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Multi-degree-of-freedom joint nonlinear motion control with considering the friction effect

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I.Introduction

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Introduction

In recent years, many scholars have done a lot of research on the model and parameter identification based on the robot dynamics.

Although the nonlinear dynamics modelingand trajectory tracking control of robots considering friction have made great progress, multi-degree-of-freedom robots for high-precision positioning requirements require a detailed analysis of the specific problem. Hence, this paper analyzes the motion and dynamic response of multi-free robots based on the demand of high motion accuracy of dulcimer service robot.

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Multi-degree-of-freedom joint nonlinear dynamic model

Construct a six-degree-of-freedom dulcimer robot model, whose expression is obtained by Lagrangian method：

$$M(q)\ddot{q}+C(q,\dot{q})\dot{q}+G(q)+f=\tau$$

Table 1 is the D-H parameter table of the dulcimer robot constructed in accordance with ergonomics after the actual measurement of the dulcimer(a is the length of the connecting rod, alpha is the angle of the connecting rod, d is the offset distance of the connecting rod, and theta is the joint angle); according to the various connecting rod and joint parameters in the table, the model of the dulcimer robot can be obtained as shown in the figure.

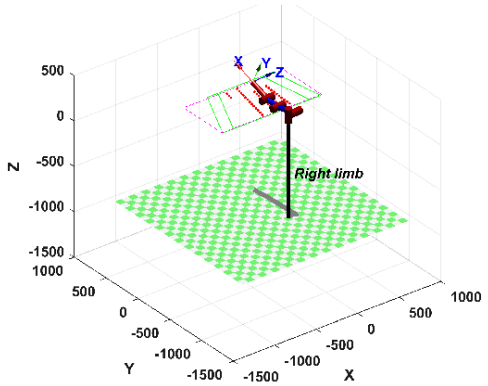

Fig. 1 Robot model

TABLE I. ROBOT D-H PARAMETER TABLE

Joint	theta	d（mm）	a（mm）	alpha
1	0	399	0	-90°
2	0	0	350	0
3	0	0	42	-90°
4	0	351	0	-90°
5	0	100	0	90°
6	0	82	0	-90°

Multi-degree-of-freedom joint nonlinear dynamic model

Using Matlab software to complete the modeling and dynamic simulation of the multi- degree-of-freedom dulcimer robot. The specific steps are shown as follows:

1)Establish the six-degree-of-freedom series mechanism of the equivalent dulcimer robot based on Matlab platform

2)Build the CAD model of the dulcimer robot by Solidworks and import the model into Matlab SimMechanics to generate the dynamic simulation model.

3)Use SimMechanics to analyze the dynamic response.

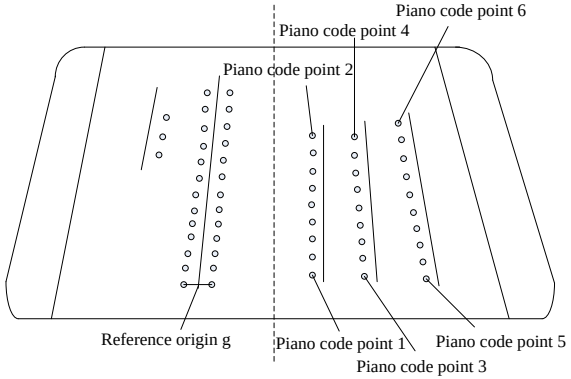

Fig. 2 Definition of piano code point position

TABLE II. THE POSITION OF EACH KEY PIANO CODE POINT

Dulcimer code point	Coordinate(x,y,z)
1	(144, 26.5, 5.151)
2	(144, 309.21, 60.1)
3	(239, 17.5711, 3.4155)
4	(215.6, 299.8871, 58.2921)
5	(335, 230.8346, 1.7173)
6	(296.7, 310.5259, 63.0815)

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Results and discussions

A. Analysis of response characteristics considering friction effect

In this paper, spherical joint bearings for robots are used to analyze the influence of friction effect. The friction coefficient of the bearing is generally between 0.01-0.02. The errors or gaps produced in the manufacturing and assembly processes will directly affect the actual friction coefficient, and the influence of different friction coefficients on the response characteristics of the joint will be analyzed later.The detailed calculation flow of the kinetic analysis model is shown in figure.

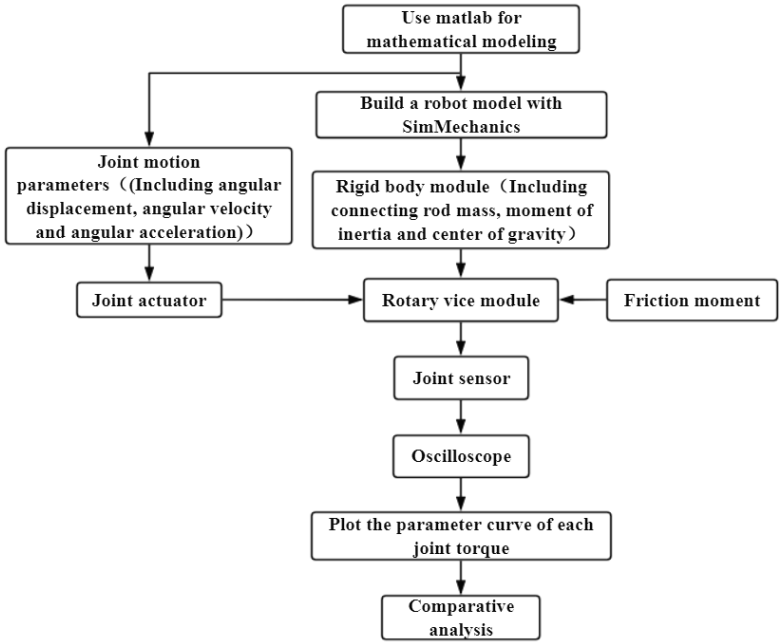

Fig. 3 Calculation process

Results and discussions

Fig. 4 show the results of the dynamic response of joint moments and the relative error curves for different joints of the dulcimer robot with or without the friction coefficient.

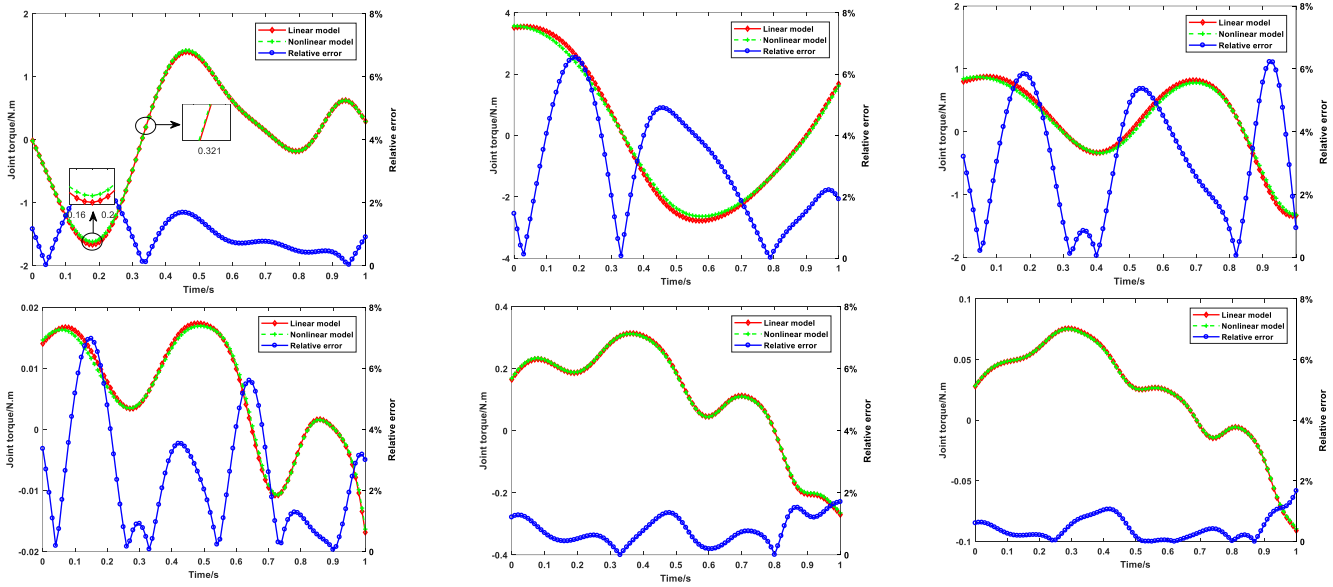

Fig.4 Joint one to six moments and relative error over time curvature

From Fig.4, it can be concluded that the influence of the friction effect on the calculation result can be up to 7%.The maximum error occurs when the joint moment changes significantly. This is due to the fact that the friction from the changed working conditions will lead to the loss of energy and consequently a change in the joints moment. Hence, the influence of friction effect is relative large and should not be ignored.

Results and discussions

B. Simulation of motion trajectories considering friction effect

Simulation of motion trajectories considering friction effect is finished as follows：

Firstly, the robot's trajectory is obtained by the Matlab platform; that is, the trajectory from key piano code point 5 (333, 230, 0) to point 6 (297, 310, 60).

Secondly, input the signal of the joints' angle and other parameters into the SimMechanics simulation model, and the results of the dulcimer robot's trajectory with considering the friction coefficient 0.01 and the ideal trajectory are solved and compared (as shown in Fig.5).

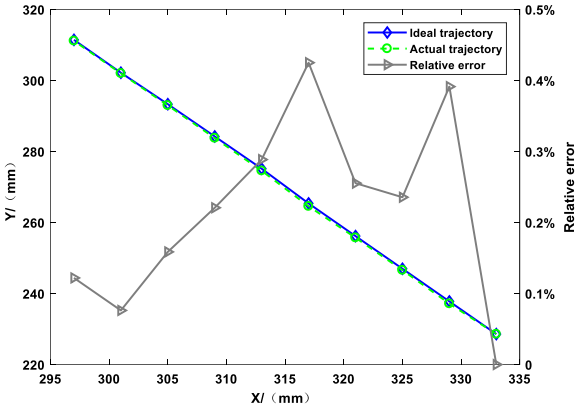

Fig.5 Comparison of running trajectories when considering friction

Results and discussions

The results on the influence of the different friction moment at each joint on the motion trajectory are shown in Fig.6.

As shown in Fig.6, the actual trajectories with considering the friction are approximate the ideal trajectories, and the maximum error is less than 0.5%. This result verifies the feasibility of the dynamics simulation for the dulcimer robot by coupling the Solidworks CAD model and Sim -Mechanics dynamics model.

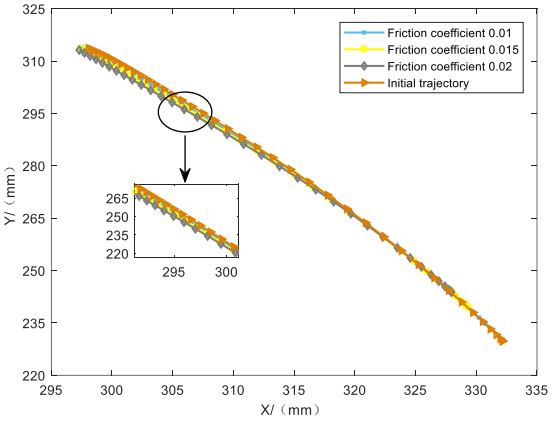

Fig.6 Trajectory curves for different friction coefficients

Results and discussions

C. Multi-joint trajectory tracking control

In order to reduce the influence of friction effect on the trajectory of the dulcimer robot and improve the positioning accuracy of the fast changeover process, the traditional PID and fuzzy PID control strategy is developed in this section, and the dynamic control of the trajectory of the robot will be realized.The curves of the simulated angle difference for each joint by PID control are shown in Fig. 7.

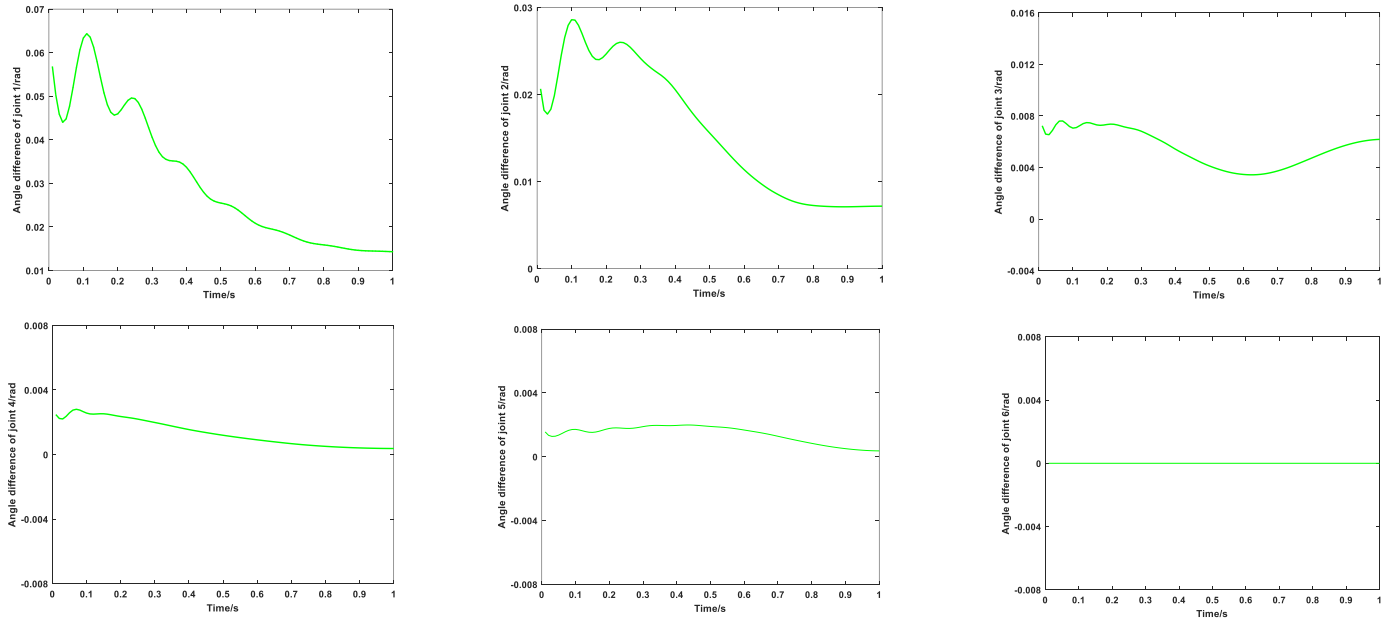

Fig.7 The angle difference curve of the joints from one to six under PID control

Results and discussions

From Fig.7, it can be seen that the absolute angle difference of each joint with the corresponding PID parameters is kept within 0.08 rad, but the angle difference of the first two joints has obvious jitter overshoot. Hence, the first two joints need to be controlled by the adaptive fuzzy PID, the design block diagram is shown in Fig.8 respectively.

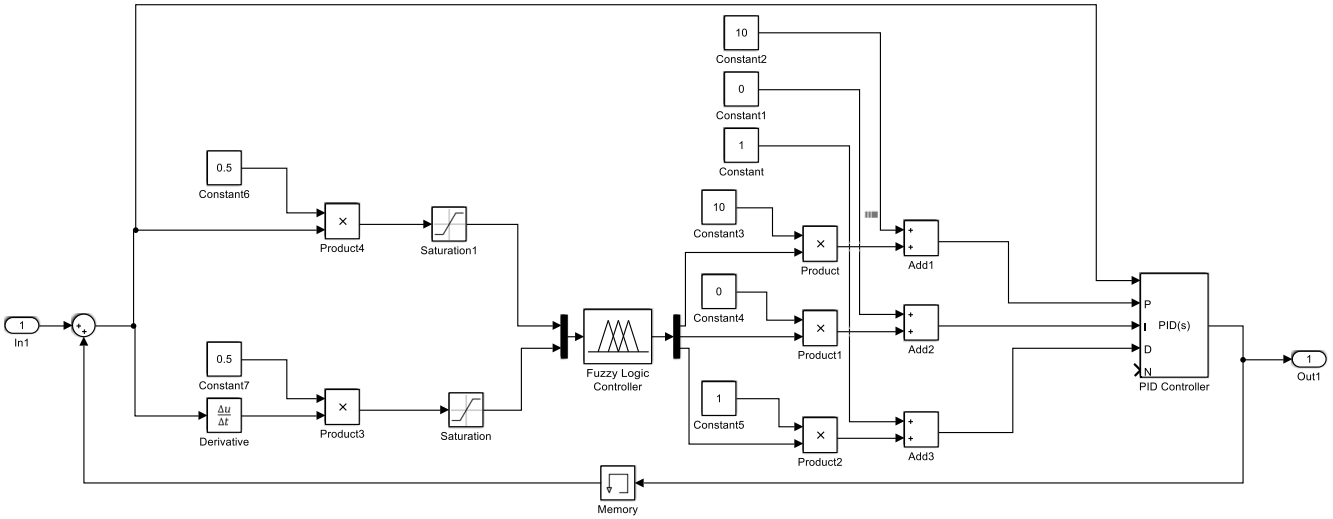

Fig. 8 Design block diagram of the Fuzzy PID controller

Results and discussions

The parameters in in Fig.11 are determined by the trial and error method and the results include that Kp1=0.1, Ki1=10, Kd1=1, Kp2=0.5, Ki2=10, Kd2=0.5. The absolute value of the angle difference for the first two joints is shown in Fig.9.

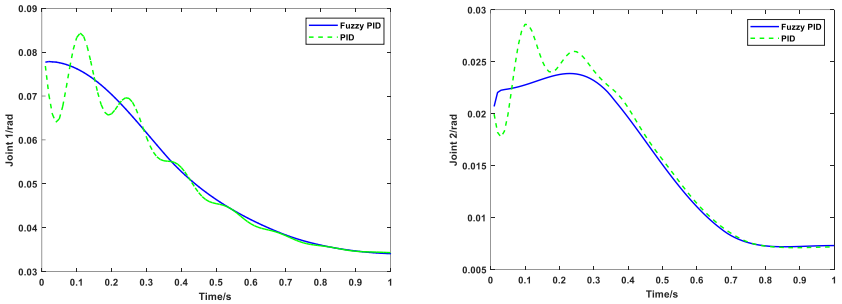

Fig. 9 Joint angle difference curve under the two controllers

As shown in Fig.9, the hybrid control strategy of traditional PID and fuzzy PID can effectively reduce the overshoot of all joints, and ensure the absolute error of each joint within 0.08 rad, which can better meet the fast changeover process and positioning accuracy of the dulcimer robot with multiple degrees of freedom.

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Conclusion

In this paper, the nonlinear dynamics simulation modeling and motion control for the dulcimer robot are studied, and the main conclusions are shown as follows:

1) The nonlinear dynamic equation for the dulcimer robot with considering the friction effect is derived; and based on Solidworks and Matlab/Simulink, the simulation model of the dulcimer robot is constructed and the accurate simulation of the dulcimer robot's motion trajectory is finished.

2) The results show that with and without considering the friction, the maximum difference on the moment response of the robot joints is 7%. With the friction coefficient increasing, the actual trajectory deviates more obvious from the theoretical trajectory, especial in the start-up stage of the robot.

3) The hybrid control strategy based on the PID and fuzzy PID can improve effectively the trajectory tracking accuracy and reduce the overshoot of the dulcimer robot, which will provide an important theoretical reference for the practical application of such multi-joint nonlinear motion control methods.