SELF-COMPENSATION METHOD FOR ERROR OF POSITIONING ACCURACY OF INTELLIGENT SYNCHRONOUS MANIPULATOR

by

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The traditional positioning method of manipulator has the problems of poor accuracy and low efficiency. According to the positioning task type of the manipulator, the positioning model of the manipulator is constructed. Set up the manipulator joint co-ordinate system, combined with kinematics analysis, through the link parameters and joint variables to achieve the positioning analysis of the manipulator. The inverse method is introduced to compensate the positioning error of the robot arm by using image feature extraction and recognition technology. The experimental results show that the average positioning error of the traditional method is 1.4 mm, while the average positioning error of the proposed method is only 0.2 mm. The performance of the proposed method is proved to be better.

Key words: *intelligent robotic arm, synchronous positioning, inverse method, positioning accuracy, error compensation, kinematic analysis*

Introduction

The industrial robot has developed from simple repetitive machine to highly flexible multi-degree-of-freedom processing units. The premise of realizing off-line programming is that the industrial robot system must have higher control accuracy. The control accuracy mainly depends on posture characteristic, trajectory characteristic and load characteristic. When different robots perform functions or tasks, they need to use robotic manipulator to achieve precise positioning. However, the positioning error of manipulator will be caused by many factors. According to different factors, the positioning error can be divided into the system error, the random error, the error caused by missing momentum of reverse positioning and the error caused by minimum possible movement [1]. According to the difference between motion variables and link structural parameters in kinematics model of articulated industrial robot, the influence mechanism of each error factor on the position error of robot end-effector can be concluded as the influence on the robot motion variables and link structural parameters, namely the error of motion variable and error of structural parameter.

The positioning error compensation based on dynamic fuzzy neural network, positioning error compensation based on UWB four reference point vector and positioning error compensation based on motion model control are commonly used methods. Because the traditional method has not established the manipulator joint co-ordinate system and lacks the kinematics analysis, the positioning analysis of the manipulator is not accurate enough. In addition, there is no inverse solution method of equation and image feature extraction and recognition

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technology, which leads to poor positioning error compensation effect. Therefore, this paper proposes a self-compensation method for positioning accuracy error of intelligent synchronous manipulator. The adaptive concept is introduced in the optimization design, so that the method can automatically identify the positioning situation of intelligent synchronous manipulator and compensate the positioning error. In addition, the self-compensation method is optimized to maximize the compensation accuracy of positioning error and improve the positioning accuracy of intelligent synchronous manipulator. This method can effectively improve the degree of compensation and compensation precision, and better realize the development of China's industry [2].

Design of self-compensation method for positioning accuracy error of manipulator

Establishment of positioning model of manipulator

Single point positioning model of manipulator

The error of parameter will cause the motion error of robot and affect the positioning accuracy. Therefore, a new error parameter is added and an error model is established. An additional rotation term $Rot(y,\beta)$ is added in the connecting rod transformation matrix. The value of twist angle is defined as zero when the axes of adjacent joints are not parallel. Then, corresponding transformation matrix is obtained. After building the kinematics model, *P,* can be used to show the theoretical position of center point of flange at the end of robot in the single positioning co-ordinate system of manipulator.

Location accuracy analysis model

In the full stroke of trajectory of manipulator, m target positions are selected. Then, we make finite *n* localization from positive direction and negative direction, so as to measure the position deviation during each movement. All the position deviations are random variables which obey the normal distribution [3]. The mathematical expectation and standard deviation of parent statistics can be approximately replaced by the statistical mean and standard deviation of finite number of samples when *n* approaches infinity. Respectively, a normal curve is drawn in negative direction, 99.73% of 4-3 *S* of all possible positions is taken as the dispersive width, so that we can calculate the location accuracy evaluation index of position error.

By analyzing the positioning accuracy model, we can get the expressions of the positioning accuracy of one-way manipulator, two-way manipulator and the whole positioning accuracy. The formula for calculating the positioning accuracy of one-way manipulator is:

$$A_u = \left(\bar{x}_j \uparrow +3S_j \uparrow\right)_{\max} - \left(\bar{x}_j \uparrow +3S_j \uparrow\right)_{\min} \tag{1}$$

The one-way positioning accuracy of manipulator is calculated from positive and negative directions, while the positioning accuracy of two-way manipulator and full manipulator does not need these two directions. The accuracy of the two-way positioning of manipulator can be calculated:

$$A_b = 2\left[\left(\bar{x}_j \uparrow +3S_j \uparrow\right)_{\max} - \left(\bar{x}_j \uparrow +3S_j \uparrow\right)_{\min}\right] \tag{2}$$

The formulas for calculating the whole repetitive positioning accuracy of manipulator is:

$$R = \left[6S_j\right]_{\max} \tag{3}$$

where S_j in eqs. (1)-(3) denotes the positioning standard deviation of manipulator, $\overline{x}_j$ – the deviation of positioning accuracy at random positions in positive and negative direction.

Kinematics analysis of intelligent synchronous manipulator

In order to find the positioning error of manipulator, it is necessary to analyze the motion of manipulator and the structure of manipulator [4].

Establishment of joint co-ordinate system of manipulator

According to the movement of the intelligent synchronous manipulator in the positioning process, the co-ordinate system of manipulator is established. Taking the joint as the research object, the co-ordinate system is established as shown in fig. 1.

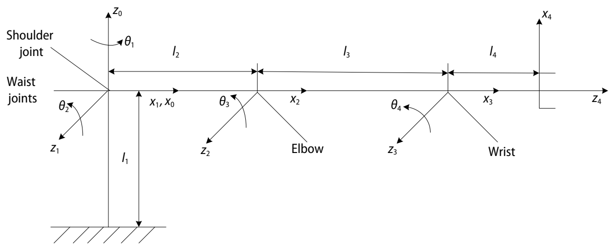

Figure 1. Schematic diagram of joint co-ordinates of manipulator

The co-ordinate transformation between the joint co-ordinate system of manipulator and the manipulator is carried out. The co-ordinate of each joint point is set: $A(x_A, y_A)$, $B(0,0)$, $C(x_C, y_C)$, $D(x_D, y_D)$, $E(x_E, y_E)$, where x_A is equal to y_A, and their values are 300. Based on the analytic geometry method, we can see that:

$$\begin{cases} x_C = -BCc\theta_2 \\ y_C = -BCs\theta_2 \end{cases}$$
$$\begin{cases} x_D = x_C + CDs\alpha \\ y_D = y_C + CDc\alpha \end{cases} \tag{4}$$
$$\begin{cases} x_E = x_D + DEc(\pi - \theta_3) \\ y_E = y_D + DEs(\pi - \theta_3) \end{cases}$$

By combining the similar terms in formulas, the co-ordinates of point *E* corresponding to point *B* can be obtained [5].

$$\begin{cases} x_E = -BCc\theta_2 + CDs\alpha - DEc\theta_3 \\ y_E = BCs\theta_2 + CDc\alpha + DEs\theta_3 \end{cases} \tag{5}$$

where α is the angle between the connecting rod CD and the vertical direction. By co-ordinate operation, we can get:

$$AD^2 = \left(x_A - x_D\right)^2 + \left(y_A - y_D\right)^2 \tag{6}$$

Because the value of α is between 0° and 90°, the co-ordinate transformation can be realized, and then kinematics analysis is performed on the manipulator and its joints after the co-ordinate transformation [6].

Forward kinematics analysis

The forward kinematics analysis of manipulator is an analysis process using the link parameters and the joint variables to express the position equation of the end effector. The parallel mechanism has the error self-compensation. When solving the forward kinematics equation of new mixed-connection palletizing robot, in order to simplify the calculation, the small deflection angle of axis can be ignored and then its value is set as zero. The parallel part is serialized by co-ordinate operation. On the basis of co-ordinate transformation, the co-ordinate system of end flange plate corresponds to the base co-ordinate system through the co-ordinate system transformation between adjacent connecting rods. When joint angle θ_n is given, the position of the end flange of robot can be calculated, that is, the forward kinematics problem.

Error source analysis

In order to compensate the positioning error of robot, it is necessary to identify the actual value of kinematics parameter of robot, and then complete the compensation. The measuring process of positioning error is shown in fig. 2.

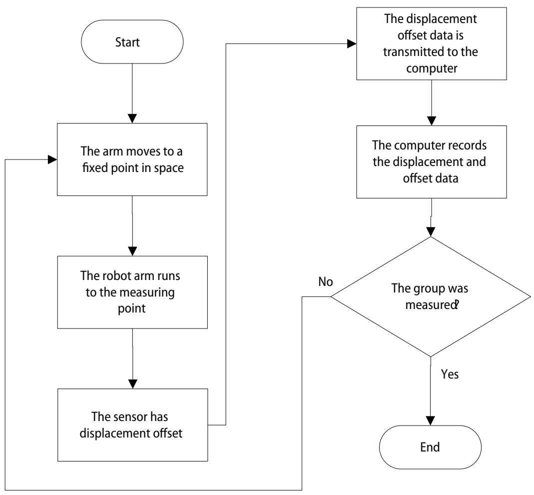

Figure 2. Flow chart of accuracy measurement for positioning error

According to the measurement process in fig. 2, the error of each step in the process of manipulator positioning is measured accurately. Meanwhile, the error source, static error, dynamic error and flexibility error are analyzed in detail. The type of positioning accuracy error is positioned to get the error distribution in the joint space, which is compensated based on different types of positioning errors.

Analysis of static error

The static error mainly refers to the error caused by the problems of sensor equipment in the process of manipulator positioning. The analog quantity angular transducer is influenced by temperature change, instability of power supply, electromagnetic interference noise and other environmental factors, so that there is a reading error between the sensor and the actual value of the detected object.

Dynamic error analysis

The dynamic errors generated in the process of manipulator positioning can be divided into three kinds of errors: the error caused by the extension of arm, the error caused by the expansion and contraction of propulsion beam and the error caused by the location of turnover mechanism.

Firstly, the telescopic mechanism of the main arm of manipulator is fully retracted. And then, the main arm and the propelling beam are leveled. The main arm and the propelling beam are dead ahead. After that, the initial height of root and end of main arm are recorded, and the positioning program of mechanical arm is started, and the arm extends slowly. Continuously, the height of end of main arm is measured, which is compared with the height of root. Meanwhile, the height difference between the front end and back end of bracket is measured to reflect the change of attitude angle of propulsion beam. In the same way, the error caused by the positioning of turnover mechanism and the expansion and contraction of propulsion beam is counted and calculated.

Flexibility error of manipulator

The flexibility error of manipulator comes from the deflection deformation of the connecting rod and the joint. The self-weight of the connecting rod and the external load will affect the positioning stability. The analysis of deflection deformation of connecting rod is relatively simple, which can be simplified into a deformation model of cantilever beam under uniform load. The moment effect of self weight of manipulator on the flexible joint always exists [7]. The corresponding flexibility error is coupled with the geometric error, but it cannot be obtained by changing the posture.

Achievement of positioning error compensation of manipulator

After the analysis results for the positioning error of manipulator are obtained, different types of positioning accuracy errors are compensated by different methods. Therefore, the compensation of the positioning error of manipulator needs three steps: compensation calculation, hardware compensation and software program compensation.

Calculation of compensation of spatial positioning accuracy

By inverse solution of equation, the theoretical value θ_i of each joint angle can be obtained when the end effector of robot reaches the desired position P [8]. Due to the influence of various error factors, the actual kinematics model of robot deviates from the theoretical kinematics model. When θ_i obtained by the inverse solution drives the robot, the actual position $P(\theta_i)$ of robot will deviate from the expected position P, namely the positioning error $\Delta R(\theta_i)$.

In order to compensate the error caused by model deviation, $-\Delta R(\theta_i)$ is given to desired position offset in advance, that is to say, $P-\Delta R(\theta_i)$ is used to calculate the inverse solution instead of P, and then the robot is driven with the joint angle $\theta_i - \Delta\theta_i$ obtained by the inverse solution. The positioning error $\Delta R(\theta_i - \Delta\theta_i)$ of robot at the working position $P-\Delta R(\theta_i)$ will cancel pre-bias $-\Delta R(\theta_i)$ out, so the actual position of robot will be close to the desired position, and the positioning accuracy of robot can be improved. Thus, the position error compensation of manipulator positioning is $\Delta R(\theta_i)$, and the positioning error compensation of posture rotation angle is $\theta_i - \Delta\theta_i$. If the first compensation does not reach the predetermined accuracy, the second compensation can be made based on first compensation. The actual position of robot will be closer to the desired position after the compensation is completed until the desired positioning accuracy is achieved.

Sensor hardware error compensation

The hardware compensation is a method to improve the positioning accuracy of manipulator by changing the control strategy of manipulator to form a fully closed-loop control system. The key to realize the closed-loop control of manipulator is to add a terminal feedback detection device. The laser tracker is used to measure the position of end-effector of manipulator in real time, and then the measured data are transmitted to the main control of manipulator and thus to achieve the full closed-loop control [9, 10]. The technology of image feature extraction and recognition is used to judge the actual position of end-effector of manipulator accurately, and the position co-ordinates are transmitted to the main control device to realize the full closed-loop control. The detection device realizes the full closed-loop control and error compensation of manipulator by installing many sensors at each joint of manipulator and comparing the real-time data of sensor and the theoretical data of each joint.

Contrastive experimental analysis

Data source

In order to prove the feasibility and validity of the self-compensation method for positioning error of intelligent synchronous mechanical arm, two different receivers were used to locate the position in real time at the same place and at the same time. Then, the positioning information was transmitted to the computer through sensors in real time and recorded. All the data generated by this position were used as the data source of simulation experiment. Based on the positioning data, the relevant error was processed, so that the relevant error compensation parameters of receiver were obtained.

Setting up initial environment and ideal positioning data

The *Y*-axis is parallel to the end of the pointing arm of robot forearm in the case of the initial position and posture of manipulator. Meanwhile, the origin point of the custom space co-ordinate system of robot was located inside the base, and its specific position was difficult to determine, and it had deviation with the robot co-ordinate system had established by simulation. Therefore, the distance error principle was adopted. The trajectory of target location of manipulator was established. The trajectory of manipulator was composed of eleven locating nodes. According to the experimental data of eleven measurement groups, the arithmetic mean error values in the space co-ordinate system were solved, respectively, and the error offset terms of these relative measurement platform were used as evaluation indexes for verifying simulation data.

Experimental process

In the simulation, the self-compensation method for the positioning error of manipulator and the traditional error compensation method were taken as the experimental verification objects. The traditional error compensation method was the contrast method in simulation experiment, and the proposed method was the experimental method. Different positioning compensation methods were used to compensate the existing errors. After that, the positioning results were measured again.

Analysis of experimental result

Based on the self-compensation method of the positioning error of mechanical arm, the positioning of mechanical arm was compensated. The compensation results were shown in tab. 1.

Table 1. Error statistics after compensation

Serial number	Average error in the *x*-direction	Average error in the *y*-direction	Average error in the *z*-direction
1	1.0085	0.3036	1.1192
2	1.0100	0.3202	1.1965
3	1.0191	0.3631	1.2080
4	1.0487	0.3179	1.2597
5	1.0581	0.2829	1.3031
6	1.0846	0.2741	1.3171
7	1.1197	0.2639	1.3860
8	1.1154	0.2410	1.4226
9	1.1712	0.2151	1.4498
10	1.1827	0.2006	1.4918

Meanwhile, the error statistics obtained by the traditional method after compensation were calculated, and error values on x, y, and z were aggregated. The direction problem during the position was ignored, and the error mean after compensation was calculated. The error values obtained by the two methods were compared. The comparison result was shown in fig. 3.

From the comparison curve in fig. 3, it can be seen that both methods can suppress the positioning error of the manipulator after compensation. The comparison results show that the average positioning error of the manipulator is 1.4 mm with the traditional compensation method and 0.2 mm with the self-compensation method. Through statistical calculation, the effective compensation rate of the traditional method is 30%, and the effective compensation rate of the proposed method is 90%. It can be proved that the method in this paper is more accurate and efficient. This is because the method in this paper can effectively compensate the positioning error of the robotic arm by using the inverse solution method of the equation and combining with the image feature extraction and recognition technology, which improves the accuracy and efficiency of the method and makes the performance of the method better.

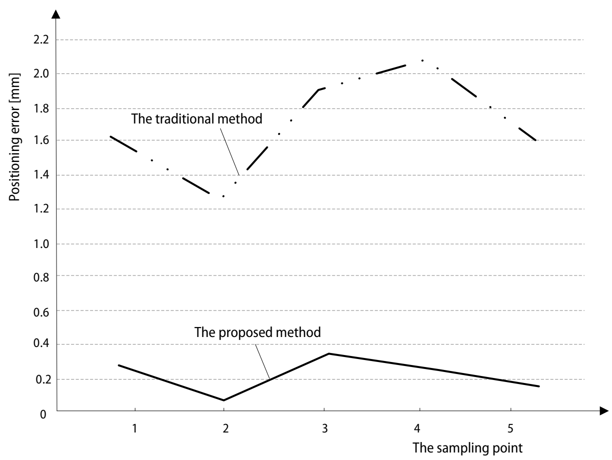

Figure 3. Curves of simulation experimental comparison

Conclusion

Aiming at the problems of poor accuracy and low efficiency of the traditional positioning method of the manipulator, this paper presents a method of automatically compensating the positioning error of the manipulator. The positioning model of the manipulator and the joint co-ordinate system of the manipulator are constructed. Combined with kinematics analysis, the positioning analysis of the manipulator is completed. By using inverse method of equation and image feature extraction and recognition technology, the robot arm positioning error is compensated. Experimental results show that the average positioning error of the method in this paper is only 0.2 mm, and the effective compensation rate of the self-compensation method is increased by 60%, which can effectively solve the control program problem that directly modifying the parameters of the robot controller cannot improve the positioning accuracy of the manipulator. However, there are many factors affecting the positioning accuracy of the robot, and there is still room for improvement of the absolute positioning accuracy of the manipulator, which will be further explored in the future research.

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