Repetitive Control of 6 Degree-of-freedom Platform Based on Modal Space Coordinate Transformation

Chenyang Zhang[a, *], Hongzhou Jiang[b]

School of Mechatronics Engineering, Harbin Institute of Technology, Harbin, 150000, China

[a]351635594@qq.com, [b]jianghz@hit.edu.cn

*Corresponding author

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Abstract: The parallel electro-hydraulic 6 degree-of-freedom platform is widely used in the simulation of flight, navigation and vehicle driving motion. With the needs of applications, the requirements for low-speed and stable running performance and good dynamic trajectory tracking accuracy are becoming higher and higher. When the platform moves at low speed, the multi-input, multi-output strongly coupled nonlinear system and the dry friction force are the main factors that cause the platform's motion trajectory and input signals to not completely coincide. However, when the platform moves at a low speed, it can be considered that the platform moves periodically stably, and the interference also repeats periodically. Aiming at this property, a repetitive control strategy based on modal space coordinate transformation is proposed to improve the low-speed motion characteristics of the platform in this paper. First, the coupled dynamics of the six-degree-of-freedom platform is decomposed, and then a repetitive controller is designed for each independent modal direction of the transfer function. The simulation results show that repetitive control has better control effect.

1. Introduction

The parallel electro-hydraulic 6 degree-of-freedom platform is widely used in the simulation of flight, navigation and vehicle driving motion. Combined with dynamic pressure feedback technology, a modal space control strategy suitable for hydraulic driven 6 DOF 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. When the platform moves at low speed, the multi-input, multi-output strongly coupled nonlinear system and the dry friction force are the main factors that cause the platform's motion trajectory and input signals to not completely coincide. However, when the six-degree-of-freedom platform moves at a low speed, it can be considered that the platform moves stably, and the interference also repeats periodically [2]. Since modal space coordinate transformation can solve the multi-input, multi-output strongly coupled characteristics of the 6 degree-of-freedom platform. At the same time, for system with periodic motion, repetitive control is not only simple but will also produces good control results [3-4]. Based on the above, a repetitive control in the independent modal space obtained based on the modal space coordinate transformation is put forward in this paper. Simulation results show that good control effect is achieved.

2. Introduction to repetitive control and modal space coordinate transformation

2.1 Introduction to repetitive control

Repetitive control is a control theory based on the internal model control. The essence of repetitive control is to use the positive feedback to eliminate the system error with that of the previous cycle and the current error as control input. In practical applications, the structure of the plug-in repetitive control system structure shown in Figure 1 is usually adopted, where $R(s)$ is the input signal, $E(s)$ is the error signal, $D(s)$ is the disturbance signal, and $Y(s)$ is the output, $U_r(s)$ is the output of repetitive controller , $C(s)$ is the original controller and $P(s)$ is the model transfer function. The $Q(s)$ and $B(s)$ are generally called low-pass filter and dynamic compensator respectively. With the advantage that the design of the original controller and that of the repetitive control can be independent of each other, moreover, repetitive controller can be applied to the original system by only adding an section to the original controller which can be without repetitive control function previously, so this control structure has been widely used.

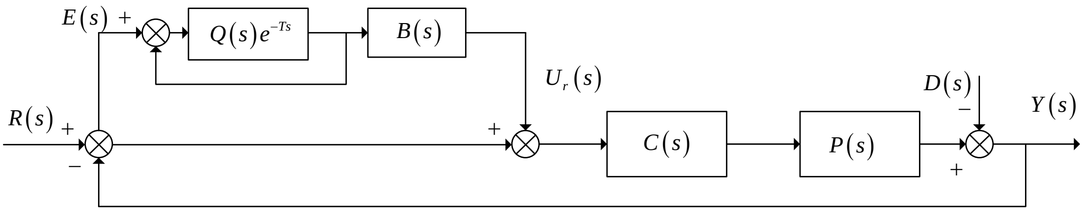

Figure 1. A plug-in repetitive control system

Generally, for $Q(s)$, a low-pass filter is often used, since filter will also cause phase lag, therefore, generally, phase advance compensation will be adopted, which should also be performed, as the dynamic compensator also cause phase lag, with τ_B and τ_Q as coefficients. In this way, the repetitive control with phase advance compensation is shown in Figure 2.

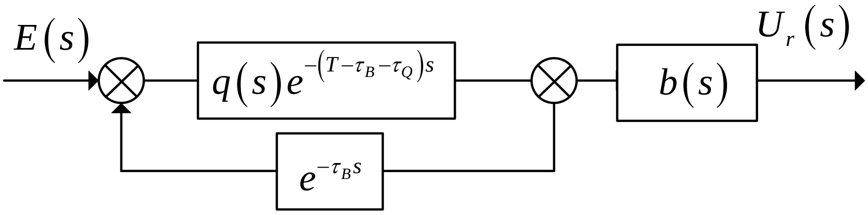

Figure 2. Repetitive controller with phase advance compensation

2.2 Modal space coordinate transformation of the 6 degree-of-freedom platform

Referring to modal space coordinate transformation, the transfer function of the 6 degree-of-freedom platform after the coordinate transformation is shown as.

$$s\left[s^2\frac{V_t}{4\beta_e A_p^2\sigma_i}+s\left(\frac{B_cV_t}{4\beta_e A_p^2\sigma_i}+\frac{K_{ce}}{A_p^2}\right)+\left(1+\frac{B_cK_{ce}}{A_p^2}\right)\right]\tilde{l}_i=K_aK_q\Sigma\tilde{i}_{u,i}\big/A_p \tag{1}$$

Where $\sigma_i=\begin{bmatrix}\sigma_1 & \sigma_2 & \sigma_3 & \sigma_4 & \sigma_5 & \sigma_6\end{bmatrix}$..

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. So when the platform move periodically, since the dry friction is only related to the direction of motion, it can be determined that the interference of the dry friction is also periodic. In this way, these interference will be eliminated by the repetitive control in different modes which obtained by modal space coordinate transformation. At the same time, due to the unit orthogonal characteristic of the modal transformation matrix, the error and phase lag caused by friction will not be reduced or enlarged.

3. Simulation and results

3.1 The establishment of simulation model

The simulation process is carried out under Matlab/Simulink as shown in Figure 3.

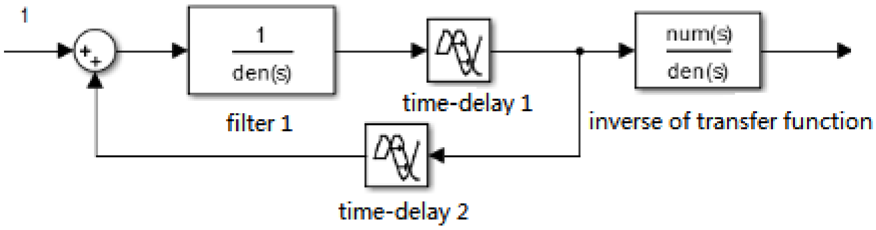

Figure 3. Repetitive controller in single modal direction

Referring to [5], Butterworth filter has a good effect on repetitive control. The time-delay block 1 is related to the lag caused by filter 1 and the period of the input signal, while the time-delay block 2 is related to the lag caused by the inverse transfer function in modal space. The input signal is set to 0.25Hz. The repetitive control parameters are set according to the transfer function of the six-degree-of-freedom platform in the modal space as shown in Table 1

Table 1 Configuration parameters of the Matlab/Simulink model of the repetitive control

Modal	Frequency/(rad/s)	time-delay 1/s	time-delay 2/s	Filter 1/(rad/s)
1	184.27	0.18	0	20
2	182.27	0.18	0	20
3	142.45	0.09	0.02	20
4	104.51	0.18	0	20
5	50.67	0.18	0	20
6	50.67	0.18	0	20

As repetitive control added, the track error of the 6-DOF platform is shown in Figure 4.

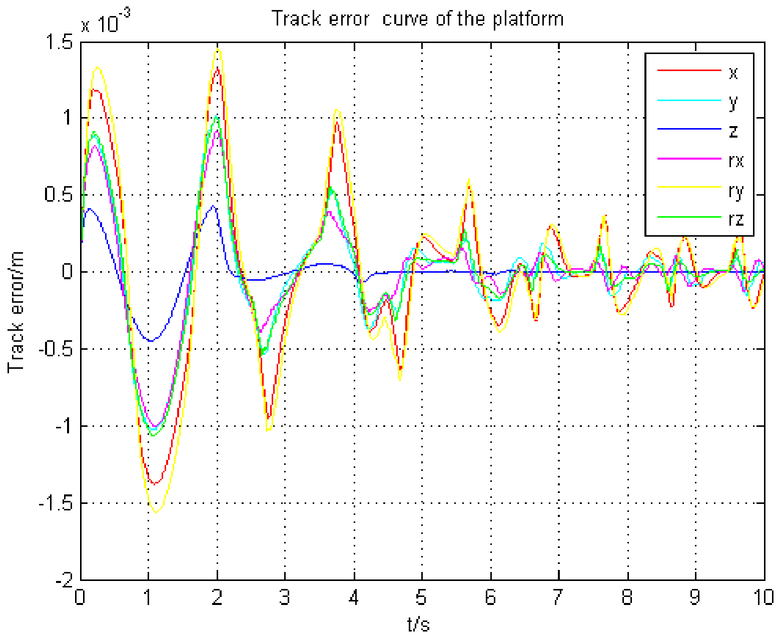

Figure 4. Track error of the 6 degree-of-freedom platform

As shown in Figure 4, repetitive control quickly reduces the error, and the deformed response of the platform due to dry friction and the transfer function is improved a lot.

4. Conclusion

When the parallel electro-hydraulic 6 degree-of-freedom platform moves at a low speed, the dry friction force and the multi-input, multi-output strongly coupled nonlinear system transfer function because certain phase lag. However, when the platform moves at a low speed, it can be considered that the platform moves periodically stably, and the interference also repeats periodically. A repetitive control algorithm in the independent modal space obtained based on the modal space coordinate transformation is put forward in this paper. In the control strategy, the repetitive control algorithm is designed in the independent modal space obtained by the modal space coordinate transformation. The simulation results show that repetitive control reduces the error quickly and the response of the platform is significantly improved.

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