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Performance Improvement of Antenna Positioning Control System Using Model Predictive Controller

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ABSTRACT
This paper has presented performance improvement of antenna positioning control system using model predictive controller (MPC). It is desired to improve the tracking performance of antenna positioning control system to meet the standards of a practical industrial system. The system is required to meet the tracking specification of rise time of less than or equal to 4 s, settling time of less than or equal to 5 s and overshoot of less than or equal to 10%. In order to achieve this, the dynamic model of direct current (DC) servomotor of antenna positioning system is obtained. An MPC controller is designed in MATLAB/Simulink environment. The dynamic model of antenna positioning system and the designed MPC are integrated to form a closed loop control system. Simulations are performed for open loop and closed loop control system in MATLAB/Simulink. The open loop simulation result showed that the tracking response performance is unsatisfactory with a rise time of 0.525 s, settling time of 4.35 s and overshoot of 34.7%. For the closed loop control, the prediction horizon of the MPC is varied and the tracking response performance of the system showed that the results meet the required specifications with 1.27 s rise time, 3.04 s settling time and 0.203% overshoot for prediction horizon 1, 0.812 s rise time, 3.28 s and 3.6% for prediction horizon 2, and 0.752 s rise time,3.33 s settling time and 6.42% overshoot.

Key words: antenna positioning control system, dc servomotor, MPC, tracking performance

INTRODUCTION

The azimuth/elevation of an antenna requires effective and accurate positioning. In this case, maintaining the antenna the position considering its azimuth/elevation, requires an efficient system with good accuracy and steady state irrespective of the uncertainties occasioned by the changes in the surrounding factors.

Parabolic antennas mounted at earth stations which are basically used in satellite tracking applications, are prone to suffer from environmental disturbance [1-2]. Over the years, Direct Current (DC) servomotor based controllers have been developed and implemented using different control algorithms. These controllers have been used to automatically position the satellite dishes [2-3]. In order to take care of the problem of pointing in satellite and movable targets tracking using servomechanism, several controller models have been presented over time [2, 4-6].

The objective is to design a Model Predictive Controller (MPC) that will provide robust and perfect tracking of antenna position with improved performance handling under disturbance effect through prediction horizon variation. In order to achieve the objective of the paper, it has been organized into five (5) parts with the following headings: introduction, methodology, simulation results and discussion, and lastly conclusion.

Problem Formulation

The objective is to design a controller for improve antenna positioning to meet the following tracking performance specifications. These performance criteria are in conformity with industrial standard [2]:

i. Rise time should be less than or equal to 4 s
ii. Settling time should be less than or equal to 5 s
iii. Overshoot less than or equal to 10%.

REVIEW OF RELATED LITERATURE

Several works have been presented in literature on antenna position control system. Before reviewing the previous work in literature, a brief description of antenna positioning control system is presented as shown in Fig. 1.

In Fig. 1, the input command to the summing point is a setpoint angular position (reference position). It is the desire position at which azimuth or elevation moto is required to run [2]. Note that the input setpoint position is converted to equivalent input voltage value by the potentiometer. The second input to the summing point is the feedback signal which represent the new position (response) of the respective DC servomotor. This signal is converted to its equivalent response voltage by the feedback sensor (potentiometer). The difference between the setpoint signal and the feedback signal is the output of the summing point, and is called position error signal $e(t)$. This signal is fed to the controller that manipulate on it to output an appropriate signal, called manipulated input $u(t)$. The manipulated signal is fed to motor, which produces proportional output, called controlled signal, to rotate the respective motor in either direction according to the sign of the error positive or negative [2]. As the setpoint or desired position is reached, the error signal reduces to zero and the motor stops [7].

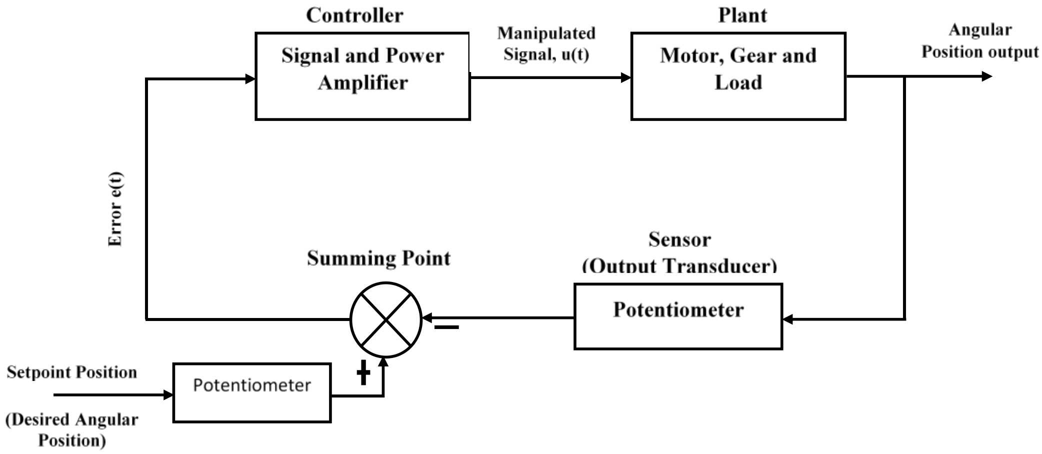

Fig. 1 Antenna positioning control system

The issue of instability has been caused by environmental perturbation and has been considered in literature. According to [1-2], antennas commonly used in satellite tracking applications are prone suffer from environmental disturbances. Soltani et al [4] presented reliable control of ship mounted satellite tracking antenna. Overseas satellite telecommunication is studied such that the control system directs on-board motorized antenna towards a selected satellite. It used the ship simulator facility to design a Fault Tolerant Control (FTC) system to maintain the tracking functionality. Nevertheless, the fault estimation proved to be an extremely difficult task. A review of most common approaches for parabolic antenna control is provided by [6]. A DC servomotor based antenna positioning control system that uses hybrid controller, which combines proportional integral and derivative algorithm and linear quadratic regulator algorithm is provided by [2]. Also in [8], modelling and simulation of antenna azimuth position control system is presented.

METHODOLOGY

Dynamic Equation of DC (Servo) Motor System

Fig. 2 shows the diagram of armature controlled DC motor. Considering the diagram, the following are defined.

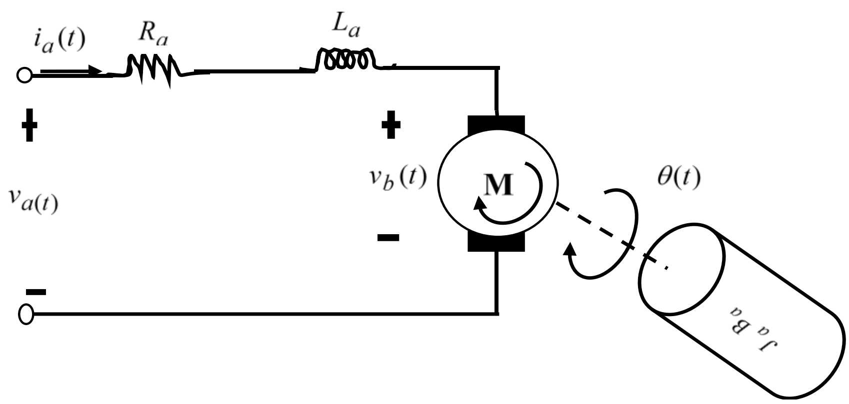

Fig. 2 DC motor diagram

Table 1 presents the parameters defined in [2, 5, 9] which has be used in this paper for modelling and simulation purpose. The voltage applied to the armature of the motor is varied without changing the voltage applied to the field in an armature-controlled separately excited DC motor [2].

Table -1 Parameters of Model with DC Servomotor[2, 5, 9]

Physical Quantity	**Definition of Quantity**	**Numerical Value**
a	Power Amplifier Pole	100
a_m	Motor and Load Pole	1.71
B_a	Motor Dampening Constant [Nm/rad]	0.01
B_L	Load Dampening Constant [Nms/rad]	1
B_m	Equivalent Viscous Friction Coefficient [Nms/rad]	0.02
J_a	Motor Inertia constant [kgm^2]	0.02
J_L	Load Inertia constant [kgm^2]	1
J_m	Equivalent moment of Inertia [kgm^2]	0.03
K	Preamplifier Gain	-
K_1	Power Amplifier Gain	100
K_B	Back emf Constant [Vs/rad]	0.5
K_g	Gear Ratio	0.1
K_m	Motor and Load Gain	2.083
K_{pot}	Potentiometer Gain	0.318
K_T	Motor Torque Constant [Nm/A]	0.5
L_a	Motor Armature Inductance [H]	0.45
N	Turns on Potentiometer	10
N_1, N_2, N_3	Gear Teeth (Respectively	25,250,250
R_a	Motor Armature resistance [Ω]	8
V	Voltage Across Potentiometer [V]	10

Applying Kirchhoff's Voltage Law (KVL) and Newton Law to the DC motor diagram in Fig. 2 gives the following equations.

$$V_a(t) = R_a I_a(t) + L_a \frac{dI_a(t)}{dt} + E_b(t) \tag{1}$$

$$E_b(t) = K_B \omega_m(t) = K_B \frac{d\theta(t)}{dt} \tag{2}$$

$$T_m(t) = K_T I_a(t) \tag{3}$$

where $V_a(t)$ is the applied voltage, $E_b(t)$ is the back electromotive force (emf), $T_m(t)$ is the motor torque, R_a is armature resistance, $I_a(t)$ is the armature current, L_a is the armature inductance, K_B is the back emf constant, K_T is the motor torque constant, $\omega_m(t)$ and $\theta(t)$ are the angular velocity and position respectively.

Substituting Eq. (2) into Eq. (1) yields:

$$V_a(t) = L_a \frac{dI_a(t)}{dt} + R_{aI_a}(t) + K_B \frac{d\theta(t)}{dt} \tag{4}$$

The torque equation is given by:

$$J_a \frac{d^2\theta(t)}{dt} + B_a \frac{d\theta(t)}{dt} = K_T I_a(t) \tag{5}$$

Taking the Laplace transformation of Eq. (4) and (5) and assuming zero initial conditions gives:

$$V_a(s) = L_a s I_a(s) + R_a I_a(s) + K_B s\theta(s) \tag{6}$$

$$J_a s^2\theta(s) + B_a\theta(s) = K_T I_a(s) \tag{7}$$

Equating (6) and (7) by making current subject in both equations gives:

$$\frac{V_a(s) - K_B s\theta(s)}{R_a + L_a s} = \frac{J_a s^2\theta(s) + B_a s\theta(s)}{K_T} \tag{8}$$

The ratio of the output (angular position), $\theta(s)$ to the input voltage, $V_a(s)$ is given by:

$$\frac{\theta(s)}{V_a(s)} = \frac{K_T}{s[(R_a + L_a s)(J_a s + B_a) + K_T K_B]} \tag{9}$$

The block model of the DC servomotor dynamic is shown in Fig. 3.

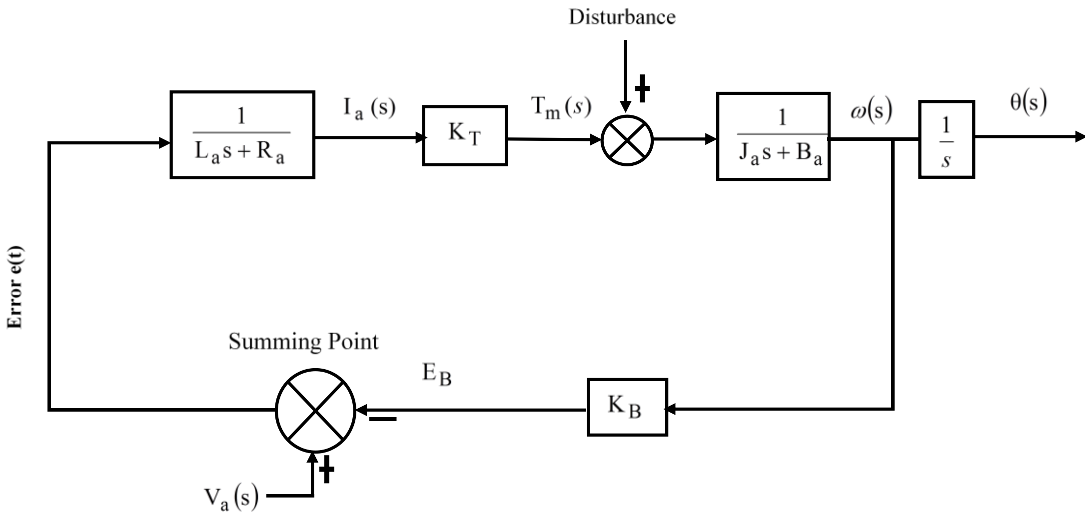

Fig. 3 Closed-loop block model of DC motor dynamic

The transfer function from reference input voltage to the angular velocity as shown in Fig. 3 (Assuming disturbance is zero) is given by:

$$\frac{\omega(s)}{V_a(s)} = \frac{K_T}{[(R_a + L_a s)(J_a s + B_a) + K_T K_B]} \tag{10}$$

In a fixed motor, the armature circuit inductance L_a is usually negligible [10], [13] and $K_T = K_{a,} R_a >> L_a$ [2]. Therefore Eq. (9) simplifies to [2]:

$$\frac{\theta(s)}{V_a(s)} = \frac{K_T/R_a}{J_a s^2 + s(B_a + K_T K_B/R_a)} \tag{11}$$

By letting:

$$B_m = B_a + K_T K_B/R_a \tag{12}$$

$$K_m = \frac{K_T}{R_a} \tag{13}$$

Dividing numerator and denominator by J_a, Eq. (11) is expressed as given by:

$$\frac{\theta(s)}{V_a(s)} = \frac{K_m}{s(s + a_m)} \tag{14}$$

where B_m equal to the equivalent viscous friction coefficient, K_m is motor and load gain, and a_m is the motor and load pole.

The parameters of the system as well as the DC servomotor are given in Table 1. Using gear ratio, the transfer function relating the angular position and armature voltage is given by:

$$\frac{\theta(s)}{V_a(s)} = 0.1 \times \frac{K_m}{s(s + a_m)} = \frac{0.2083}{s(s + 1.71)} \tag{15}$$

Generally, the closed loop block diagram of the antenna DC servomotor control system is shown in Fig. 4.

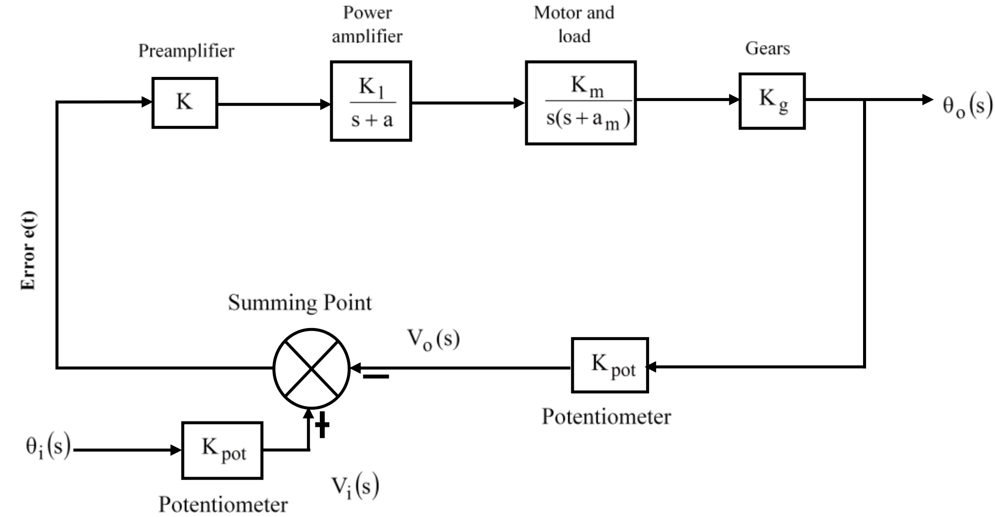

Fig. 4 Closed-loop block diagram of antenna DC servomotor control system

with $a = 100$, $K_1 = 100$, $K_{pot} = 0.318$, defined in Table A1. The closed-loop transfer function without the) controller [2] is found to be considering the closed-loop diagram shown in Fig. 4.

$$\frac{\theta_o(s)}{\theta_i(s)} = \frac{6.63K}{s^3 + 101.71s^2 + 171s + 6.63K} \tag{16}$$

According to Routh-Hurwitz criterion [9], [7], [2], the system will give stable response with value of K in the range $0 < K < 2623$. The gain has been chosen in [11], [2] to be 100 for design convenient and energy consumption reduction.

CONTROLLER DESIGN AND SYSTEM CONFIGURATION

Controller Design

The implementation of Model Predictive Control (MPC) has been achieved using MATLAB. In other to implement a MPC on any process, the following steps are necessary [12]:

i. A discrete step response model with length N and sample time Δt is developed;
ii. Specification of prediction and control horizon is established such that $N \geq P \leq M$;
iii. Weighting w on the control action is specified.

In this paper, to design a MPC, the above steps are adhered to and are maintained in designing the MPC in Simulink. The procedure and the parameters chosen are summarised as follows: the number of manipulated variable, measured output, and measured disturbance selected equal to one respectively. The horizon are selected as follows: control interval (time units) = 1.0, prediction, prediction horizon (intervals) was varied in the interval: $1 \leq P \leq 3$, and control horizon (interval) = 1. The constraints on manipulated variables are: Minimum = -25, Maximum = 25, Max Down Rate = -5, Max Up Rate = 5; constraints on output variables are: Minimum = -75, Maximum = 25. The weigh tuning was set at 0.6.

System Configuration

In this paper, simulations are conducted for open loop and closed loop control for antenna positioning Fig.5 and 6 show the Simulink model for open loop and closed loop control simulations.

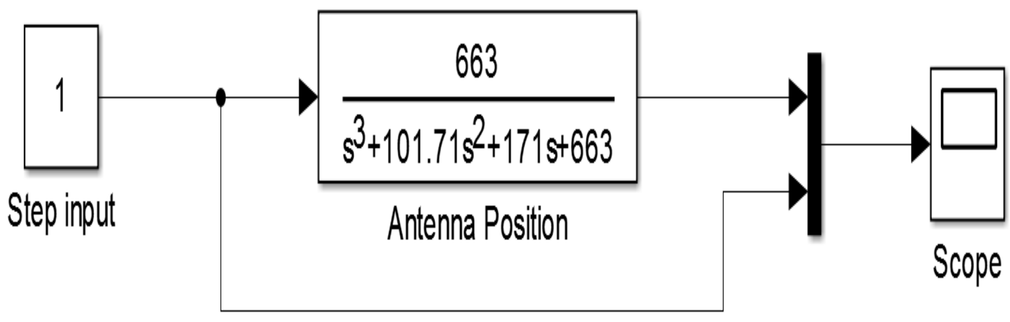

Fig. 5 Open loop antenna positioning control

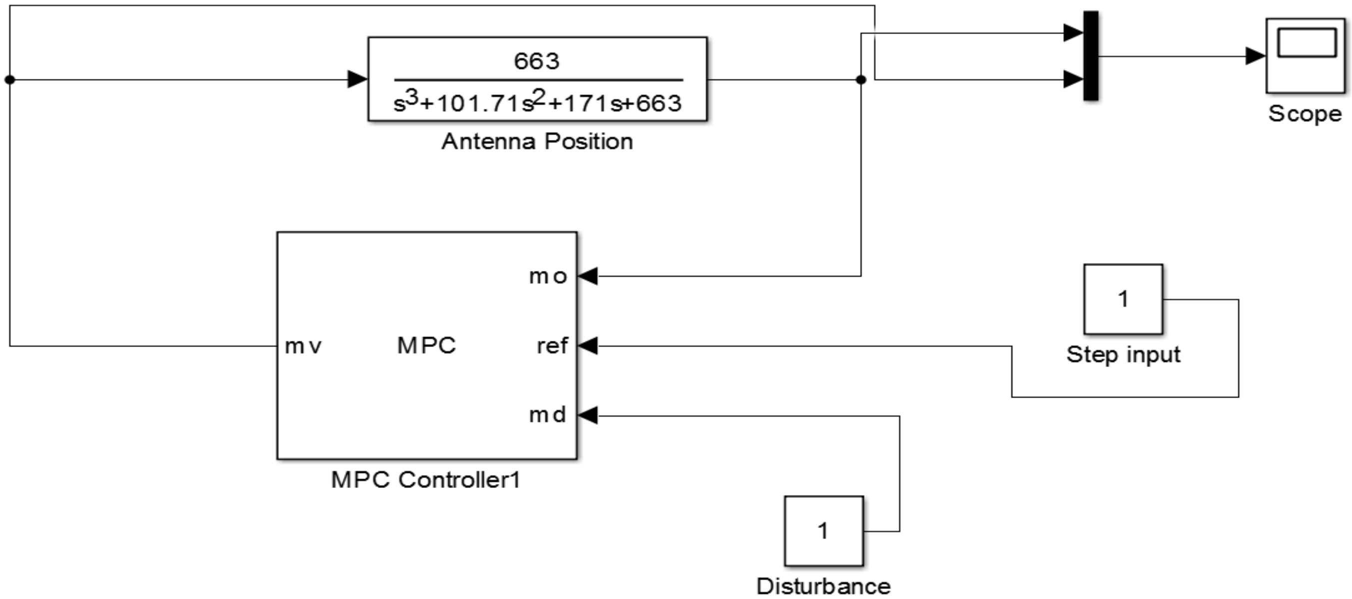

Fig. 6 Closed loop antenna positioning control

SIMULATION RESULT AND DISCUSSION

Simulation Result

Simulation results for open loop control and closed loop control of antenna positioning system are shown in Fig. 7 through 10. The simulation for the closed loop control was carried out by changing the prediction horizon. The performance analysis is shown in Table 2.

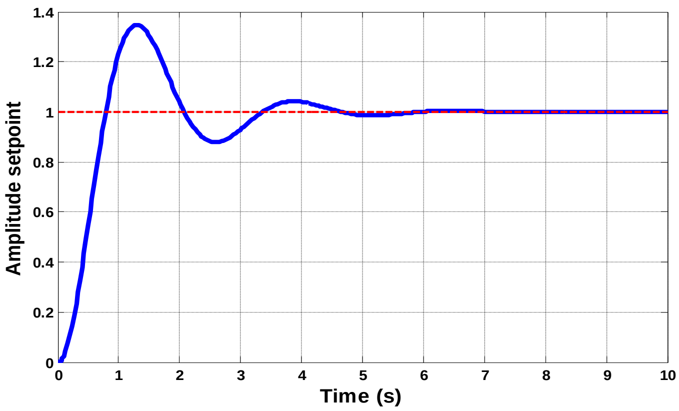

Fig. 7 Open loop step response

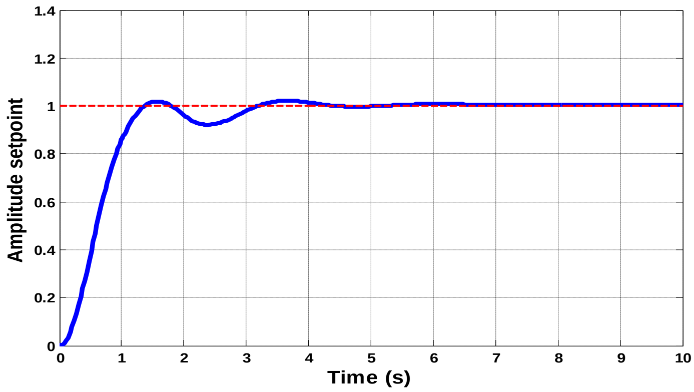

Fig. 8 Closed loop step response (prediction horizon = 1)

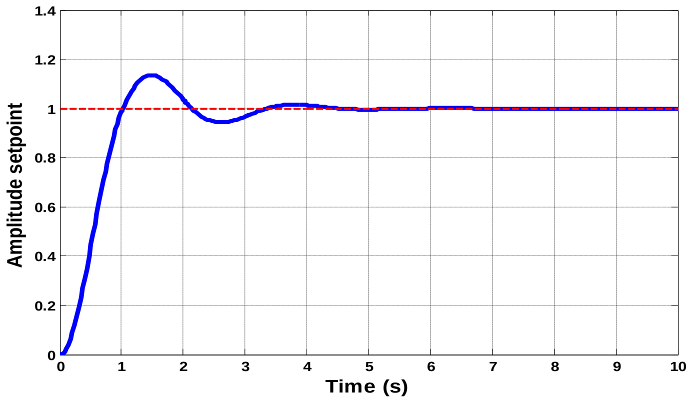

Fig. 9 Closed loop step response (prediction horizon = 2)

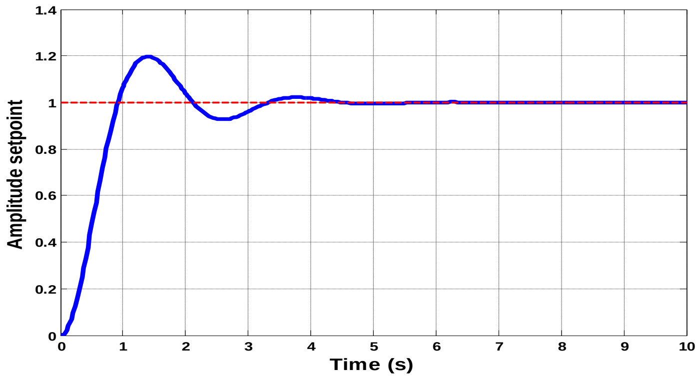

Fig. 10 Closed loop step response (prediction horizon = 3)

Table 2 Performance Analysis

System State	Rise time	Settling time	Overshoot	Remark
Open loop	0.525 s	4.35 s	34.7%	Unsatisfactory
Closed loop (prediction horizon = 1)	1.27 s	3.04	0.203%	Satisfactory
Closed loop (prediction horizon = 2)	0.812 s	3.28 s	3.6%	Satisfactory
Closed loop (prediction horizon = 3)	0.752 s	3.33 s	6.42%	Satisfactory

Discussion

Fig. 7 shows the step response tracking performance of the antenna positioning system without the inclusion of the designed MPC controller. It can be seen that the system in this case shows high degree of instability with 34.7% peak performance. In Fig. 8, the step response performance with the inclusion of the controller, choosing a prediction horizon of 1, shows that step response characteristic of the system has been greatly improved with 0.203% peak performance. In Fig. 9 and 10, the prediction horizon of the controller was selected at 2 and 3 such that the step response performance characteristics are improved with 3.6% and 6.4 % overshoot respectively. Table 1 summarises the step response characteristics for various state of the system considered in this paper.

CONCLUSION

The paper has presented performance improvement of antenna positioning control system using model predictive controller (MPC). The study was based on antenna azimuth positioning control for an antenna system utilizing the dynamic model of DC servomotor. The essence of this research was to improve the response performance of an antenna positioning system in the presence of disturbance. Further investigation was based on the effect of the variation of the prediction horizon of the designed MPC. The overall tracking performance of the system was improved with the inclusion of the MPC within the limit of prediction horizon chosen in this paper compareto the uncompensated system.

REFERENCES

[1]. J.K. Kim, K.R. Cho and C. S. Jang, Fuzzy Control of Data Link Antenna Control System for Moving Vehicles, ICCAS, **2005**.

[2]. L.A. Aloo, P. K. Kihato and S. I. Kamau, DC Servomotor-based Positioning Control System Design using Hybrid PID-LQR Controller, *European International Journal of Science and Technology*, **2016**, 5 (2), 17-31.

[3]. T.V. Hoi, N. T. Xuan and B. G. Duong, Satellite Tracking Control System Using Fuzzy PIDController,*VNU Journal of Science: Mathematics and Physics*, **2015**, 31 (1), 36-46.
[4]. M. N. Soltani, R. Zamanabadi and R. Wisniewski, Reliable Control of Ship-Mounted Satellite Tracking Antenna, *IEEE Transactions on Control Systems Technology*, **2010**, p. 99.
[5]. L. Xuan, J. Estrada, and J. Di Giacomandrea, *Antenna Azimuth Position Control System Analysis and Controller Implementatio*n, Design Problem, **2009**.
[6]. M. Ahmed, S.B. Mohd Noor, M. K. Hassan and A. B. Che Soh, A Review of Strategies for Parabolic Antenna Control, *Australian Journal of Basic and Applied Sciences*, **2014**, 8(7), pp. 135-148.
[7]. K. Ogata, *Modern Control Engineering*, 5th Edition, Prentice-Hall Inc. USA, p.95-96, **2010**
[8]. B. Temelkovski and J. Achkoski, Modelling and Simulation of Antenna Azimuth Position Control System, *International Journal of Multidisciplinary and Current Research*, **2014**, Vol 2, pp. 254-257.
[9]. N.S. Nise, *Control System Engineering*, 6th Edition John, Wiley & Sons, **2011**.
[10]. I. J. Nagrath and M. Gopal, *Control Systems Engineering*, 4th Edition, New Age International Publishers, **2005**.
[11]. A.R. Chishti, S.F. Bukhari, H.S. Khaliq, M.H. Khan and S.Z. Bukhari, *Radio Telescope Antenna Azimuth Position Control System Design and Analysis in MATLAB/Simulink using PID&LQR Controller*. The Islamia University of Bahawalpur, Pakistan. **2014**.
[12]. S. Ciannella, *Applied Model Predictive Control –a brief guide to MATLAB/Simulink MPC toolbox*, Technical Report, pp. 1-64, **2014**.
[13]. C. Mbaocha, P. Eze and V. Uchegbu, *Positioning Control of Drilling Tool Device for High Speed Performance*, International Journal of Electrical and Electronics Research, 3 (2), pp. 138-145, **2015**.