, overshoot and settling time. It can be seen that the system is highly unstable during the uncompensated state. On compensating the system greater stability is achieved. Overall performance result as shown in Table I indicated that the digital compensator provided improved performance with a rise time of 0.8 s, overshoot of 0.022 %, and settling time of 0.98 s with 2 % criterion. The Bode plot in Fig. 8 showed that closed loop servo control system is stable for the continuous time analysis while the Root locus plot of the unit circle in Fig. 11 indicated that the discretised closed loop servo system for ground station satellite antenna is stable as all the poles and zeros are within the unit circle.

V. Conclusion

The paper has designed a digital compensator to improve the tracking performance of a servo control system for ground station satellite antenna. The objective was to reduce cost effect associated with elevation/azimuth tracking. In order to improve the position system of the antenna for optimal reception and reduced cost, a digital compensator is designed to effectively reduce the transient response characteristics. With the rise time reduced, the overshoot greatly reduced, and the settling reduced, the speed, position and reception of the antenna system will be largely improved. This ensures the cost effectiveness of the system in terms of operation is guaranteed. Generally, the elevation/azimuth performance has been improved.

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