

A novel feed-forward/feedback controller for satellite tracking systems

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Abstract. In this paper, we study the design of a new control structure for the pedestal of the parabolic antenna by means of which tracking the mobile satellites placed at the fixed circuit of earth is conducted with more accuracy than the present classic control methods. One of the methods for the observation of mobile satellites is called Two Line Elements (TLE) tracking. The structure of control system in this paper is composed of Feed-forward and Feedback controller. The Feed-forward and Feedback method in this kind of pedestals can be considered as a new method which highly increases the tracking accuracy. In this paper, it is shown that tracking satellites by means of Feed-forward and Feedback controller will be conducted with more accuracy than the ordinary controllers of these kinds of pedestals. The cost of designing such systems with such an advanced technology is so high, and to track the pedestal with more accuracy, its mechanical structure and designing may require undergoing a lot of changes, whereas the presented method in this paper can increase the accuracy of the pedestal of the parabolic antenna and meet the requirements of the manufacturers without any mechanical changes and designing-which would require a considerable amount of cost.

Key words. Feedback-forward control, satellite tracking controller, parabolic antenna.

1. Introduction

Satellite ground station is applied to a location where there is equipment by which the required information for telecommunication, television, metrology, etc. can be received from and sent to satellites. Parabolic antenna is one of the important equipment, which is considered as the ground receiver and sender [1–4]. Parabolic antennas are consisted of different parts including reflector, feed, pedestal, and low-noise amplifier. To receive information from the satellite, the reflector installed in the ground station should be placed against the antenna installed on the satellite with appropriate accuracy and tracking the satellite.

First method: The position control is based on the common PI controller. In

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this method, adjustment of the control coefficients is done according to methods the designing bases of which are referred to in the enclosed essays [5, 6]). Also, we have simulated a similar trend and consider it as the basis for comparison with the new control algorithm.

Second method: Second method includes utilizing the algorithm of generating velocity trapezoidal command. Concerning the second algorithm, there are researches with the designing aim of placing the tools in the desirable position with a defined accuracy [7, 8]. In the Feed-forward and Feedback control algorithm designed by the authors, which is the main subject of this paper, we present a new model in which the antenna tracks the satellite with higher accuracy compared to the common models. Regarding this, we calculate the tracking error of this controller and through comparing the two structures mentioned above, it is demonstrated that the designed control with the second method, tracks the satellite with higher accuracy and renders better results.

2. Modeling and designing control algorithm

2.1. DC motor modeling

To control motor's velocity, we use armature control method. In this method, assuming that the field flux is fixing, the flow is fixed and field E_{b} is in proportion with ω, which is shown in the equation

$$E_{\mathrm{b}}(t) = K_{\mathrm{b}}\omega(t)\,, \tag{1}$$

$$T_{\mathrm{m}}(t) = K_{\mathrm{T}} I_{\mathrm{a}}(t)\,, \tag{2}$$

$$T_{\mathrm{m}}(t) = J_{\mathrm{m}}\frac{\mathrm{d}\omega(t)}{\mathrm{d}(t)} + B_{\mathrm{m}}\omega(t) = J_{\mathrm{m}}\frac{\mathrm{d}^2\theta(t)}{\mathrm{d}(t)} + B_{\mathrm{m}}\frac{\mathrm{d}\theta(t)}{\mathrm{d}(t)}\,. \tag{3}$$

In the end, the transformation function of DC motor is obtained as equations

$$\frac{\theta(s)}{V_{\mathrm{a}}(s)} = \frac{K_{\mathrm{b}}}{(JL_{\mathrm{a}}s^3 + (R_{\mathrm{a}}J + BL_{\mathrm{a}})\,s^2 + (BR_{\mathrm{a}} + K_b^2)\,s} \tag{4}$$

and

$$\frac{\omega(s)}{V_{\mathrm{a}}(s)} = \frac{K_{\mathrm{b}}}{JL_{\mathrm{a}}s^2 + (R_{\mathrm{a}}J + BL_{\mathrm{a}})\,s + (BR_{\mathrm{a}} + K_b^2)}\,. \tag{5}$$

In the above equations V_{a} is the armature voltage (V), R_{a} is the armature resistance (Ω), L_{a} denotes the armature inductance (H), I_{a} represents the armature current (A), E_{b} stands for the back emf (V), ω denotes the angular speed (rad/s), T_{m} is the motor torque (Nm), θ represents the angular position of the rotor shaft (rad), J_{m} is the rotor inertia (kgm^2), B_{m} stands for the viscous friction coefficient (Nms/rad), K_{T} is the torque constant (Nm/A) and K_{b} is the back emf constant

(Vs/rad). The DC motor parameter are listed in Table 1.

Table 1. DC motor parameters

R_a	L_a	K_b	J_m	B_m
3.14 Ω	0.033 H	1.4 Vs/rad	0.035 kgm^2	0.006 Nms/rad

2.2. Design of motion generator

The satellite TLE file includes information such as velocity and position of each satellite at any moment, using TLE file and numerical calculations, to have the position and velocity of satellite. We assume that the output of TLE file is such that the satellite in the time t has the position p and velocity v. So the mechanical response of the system to the velocity command is so important. In other words, the speed control loop should work well, i.e., at the time t, we should definitely reach the position p, which is obtained from the calculation of the system's speed, and move with the velocity v at that point.

In this method, we want to go from the position X_0 and with the velocity V_0 to the position X_1 and with the velocity V_1 in the shortest possible time. We know that the system's acceleration is a and the maximum velocity is $V_{\max}$, so we go toward the target point with the most possible acceleration till we get to velocity $V_{\max}$ and then in the vicinity of the target point, we stop with the highest acceleration and reach the target point with least error. The described procedure is illustrated in Fig. 1. Now based on the mentioned issues, we solve the problem and study the different cases which arise.

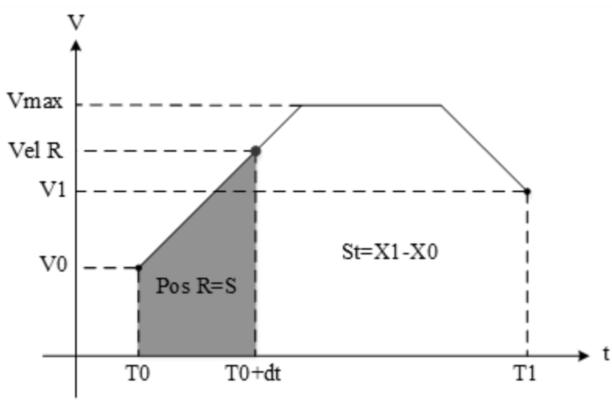

Fig. 1. Motion generator

2.2.1. Main equations of velocity and position. We first analyze the critical case of the problem and then based on that, study other possible positions. In this case, the critical point is only the instance we reach $V_{\max}$ and call it X_1^*. Figure 2 shows the critical position.

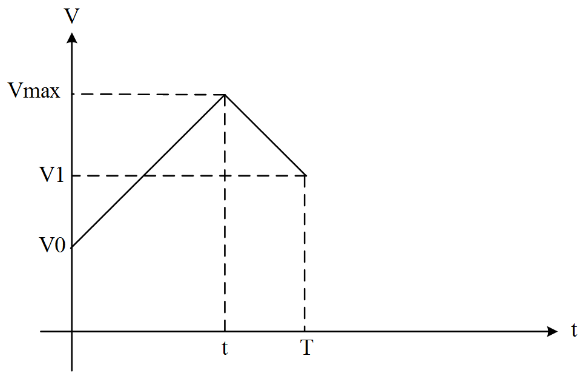

Fig. 2. Critical position

The critical case of the problem is described by equation.

$$\Delta X^* = \frac{{V_{\max}}^2}{a} - \frac{{V_0}^2 - {V_1}^2}{2a}\,. \tag{6}$$

If X_1 is larger than X_1^*, i.e, if the target point is larger than the critical point, we would reach the velocity $V_{\max}$ and then continue moving and start reducing speed.

In this case, assume $|\Delta X| > \Delta X^*$, then we will have:

$$T = \frac{X_1 - X_0}{V_{\max}} + \frac{V_{\max}}{a} - \frac{V_0 + V_1}{a} + \frac{V_0^2 + V_1^2}{2aV_{\max}} \tag{7}$$

and

$$t_2 = T - \frac{V_{\max} - V_1}{2}\,. \tag{8}$$

3. Simulation

3.1. Simulation of DC motor's speed control by PID method

PID controller is one of the commonest controllers used in the automation industry. The advantage of this controller is that it is easy and cheap to implement. Adjusting the control gains is the outstanding feature of this controller. For this purpose, different methods, including Ziegler-Nicholas rules have been provided. For this purpose, we add the transformation of the model presented in Fig. 3, and considering Ziegler-Nicholas rules, we adjust the controller coefficients and place it in the best position. The step respond of DC motor's speed control for the 1200 rpm is shown in Fig. 4.

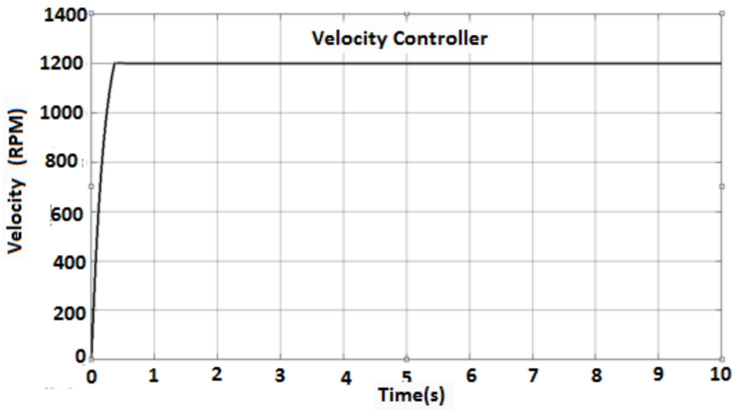

Fig. 3. Model response

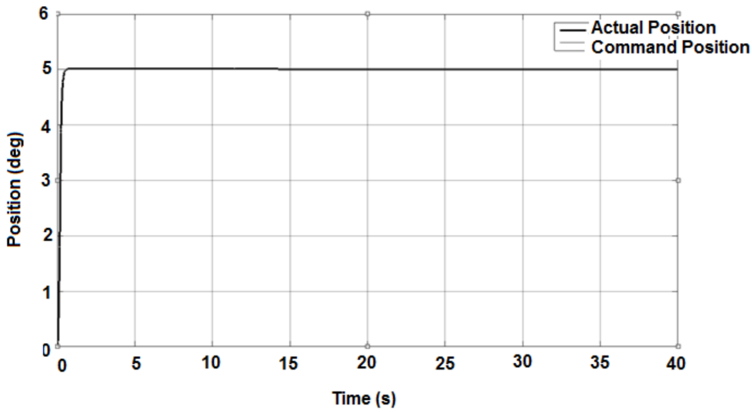

Fig. 4. Step respond of DC motor's speed control

3.2. Simulation of DC motor's position control

The aim of position control is to direct the system toward the intended angle and keep it at that point with the defined accuracy. For this purpose, we control the position of the gearbox motor's system of each axis by means of a PI controller. Since both azimuth and elevation axes are similar to each other, it suffices to first simulate an axis and then generalize it to the second axis. To control the position of the motor, we have two control loops. The first control loop is speed control loop and the second one is position control loop. We simulated the speed control, and now to simulate the position control, we add a PI control loop to the speed control loop. It is worth noting that the velocity of control loop is slower than the speed control loop called control external loop. After adjusting PI gains, you can see the step response of the system in Fig. 4. The sign accuracy on this controller is 0.02 degree.

3.3. Simulation of parabolic antenna controller tracking algorithm

One of the major requirements for the appropriate performance of ground stations' antennas is knowing the current position of the satellite and prediction of its future position.

3.3.1. Tracking satellite by PI position controller. We apply the tracking command of the satellite obtained from TLE to azimuth and elevation command to the system's input. In Fig. 5, the controller respond is shown after applying the position command. In Fig. 6 the controller tracking error, which amounts to -0.25 to $+0.25$, is shown.

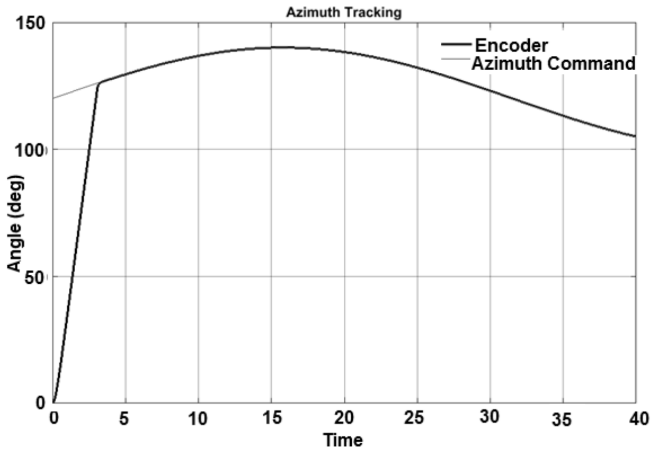

Fig. 5. Controller respond

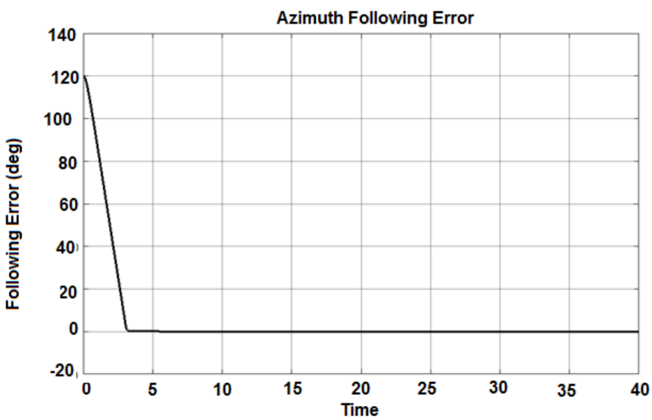

Fig. 6. Controller tracking error

3.3.2. Satellite tracking by means of feed-forward and feedback position. We apply the satellite tracking command, which is obtained from the output of TLE to azimuth and elevation command, to the simulated model in Fig. 7. The simulated model from the position controller of Feed-forward and Feedback for the azimuth axis. In Fig. 8, it can be seen the controller tracking error, which amounts to –0.05 to +0.05 and has considerably decreased compared to the previous control structure.

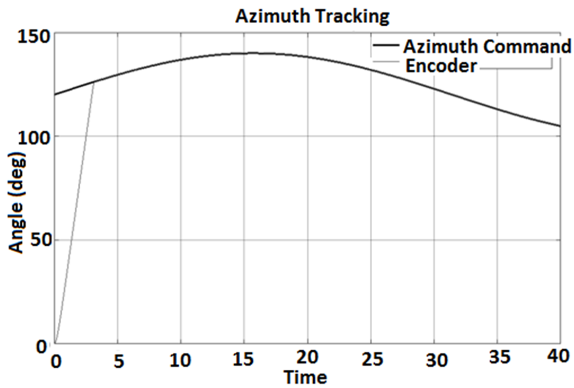

Fig. 7. Controller respond

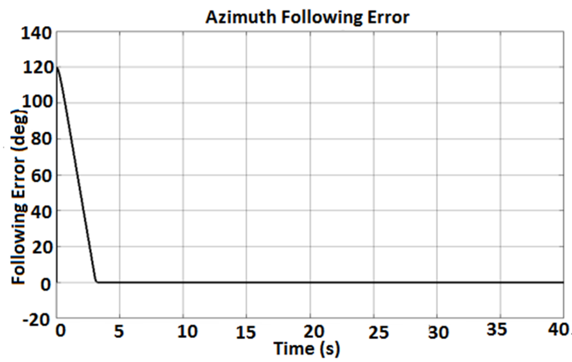

Fig. 8. Controller tracking error

4. Conclusion

Our main purpose is designing a new controller for controlling the pedestal of the parabolic antenna, which tracks the satellites with a higher accuracy than the common controllers, without any changes in the mechanical parts of the system, just through the improvement of algorithm. We first addressed the design of DC motor used in the azimuth and elevation of the parabolic antenna. Then we controlled the velocity of the DC motor by means of PID. In the first method the control was performed with PI, which is a common method for these pedestals. The second method is the algorithm of Feed-forward and Feedback, which is a new method for controlling this kind of pedestals. After conducting the simulations and extracting the results, it was observed that in designing the control with Feed-forward and Feedback, the accuracy of tracking the satellite improved considerably and traced with less error. Given the results and comparing them with each other, it was observed that when using Feed-forward and Feedback controller, the tracking error decreased by 20 % compared to PI controller, and the implementation of this Feed-forward control structure on a practical sample is being conducted by the authors.

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