Research on Robot Joint Error Based on Neural Network

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ABSTRACT: Since the beginning of the 21st century, robots have played an important role in both daily life and industrial production. This paper aims to evaluate the types of robot joint errors. First, the types of robot joint errors are described, and the two characteristic indexes, $\Delta p$ and $\Delta R$, are identified. Next, robot joint errors are divided into adjustable ones and nonadjustable ones. A robot joint error type model is established using PB neural network model. The areas of adjustable joint errors and nonadjustable joint errors are defined. Finally, reasonable suggestions are given for different types of robot joint errors.

Keywords: joint error of robot adjustable and nonadjustable; PB neural network

1 INTRODUCTION

With the progress of science and technology, robots have become an important tool to replace human labor. In everyday life, they liberate man from repeated labor. In industrial production, they can perform high-risk, high-precision or heavy tasks. For this reason, research on robots has drawn wide attention. Modern research on robots started back in the Second World War with the intention to use them in the production of radioactive, toxic materials or materials hazardous to the human health. The manipulation accuracy of robots is directly decided by how flexible the robots are. Factors affecting the flexibility of robot joints include the joint clearance and the transmission system design, among which joint errors are an unignorable factor. As early back as the end of last century, people investigated the pose error of robots and concluded that robot joint errors are stochastic during work and cannot be resolved by calibration method. In 2003, researcher Song Y.E. et al examined the effect of joint clearance on the accuracy of robot movement using two-dimensional vector expression, and established the functional relationship between joint clearance errors and the accuracy of robot motion [1]. Besides, joint rigidity errors may also affect the accuracy of robot movement. In 2013, researcher Zhang X.P. made a study and established the mapping relationship between joint rigidity errors and the accuracy of robot movement, providing a theoretical base for identifying the rigidity behavior of robots [2]. In this paper, robot joint errors will be examined using neural network to provide theoretical basis for the design of robots.

2 JOINT ERRORS OF ROBOT

With regard to robot joint errors, there are two kinds of models: the MD-H model and the POE model [3-7], each having their respective scopes of application. Following is a description of the error characteristic indexes of the MD-H model.

The chain rule is an important theoretical base for robot joint error parameter models. Its model expression is shown in formula (1) below.

$$ i-1^T = \text{rot}(z_i, \theta_i) \cdot \text{tran}(0, 0, d_i) \cdot \text{tran}(d_i, 0, 0) \cdot \text{rot}(x_i, \alpha_i) $$

(1)

From Figure 1, when the adjacent rotary axes of rotation are nearly parallel, this model expression is
not complete. Hence error correction was made by adding $\beta_i$ as the correction factor to indicate the additional rotation around y-axis. This makes no difference to the essential of the model. The modified model is called the MD-H model as shown in formula (2) [4].

$$\begin{align*}
\Delta a_m = a_m - a_n = \sum_{j=1}^{42} \frac{\partial a_j}{\partial a_j} \Delta a_j = \left[ \frac{\partial a_1}{\partial a_1}, \cdots, \frac{\partial a_{42}}{\partial a_{42}} \right] \Delta a = H_a \Delta a \\
\Delta a_n = n_m - n_n = \sum_{j=1}^{42} \frac{\partial n_j}{\partial a_j} \Delta a_j = \left[ \frac{\partial n_1}{\partial a_1}, \cdots, \frac{\partial n_{42}}{\partial a_{42}} \right] \Delta a = H_n \Delta a
\end{align*}$$

(9)

Where: $\Delta p$ and $\Delta R = [\Delta n, \Delta o, \Delta a]$ is the error function [8-12]. When $\Delta p$ and $\Delta R$ are within a given limit, the robot joint error is an adjustable one; when they exceed this limit, the robot joint error is a nonadjustable one [13-14]. Next, we are going to evaluate robot joint errors using BP neural network.

3 NEURAL NETWORK MODEL

Neural network model was originated from neurobiology. Its calculation is similar to the reaction of neurons in biology as shown in Figure 2.

In neural network, the axon terminals contained in many different neurons can come into the dendrites of the same neuron and generate a large number of synapses. The neurotransmitters released by all synapses from different sources can make a difference to the membrane potential variation of the same neuron. This demonstrates the ability of neurons to spatially synthesize information. That is, neurons are able to synthesize different sources of information dendritically. Based on this ability, people have created artificial neuron model by simulating the reaction process of neurons as shown in Figure 3, where symbols are used as described in Table 1 [15-16].
Table 1. Description of symbols used in the mathematical model.

| Symbol | Description |
|--------|-------------|
| $x_1, x_2, \ldots, x_n$ | Input part of neuron, i.e. information transmitted from the upper level |
| $\theta_i$ | Threshold of neuron |
| $y_i$ | Output of neuron |
| $f[u_i]$ | Excitation function |

$f[u_i]$ decides the output form when the threshold $\theta_i$ is reached under the joint action of inputs $x_1, x_2, \ldots, x_n$. Figure 4 displays the images of two excitation functions, of which the second is used in our model.

![Excitation functions](image-url)

Figure 4. Typical excitation functions.

Here:

$$u_i = \sum_j w_{ij} x_j - \theta_i$$  \hspace{1cm} (10)

So

$$y_i = f[u_i] = f\left(\sum_j w_{ij} - \theta_i\right)$$  \hspace{1cm} (11)

Formula (2) is the full mathematical model expression of single neurons.

**BP neural network** is a multilayer feed-forward network that uses the minimum mean-square error calculation. When back propagation is applied to a multilayer feed-forward network, **Sigmoid** is used as the excitation function. The following procedure is used for the recursion of $w_{ij}$, namely the weight coefficient of the network. Assuming there are $n$ neurons on each layer, for neuron $i$ in layer $k$, there are $n$ weight coefficients $w_{ij}, w_{i2}, \ldots, w_{in}$. Besides, one more $w_{i(n+1)}$ is selected to indicate $\theta_i$. When inputting sample $x$, we take $x=(x_1, x_2, \ldots, x_n, 1)$.

1. Assign a value to $w_{ij}$. Assign a small non-zero random number to the $w_{ij}$ of each layer, and $w_{i(n+1)}=-\theta_i$.
2. Input sample $x=(x_1, x_2, \ldots, x_n, 1)$ and the anticipated output $y=(y_1, y_2, \ldots, y_n, 1)$.
3. Calculate the output of each layer. For output $x_a$ of neuron $i$ on layer $k$, we have
   $$y_i^k = f[u_i^k]$$  \hspace{1cm} (12)
   Here:
   $$u_i^k = \sum_j w_{ij} x_j^{k-1} - \theta_i^k$$  \hspace{1cm} (13)
   Here: $x_{i(n+1)}^1 = 1$, $w_{i(n+1)} = -\theta_i$
4. Derive the calculation error $d_i^k$ of each layer. For the output layer, $k=m$, we have
   $$d_i^m = x_i^m (1 - x_i^m)\sum_j w_{ij} x_j^{k-1} - \theta_i^k$$  \hspace{1cm} (14)
   For other layers, we have
   $$d_i^k = x_i^k (1 - x_i^k)\sum_j w_{ij} x_j^{k-1} - \theta_i^k$$  \hspace{1cm} (15)
5. Correct $w_{ij}$ and $\theta_i$. We have
   $$w_{ij}(t+1) = w_{ij}(t) - \eta d_i^k x_j^{k-1}$$  \hspace{1cm} (16)
6. After deriving the weight coefficient of each layer, we can determine if it conforms to the requirement according to a given standard. If the result is No, go back to step (3). Otherwise end the calculation.

### 4 EVALUATION RESULTS

A spot survey was carried out on nine processing jobs of a processing plant by selecting ten industry robots randomly from these jobs and calculating the errors according to the error calculation method described in Section 2. The errors of the jobs were equalized. The calculation results are presented in Tables 2 and 3.

#### Table 2. Robot joint errors (1).

| No. | 1   | 2   | 3   | 4   |
|-----|-----|-----|-----|-----|
| $\Delta p$ | 0.021 | 0.029 | 0.032 | 0.021 |
| $\Delta R$ | 0.044 | 0.036 | 0.047 | 0.061 |

#### Table 3. Robot joint errors (2).

| No. | 1   | 2   | 3   | 4   | 5   |
|-----|-----|-----|-----|-----|-----|
| $\Delta p$ | 0.039 | 0.042 | 0.043 | 0.047 | 0.052 |
| $\Delta R$ | 0.076 | 0.079 | 0.073 | 0.064 | 0.084 |
Figure 5 is the chart programmed on Matlab according to the calculation procedure of BP neural network. Here, “*” stands for the adjustable area of robot joint errors, and “O” is the nonadjustable area of robot joint errors. The type or robot joint errors can be determined simply by correlating the index parameters of the tested object to the distribution area of the characteristic values.

Occurrence of nonadjustable robot joint errors indicates problems with the robot joint design. The designer should properly check the design parameters and readjust any defective parameter to prevent inaccurate movement of the robot that may impair the work efficiency of the robot.

5 CONCLUSIONS

BP neural network model was applied to the evaluation of robot joint errors. Data were acquired by real survey and the evaluation reality was objectively reflected from the perspective of data. Compared with other evaluation schemes for error types, this evaluation model has wider application and easier operation. It is noted that, although BP neural network is widely used for evaluation, training errors have to be properly estimated for neural network. Once this error estimation is improper, the calculation result would be incorrect.

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REFERENCES

[1] Song Y.E., Wu L., Dai M. 2003. Analysis on the joint clearance errors of robots, Chinese Journal of Mechanical Engineering, 39(4): 11-14.
[2] Zhang X.P. 2013. Parametric Calibration Method and Empirical Research on 6DOF Joint Robot, Doctoral dissertation, Huazhong University of Science & Technology.
[3] Xiong Y, Xiong X. 2007. Algebraicstructure and geometric interpretation of rigid complex fixture systems. IEEE Trans. Autom. Sci. Eng., 4(2): 252-264.
[4] Seiji A., Masato S., Tomokazu T., et al. 2012. Calibration of kinematic parameters of robot arm using laser tracking system: Compensation for non-geometric errors by neural networks and selection of optimal measuring points by genetic algorithm. Int. J. Automation Technology, 6(1): 29-38.
[5] Alici G., Jagielski R., Sekercioglu Y., et al. 2006. Prediction of geometric errors of robot manipulators with Particle Swarm Optimization method. Journal Robotics and Autonomous Systems, 54(12): 956-966.
[6] Dumas C., Caro S., Cherif M. et al. 2010. A methodology for joint stiffness identification of articulated robots. IEEE/RSJ International Conference on Intelligent Robots and Systems, pp: 464-469.
[7] Mustafa K., Yang G., Yeo H., et al. 2008. Kinematic calibration of a 7-DOF self-calibrated modular cable-driven robotic arm. Proceedings IEEE Conference Robotics and Automation, pp: 1288-1293.
[8] Meng Y., Zhuang Q. 2007. Autonomous robot calibration using vision technology. Robotics & Computer Integrated Manufacturing, 23(4): 436-46.
[9] He B., Zhao J., Yang N., et al. 2010. Kinematic-parameter identification for articulated-robot calibration based on POE formula. IEEE Transactions on Robotics, 26(3): 411-423.
[10] Alici G., Shirinzadeh B. 2005. Enhanced stiffness modeling, identification and characterization for robot manipulators. IEEE trans. Robotics, 21(4): 554-564.
[11] Wang F. 2012. Parameter Identification and Fuzzy Control of Flexible Joint Robot, Doctoral dissertation, Beijing University of Posts & Telecommunications.
[12] Chaoui, H., P. Sicard, and A. Lakhsasi. 2004. Reference model supervisory loop for neural network based adaptive control of a flexible joint with hard nonlinearities. Proc. Canadian Conf. Electri. Comput. Eng., Vol. 4, Conf [C], 2029-2034.
[13] Chatlatanagulchai W., Meckl P.H. 2005. Intelligent control of a two-link flexible-joint robot, using backstepping, neural networks, and direct method. IEEE/RSJ International Conference on Intelligent Robots and Systems, pp: 1594-1599.
[14] Hong S.B. 2010. Mixed control scheme for the carrier attitude, coordinated multi-joint movement and active flexible vibration control of free-floating base flexible space manipulator with undetermined parameters. Journal of Vibration and Shock, 29(11): 94-255.
[15] Wang X.Y. et al. 2010. Mathematical Modeling and Mathematical Experiments. Beijing: Science Press.
[16] Zhong Y.Z. et al. 2010. Mathematical Modeling. Shanghai: Tongji University Press.