Study on Diagonal Fuzzy Variable Structure Control for Parallel Robot

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Abstract. A diagonal fuzzy variable structure contrail tracker is designed to the established system model on 2-DOF, which is based on the movement requirement of the terminal of the machine and the kinematics analysis giving the anticipant angle displacement of every performing part under a definite disturbance. It is testified that the control method realizes the contrail track of expected by simulation, which indicates that the output of the fuzzy variable structure controller is smooth, and has no obvious oscillation and the advantages of the rapid reduction of the input space and the output space. It can guarantee the rapidity and accuracy related to the anticipant track.

Introduction

Parallel robot is one kind of new mechanism. It has the merit which the traditional series robot is unable to compare. Parallel robot possesses the characteristics of large rigidity, strong load bearing capacity, small error, high precision, small dead weight load, good dynamic performance, and easy control[1]. A kind of diagonal fuzzy variable structure control algorithm is adapted to the parallel robot mechanism. It combines with the adaptive control and the fuzzy control to replace the switch control of the traditional variable structure control, and it can realize the request of the branch driving pair motion track which the movement platform real-time obtained.

Establishment of the parallel robot control system model

1. Description of the parallel mechanism

The coordinate system is established in Figure 1. The geometry parameter of the parallel mechanism is as follows:

The connecting rod length is equal: L11=L12=L21=L22=L31=L32=L1=244mm;

The position of the electrical machinery: A1 (xa1, ya1), A2 (xa2, ya2), A3 (xa3, ya3);

In the coordinate system coordinates are: A1 (0,250), A2 (433, 0) A3 (433, 500);

Connecting rod joint: B1 (xb1, yb1), B2 (xb2, yb2), B3 (xb3, yb3).

A1, A2, A3 are the Input values of the agency to achieve the motion control of the terminal position C (X, Y) of the parallel linkage.

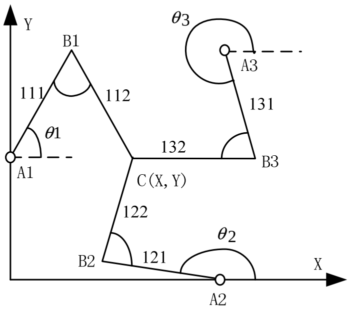

Fig.1 Schematic diagram of parallel mechanism

2. Establishment of the control system model

Regarding this organization, the terminal position C (X, Y) of the parallel linkage is a complex nonlinear function of the various joints physiological load, and in the rate process various legs have the misalignment coupling function, therefore it is difficulty to achieve the direct position control by using the terminal potential motion control. The dynamics decoupling based on dynamics model

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control method is used, and the control structure of the various legs distinction closed loop is adopted. Through control algorithm's design, the system consider the robot on the role of each branch deputy campaign in real-time process, also said that the slip motion pair under the interference, it can also obtain the good control performance.

The AC servo motors are used respectively in various implementing agency[2], the system control structure is shown in Figure 2.

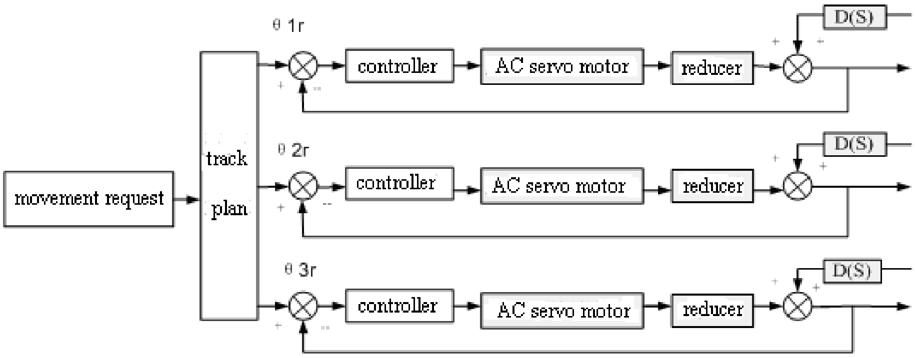

Fig.2 Control structure drawing of the parallel robot system

3. Angular displacement solution of various legs

The C (X, Y) of the parallel mechanism represents the terminal position and movement. When you know the action requirements, the angular displacement of the active deputy on the A1B1C, A2B2C, and A3B3C can be obtained according to the kinematic analysis of the parallel robot.

4. Control algorithm

The Sliding mode controller design does not need to make the special decoupling because the design process itself is a decoupling process. The design of multiple controllers may carry on independently according to the system of the parallel robot organization.

The slip control system model is shown in Figure 3. In the figure, J is the total shaft inertia of the AC servo motor, L_p is the winding inductance, R_p is the winding resistance, K_{pre} is the speed loop gain, K_v is the velocity feedback coefficient, K_i is the current feedback gain, K_a is the power amplifier gain, K_{tp} is the torque constant, i as the reduction ratio. The servo motor model can be seen in reference [1].

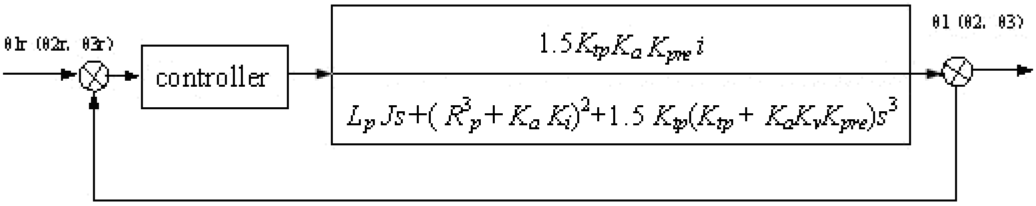

Fig.3 Control system model

The parameters of the robot servo motor are as follows: K_{pre} =88, K_i =2.2, K_a =6, K_{tp}=3.41 $N{\cdot}m/A$, L_p =0.03837 H, R_p =5.09Ω, J=0.39 $kg{\cdot}m^2$. The speed ratio of deceleration devices is i=40. Joint part of the device driver in the slow side for the moment of inertia is 0.1 $kg{\cdot}m^2$. The mathematical model of this executive mechanism is a three-order system[3], its transfer function can be expressed as:

$$G(s) = \frac{b_0}{s^3 + a_2 s^2 + a_1 s + a_0} . \tag{1}$$

The differential equation under the case of external interference is:

$$y''' + a_2 y'' + a_1 y' + a_0 y = b_0 u + d(t) . \tag{2}$$

In the formula, y is an output, u is an input, $d(t)$ is an equivalent of the uncertain disturbances, y_d is defined as the desired trajectory, and the trajectory error $e = y - y_d$.

The sliding surface is defined as: $S = e'' + c_1 e' + c_0 e$.

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In order to ensure the asymptotic stability of the sliding mode, it is required the roots of the equation $S = 0$ are all in the negative half-plane; In order to ensure that all states can reach the sliding mode, it should meet the conditions: $SS' < 0$.

It is that:

$$SS' = S[b_0 u + d(t) - y_d''' - a_2 y_d'' - a_1 y_d' - a_2 e'' - a_1 e' - a_0 e + c_1 e'' + c_0 e'] < 0 . \quad (3)$$

Let the equivalent uncertain external disturbance is bounded, and satisfy the equation of $| d(t) |< D$, and when it meets the equation (3), the system can satisfy the condition.

$$u = 1/b_0[y_d''' + a_2 y_d'' + a_1 y_d' + a_0 y_d + a_2 e'' + a_1 e' + a_0 e - c_1 e'' - c_0 e'] - KS - (\varepsilon + D/b_0)\operatorname{sgn}(S) . \quad (4)$$

Control action u can be divided into two parts:

a. $1/b_0[y_d''' + a_2 y_d'' + a_1 y_d' + a_0 y_d + a_2 e'' + a_1 e' + a_0 e - c_1 e'' - c_0 e']$ is used to offset the system's original dynamics characteristic.

b. $- KS - (\varepsilon + D/b_0)\operatorname{sgn}(S)$ is used to establish the new dynamics characteristic. The switching control $- KS - (\varepsilon + D/b_0)\operatorname{sgn}(S)$ is made up of two parts, one of the items used to compensate the system uncertainty of external interference.

The diagonal line in the diagonal angle FLC is very similar to the sliding mode *S* in the variable structure control[4], so the diagonal line of the diagonal fuzzy controller is instead by the sliding mode *S* of the variable structure control. After the change, the transmission characteristic of the diagonal angle FLC may express as:

$$u_{fuzz} = -K_{fuzz}(S) sign(S) . \quad (5)$$

It should meet the following conditions:

a. $- e_{\max} \le e \le +e_{\max}$

b. $- e'_{\max} \le e \le +e'_{\max}$

c. $0 \le K_{fuzz} \le u_{\max} = K_{fuzz} |_{\max}$

d. $K_{fuzz}(S_1) \le K_{fuzz}(S_2), |S_1| \le |S_2|$

When distance between the *S* to the diagonal line *S*=0 is increased, the size of the control signal increases. The improved fuzzy controller replaces the switching control item of the variable structure control, and the other parts remain unchanged. Therefore, according to Equation (5), it can get a new fuzzy variable structure controller.

$$u_{smflc} = 1/b_0[y_d''' + a_2 y_d'' + a_1 y_d' + a_0 y_d + a_2 e'' + a_1 e' + a_0 e - c_1 e'' - c_0 e'] + u_{fuzz} . \quad (6)$$

u_{fuzz} is an output of the fuzzy controller, u_{smflc} is a total output of the variable structure fuzzy controller.

The domain is [-3,3] after normalizing the input *S* and output of the fuzzy controller. *S* linguistic variables are {SMB, SMM, SMS, SZ, SPS, SPM, SPB} and *U* linguistic variables are {UMB, UMM, UMS, UZ, UPS, UPM, UPB}. The membership functions of *S* linguistic variables and *U* linguistic variables are shown in figure 4 and figure 5.

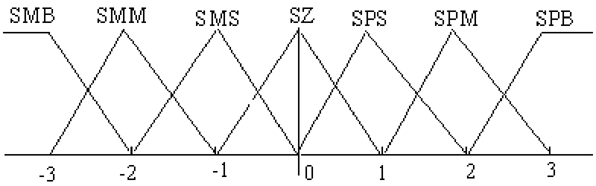


Fig.4 *S* linguistic variables

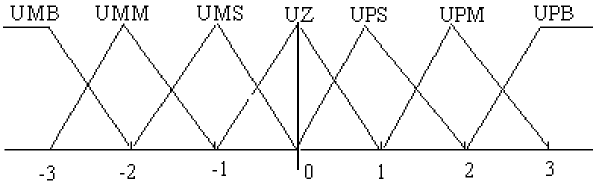


Fig.5 *U* linguistic variables

Fuzzy control rules are following:

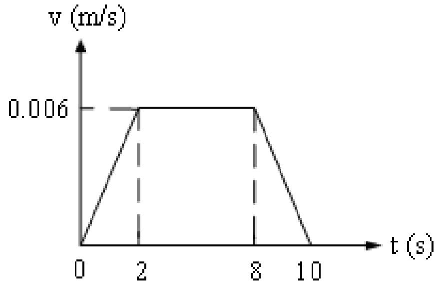
IF S=SMB THEN U=UPB; IF S=SMM THEN U=UPM;
IF S=SMS THEN U=UPS; IF S=SZ THEN U=UZ;
IF S=SPS THEN U=UMS; IF S=SPM THEN U=UMM;

IF S=SPB THEN U=UMB

The output value uses the gravity model approach to carry on the clear computation.

Simulation

The simulation model is founded on the Matlab/Simulink, according to the system movement request[5], the active input pair is real-time calculated and the simulation step is taken 0.001.It is requirement of the system that the parallel robot moving platform should move from point (0.25m, 0.25m) to point (0.3m,0.3m) in the XY plane within 10 minutes. The velocity of X direction and Y direction is shown in Figure 6.



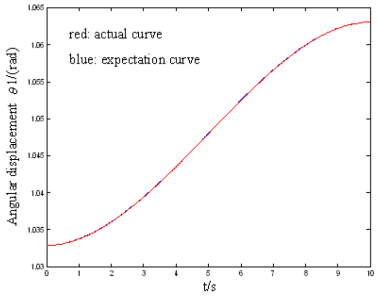
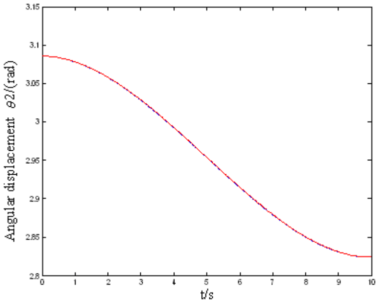


Fig.6 Velocity of X direction and Y direction Fig. 7 The tracking trajectory of limb A1B1C

Adding some support on the road in all the interference, the branch trajectory tracking simulation results are shown in figures as following:



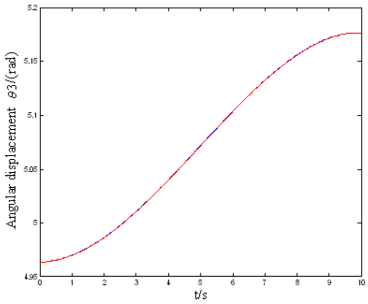


Fig.8 The tracking trajectory of limb A2B2C Fig.9 The tracking trajectory of limb A3B3C

Conclusion

The simulation results show that the trajectory tracking of the parallel robot is realized by diagonal fuzzy variable structure control. The expectation angular displacement curve and the actual angular displacement curve of the driving pair superposes nearly. The anti-interference ability of the system is strong and the change to the object’s parameters is insensitive. This method of the diagonal fuzzy variable structure control owns a good control quality.

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