Predictive Function Control of 6 Degree-of-Freedom Platform System Based on Modal Space Coordinate Transformation

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Keywords: Predictive Function Control, Modal Space, 6 Degree-of-Freedom Platform

Abstract: For its high load carrying capacity, good dynamic performance and precise positioning, the electro-hydraulic 6 degree-of-freedom platform becomes more and more popular in field of motion simulator, and so on. But limited by the order of the transfer function, conventional proportional plus dynamic pressure feedback control does not produce better control results, for step signals. Due to the advantages of good control effect and relatively simple process, predictive function control has been well applied with the development of computer technology. Based on the above, a predictive function control algorithm based on modal space coordinate transformation is proposed in this paper. First, the transfer function of the platform in the modal space coordinates is transformed into the form of the state space, then predictive function control algorithm is designed for the independent state space equation previously obtained. Simulation results show that predictive function control produces better control effect.

1. Introduction

6 degree-of-freedom platform is essentially a complex nonlinear time-varying system. Because of its complex structure and dynamic coupling, how to improve its dynamic characteristics has always been an important research direction. Combined with dynamic pressure feedback technology, a modal space control strategy suitable for hydraulic driven 6 degree-of-freedom motion simulator is proposed by Jiang [1]. This method maps the control and feedback variables of the joint space to the modal space, therefore every degree of freedom can be individually controlled and adjusted. Simulation results show that the modal space controller has better control performance in almost all aspects compared with the traditional PID controller. However, for simple step signals, the conventional proportional plus dynamic pressure feedback control is limited by the parameter acquisition of the dynamic pressure feedback and the basic form of the transfer function. With the development of computer control technology, the potential of state-space-based control methods has been released [2, 3]. A modal space based predictive function control algorithm for the dynamic characteristics of the 6 degree-of-freedom platform is proposed in this paper. The predictive function control produces better control results, comparing with the proportional plus dynamic pressure feedback control.

2. Predictive function control based on modal space coordinate transformation

2.1 Introduction to predictive function control

Predictive function control is the third generation model predictive control algorithm. This control method has structured control inputs, that is, the control input at each time is regarded as a linear combination of a number of previously selected base functions. The solution method of the linear combination coefficient of the base function is to select some fitting points in the time domain, so that the output of the prediction process is closest to the corresponding value of the reference trajectory that is intended to track at these fitting points. First, the linear coefficient is obtained through online optimization, and then the control input can be calculated. In predictive function control, the structure of control input is often regarded as a key issue that affects the system performance. Usually the reference trajectory is in first-order exponential form as [4]:

$$y_r(k+i) = c(k+i) - \beta^i \left[c(k) - y_p(k) \right], 0 \le i \le P \quad (1)$$

Where $y_r(k+i)$ is the reference trajectory of the time $k+i$, $c(k+i)$ and $c(k)$ are the tracking value of the time $k+i$ and k, β is the attenuation coefficient, $\beta = \exp(-T_s/T_r)$, T_r is the expected closed-loop response time of the reference trajectory, and $y_p(k)$ is the actual output value of the process at the time k.

In order to make convenient calculation and the control more effective, a discrete state space model is often used, as the model of the predictive function control algorithm. The prediction model of a single-input single-output system is:

$$\begin{cases} X_m(k) = A_m X_m(k-1) + B_m u(k-1) \\ y_m(k) = C_m X_m(k) \end{cases} \quad (2)$$

Where $X_m(k)$ is the state vector of the prediction model, $y_m(k)$ is the output of the prediction model, $u(k-1)$ is the control input of the system, A_m, B_m and C_m are the coefficient matrices of the prediction model.

Recursively, the calculated output of the model at the time $k+i$ is:

$$y_m(k+i) = C_m A_m^i X_m(k) + \mu(k)^T g_k(i) \quad (3)$$

In the formula, $g_k(i) = \left[g_{k1}(i), g_{k2}(i), \cdots, g_{kN}(i) \right]^T$ represents the predictive control process, which is related to the prediction model of state space, $\mu(k)^T g_k(i)$ is the function output of the model and $C_m A_m^i X_m(k)$ is the free output of the model.

Generally, the optimization is usually selected, so that the squared sum of the difference between the process prediction output and the reference trajectory value at each fitting point in the prediction time domain is minimized:

$$J(k) = \sum_{i=1}^{n_s} \left[y_p(k+h_i) - y_r(k+h_i) \right]^2 \quad (4)$$

2.2 Predictive function control based on modal space coordinates transformation

Generally, predictive function control can achieve better results. However, for 6 degree-of-freedom platform, it is very difficult to obtain parameters that need to be calculated due to the high coupling of the dynamic, so as for a certain degree of freedom of the platform. For multi-degree-of-freedom, it will be even more. By using modal space coordinate transformation, the system is decomposed into six independent third-order systems along the modal direction. Which includes an integration section and a two-order oscillation section, which is completely identical in form to the transfer function of a single system. Therefore, through the modal space coordinate transformation, the dynamic coupling characteristics of the 6 degree-of-freedom platform disappear. If predictive function controller is designed on the model of state space calculated after modal space coordinate transformation, the dynamic characteristics will be further improved. The model of the six degree of freedom platform in state space is:

$$\begin{bmatrix} \dot{l} \\ \ddot{l} \\ \dot{p}_L \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & -\sigma_i B_{act} - B_c & \sigma_i A_p \\ 0 & -CA_p & -CK_{ce} \end{bmatrix} \begin{bmatrix} l \\ \dot{l} \\ p_L \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ CK_a K_q \end{bmatrix} i_q \tag{5}$$

Where $\sigma_i = [\sigma_1 \quad \sigma_2 \quad \sigma_3 \quad \sigma_4 \quad \sigma_5 \quad \sigma_6]$.

Therefore, through the modal space coordinate transformation, the model of the six-degree-of-freedom platform becomes six independent sets of state space equations, and the predictive function controller can be designed separately to obtain the control effect.

3. Simulation and results

3.1 The establishment of simulation model

According to the modal space coordinate transformation, position and attitude signals of the platform converted into the displacement signal of the hydraulic cylinder need to be subjected to modal space coordinate transformation first， and so to the load pressure signal and the speed signal obtained by the differentiator. Then, the control signal calculated from the predictive function control should be converted to the corresponding servo valve in inverse transform. Model of prediction function control of a single modal is shown in Figure 1.

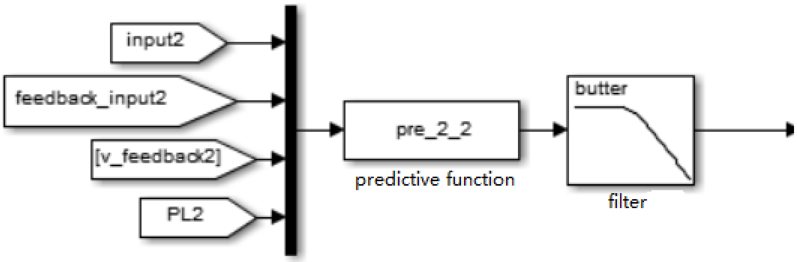

Figure 1. Model of predictive function control in single modal direction

The calculation of the parameters related to the prediction function is implemented in the form of s-function. At the same time, in order to the smoothness of the signal and to ensure the stability of the predictive function control algorithm, the signal of the predictive function is filtered. In order to verify the superiority of the model, the proportional plus dynamic pressure feedback model was set as a control group.

3.2 Analysis of the results

In order to maximize the stability of the output signal for the predictive function control, double prediction period was adopted. The parameters of the simulation model of the predictive function control and the proportional plus dynamic pressure feedback are shown in Table 1.

Table 1 Parameters of the Simulink model of the predictive function control and the proportional plus dynamic pressure feedback

Modal	Frequency/ (rad/s)	Tr/s	T1/s	T2/s	Dynamic pressure feedback coefficient	Proportional control coefficient
1	184.27	0.01	1	28	2.5e-5	10
2	184.27	0.01	1	28	2.5e-5	10
3	142.45	0.05	5	45	7.5e-6	3
4	104.51	0.015	40	60	1.125e-5	3.5
5	50.67	0.03	40	90	2.5e-6	1.5
6	50.67	0.03	40	90	2.5e-6	1.5

According to the model parameters above, set step signal as the input signal, simulation results of the predictive function control and the proportional plus dynamic pressure feedback are shown in Figure 2.

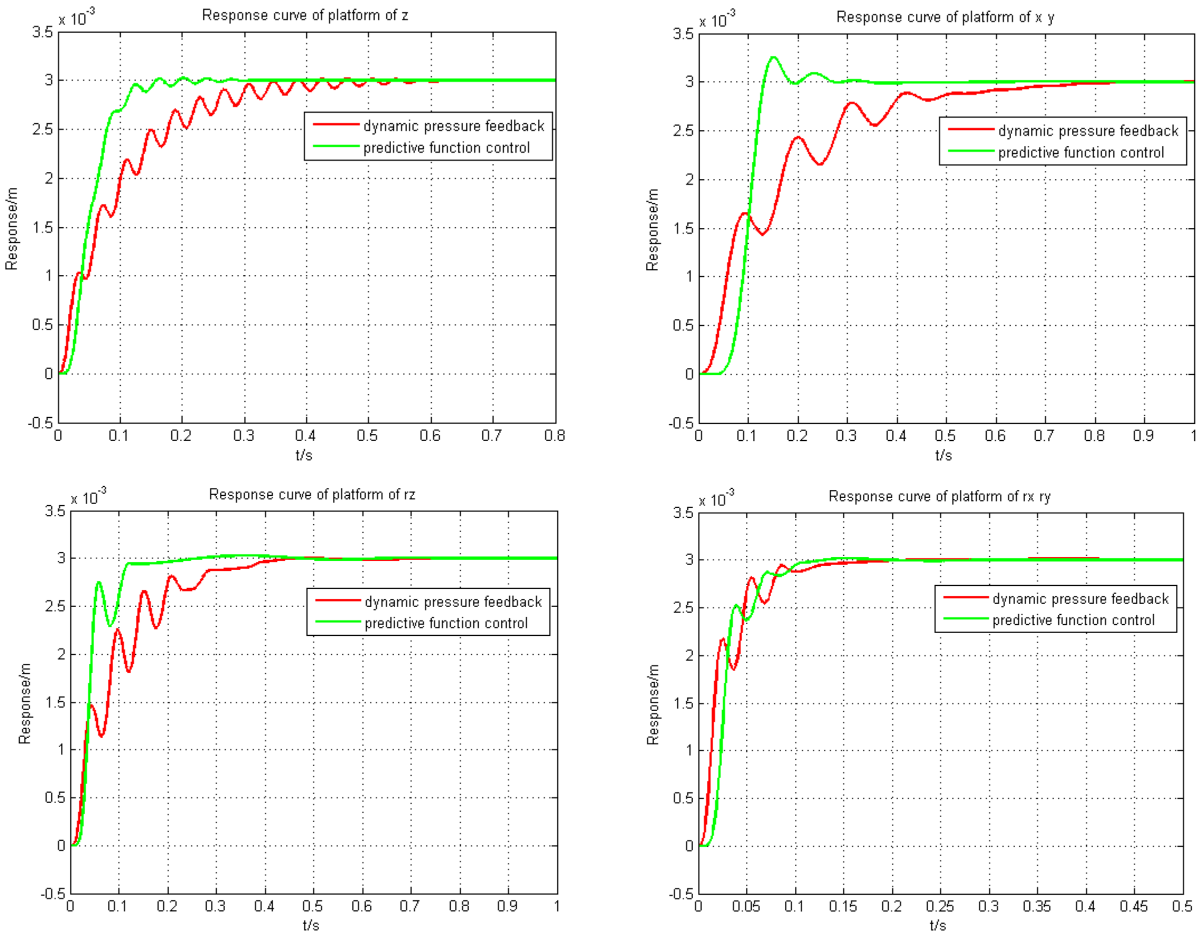

Figure 2. Response curve of proportional plus dynamic pressure feedback and predictive function control

Simulation shows that predictive function control has better results. Not only the rise time is short, but the transition process is also good, the fluctuation of the response curve is lighter. Therefore, the prediction function space has better control effect.

4. Conclusion

A modal space based predictive function control algorithm was proposed in this paper. Simulation results show that predictive function control has better results than the proportional plus dynamic pressure feedback control in all directions of freedom. Not only the rise time is short, but the transition process is also good.

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