Research on ship-borne UXB antenna servo system based on LQG controller

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Abstract. Linear Quadratic Gaussian optimal control which is namely LQG control algorithm, is superior to PI control algorithms in control performance, such as adjusting time and overshoot. In closed-loop system, LQG has good anti-interference ability and stability. In order to reduce the pointing error and tracking error, to ensure the direction accuracy and tracking accuracy of the ship borne UXB antenna, the LQG controller is designed and the mathematical model is set up. Finally, using MATLAB software to build a model and the simulation experiment is carried out by based on the designed LQG controller.

1. Introduction

With the development of deep space exploration, the antenna beam is getting narrower and narrower. Compared with the USB and UCB antenna, the UXB antenna puts forward higher requirements for the pointing precision and tracking precision of the servo system. At present, the antenna servo control system of domestic land station adopts PID control algorithm. The traditional PID controller has many advantages, such as simple structure and design without considering the dynamic performance of the antenna. So it is widely used in the field of control. However the ship-borne UXB antenna is affected by the ship-sway and the gust of the outside, the control effect of the traditional PID controller has been difficult to meet the requirement of the direction precision of the UXB antenna.

Linear Quadratic Gauss control algorithm is the optimal control strategy established under the linear two-order Gauss optimal control state space model. The LQG controller consists of the optimal feedback gain controller and the Kalman filter for the system which has a good performance in industry. Compared with the PI controller, the LQG controller has better anti-interference ability and can significantly improve the tracking precision of the antenna under the ship-sway interference.

2. Design of THE LQG optimal controller

LQG control is stochastic optimal control under the effect of white noise disturbance of Gauss distribution. According to the principle of separation, this algorithm can be decomposed into 2 aspects, namely linear quadratic optimal control and Kalman filter.

2.1 Design of linear quadratic optimal control (LQR).

It is assumed that the state equation of a discrete linear constant system is as follows:

$$x(k+1) = Ax(k) + Bu(k) \qquad (1)$$

$$y(k) = Cx(k) \qquad (2)$$

In the form, A is a matrix of $n \times n$ system, B is a $n \times p$ control matrix, C is a $q \times n$ observation matrix, $x(k)$ is a n dimensional state vector, $u(k)$ is a p dimension input vector, $y(k)$ is a q dimension output vector.

It is required to seek the control vector $u^*(t)$ to make the quadratic form object function minimum:

$$J = \tfrac{1}{2}\sum_0^N[x^T(k)Qx(k) + u^T(k)Ru(k)] \tag{3}$$

In the form, Q is a semi-positive definite symmetric constant matrix; R is a positive definite real symmetric constant matrix.

Using the method of Lagrange multipliers, the optimal control law can be derived:

$$u^*(k) = -R^{-1}B^TA^T[S(k) - Q]x(k) = -K(k)x(k) \tag{4}$$

In the form, K is the optimal feedback gain matrix, $S(k)$ must satisfy the Riccati difference equation:

$$S(k) = Q + A^TS(k+1)[I + BR^{-1}B^TS(k+1)]^{-1}A \tag{5}$$

Therefore, the design of the LQR controller is attributed to the problem of solving the Riccati equation, and find the optimal feedback gain matrix K.

Based on the accumulation of equipment data, the input and output relationship is as follows:

$$x(k+1) = \begin{bmatrix} 1.708 & 0 & 1 & 0 \\ -0.7349 & 0 & 1 & 0 \\ -0.0375 & 0 & 0 & 1 \\ 0.04807 & 0 & 0 & 0 \end{bmatrix}x(k) + \begin{bmatrix} 0.8604 \\ -1.718 \\ 1.119 \\ -0.2484 \end{bmatrix}u(k) + \begin{bmatrix} 0.117 \\ -0.8362 \\ 1.3505 \\ -0.563 \end{bmatrix}w(k) \tag{6}$$

$$y(k) = [1 \quad 0 \quad 0 \quad 0]x(k) + v(k) \tag{7}$$

Select $Q = \text{diag}[10,1,1,1]$, $R = 4$. Using the dlqr（A, B, Q, R） functions of MATLAB, calculate the gain matrix $K_u = [0.7786 \quad 0.4726 \quad 0.03914 \quad 0.1069]$.

2.2 The design of Kalman filter

For the stochastic control system, the system is disturbed by the process disturbance and the output noise, the observed data is inaccurate due to the influence of random disturbance and output measurement noise. So the state of the system must be reconstructed. Obtaining real and useful data from signals or data contaminated by random disturbance and noise will be accomplished by the Kalman filter.

It is assumed that the discrete state equation of the control object model is as follows:

$$x(k+1) = Ax(k) + Bu(k) + Gw(k) \tag{8}$$

$$y(k) = Cx(k) \tag{9}$$

In the form, $w(t)$、$v(t)$ are white noise signals, $w(t)$ is system interfering noise, $v(t)$ is system measurement noise, G is a noise gain array.

$$E\{w(k)\} = E\{v(k)\} = 0 \tag{10}$$

$$E\{w(k)w(k)^T\} = Q \tag{11}$$

$$E\{v(k)v(k)^T\} = R \tag{12}$$

The state of the estimate is expressed in $x(k|k)$, the covariance $p(k|k)$ of the estimated state is defined as:

$$p(k|k) = E\{[x(k) - x(k|k)][x(k) - x(k|k)]^T\} \tag{13}$$

The estimated value of the state variable $x(k)$ is obtained when the covariance is minimization. The algorithm for the cyclic estimation of the state variable $x(k)$ is as follows:

$$x(k|k-1) = Ax(k-1|k-1) + Bx(k) \tag{14}$$

Calculating the error variance of the predicted state $p(k|k-1)$:

$$p(k|k-1) = Ap(k|k-1)A^T + GQG_1^T \tag{15}$$

The calculation method of filter gain matrix $K_f(k)$:

$$K_f(k) = p(k|k-1)C^T[Cp(k|k-1)C^T + R]^{-1} \tag{16}$$

The variance of calculation error of filter estimation $p(k|k)$:

$$p(k|k) = [I - K_f(k)C]p(k|k-1) \tag{17}$$

There is no disturbance and noise in the system that composed of the States predicted by the Kalman optimal estimator.

Select $Q = 1$, $R = 1$. By using the discrete Kalman recursive formula, the convergent filter feedback gain can be obtained:

$$K_f = [-1.591 \quad -0.1013 \quad 1.388 \quad -0.6111]^T \qquad (18)$$

3. Simulation experiment

By using MATLAB to build a model for the loop of a ship-borne UXB servo system, design the PID controller and the LQG controller respectively. According to the design of the LQG controller, the position loop simulation model based on the LQG controller can be completed, as shown in Figure 1.
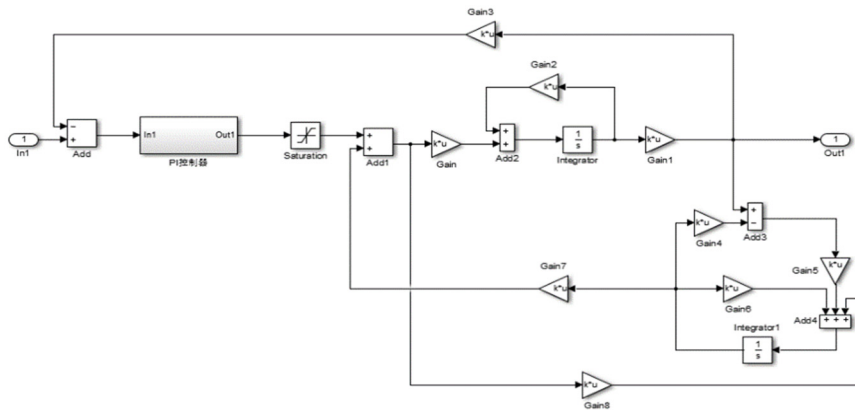

Fig. 1. Position loop model of LQG controller

According to the existing equipment, the position loop based on PID controller is simulated, as shown in Figure 2.
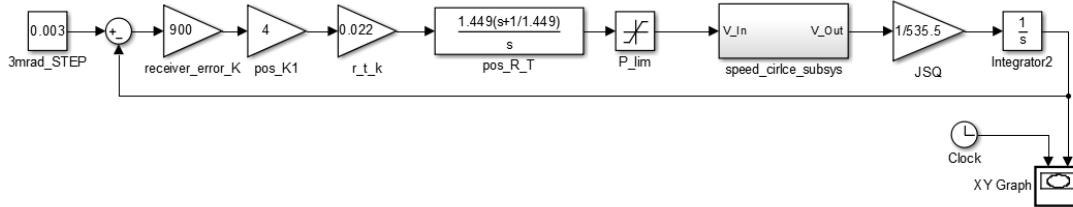

Fig. 2. Position loop model of PID controller.

The step test is carried out on the position loop model of PID controller and LQG controller separately.

Table 1. Performance comparison

Controller	Adjusting time	Overshoot	Bandwidth
LQG	0.7	0	4
PID	1.3	12%	1.77

After proper overshoot, the step response of the LQG controller eliminates the error according to the optimal curve. It fully shows the superior performance of the optimal control.

4. The conclusion

By analyzing the working principle of LQG controller, the linear quadratic optimal control and Kalman filter are designed respectively. According to the parameters of the ship's UXB antenna servo system, adjust LQR controller and Kalman filter. By using MATLAB simulation, the position loop of servo system based on PID controller and LQG controller is set up respectively. Through

testing, it is proved that the dynamic performance of the LQG controller is far superior to the PID controller.

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