Studies on key technologies of improving the kinematic accuracy of series mechanical arm

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Abstract:
With the rapid development of economy and technology, China's industrial production domain has achieved substantial progress. Widely application of industrial robot has directly manifested this progress. Series mechanical arm can be one of core technologies of industrial robot. As the application environment of industrial robot is getting more complicated, the kinematic accuracy of series mechanical arm is attracting more attention in this domain. Thus this article has carried out specific research on key technologies of improving the kinematic accuracy of industrial robot in hope of bringing inspirations for relevant researchers.

Keywords: series mechanical arm; kinematic accuracy, key technology

1. INTRODUCTION

In China's industrial robot industry, series structure, parallel structure, and parallel serial structure are several common robot joint connection modes. Series structure among all is the mostly widely applied in China's industry domain. This article has carried out specific research on key technologies of improving kinematic accuracy of series mechanical arm, for the purpose of ensuring that series structure robot can better serve China's industrial development.

2.ANALYSIS ON ACCURACY OF SERIES MECHANICAL ARM

To complete this research with high quality guaranteed, we need to have an in-depth understanding of the accuracy of industrial robot's series mechanical arm. Table 1 has directly displayed factors influencing the kinematic accuracy of series mechanical arm. We can have a better understanding of how accuracy of series mechanical arm is produced. Influence by its feature that the structure and each axle are independent, series mechanical arm has an inherent feature of poor rigidity which will cause the accumulative expansion of various error with the increase of series joints. Thus the kinematic velocity and accuracy of series mechanical arm will be affected, application efficiency and quality of series mechanical arm will be reduced [1].

Table 1 Factors influencing the kinematic accuracy of series mechanical arm

Error	Composition
System	Rigidity and geometric error;
Random	Load error, vibration error;
System and random	Positioning deviation, reverse error, positioning dispersion;

2. MECHANICAL ARM'S MOVEMENT TRAJECTORY PLANNING

For series mechanical arm, change of location, speed, and accelerated speed during the implementation process of operation tasks will cause the reduction of kinematic accuracy of series mechanical arm, which means rapid and precise trajectory planning algorithm plays a vital role in improving kinematic accuracy of series mechanical arm. During, Cartesian space and joint space are both important contents in mechanical arm's movement trajectory planning. Considering article length limited, the author has only an in-depth analysis on trajectory planning of joint space.

Quintic polynomial interpolation algorithm is widely used in this domain. But there exist the deficiency in this algorithm, i.e. ignoring the limiting factor of joint trajectory. Thus this article has put forward a time optimal trajectory planning method. In the application of time optimal trajectory planning, the author has indicated the speed trajectory of space trajectory planning by quantic polynomial interpolation algorithm as $\dot{\theta}(\tau)=(\theta_f-\theta_i)\frac{1}{T}\dot{S}(\tau)$, and we can obtain $\tau=(t-t_i)(t_f-t_i)$ by converting this formula, and thus finally obtain $\dot{S}(\tau)=\frac{1}{2(\theta_f-\theta_i)}P$. Therefore simplify $\dot{S}(\tau)$ into a quadratic equation of τ , and the trajectory planning of this joint space can be realized with high quality guaranteed[2].

3.MECHANICAL ARM'S PARAMETER CALIBRATION AND COMPENSATION METHOD OF CONTROL VARIABLE

For series mechanical arm studied in this article, 80% errors belong to geometric errors, which make it of great significance to study the compensation method of mechanical arm's parameter calibration and control variable.

(1) Calibration of mechanical arm

Task operation in series mechanical arm can divided into continuous pose position change of its end effectors, which is reason why kinematic accuracy control of series mechanical arm is influenced by machining accuracy, assembly error, transmission error, abrasion, environment and other factors. To reduce the effect to the maximum extent, calibration method should be used in series mechanical arm. Table 2 has directly displayed the steps of this calibration method.

Table 2 Calibration steps of series mechanical arm

Step	Content
Step 1	Establish a kinematic model of series mechanical arm;
Step 2	Collect relevant data by using detecting techniques;
Step 3	Detect actual parameters of kinematic model through application algorithm;
Step 4	Confirm and apply actual kinematic model;

(2) Calibration algorithm of mechanical arm

After a brief understanding of mechanical arm calibration, we need to know calibration algorithm of mechanical arm. It is easy to find through combining with relevant document literature that, the purpose of calibration algorithm of mechanical arm is to obtain the optimal corrected value of geometrical parameters. Thus the author has directly displayed steps of this algorithm in table 3.

Table 3 Steps of calibration algorithm of mechanical arm

Step	Contents
Step 1	Confirm mechanical design values of each linkage of series mechanical arm according to D-H method;
Step 2	Confirm the theory location and pose position value of end effectors;
Step 3	Measure actually arrived location and pose position and set as data sample;
Step 4	Calculate position and pose position errors through comparison;
Step 5	Set position and pose position errors as the first generation population of GA;
Step 6	Calculate the position and pose position after regulation;
Step 7	Substitute result into genetic algorithm;
Step 8	Repetitive operation until obtaining the result satisfying GA;

(3) Compensation principle of control variable

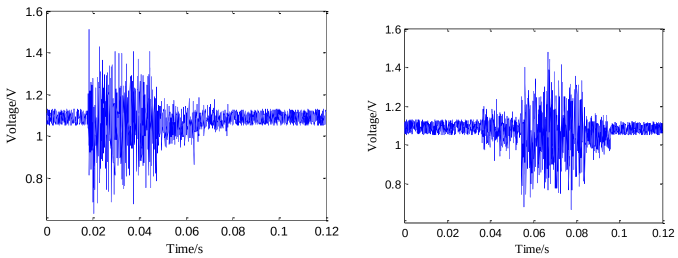
Represent the end pose position of series mechanical arm as $P = F(g(a,d,a),\theta)$, thus we can obtain $Pa = F(g(a_a,d_a,a_a),\theta)$, i.e. actual pose obtained under the control of theoretical rotation variable. Through further analysis, we can obtain the variable quantity of the pose of mechanical arm caused by tiny joint angle variable, i.e.:

$$\left[F(g(a,d,a),(\theta+\Delta\theta)) - F(g(a,d,a),\theta)\right] = \begin{bmatrix} J_{11} & \cdots & J_{16} \\ \vdots & \ddots & \vdots \\ J_{61} & \cdots & J_{66} \end{bmatrix}$$

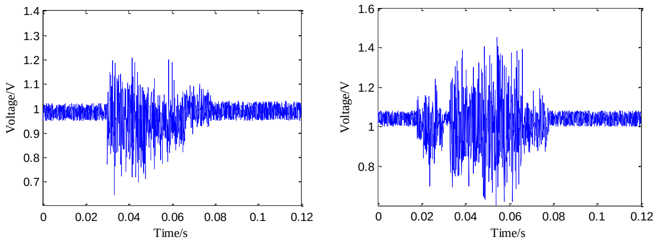
Jacobian matrix multiplication is used in the description of this variable. Its simplified description is shown as follows:

$$\begin{bmatrix} J_{11} & \cdots & J_{16} \\ \vdots & \ddots & \vdots \\ J_{61} & \cdots & J_{66} \end{bmatrix} = J$$

Considering linkage parameter of degree of freedom of series mechanical arm is given, we can apply NDI three-dimensional dynamic displacement measurement system for actual pose position measurement. In addition, take internal force and torque as incentive which is caused by the effect on the mechanical arm. By using the theory of mechanical admittance and different conditions, the vibration signal of mechanical arm is shown in figure 1. When considering the flexibility of joint, it equivalents to dimensional linear spring, which is expressed in figure 2.



(a) (b)



(c) (d)

Figure 1. Vibration signal of mechanical arm of various types of faults

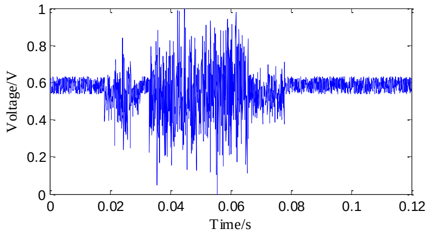
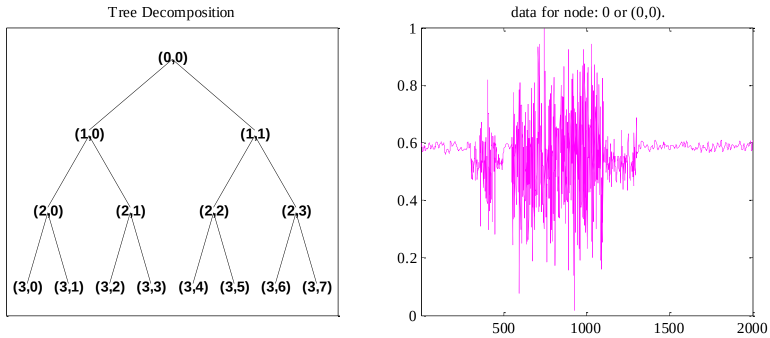


Figure 2. Standard vibration signal of mechanical arm spring falling off

Result of measurement as sample can aggregate genetic algorithm to obtain revised quantity of joint variable of mechanical arm, thus positional accuracy of series mechanical arm can be truly improved due to this. This method has high reliability and effectiveness. Based on the wavelet transform, wavelet base analysis is used to eliminate low amplitude noise and undesired signal. As shown in figure 3-4.



(a) (b)

Figure 3. Denoised vibration signals of the wavelet threshold function(Fig. A is a wavelet packet tree structure; FIG. B is a vibration signal that is denoised by a wavelet threshold function)

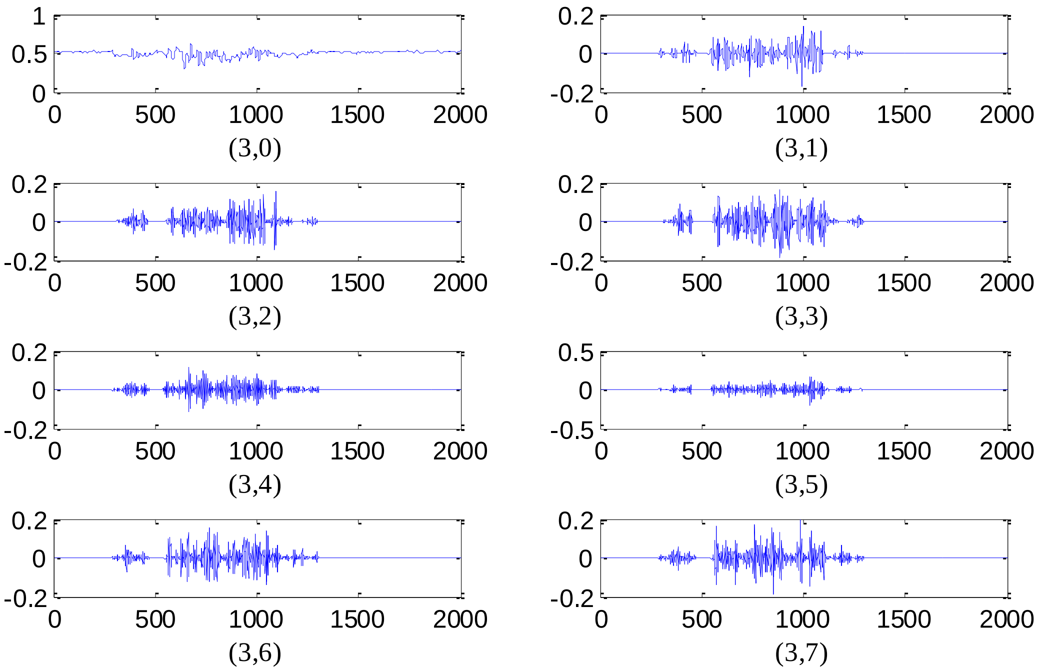


Figure 4. Reconstruction signals of the coefficient of various nodes

3.4Compensation algorithm of control variable

In the compensation algorithm of control variable related to series mechanical arm, table 4 has directly displayed steps of this algorithm. Thus we can deepen our understanding of mechanical arm's parameter calibration and compensation method of control variable. It is worth noticing that this algorithm can directly apply measurement data recorded in above mechanical arm's parameter calibration method.

Table 4.Vibration signal characteristic vector of robot arm under different conditions

X1	X1	X2	X2	X2	X2	X3	X3
1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.0032	0.0027	0.0025	0.0019	0.0013	0.0015	0.0022	0.0022
0.0017	0.0029	0.0027	0.0021	0.0009	0.0025	0.0021	0.0023
0.0022	0.0019	0.0017	0.0022	0.0015	0.0021	0.0023	0.0025
0.0022	0.0021	0.0029	0.0025	0.0012	0.0017	0.0020	0.0025
0.0027	0.0029	0.0023	0.0017	0.0015	0.0025	0.0025	0.0027
0.0027	0.0021	0.0022	0.0022	0.0013	0.0023	0.0022	0.0022
0.0027	0.0027	0.0025	0.0021	0.0009	0.0021	0.0023	0.0021

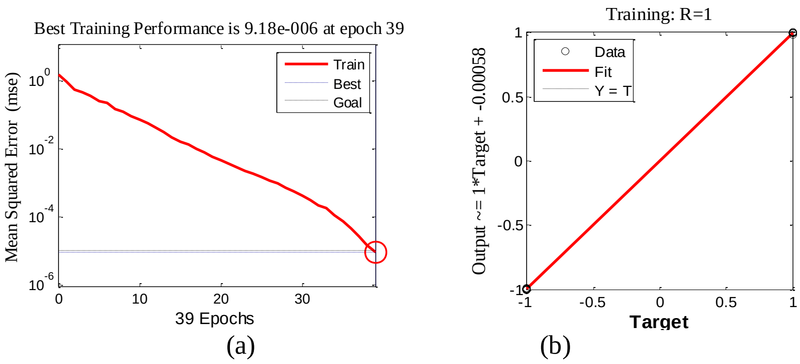


Figure 7.Results of the BP network training;a is results of network error changes; b is results of overall goodness of fit of network

Table 5 Steps of compensation algorithm of control variable

Step	Content
Step 1	Confirm kinematic model of DOF mechanical arm;
Step 2	Collect multiple groups of data as sample and apply to three-dimensional dynamic displacement measurement system;
Step 3	Use GA to search for optimal compensation value of rotation variable;
Step 4	Put compensation value into application and measure its feasibility and validity;

To complete this research profoundly, we should pay attention to the implementation steps of this compensation algorithm of control variable. Table 6-7 has provided a direct display of the implementation steps of this algorithm, which can help us have a deep understanding.

Table 6 Diagnostic test results of vibration signal characteristic vector of robot arm under different conditions

state	feature vector	Type encoding
normal	[1.0,0.0043,0.0017,0.0022,0.0022,0.0027,0.0027,0.0027]	[1,0,0,0]
normal	[1.0,0.0037,0.0029,0.0019,0.0021,0.0029,0.0021,0.0028]	[1,0,0,0]
normal	[1.0,0.0037,0.0024,0.0028,0.0040,0.0032,0.0035,0.0036]	[1,0,0,0]
Loosen	[1.0,0.0025,0.0027,0.0018,0.0029,0.0024,0.0023,0.0026]	[0,1,0,0]
Loosen	[1.0,0.0019,0.0021,0.0023,0.0025,0.0017,0.0032,0.0021]	[0,1,0,0]
Loosen	[1.0,0.0019,0.0024,0.0026,0.0028,0.0026,0.0029,0.0018]	[0,1,0,0]
Excessive	[1.0,0.0014,0.0009,0.0016,0.0012,0.0016,0.0014,0.0009]	[0,0,1,0]
Excessive	[1.0,0.0015,0.0026,0.0021,0.0018,0.0025,0.0024,0.0021]	[0,0,1,0]
Excessive	[1.0,0.0012,0.0020,0.0017,0.0016,0.0018,0.0013,0.0014]	[0,0,1,0]
Spring fall off	[1.0,0.0033,0.0031,0.0034,0.0030,0.0035,0.0033,0.0034]	[0,0,0,1]
Spring fall off	[1.0,0.0032,0.0034,0.0026,0.0026,0.0028,0.0032,0.0031]	[0,0,0,1]
Spring fall off	[1.0,0.0036,0.0042,0.0040,0.0045,0.0030,0.0033,0.0037]	[0,0,0,1]

Table 7 Implementation steps of compensation algorithm of control variable

Step	Content
Step 1	Calculate the theoretical rotation joint variable of mechanical arm;
Step 2	Apply NDI system to measure the actual arrival pose position of the end effector of mechanical arm;
Step 3	Set NDI measurement result as an GA individual and then constitute a group;
Step 4	Substitute corrected value and stop calculating after fitness function has satisfied the needs;
Step 5	Combine GA for loop operation until step 4;
Step 6	Obtain the last generation of GA application, thus we obtain the optimal revised solution of compensation algorithm of control variable.

4. CONCLUSION

In the research carried out on improving the kinematic accuracy of series mechanical arm, the author has firstly conducted in-depth analysis on the accuracy of series mechanical arm, and then carried out in-depth research on kinematic trajectory planning of mechanical arm, parameter calibration of mechanical arm, and compensation method of control variable and other key technologies of improving kinematic accuracy of series mechanical arm. Through the analysis of the experimental data, the author has found that internal parameters and external configuration have different levels of influence on vibration displacement of series manipulator, which has a large stable area. Due to the limitation of article length, the author still hopes that contents in this article can bring some enlightenments for relevant research personnel.

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