Survey on Robot Error Compensation Methods

Liwu Ma[1, a], Yongluo Liu[1, b], Wenqiang Wang[1, c]

[1]Shanghai University of Engineering Science, Shanghai 201600, China.

[a]337262585@qq.com, [b]1256994474@qq.com, [c]1550049326@qq.com

Abstract

Advanced measurement methods are used to measure the error of the end effector, and the robot model is established. The parameter identification method of the error model is used to accurately calculate the actual parameters of the model. By modifying the original system control algorithm of the robot or adding additional additional control algorithms. To compensate for the measured error.

Keywords

Industrial robot,Error compensation,Kinematics,Genetic algorithm.

1. Introduction

End positioning accuracy is an important performance indicator for industrial robots. With the increasing use of industrial robots in various industries, people have put forward higher requirements for end positioning accuracy. However, due to various error factors, there is always a certain error between the actual pose of the robot end and the corresponding theoretical pose. This error seriously affects the promotion of robot applications.

Generally, the end positioning accuracy can be divided into repeated positioning accuracy and absolute positioning accuracy. The repeat positioning accuracy describes the accuracy at which the end returns to the teach point. The absolute positioning accuracy is actually the closeness of the actual pose and the expected pose of the controller. There are two main ways and means to improve and improve the accuracy of robots in the design, manufacture, assembly and control of integrated robots:

(1) Prevention of errors. From the perspective of design and manufacturing assembly control, improve the rationality of the design, maximize the manufacturing and assembly accuracy, reduce the machining error and assembly error as much as possible, and try to use high-performance controllers to improve the control accuracy, so that from the source Reduce the error of the robot. However, limited to the actual production capacity and economy, this method has great limitations. In addition, this method fails the error caused by mechanical wear, environmental factors and dynamic factors.

(2) Compensation method for error. That is, the calibration method uses advanced measurement methods to measure the error of the end effector, and at the same time establishes the robot model, and uses the parameter identification method of the error model to accurately calculate the actual parameters of the model, by modifying the original system control algorithm of the robot or adding extra An additional control algorithm to compensate for the measured error. This method can achieve the purpose of improving the accuracy of the robot, but can only compensate some error sources (such as the parameter error caused by the static factors of the connecting rod), and the cost is low, which is the main way to compensate the robot error.

2. Industrial Robot Error Compensation Technology

Industrial robot error compensation technology usually includes four parts: kinematics modeling, pose measurement, parameter identification and error compensation. For the configuration of the robot, selecting the appropriate kinematic model and measurement scheme is the premise of calibration. Kinematic modeling refers to the process of establishing a mathematical model that describes the relationship between the geometrical characteristics of the robot and the end motion. The pose measurement is the process of acquiring the coordinates of the end effector in the reference coordinate system. Parameter identification is the process of solving the actual structural parameters of the robot for the established calibration model. Error compensation refers to the process of updating the kinematics model according to the actual structural parameters of the robot or modifying the controller control scheme to minimize the end pose error.

Error compensation is the most critical step for robot calibration. Generally, the joint angle is obtained by inverse kinematics, and then the Newton-Raphson method is used to compensate the joint angle to achieve error compensation. The N-R method achieves accurate calculation by iterative method, but there are defects, the calculation amount is large, and it is difficult to achieve fast compensation. There are two main types of error compensation methods: kinematics-based methods and workspace-based interpolation methods. According to the different compensation objects, there are mainly two compensation methods based on kinematics model:

(1) Joint space compensation: It is considered that the end pose error is caused by the code wheel error, and the error is directly corrected in the joint space of the robot, thereby improving the pose accuracy.

(2) Differential error compensation: It is considered that the end error is due to the slight deviation of the rod, and the error is compensated to the nominal parameter of the rod, so as to achieve the purpose of precision compensation. Workspace-based interpolation requires measurement of the pose of a particular mesh point in the robot's workspace at the end of the robot. Interpolation techniques such as bilinear interpolation and polynomial fitting are used in the workspace to fit joint compensation commands corresponding to different positioning errors.

3. Kinematics Based Error Compensation

In terms of error compensation methods, many scholars have proposed related methods. Omodei et al. proposed a compensation method, adding a round bar at the end of the robot, and then driving the robot so that the round bar is inserted into the calibration plate with 81 holes in a known spatial position one by one, and the corresponding joint reading and the teaching instrument reading are recorded. Then according to the actual pose of the hole, the positioning error of the end can be calculated, and the calibration of the robot is realized. In addition, Omodei et al. use the laser triangulation method to add a mirror at the end to measure the deviation of the trajectory when the robot moves along the specified trajectory. In the parameter identification process, nonlinear optimization, linear iteration, The three methods of extended Kalman filtering are carried out. After comparison, the extended Kalman filter method has less computational complexity, better reliability and stronger robustness than the traditional least squares method. Khalil et al. proposed a general method to identify the parameters of the robot, considering the robot position variable and the workpiece position variable, and solved the problem of the optimal configuration of the robot in the identification process. Tang et al. used a flat panel system to measure the pose of the robot. By placing the flat plate on the XY plane and then bringing the test piece at the end close to the flat plate, a part of the end pose matrix calculated by the forward kinematics is known. Based on this information, a system of equations can be established. Ikits et al. made some corrections to the Tang method, re-established the base coordinate system, calculated the chi-square function of the parameter error using the maximum likelihood estimation, and then obtained the actual structural parameter value by the optimization method. In recent years, with the popularity of laser tracking systems and the maturity of image processing algorithms, some new calibration algorithms have been proposed. Nubiola et al. used a 29-parameter calibration model to calculate the optimal value of the structural parameters using the minimum mean square error based on the data collected by the laser tracker. Sargeant defines the reference coordinate system of each joint and camera in the field of view of the network camera, forms an atlas according to the trajectory of the robot, and then extracts a set of equations from the model, and uses the iterative method to calculate the unknown variables. Aghili uses a kinematic closed-loop approach to add additional kinematic parameters to the internally constrained internal joints, solving the problem of adaptive control of multi-machine collaboration. This technique requires no precise sensors and observation equipment. Economic advantage. Santolar et al. used a circumferential point analysis method of probability propagation calculation to evaluate the accuracy of the calibrated manipulator.

Zhang Qixian et al. first paid attention to the problem of industrial robot error analysis in China, and gave the probability analysis of error and Monte Carlo simulation . Cai Hejun et al. realized the recognition and simulation of kinematic structural parameters based on MDH model and differential transformation relationship . Jiao Guotai gave a formula for calculating the end pose error based on the structural error of industrial robots . In terms of error model, Zhou Xuecai et al. proposed a distance error model without coordinate system transformation ; Zhu Wei studied the error compensation technique based on MDH model . In terms of calibration tools, relevant scholars have also proposed different methods, such as based on planar templates, based on spatial interpolation, based on plane accuracy, based on distance error, based on calibration balls, and based on hand-eye calibration , this method The similarity is that the complex nonlinear relationship in the calibration process is transformed into a relatively simple linear relationship for processing, which simplifies the calculation. Ye Shenghua et al. used laser tracker to achieve calibration and error compensation for structural parameters . In terms of visual calibration, Lu Yiting used a monocular camera as the main measurement tool, and used the relationship between the camera coordinate system and the robot end effector coordinate system for hand-eye calibration; Wang Shoukun and others used the group intelligence optimization algorithm to achieve visual calibration.

4. Neural Network Based Error Compensation

With the rise of artificial intelligence, related algorithms have also been applied to the robot calibration. Real-time error compensation based on neural network. The artificial neural network has strong self-learning and self-adaptive ability, and has large information storage capacity and good fault tolerance. It can realize parallel association search solution space and complete adaptive reasoning. Therefore, the neural network is used as a tool for robot error compensation. Through the training, the action law of the robot error source is obtained, which not only overcomes the difficulty of selecting the error model but also improves the real-time performance of the error compensation. The disadvantage of this method is that the measurement workload is large. According to its compensation principle, it can be roughly divided into the following two compensation channels:

(1) Neural network compensation of joint coordinates. The process is shown in Figure 1. The desired Cartesian coordinate position is obtained by kinematic inverse solution to obtain the joint angle. After the joint angle error is found by the BP network, the robot is driven by the sum of the two to compensate the error.

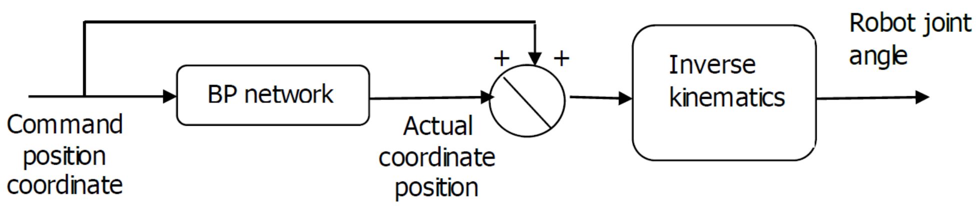

Fig 1. Neural network compensation of joint coordinates

(2) Neural network compensation for Cartesian coordinates. As shown in Fig. 2, the appropriate joint angle is first given, and then the kinematic inverse solution is performed, and the positioning error can also be compensated. The magnitude of the offset is determined by the BP network.

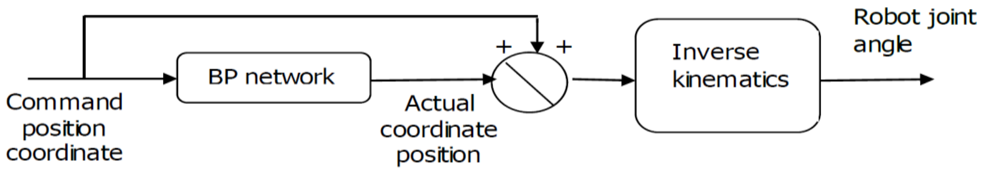

Fig 2. Neural network compensation for Cartesian coordinates

Angelidis et al. used artificial neural networks to predict and compensate for end pose errors in off-line programming . Hosseininaveh has designed a stereo imaging network for non-standard six- degree-of-freedom robots, using particle swarm optimization to solve the inverse kinematics of robots . Aoyagi uses artificial neural networks to compensate for non-geometric errors and selects the best observation points based on genetic algorithms . Nguyen uses extended Kalman filter (EKF) to identify geometric parameters and artificial neural networks (ANN) to compensate for non-geometric errors . Dabbagh uses the fuzzy adaptive (FA) algorithm to optimize the differential evolution (DE) algorithm, and then based on FADE to propose a dynamic parameter identification framework for predicting the centroid parameters of the CRSA456 robot, which is better than the traditional method.

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