Study on the Simulation of the APT Rough Tracing System Based on the Predictive Control Technology

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Abstract

Laser space offers an attractive alternative in the military fields for its many advantages of wide bandwidth, high code rate, low power consumption and large capacity. Because the narrow laser beam will lead to many challenges in laser beam pointing, therefore, APT (acquisition, pointing and tracking) technology is one of key technology for the laser space communication. The ATP rough tracing servo turntable studied in this paper adopts two-axes-four-frame structure. In order to increase the tracking precision, the predictive control algorithm is adopted in the rough tracking position loop. The simulation result shows that, comparing with common PI controller, the predictive control algorithm could improve the dynamic response characteristics of the system and increase the tracking precision.

Keywords: Laser space communication, Rough tracing, Predictive control technology

1. Introduction

APT system generally needs higher acquiring scope and control accuracy. Therefore, it usually adopts compound axis structure. The rough tracing system should have large dynamic scope, narrow control bandwidth and low resonance frequency. It mainly carries out the optic axis's initial pointing and realizes acquiring and rough tracing. The position loop of rough tracing system usually adopts PI control algorithm or lag-leading control algorithm. The fractional order control algorithm was also used in the APT rough tracing system and achieved good control effect. In this paper, the dynamic matrix control (DMC) algorithm will be used into rough tracing system to improve the dynamic response characteristics of the rough tracing system (Hu, 2005; Toyoda Masahiro, 2006; Liu, 2006; Shinhak Lee).

2. Components of the APT System and Control Requirements

The components of the compound axis APT system are shown in Figure 1, and the rough tracking system is composed by the gimbals servo turntable and the rough tracking CCD. The main components of the fine tracing system are the fast steering mirror and the fine tracing detector, and the fine tracing system could further correct the residual error which could not be compensated by the coarse tracing loop, to satisfy the aiming and tracing accuracy required by the system.

The sample period of the rough tracking system is 0.02S. The overshoot should be lower than 20%. The cut-off frequency should be lower than 5.8Hz according to the relation of sample period, cut-off frequency and overshoot. The bandwidth of the rough tracking system should be lower than 10Hz. In order to reduce the time delay of motor, broaden the speed regulation scope, restrain the influence of moment of force fluctuation and avoid the resonance of position loop and speed loop, the bandwidth of speed loop should be more than 3 times the bandwidth of speed loop of position loop (Tzung-Hsien Ho, 2005; Tong Luo, 2002; Shinhak Lee, 2000).

3. Design of Speed Loop of Rough Tracking System

From Figure 1, the rough tracking system is composed by the speed loop and the position loop.

The mathematical model of the speed loop is

$$W_m(s) = \frac{1/K_b}{(T_m s + 1)(T_e s + 1)} = \frac{0.1483}{(1 + 3s)(1 + 0.0031s)} \tag{1}$$

To make the compensated speed loop satisfy the bandwidth requirement, the cut-off frequency of the compensated speed loop is $\omega_c = 100 rad/s$, and the compensation system of the speed loop designed by adopting the frequency characteristic method of the classical control theory is

$$G_c(s) = \frac{4046(0.01s+1)(0.0031s+1)}{(0.02s+1)(0.002s+1)} \tag{2}$$

The step response of the compensated speed loop is shown in Figure 2. The open loop and closed loop frequency characteristic of compensated speed loop is shown in Figure 3 and Figure 4. From which we can see that the overshoot of speed loop is 17%, the settling time is 0.09S, the phase margin is 59.7^0, the bandwidth is $168 rad/s \approx 26.8 Hz$. It can satisfy the requirements of the rough tracking system.

According to the error index of the tracking system and the maximum work angle speed and the maximum acceleration of the system, the open loop gain required by the system can be confirmed by K=2000.

The uncompensated transfer function of the position loop is

$$P_0(s) = \frac{2000(6s+600)}{s(0.0001s^3 + 0.066s^2 + 8.02s + 601)} \tag{3}$$

4. Design of Position Loop of Rough Tracking System Based on Predictive Control Technology

In the designing procedure of predictive control algorithm, the predictive model is established according to the features of controlled process. The future output of system can be predicted by the predictive model. Then adopting the optimization and feedback compensation, one optimal control series can be determined by optimal calculating for one performance index. In essence, prediction control take the cost of using part optimizing instead of global optimizing, take account of producing reality by feedback and optimizing. So the control effect of prediction control is between optimizing control and PID control (Phillip D. Schnelle, 1997; Wang, 2002; Endra Joeliant, 2011).

4.1 Establish the Predictive Model of Rough Tracking System

The predictive model of rough tracking system is (Chen Qiao, 2009)

$$Y_m(k+1) = G\Delta U(k) + G'U(k-1) \tag{4}$$

If consider the influence of the moment of force fluctuation, the predictive model of rough tracking system is

$$Y_m(k+1) = (G+\Delta G)\Delta U(k) + (G'+\Delta G')U(k-1) \tag{5}$$

In the above two expressions:

$Y_m(k)$ is the output matrix of predictive mode of future P sample periods, G is dynamic matrix, U(K) is controlling amount matrix, Δ U(K) is the increment of controlling amount matrix, Δ G is system parameter uncertainty. N is model length, M is control time domain, P is optimization time domain, $g_i(i=1,2,\cdots N)$ is the amplitude of impulse response in sampling moment.

$$Y_m(k+1) = [y_m(k+1/k), y_m(k+2/k), \cdots y_m(k+p/k)]^T \tag{6}$$

$$G = \begin{bmatrix} g_1 & 0 & \cdots & 0 \\ g_2 & g_1 & \cdots & \vdots \\ \vdots & \vdots & \vdots & 0 \\ g_p & g_{p-1} & \cdots & g_{p-m+1} \end{bmatrix}_{P\times M} \tag{7}$$

$$G' = \begin{bmatrix} g_n - g_{n-1} & g_{n-1} - g_{n-2} & \cdots & g_3 - g_2 & g_2 \\ 0 & g_n - g_{n-1} & \cdots & g_4 - g_3 & g_3 \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ 0 & 0 & g_n - g_{n-1} & \cdots & g_{p+1} \end{bmatrix}_{P \times N} \tag{8}$$

$$\Delta G = \begin{bmatrix} \Delta g_1 & 0 & \cdots & 0 \\ \Delta g_2 & \Delta g_1 & \cdots & \vdots \\ \vdots & \vdots & \ddots & 0 \\ \Delta g_p & \Delta g_{p-1} & \cdots & \Delta g_{p-m+1} \end{bmatrix}_{P \times M} \tag{9}$$

$$\Delta G' = \begin{bmatrix} \Delta g_n - \Delta g_{n-1} & \Delta g_{n-1} - \Delta g_{n-2} & \cdots & \Delta g_3 - \Delta g_2 & \Delta g_2 \\ 0 & \Delta g_n - \Delta g_{n-1} & \cdots & \Delta g_4 - \Delta g_3 & \Delta g_3 \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ 0 & 0 & \Delta g_n - \Delta g_{n-1} & \cdots & \Delta g_{p+1} \end{bmatrix}_{P \times N} \tag{10}$$

4.2 Feedback Compensation

Because the system has various disturbances, so the predictive should be corrected. If y(k) is the real output of the rough tracking system, e(k) is the error of predictive model, then

$$e(k) = y(k) - y_m(k) \tag{11}$$

The predictive output can be corrected by error weight matrix h, and then the predictive output can be expressed as

$$Y_p(k+1) = Y_m(k+1) + he(k) = (G + \Delta G)\Delta U(k) + (G' + \Delta G')U(k-1) + he(k) \tag{12}$$

In the above expression:

$$Y_p(k+1) = [y_p(k+1), y_p(k+2), \cdots y_p(k+p)]^T \tag{13}$$

$$h = \begin{bmatrix} h_1(k) & h_2(k) & \cdots & h_p(k) \end{bmatrix} \tag{14}$$

4.3 Optimization Design

By comparing the real output of the rough tracking system and the predictive output after feedback compensation, the quadratic form optimum performance index of predictive error can be expressed as

$$J_P(k) = [Y_m(k+1) - Y_r(k+1)]^T Q[Y_m(k+1) - Y_r(k+1)] + \Delta U^T(k)R\Delta U(k) \tag{15}$$

In the above expression, Q is predictive output error weight matrix, R is controlling amount weight matrix.

4.4 Simulation of the APT Rough Tracing Subsystem Based on Predictive Control

Let the sample period T_s is 0.02S, P=5, M=5, N=20, Q and R is unit matrix. $h = \begin{bmatrix} 1 & 0.2 & \cdots & 0.2 \end{bmatrix}_{N \times 1}^T$, $\Delta G = 0.1G$.

According to the transfer function of the uncompensated rough tracking system, the dynamic matrix can be determined as

$$G = \begin{bmatrix} 192.9542 & 0 & 0 & 0 & 0 \\ 392.6568 & 192.9542 & 0 & 0 & 0 \\ 592.3239 & 392.6568 & 192.9542 & 0 & 0 \\ 791.9912 & 592.3239 & 392.6568 & 192.9542 & 0 \\ 991.6584 & 791.9912 & 592.3239 & 392.6568 & 192.9542 \end{bmatrix} \tag{16}$$

$$\Delta G = \begin{bmatrix} 19.29542 & 0 & 0 & 0 & 0 \\ 39.26568 & 19.29542 & 0 & 0 & 0 \\ 59.23239 & 39.26568 & 19.29542 & 0 & 0 \\ 79.19912 & 59.23239 & 39.26568 & 19.29542 & 0 \\ 99.16584 & 79.19912 & 59.23239 & 39.26568 & 19.29542 \end{bmatrix} \tag{17}$$

We can obtain the predictive error is

$$e = \begin{bmatrix} 0.0000 \\ -0.5664 \\ -1.1245 \\ -1.2597 \\ -1.1200 \end{bmatrix} \tag{18}$$

The step response of the rough tracking system based on predictive control is shown in Figure 5, and the system overshoot of the system is $\sigma_P = 14\%$, the settling time is 0.9S, and the steady-state error of the system is 1.6877e-007. The closed loop frequency characteristic of the position loop is seen in Figure 6, and the bandwidth of the position loop is 46.8 rad/s (7.45 Hz), which could satisfy the bandwidth requirement of the APT system for the rough tracing subsystem.

In order discuss the influence of system parameter uncertainty, separately let $\Delta G=0.1G$, $\Delta G=0.3G$, $\Delta G=0.5G$, the step response of system is shown in Figure 7, from which we can see that the larger the ΔG is, the longer the settling time, the larger the overshoot is, the poorer the system performance is.

5. Conclusions

In the design of the algorithm of the rough tracking system, in order to overcome the deficiency that the traditional PID and enhance the tracking precision of the rough tracking system, the dynamic matrix control algorithm is used into the rough tracing system. Simulation result shows that the rough tracing system has good dynamic response characteristics. It can satisfy the requirements of the APT system for the rough tracing subsystem.

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Figure 1. Block Diagram of APT System

Figure 2. Step Response of Compensated Speed Loop

Figure 3. Open Loop Frequency Characteristic of Compensated Speed Loop

Figure 4. Closed Loop Frequency Characteristic of the Compensated speed Loop

Figure 5. Step Response of Position Loop Based on Predictive Control

Figure 6. Closed Loop Frequency Characteristic of the Compensated Position Loop

Figure 7. Step Response of Position Loop for Different ΔG