RADIO TELESCOPE ANTENNA AZIMUTH POSITION CONTROL SYSTEM DESIGN AND ANALYSIS IN MATLAB/SIMULINK USING PID & LQR CONTROLLER

BY

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Abstract. A position control system converts an input position command to an output position response. Antennas, computer disk drives and robot arms contains many applications of position control system. The radio telescope antenna utilizes position control systems. In this paper the design and control of antenna azimuth position has been implemented. The response of the system is analysed and results are drawn by using PID controller, the results of PID controller are further improved by adding Linear Quadratic Regulator. We have seen that the LQR results are much better than the results obtained by PID controller.

Key words: LQR; PID controller; system response; azimuth position control; MATLAB simulation.

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1. Introduction

Currently the modern world depends on control systems. Various applications in our surrounding use the concepts of control systems. Such applications include the automatic lifts, robotics, the rocket fire and the space shuttle lifts of to earth, car’s hydraulic pistons and many other real life applications. Our body organs as pancreas which regulates our blood sugar, heart which pumps through all parts of our body and brain which controls electric pulses through our backbone etc. all are natural control systems. So control systems have lot of applications in our life, we are surrounded by modern technologies which based on scientific innovations. One would have heard about an aircraft flying in auto mode, a moving vehicle without operator and an antenna which gives maximum auto signal strength all are the applications of control systems.

Control system is a system designed for obtaining required characteristics of a process. For getting desired yield with desired performance many subsystems and processes linked in a control system (Nise, 2000). An example of control system is shown in Fig. 1.

![Fig. 1 – Control System.](image)

The position of antenna is controlled by using gears and feedback potentiometer. Antenna azimuth is also controlled by using some controllers. We will check response of the system without using any controller. For getting a better response we will use PID controller and we will see that response will be better than without controller, further we will use LQR controller for getting better response than PID. Commanding the place of an antenna is called azimuth. Getting the output angle of the antenna \( \theta_o(t) \) from the angle of potentiometer \( \theta_i(t) \) as input is the purpose of this scheme. System concept for controlling the position of antenna azimuth is shown in Fig. 2 (Okumus et al., 2012).

![Fig. 2 – Antenna position control system concept.](image)
A more detailed layout of the system is shown in Fig. 3 (Okumus et al., 2012). In input displacement is given to the system, potentiometer converts it into voltage. Similarly, due to the feedback potentiometer output angular displacement converted to voltage.

![Position control system of antenna azimuth detailed layout](image)

**Fig. 3** – Position control system of antenna azimuth detailed layout.

After that differential amplifier check how much the obtained signal is different from the given signal and also find the error. Power amplifier amplifies the input signal. Motor will run until the error approaches to zero. It is assumed that this system using a fixed field DC servo motor (Xuan et al., 2009). Fig. 4 (Nise, 2000), shows the system for controlling the position of antenna azimuth schematic representation.

![System for controlling the position of antenna azimuth schematic diagram](image)

**Fig. 4** – System for controlling the position of antenna azimuth schematic diagram.
A block diagram representation of the system for controlling the position of antenna azimuth is shown in Fig. 5 (Nise, 2000).

![Block diagram of control system for antenna azimuth position.](image)

**2. Modelling of System in MATLAB/Simulink**

As aforementioned system for controlling the position of telescope antenna comprises of two potentiometers one is utilized at input and one at output as transducer, a power amplifier, a preamplifier, a load and a motor. Fig. 6, shows the comprehensive block diagram of the system for controlling the position of antenna.

![System for controlling the position of antenna detailed block diagram.](image)

Motor and load have transfer function as

\[
\frac{\Phi_m(s)}{E_a(s)} = \frac{K_m}{s(s + a_m)}
\]

(1)

By using gears the damping and the inertial components of the system can be modified as
In the above equation, \( N_1 \) and \( N_2 \) represent the gear teeth as shown in Fig. 3. The calculation of inertial and damping components is given as

\[
J = J_a + J_L(K_e)^2 = 0.02 + 1(0.1)^2 = 0.03
\]

\[
D_m = D_a + D_L(K_e)^2 = 0.01 + 1(0.1)^2 = 0.02
\]

Motor and load block’s pole and zero is represented as

\[
a_m = \frac{D_m}{J_{R_a}} K_b K_t = \frac{(0.02)(8) + (0.5)(0.5)}{(0.03)(8)} \geq 1.71
\]

\[
K_m = \frac{K_{L_a}}{J_{R_a}} = \frac{0.5}{(0.03)(8)} \geq 2.083
\]

In the above equations, \( R_a \) is the resistance (\( \Omega \)) of the motor, \( K_b \) and \( K_t \) are the back EMF and torque constant of the motor respectively. Parameters for preamplifier, power amplifier and gears of above block diagram are given in Table 1.

<table>
<thead>
<tr>
<th>Parameters of Antenna Block Diagram</th>
<th>Parameters</th>
<th>Configurations</th>
</tr>
</thead>
<tbody>
<tr>
<td>( K )</td>
<td>( \ldots )</td>
<td>( \ldots )</td>
</tr>
<tr>
<td>( K_{pot} )</td>
<td>0.318</td>
<td>( \ldots )</td>
</tr>
<tr>
<td>( a )</td>
<td>100</td>
<td>( \ldots )</td>
</tr>
<tr>
<td>( K_f )</td>
<td>100</td>
<td>( \ldots )</td>
</tr>
<tr>
<td>( K_g )</td>
<td>0.1</td>
<td>( \ldots )</td>
</tr>
</tbody>
</table>

In Table 1, gain value “\( K \)” represents the preamplifier block. The value of preamplifier gain “\( K \)” can be found out for stable system by utilizing the Routh-Herwitz criterion. According to this criterion, system will give stable response if we take the value of gain “\( K \)” in the range 0-262.3. Here, the value of gain taken is 100 which is in the above mentioned range.

The close loop transfer function of system for controlling the position of antenna azimuth (Nise, 2000) is provided as

\[
\frac{\theta_o(s)}{\theta_i(s)} = \frac{6.63K}{s^3 + 101.71s^2 + 171s + 6.63K}
\]

If we use the value of gain “\( K \)” as we have find by using Routh-Herwitz criterion. Then, the equation in (7) can be written as
Now we can represent the state space of our close loop transfer function. First time Kalman represent the state space in 1959 (Kalman, 1960) and this step gives a new concept in world to control the systems and later concept named as “modern control theory”. State of close loop transfer function of azimuth position control of antenna is represented as

\[
\frac{\theta_2(s)}{\theta_1(s)} = \frac{663}{s^3 + 101.71s^2 + 171s + 663}
\]

(8)

We can find the response of control system of antenna azimuth position by using close-loop transfer function given in (8). But first we find open loop response then move towards close loop response. For open loop response of control system of antenna azimuth position we need a transfer function without feedback in which we will deal with a power amplifier and a motor with load which is given as

\[
G(s) = \frac{20.83}{s^2 + 101.71s + 171}
\]

(9)

Fig. 7, shows the open loop step and impulse response of the system for controlling the azimuth position of telescope antenna. We have got an idea that this resultant response is not good. Open loop response does not give us desired response. So, for getting desired response we will use close loop system. Close loop system will provide us a good and stable response.
Fig. 7 – Open Loop Response.

Fig. 8, shows the close loop step and impulse response of the system for controlling the position of telescope antenna. As we discuss earlier that close loop system provide us a good response. By comparing with open loop response we have got an idea that the close loop response is better than open loop but for our system this response is not good. This response is without any controller. For getting more stable response we will use a controller in the next section.

Fig. 8 – Close Loop Response.
Poles and zeros of the system can be found out by using MATLAB and we can draw them on the complex plane.

Fig. 9, shows the poles and zeros map of the system by using MATLAB. In the complex plane graph, red crosses show the poles location of the azimuth position control process of antenna. There is no zero in this system that’s why no circle located on the complex plane for zero representation.

Now, we move forward and find the root locus of azimuth position control process of antenna by using MATLAB. Evans provides the root locus investigation in 1948 (Evans, 1948) which was a big contribution in the field of linear feedback control systems.

Fig. 10, shows the root locus of the antenna position control system in azimuth angle. Due to absent of zero all poles approaches to infinity.
Control system azimuth position of antenna can also be implemented by using Simulink. Fig. 11, shows the Simulink representation of control system antenna azimuth position.

![Simulink representation of control system of antenna azimuth position]

It gives the same response of system as shown in Fig. 08. System have 10 sec settling time and overshoot about 35%. Little oscillations also present in the system response.

3. Response of the System by Using PID Controller

In general use, the proportional integral differential (PID) controller (Franklin et. al., 2002; Kamen, 1999) is possibly the very common controller. Numerous programmable logic controllers (PLC’s) support a kind of processes with this structure; for example, pressure, flow rate, position controlling in azimuth antenna and force loops are applied using PID controller. PID controller simplified by placing one or two values from the three gains to zero. For example, if the differential (’D’) gain set to none then PID controller reduces to a simple PI controller. Control system design problems were first proposed by Minorsky (1922), where the PID controller was first formulated. Functional algorithms for PID controller offered by Ziegler and Nichols (1942) still using in the practice of control engineering. Fig. 12, shows the implementation of the position control system antenna azimuth using Simulink.

![Implementation of System Using PID Controller]
By using PID, the close loop transfer function of position control system of antenna azimuth is expressed as

$$\frac{\theta_s(s)}{\theta_i(s)} = \frac{663K_d s^2 + 663K_p s + 663K_i}{s^4 + 101.71s^3 + (171 + 663K_d)s^2 + 663K_p s + 663K_i}$$  \hspace{1cm} (10)$$

By assuming the values $K_p=16$, $K_d=5$ and $K_i=2$ provides the most stable response of position control system of antenna azimuth. Fig. 13, shows the close loop response of position control system of radio telescope antenna azimuth by using the PID controller.

For getting best response of position control system of antenna azimuth we must have to use a controller which is PID that we have used here. This is one of the best controllers as we have seen here gives us better results. Antenna response by using PID controller is more stable as shown in Fig. 13 than the response without PID controller as shown in Fig. 8. Here, Fig. 14, shows the bode plot of the position control system of antenna azimuth.

Fig. 13 – Response of Position Control System of Antenna Azimuth by using PID Controller.

Fig. 14 – Bode Plot of Position Control System of Antenna Azimuth.
4. Response of the System by Using LQR Controller

Linear Quadratic Regulator (LQR) is one of the modern controllers nowadays. It uses state space approach to analyse and controlling of such type of systems. It is very simple to work with multi output system by using state space method.

The results of the PID Controller are enhanced considering the disturbance in the system, the use of LQR controller is necessary. In this section we have designed the observer and after that implemented with the LQR controller.

The linear quadratic regulator is implemented on the given system matrices A,B,C and D. we have designed the observer in which the eigen values of the observer are kept twice or thrice the eigen values of Ac, which represents close loop matrix of the system. We have defined Q and R matrices for the regulator design and K is the gain matrix.

\[ Q = C^T C \]
\[ R = 1 \]
\[ [K, P, E] = \text{lqr}(A, B, Q, R) \]
\[ K = [1.5190 \quad 16.6030 \quad 27.4624] \]

After that we have implemented the pole placement method for better response of the system using Matlab commands. For observer the L need to be nxp matrix where n represents dimension of x and p represent direction of y.

\[ \text{Lam} = [1 \times 1.0 \times 10^2 \times (-1.07) \quad 4 \times 1.0 \times 10^2 \times (-0.083 - 0.02i) \]
\[ \quad 4 \times 1.0 \times 10^2 \times (-0.083 + 0.02i)] \]
\[ L = \text{place}(A', C', \text{Lam}) \]

The following graph shows the observer design response.

![Graph](image)

Fig. 15 – Response of Position Control System without LQR Controller.
The composite system response is shown in the Fig. 16, for which we have taken the following matrices,

\[
A_H = [A -B*K; L*C A-B*K-L*C]
\]
\[
B_H = [B; B]
\]
\[
C_H = [C \ 0 \ 0 \ 0]
\]
\[
D_H = [0]
\]

The results are plotted in the graph shown below using LQR Regulator

Fig. 16 – Response of Position Control System of Antenna Azimuth by using LQR Controller.

5. Conclusions

Here, we have controlled the azimuth position of the radio telescope antenna by designing in MATLAB/Simulink. Firstly, we have found the response without using any controller and notice that the response is not good. After that, we have implemented our response by using PID controller and we have got an idea that the response is much better than the response without controller. After wards due to presence of disturbance in the system the response gets worst, which is further improved by using advanced control of Linear Quadratic Regulator. There are many controllers that we can use for getting better response of any system which is under observations.

6. Future Work

In the future, we can implement it by using robust control design which can cater the disturbance better making the system more efficient and stable. Moreover work can be done by using different parameters to implement this radio telescope antenna azimuth position control system for getting improved results.
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REFERENCES


PROIECTAREA ŞI ANALIZA ÎN MEDIUL MATLAB/SIMULINK A UNUI SISTEM DE CONTROL AL AZIMUTULUI UNUI RADIOTELESCOP FOLOSIND REGULATOARE PID & LQR

(Rezumat)

Un sistem de control al poziției convertește o comandă generată de o poziție de intrare într-o poziție de ieșire. Radiotelescoapele, unitățile de stocare dintr-un calculator și brațele robotizate conțin multe aplicații ale sistemului de control al poziției. În această lucrare se evaluatează o arhitectură proiectată pentru controlul azimutului unui radiotelescop. Răspunsul sistemului este analizat, rezultatele fiind obținute în urma utilizării unui regulator PID. Aceste rezultatele sunt îmbunătățite prin adăugarea unui regulator LQ. Evaluarea performanțelor relevă rezultate mult mai bune pentru abordarea bazată pe LQ decât rezultatele obținute de abordarea PID.