Journal of Engineering Mechanics and Machinery (2023)
Clausius Scientific Press, Canada

DOI: 10.23977/jemm.2023.080304
ISSN 2371-9133 Vol. 8 Num. 3

Research on a Machine Measurement Calibration Method Based on Laser Displacement Measurement

Liu Hai

Wuchang Shouyi College, Wuhan, 430064, China

Keywords: Laser displacement measurement; Machine measurement; Calibration method

Abstract: Large irregular thin-walled components such as aviation structural components and aerospace structural components have large size specifications, complex structures, multiple machining features, and high accuracy requirements. During the machining process, the workpiece is prone to deformation, and product inspection and quality control are extremely important. In the operation process of industrial robot processing systems, frequent replacement of end tools and various vibrations and collisions during processing can cause tool positions to shift. Therefore, before operating the processing system, it is necessary to implement reasonable calibration of the true position of the end tools of the robot to ensure that the processing system has the necessary positioning accuracy. The use of traditional methods for error calibration of sensors without considering the measurement and processing of sensor displacement information leads to large errors in nonlinear error calibration results and poor calibration results. In response to this issue, this article proposes a method of using laser displacement sensors to autonomously calibrate the robot tool coordinate system. The principle is simple, reliable, highly automated, and easy to implement. This method achieves synchronous movement of the laser displacement sensor and the digital height gauge by developing a synchronous measuring fixture device, and eliminates installation errors by using a two axis fine adjustment device.

1. Introduction

With the development of modern industry, displacement measurement has become increasingly important in production and processing. Laser displacement measurement can accurately measure the position, displacement, and other changes of the measured object. It is mainly used in measuring geometric quantities such as displacement, thickness, vibration, distance, diameter, etc. Compared with traditional measurement methods, it has advantages such as high sensitivity, strong resistance to electromagnetic interference, corrosion resistance, and small volume [1]. The existence and development of sensors have made important contributions to the progress of scientific research in China. However, with the continuous deepening of research in high-precision and cutting-edge fields, the requirements for measurement technology accuracy and speed are increasing. The actual and theoretical characteristics of sensors currently used may have certain deviations, resulting in nonlinear errors and a decrease in measurement accuracy. Therefore, in order to ensure measurement accuracy, it is necessary to calibrate the sensors before each measurement [2]. Laser displacement sensors are an emerging non-contact measurement tool widely used in precision displacement detection, precision component measurement, and rail transit. It has the characteristics of strong adaptability, fast speed, and high accuracy, and is mainly used for measuring geometric quantities such as object displacement, thickness, vibration, diameter, etc. [3]. Laser displacement sensors are widely used in fields such as laser displacement control and target detection. Design automatic calibration algorithms for laser displacement sensor ranging to optimize sensor design and improve the target detection and recognition capabilities of laser sensors. Laser displacement sensors are generally installed on large instruments and equipment, and the displacement is displayed as a parameter, requiring on-site calibration and error compensation. The principle of its application is laser triangulation, and in recent years, many scholars have conducted in-depth research and achieved a lot of results. The laser triangulation method can achieve non-contact and high-precision displacement measurement, and is widely used in precision displacement measurement [4].

With the continuous improvement of automation in the manufacturing industry, the popularity of industrial robots is also constantly increasing. In practical applications, industrial robots mainly rely on various tools assembled in the end flange to complete corresponding machining target tasks [5]. Once the selected tool is assembled, its position transformation relationship relative to the robot's end coordinate system is determined. The standard gauge block commonly used in length measurement has a high flatness and smoothness on its working surface, which is a mirror reflection and cannot calibrate laser displacement sensors [6]. In practical applications, deviations in tool assembly positions, collisions in robot system operations, and machining vibrations can cause deviations between the actual position of the tool and the predetermined position. This can lead to a decrease in the accuracy of the calibrated tool coordinate system, resulting in the robot system's machining accuracy not meeting the technical requirements, and may even affect the normal operation of the production line, resulting in waste of time, funds, and raw materials. In laser displacement measurement, one-dimensional position sensitive devices (PSD) are often used as displacement detection devices. PSD devices provide current output with small output signals, usually at the microampere level. Therefore, the design of amplification and driving circuits plays a crucial role in the accuracy and stability of system displacement measurement [7]. On the basis of Big data sampling and information fusion of laser displacement sensor information, the design of laser displacement sensor ranging automatic calibration is to build Big data analysis model of laser displacement sensor ranging automatic calibration, and combine multi-dimensional information analysis method to restructure Big data feature space to improve the ability of laser displacement sensor ranging automatic calibration.

2. Measurement Principles and Calibration Methods of Laser Displacement Sensors

2.1. Measuring Principle

The laser is directed towards the surface of the measured object through a lens, and the reflected laser is received by the internal CCD camera through the receiver lens [8]. Based on the angle change and the distance between the known laser and camera, the distance between the displacement sensor and the measured object can be calculated, as shown in Figure 1.

The principle of laser triangulation is that the laser emitting point, target point, and receiving point form a triangle, and the position of the target point is calculated by knowing the angle and position information of the emitting point and receiving point [9]. In the laser displacement sensor, there are mainly two optical systems, one is the laser exit system, and the other is the Photosystem. The beam emitted by the laser is collimated by the lens and then shines onto the surface of the measured object. The scattered light from the measured surface is projected onto the PSD photosensitive surface through the imaging lens. During the process of object movement, in order to ensure that the image points are always clearly projected onto the PSD photosensitive surface and meet the imaging formula, the optical path design must also comply with Scheimpflug's law, which means that the laser axis, imaging lens plane, and PSD imaging surface intersect at a point. The output system in laser sensors is widely used in the form of a laser with an aperture. Its function is to generate stable and uniform light points that illuminate the measured object. This light point cannot be too large or too small. If the light point is too large, the height of the surface of the measured object illuminated by the light point will change, and the image formed in the camera will have significant interference. If the light point is too small, the brightness of the image formed by the receiving lens is weak, which can lead to significant errors in calculating the position of the centroid of the spot due to environmental noise.

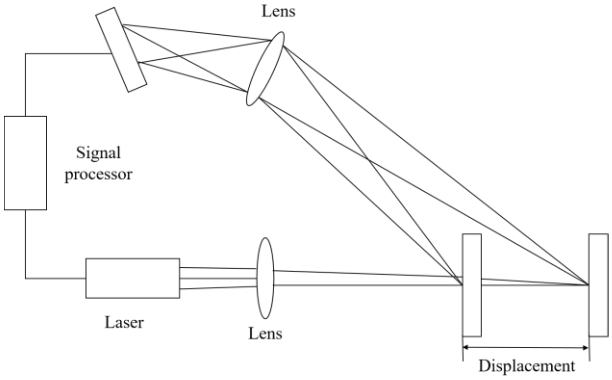

Figure 1: Measurement principle of laser displacement sensor

2.2. Calibration

For laser displacement sensors with a measurement range of 10-200mm and an accuracy of ±2%, a digital height gauge with a graduation value of 0.01mm, a measurement range of 0-300mm, and a maximum allowable error of ± 0.04mm is used. In the diffuse reflection installation method, the incident light emitted by the sensor is vertically projected onto the surface of the object, and then reflected back to the CCD image surface of the sensor. The height of the measured object surface is determined based on the position of the CCD imaging height direction. The height measurement range of the sensor is related to the sensing range of the CCD. If the center position of the CCD height direction is set as the measurement center of the sensor, the maximum height pixel value of the CCD determines the measurement limit space. The accuracy of sensor height measurement depends on the number of pixels per unit area (image resolution) of the CCD image. The more pixels per unit area, the higher the image resolution, and the higher the height measurement accuracy [10].

3. Calibration Method for Robot Tool Coordinate System

3.1. Tool Automatic Calibration Method Based on Laser Displacement Sensor

At present, research on tool coordinate systems mostly adopts the multi-point calibration method. Traditional robot parameter calibration usually requires the use of expensive and complex industrial equipment such as laser trackers and coordinate measuring machines. One of the characteristics of automated calibration of tool coordinate systems is that there is basically no need for robot control during the calibration process; However, in actual calibration, without manipulation and calibration, calibration accuracy cannot be guaranteed. In practical applications, linear Structured light 3D sensors and translational scanning mechanisms are often used together to measure flat objects. This method has been widely used in flaw detection, quality control, geometric dimension measurement, positioning and assembly. However, before use, it is necessary to unify the scanner mechanism coordinate system and sensor coordinate system, that is, calibrate the scanning direction of the scanning mechanism. The TCP multi-point calibration method is used by a robot to move the TCP from multiple directions to the same point and obtain the TCP position through operation, which is the position of the robot tool coordinate system origin relative to the robot end coordinate system. TCF multi-point calibration is achieved by controlling the end of a robot tool to reach several specific calibration points in space, and calculating the posture of the robot tool based on the positional relationship of the calibration points.

This article uses a low-cost and easy-to-use laser displacement sensor to indirectly measure the external information of the cube calibration object, and uses multiple measurement points for multi plane fitting and multi plane angle constraints. The multi-point calibration method includes two parts: TCP multi-point calibration (3-6 points) and TCF multi-point calibration. When using the multi-point calibration method for TCP point position calibration, the tool end needs to be moved to a fixed position; However, in actual calibration, without manipulation and calibration, the TCP points of uncalibrated tools cannot be moved to the fixed position in the robot space, indicating that the six point calibration method cannot meet the needs of autonomous calibration. The positioning accuracy of robots is one of the most important indicators to measure their performance. Its repeated positioning accuracy is mainly affected by joint control errors, and robots currently used domestically and internationally can generally reach the submillimeter level. A tool automatic calibration method based on laser displacement sensors. In practical application, the corresponding sensing element coordinate system is placed in the robot's spatial dimension chain, and the posture correlation measured by the tool in this coordinate system is converted into posture correlation in the end coordinate system, thereby achieving the calibration goal.

3.2. Comparative Experiment

In the actual machining process, currently only manual multi-point calibration method is used to determine the position parameters of tool TCP for tools. The laser source used in the experiment is a tunable red laser module, with a laser source power of 150W and a laser wavelength of 650nm. For the convenience of testing, a straight line light source with a line width of 2nm is selected, and the distance between the laser light source and the PSD device is 22.9nm. Usually, when assembling robot end tools, the tools need to be located in different positions to implement multi-point calibration. Based on manually calibrated TCP position data, the actual effectiveness of this automatic calibration scheme is evaluated by comparing the automatic calibration data with the reference data. In the calibration experiment, a precision displacement platform with a resolution of 0.001mm is used, moving a fixed distance each time. The system controls the sliding table to move in 2mm steps, covering the effective photosensitive area length of the PSD device from 0 to 15mm. Each step of movement records the output voltage of the I/V signal conditioning circuit and the displacement value measured by the system. In this experiment, the robot was manipulated to move the end tool to 5 positions, and the TCP position calibration results obtained are shown in Table 1.

The results of automatic calibration are basically consistent with those of manual calibration, with an average deviation of 1.55mm, which can be used in robot applications with general accuracy requirements. At the same time, the automatic calibration scheme takes about 1 minute to complete the calibration process, while the manual calibration method usually takes about 10 minutes, greatly improving the calibration efficiency, thus proving the effectiveness of the tool coordinate system automatic calibration scheme.

Table 1: Calibration results of the tool coordinate system with TCP multi-point calibration method

Number	Automatic calibration results/mm	Manual calibration results/mm	Gap in calibration results/mm
1	[18.875,0.112,329.278]	[15.975,0.289,338.385]	2.368
2	[5.437,-15.727,321.786]	[6.737,-13.782,334.562]	0.795
3	[0.319,-25.547,327.216]	[0.886,-21.019,328.455]	1.529
4	[2.316,-27.825,329.216]	[2.369,-29.016,330.912]	1.211

4. Conclusions

For the TCP multi-point calibration method commonly used in robot processing applications, this article analyzes its shortcomings that are difficult to meet automated operations. For the TCP calibration of industrial robots, a strategy is proposed to use laser displacement sensors to achieve autonomous calibration of robot tools. The effectiveness of this method is verified through comparative experiments of manual and automatic calibration. The automatic calibration method for laser displacement sensor ranging reduces the error of automatic calibration by optimizing the sensor displacement parameters, and has high practical applicability. Compared with traditional methods, the calibration process error of this method is smaller and the calibration effect is better. This method is suitable for on-site calibration of laser displacement sensors, with simple operation and good economy, and can be well applied in displacement measurement. The proposed method in this article can meet the needs of sensors in technological development and help China achieve more excellent results in the field of high-precision and cutting-edge technology.

Acknowledgements

Scientific Research Plan Guiding Project of Education Department of Hubei Province<< Development of a multifunctional non-contact static error measuring platform>>Project No: B2014257.

References

[1] Shao Xin, Ji Li, Zou Huaiwu, Xie Yangmin. A parameter calibration method of manipulator based on laser displacement measurement [J]. Journal of Beihang University, 2022, 48(11):2281-2288.

[2] Zhou Yu, Li Yue, Li Weiping, et al. Design and calibration of laser displacement sensor [J]. Sensors and Microsystems, 2020, 39(11):4.

[3] Dai Jie, Ma Liqun, Gao Ting, et al. Calibration method of pixel equivalent of line laser displacement sensor [J]. Measurement technology, 2019, 39(6):5.

[4] Zhao Lihua. Research on automatic calibration method of laser displacement sensor based on big data analysis [J]. Laser Journal, 2019, 40(11):4.

[5] Liu Changwen, Duan Fajie, Li Jie, et al. Scanning direction calibration method of linear structured light 3D sensor [J]. China Laser, 2023, 50(5):0504001.

[6] Chen Wei, Ye Songtao, Zhang Haiyang, et al. A calibration method of robot tools based on laser displacement sensor [J]. High-power converter technology, 2020(003):000.

[7] Yuan Xin, Jing Genqiang, Peng Lu, et al. On-line calibration method and system design of laser projection displacement meter [J]. Chinese journal of scientific instrument, 2019(6):8.

[8] Li Jiaqi, Li Jing. Design of laser displacement measurement system based on FPGA [J]. Industrial Control Computer, 2019, 32(8):2.

[9] Wang Zhichao, Mao Liwei, Zhang Manshan, et al. Calibration method and uncertainty analysis of laser displacement sensor based on digital display height ruler [J]. Metrology, 2019(9):3.

[10] Fan Yuan, Wu Shenjiang, Hao Dongjie. Precise measurement of micro-displacement by direct laser triangulation [J]. Journal of Xi 'an University of Technology, 2018, 38(1):5.