Research on Trajectory Tracking Control Method of Delta Parallel Cleaning Mechanism

Jiangfan Shen[1, a], Yichen Yuan[1, b], Zunyao Zhou[1, c], Rongxin Li[1, d]

[1]Electrical Engineering & Automation, Civil Aviation University of China, TianJin 10059, China.

[a]1171579024@qq.com, [b]2924656171@qq.com, [c]31299239013@qq.com, [d]41125505826@qq.com

Abstract

Delta parallel robots have a series of advantages such as high rigidity, strong carrying capacity and non-accumulation of position error. At the same time, they have high nonlinearity and strong coupling, so it is extremely difficult to control them accurately. A three-degree-of-freedom Delta parallel cleaning mechanism driven by DC servo motor is used to analyze the kinematics positive and inverse solutions. The simulation model of parallel cleaning mechanism is established and the fuzzy adaptive PID cleaning trajectory tracking control algorithm is designed. MATLAB simulation results show that the algorithm can track the desired cleaning trajectory quickly and accurately, and has strong anti-interference ability.

Keywords

Delta parallel robot, Trajectory tracking, Kinematics positive solution inverse solution, Fuzzy adaptive PID.

1. Introduction

Due to environmental pollution, the airport's embedded navigation aids cause their luminous intensity to decrease and endanger aviation safety. Therefore, regular cleaning is required. Automatic cleaning of lamps is an important means to improve the cleaning efficiency. The end of the Delta parallel mechanism is used to carry the cleaning nozzles to align the light-emitting ports for automatic cleaning of the lamps. The precise control of the end of the parallel cleaning mechanism is the key to automatic cleaning. As a background, the focus is on the problem of trajectory tracking control at the end of the Delta parallel cleaning mechanism.

In 1985, Dr. Clavel invented a class of three-degree-of-freedom spatial translation parallel structure, known as the Delta robot [1]. The Delta robot overcomes many of the shortcomings of the parallel mechanism, with high precision, high stiffness, fast speed and large carrying capacity. And so on, it is widely used. Most of the early parallel cleaning mechanism control strategies used traditional PID control, but because the parallel robot is a nonlinear system with complex structure, multi-variable and multi-parameter coupling, it is difficult to obtain the exact value of the physical parameters of the system. There is inevitably uncertainty in the model. In this case, the traditional PID control is difficult to achieve good control effects. For the control and optimization of parallel mechanisms, many domestic and foreign scholars have done research. In the literature [2], a neural network controller is designed for a linear Delta-like mechanism, and the timeliness of the neural network algorithm is verified. In 2016, Li Lili took the PC and the lower robot air machine as the core, and built the control system of the three-degree-of-freedom high-speed Delta robot, which has the advantages of economy and short development time, and became the new direction of the development of robot control system [3]. Fuzzy control is an effective means to control controlled objects with time-varying parameters and nonlinearity because it does not depend on the mathematical model of the controlled object, has good robustness and nonlinear control characteristics. Yunhua Yin and others from North University of China proposed an adaptive fuzzy PID controller to overcome the shortcomings of the traditional PID controller, but there is no practical application, only in the simulation stage [4].

In summary, the research is based on Delta parallel mechanism, based on kinematics trajectory tracking control problem, fuzzy adaptive PID cleaning trajectory tracking control algorithm is adopted to improve the accuracy, flexibility and anti-interference ability of system control.

2. Parallel Cleaning Mechanism Analysis

The three-degree-of-freedom Delta parallel mechanism adopted by the automatic cleaning mechanism has simple and compact structure, good kinematics and dynamic characteristics, and has the advantages of high rigidity, strong carrying capacity, high precision, small self-weight load ratio and good dynamic performance. The three-degree-of-freedom Delta parallel cleaning mechanism mainly comprises a static platform, a moving platform, a servo motor, three active arms and three slave arms. The specific structure is shown in Fig. 1.

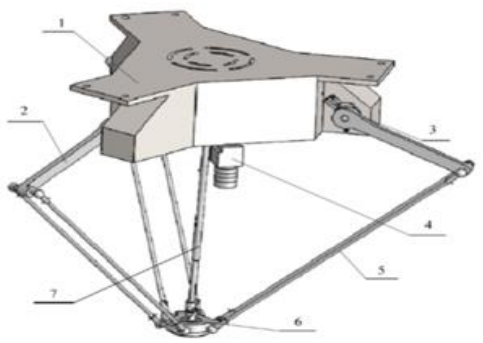


Fig. 1 Three-degree-of-freedom Delta parallel cleaning mechanism

The parts in Fig. 1 are: 1 static platform,2 active arm,3 limit switch,4 camera,5 slave arm,6 moving platform,7 rotating shaft. The parallel mechanism works with two platforms: static platform and dynamic platform. The static platform is generally connected with the fixed device. It is the main bearing device for installing fixed parts, steering gear and other main components. The moving platform is mainly used to install and fix the end. The mechanism of the controller and can prevent relative movement of the end effector and the robot arm. When the parallel mechanism is working, the steering gear provides a power source for the active arm, and the steering gear is evenly dispersed and mounted on the three corners of the static platform. The active arm and the follower arm connect the moving platform and the static platform, and each of the follower arms is composed of a parallelogram closed loop composed of four ball joints and rods. Due to the nature of the parallelogram, such three sets of parallelogram mechanisms keep the moving platform and the static platform in a parallel relationship. During operation, the steering gear transmits power to the active arm, and the active arm transmits power to the slave arm through the ball joint. The slave arm finally transmits power to the moving platform to complete the control of the end effector.

2.1 Positive Kinematics of Delta Parallel Cleaning Mechanism

The kinematics positive solution is the positional parameter of the output position of the cleaning mechanism. Under the condition of the output angular displacement of the known motor The solution process of the forward solution of the parallel mechanism is very complicated compared with the solution process of the inverse solution. Most of the inverse solutions are solved by the above vector method, and the solution process of the positive solution is generally solved by the geometric analysis algorithm. Zhao Jie[5] of Harbin Institute of Technology simplified the parallel mechanism and found that the static platform and the moving platform are always parallel. By translating the slave arm in the model, the problem of solving the positive solution of the mechanism is transformed into a known all. The problem of solving the vertex coordinates of the triangular pyramid with side length and 3 vertex coordinates.

$$\begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix} = \begin{bmatrix} (R+L_b)\cos\left((i-1)\cdot 120^\circ\right) + \frac{r\left(\cos\left((i-1)\cdot 120^\circ - \phi_i\right) - \cos\left((i-1)\cdot 120^\circ - \phi_i\right)\right)}{2} \\ (R+L_b)\sin\left((i-1)\cdot 120^\circ\right) + \frac{r\left(\sin\left((i-1)\cdot 120^\circ - \phi_i\right) - \sin\left((i-1)\cdot 120^\circ - \phi_i\right)\right)}{2} \\ L_b\sin\theta \end{bmatrix} \quad (1)\ (1)$$

L_b is the length of the driving arm, R is the radius of the circumscribed circle of the static platform, r is the radius of the circumscribed circle of the moving platform, $\phi_i = \frac{4i-3}{6}\pi$, θ is the input angle of the driving arm.

2.2 Kinematic Inverse Solution of Delta Parallel Cleaning Mechanism

The kinematic inverse solution is to solve the relationship between the input and the end pose output of each servo under the premise of the known target position. A simplified model of the three-degree-of-freedom Delta parallel mechanism is established by using space geometry and vector algebra, and the inverse solution equation of the parallel mechanism position is obtained [6]. The static platform and the movable platform of the cleaning mechanism are connected to the driven arm through the active arm, and the active arm is driven by the steering gear during operation, and then the active arm drives the driven arm to move together, and finally the driven arm controls the movement state of the terminal moving platform. It can be seen from the above analysis that the inverse solution of the cleaning mechanism is to solve the rotation angle of the motor, that is, the angle of the active arm relative to the static platform, at the coordinates of the static platform coordinate system at the center of the known moving platform. The position solution of the inverse motion of the Delta parallel robot can be obtained as

$$\theta_i = 2\arctan\left(\frac{-A \pm \sqrt{A^2 - B^2 + C^2}}{B - C}\right) \quad (2)$$

$$\begin{cases} A = 2L_b\left[R - r - \left(x\cos\phi_i + y\sin\phi_i\right)\right] \\ B = 2L_b Z \\ C = x^2 + y^2 + z^2 + (R-r)^2 + {L_b}^2 - {L_a}^2 - 2(R-r)\left(x\cos\phi_i + y\sin\phi_i\right) \end{cases} \quad (3)$$

θ_i is the angle of rotation of the motor, the coordinate of O' is $(x, y, z)^T$, L_a is the length of the slave arm, L_b is the length of the drive arm, R is the radius of the circumscribed circle of the static platform, and r is the radius of the circumscribed circle of the moving platform, $\phi_i = \frac{4i-3}{6}\pi$.

3. Fuzzy PID Track Tracking Controller

3.1 Fuzzy Adaptive PID Controller

Define the input and output fuzzy sets and determine the number category according to the control law of the fuzzy PID controller and the control method of the classic PID, and take into account the control accuracy. To improve the response characteristics of the system [7], take 3 fuzzy sets N (negative), Z (zero), P (positive)

$$e,ec = \{N,Z,P\} \quad (4)$$

The output $\triangle K_P$,$\triangle K_i$,$\triangle K_d$ also take 3 fuzzy sets

$$\triangle K_P,\triangle K_i,\triangle K_d = \{N,Z,P\} \quad (5)$$

According to the control requirements, each input and output variable is defined as follows

$$e,ec = \{-1,0,1\} \quad (6)$$

$$\triangle K_P,\triangle K_i,\triangle K_d=\{-0.01,0,0.01\} \quad (7)$$

A fuzzy algorithm is used to determine the tuning algorithm of PID parameters. The K sampling time is set to

$$\begin{cases} K_P = K_{p0} + \Delta K_p \\ K_i = K_{i0} + \Delta K_i \\ K_d = K_{d0} + \Delta K_d \end{cases} \quad (8)$$

K_{p0}, K_{i0}, K_{d0} are the initial parameters of the traditional PID controller.

3.2 Establishment of Fuzzy Rules

According to the influence of parameters K_P, K_i, K_d on the output characteristics of the system, the self-tuning principle of the system for different deviation and deviation rate change parameters K_P , K_i , K_d can be summarized:

1. When the deviation is large, a larger K_P and a smaller K_d should be taken in order to speed up the response speed of the system and prevent the differential over-saturation caused by the instantaneous increase of the deviation at the beginning to make the control action beyond the allowable range. In addition, in order to prevent the saturation of the integral and avoid the overshoot of the system response, the K_i value is small.
2. When the deviation and rate of change are medium, in order to reduce the overshoot of the system response and ensure a certain response speed, K_P should be smaller. In this case, the value of K_d has a great influence on the system, and should be taken smaller. The value of K_i should be appropriate.
3. When the variation of the deviation is small, in order to make the system have better steady-state performance, the value of K_P and K_i should be increased. At the same time, to avoid the oscillation of the output response around the set value, and considering the anti-interference ability of the system, it should be appropriately selected K_d. The principle is: when the rate of change of deviation is small, K_d is larger; when the rate of change of deviation is larger, K_d takes a smaller value, usually medium.

Refer to the above self-tuning principle to establish a suitable fuzzy rule inference table for e, ec, K_P, K_i, K_d as shown in Table 1, Table 2.

Table 1. Proportional parameter value fuzzy rule table

ec e	N	Z	P
N	N	N	N
Z	N	P	P
P	P	P	P

Table 2. Integral parameter value fuzzy rule table

ec e	N	Z	P
N	Z	Z	Z
Z	P	P	P
P	Z	Z	Z

4. Cleaning Mechanism End Tracking Control Modeling

The block diagram of the closed-loop control system of the parallel cleaning mechanism is shown in Fig. 2

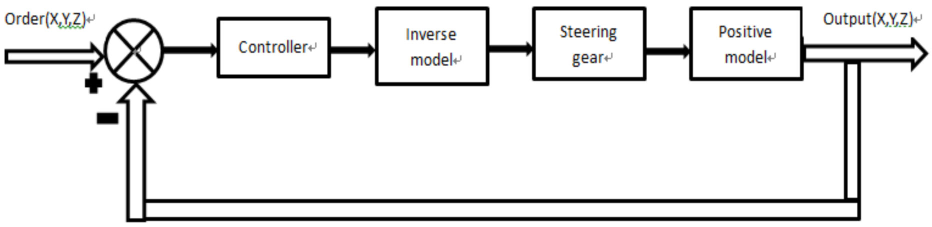


Fig 2. Block diagram of closed-loop control

4.1 Cleaning End Traditional PID Control Simulation Model

The closed-loop control simulation model shown in Fig.3 [8], in which the controller selects the PID controller. The position is controlled by PID, and the parameters of the PID are adjusted during simulation. n_j and z_j are still the solution of the inverse solution and the positive solution of the parallel cleaning mechanism. The Generator1 is the package module of the motor. Here, the load is independent from the module, which can easily change the given load at any time during the simulation. The positive solution output is used as position feedback to form a closed loop.

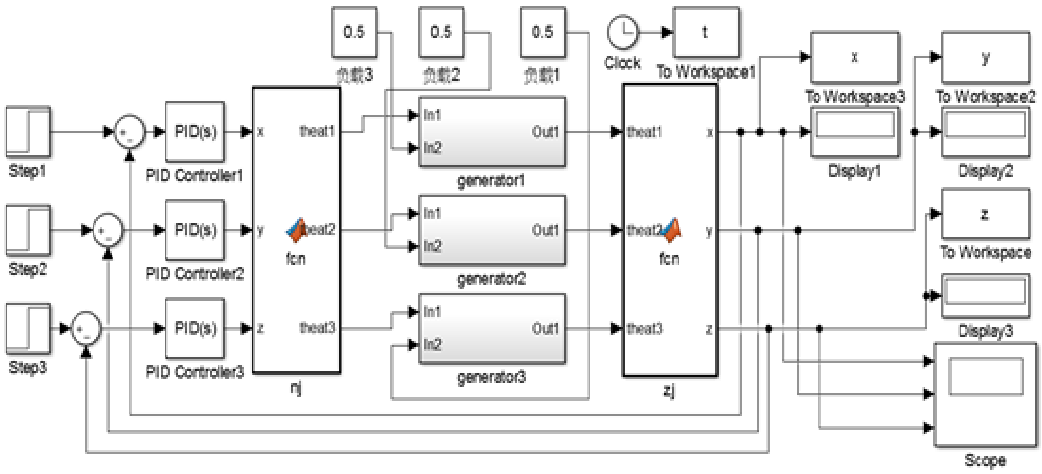


Fig.3 Traditional PID simulation model

4.2 Cleaning End Fuzzy PID Control Simulation Model

Replace the PID module in Fig.3 with the Fuzzy PID module. The other modules and links remain unchanged. The fuzzy PID can auto-define the parameters of the PID. The Fuzzy PID module is a package module. Its subsystem is shown in Fig.4

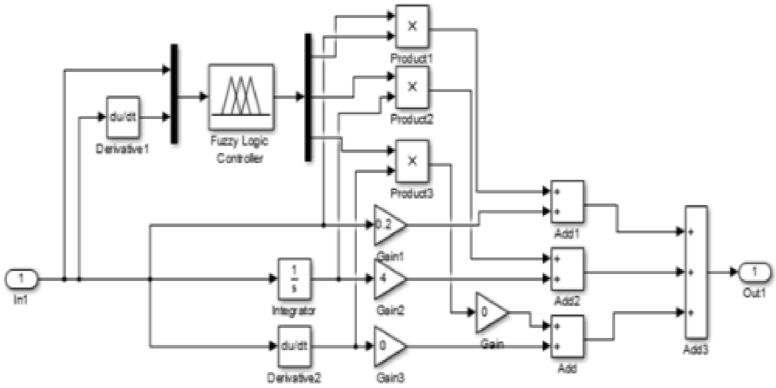
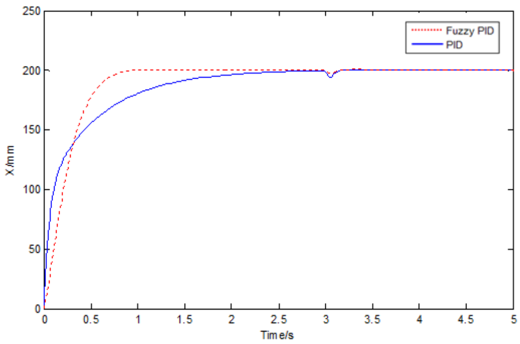


Fig.4 Fuzzy PID subsystem

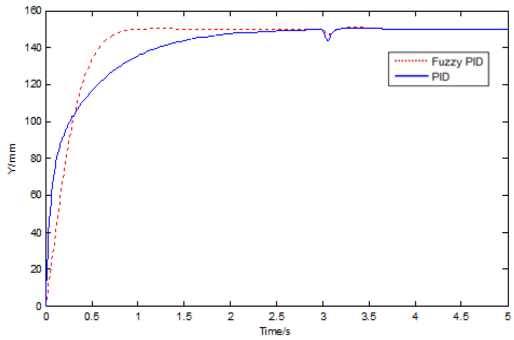
5. Simulation Result Analysis

5.1 Analysis of Simulation Results with Input as Step Signal

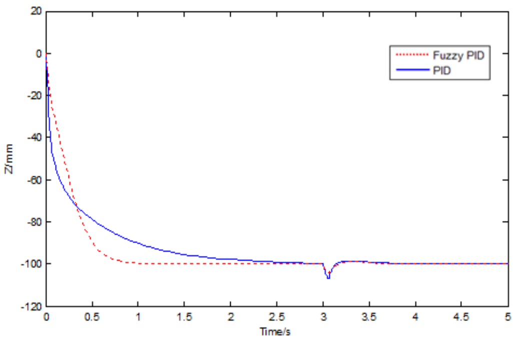
During the simulation, a set of target values is selected. The target value input coordinates are selected as step signals of (200, 150, -100), that is, the input of x is 200 mm, the input of y is 150 mm, and the input of z is -100 mm. The curve of the output of the simulated x, y, and z is shown in Fig.5. (a) is the output curve of x, (b) is the output curve of y, and (c) is the output curve of z. In order to facilitate comparison with the curve of the PID output, the curve of the PID output and the fuzzy adaptive PID output are displayed on the same interface. The dotted line curve is the position output of the fuzzy adaptive PID control, and the solid line type curve is the position output of the PID control.



(a) X-axis position output curve



(b) Y-axis position output curve



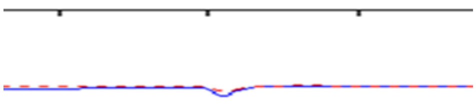
(c) Z-axis position output curve

Fig.5 step signal position output comparison curve

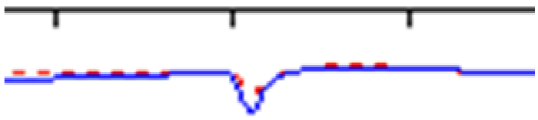
As can be seen from the above three figures, the graph (a) is the curve of the position output x. Using fuzzy adaptive PID control, it can be seen from the curve that the curve changes rapidly in the initial 0.8s time of the simulation, and it is stable in the 1s or so, and there is no overshoot. The PID control is used to set the parameters, and the stability is achieved in about 2.5s. At this time, the x-axis is stable at 198mm and the steady-state error is 2mm. The graph (b) is a curve of the position output y. Using fuzzy adaptive PID control, it can be seen from the curve that the curve changes rapidly in the initial 0.8s time of the simulation, and the change trend is relatively flat. It stabilizes at about 1s and stabilizes at 150mm. The PID control is used to set the parameters, and the stability is achieved in about 2.5s. At this time, the y-axis is stable at 149mm and the steady-state error is 1mm. The graph (c) is a curve of the position output z. Using fuzzy adaptive PID control, it can be seen from the curve that the curve changes rapidly in the initial 0.7s time of the simulation, and stabilizes at about 0.8s. At this time, the z-axis is stable at -100mm. The PID control is used to set the parameters, and the stability is achieved in about 2.7s. At this time, the z-axis is stable at the position of -99mm, and there is an error of 1mm.

5.2 Simulation Analysis of Anti-Interference Ability

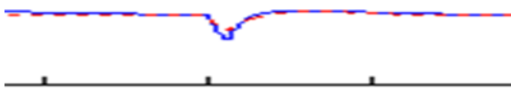
In order to verify the anti-interference ability of the control system, an interference signal is added when the simulation time is 3 seconds, which is added at the load end of the motor. Fig.6 is a graph showing the effect of the interference signal on the output curve at 3 seconds for the X, Y, and Z axes.



(a) X-axis output curve after interference



(b) Y-axis output curve after interference



(C) Z-axis output curve after interference

Fig.6 three-axis output curve graph after interference

The disturbance is added to the PID control and the fuzzy adaptive PID control at 3 s. The fuzzy adaptive PID control is restored to stability after 0.25s, reaching the coordinate position before the disturbance, and the overshoot of the three axes is very small, respectively 2mm, 2mm, 5mm. The recovery time of the PID control needs 0.4s, and the overshoot of the three axes is relatively large, respectively 5mm, 5mm, 8 mm.

5.3 Sinusoidal Signal Tracking Simulation Analysis

The simulation input expects to track the signal function x = sin(t), y = sin(t), z = t. The sinusoidal signal has an amplitude of 2 mm, the frequency of 0.3 Hz, and the unit of t is seconds. Since the three-axis simulation graph is similar, only the x-axis graph is analyzed, and the curve of the output of the simulation x is as shown in Fig.7. In order to make the visual effect better, perspective Fig.8 is used, and the curves of the PID output and the fuzzy adaptive PID output are displayed on the same interface. The solid line curve is the position output of the fuzzy adaptive PID control, the dotted line curve is the position output when the PID is controlled, and the dotted line type curve is the desired tracking curve.

As can be seen from the above two figures, the tracking error of the fuzzy adaptive PID control is almost zero, and a stable tracking effect can be achieved. The tracking error of the PID control is 0.2mm, and the signal curve cannot be accurately tracked from 7s, the response time is longer, the response speed is slower, and the stability is worse.

The analysis shows that the fuzzy adaptive PID improves the response speed compared with the traditional PID control, and can quickly restore the stable state and the overshoot is small when disturbed. It is shown that the fuzzy PID closed-loop control can adjust the PID parameters online, so that the system tends to be stable faster and achieve fast and accurate tracking of the target position. It can be seen that the control method is effective and feasible.

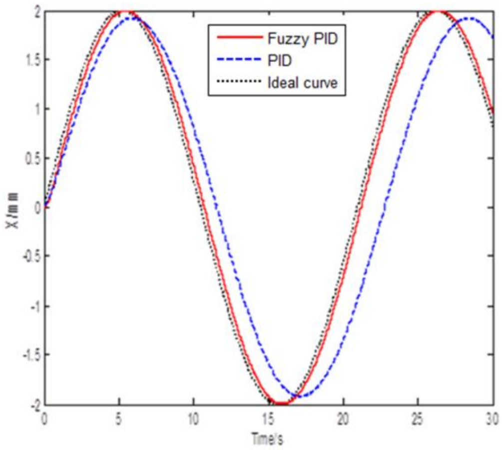


Fig.7 X-axis position output curve

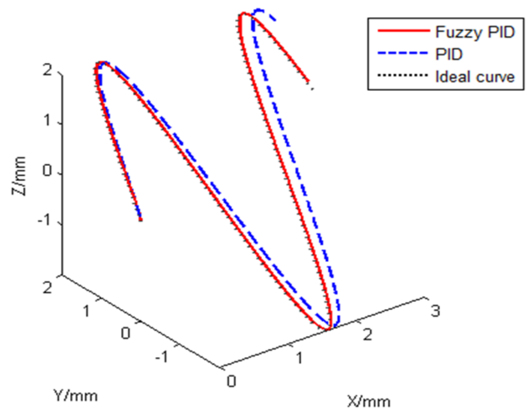


Fig.8 3D output position tracking curve

6. Conclusion

Delta parallel cleaning mechanism is a serious uncertainty system due to factors such as friction and load. It will generate error and external interference. Therefore, the fuzzy adaptive PID controller is designed. The MATLAB simulation software is used to establish the closed-loop control system of the parallel cleaning mechanism. In the tracking simulation of step signal and sinusoidal signal, the accuracy, fastness and anti-interference of fuzzy adaptive PID controller are obviously better than traditional PID controller, which indicates that the designed fuzzy adaptive PID controller has higher precision trajectory tracking. And has better anti-interference ability, can overcome the influence of uncertain factors.

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