An Optical based Non-Contact Five-Axis Machine Tool Calibration IOT System

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***Abstract*—Cutting tool machining quality and accuracy calibration has always been an important indicator of the performance of machine tools, machine tool testing technology is particularly the key point. In this paper, an optical based non-contact five-axis machine tool calibration system with IOT feature is presented. It can be obtained once the three-dimensional detection signals, combined with embedded systems for data calculation and communication using Wi-Fi wireless. Test hardware includes two sets of laser light source, two sets of photoelectric sensors and spherical lens and DSP processor. The proposed calibration IOT system has simple for setup, low cost, high precision features for calibration five-axis motor and static error.**

Keywords: Five-Axis Cutting Tool Machine, Calibration Algorithm, IOT, Sensor, Non-Contact.

I. Introduction

Today's industrial technology continues improved; machine tool industry has been gradually replaced traditional three-axis machine tools by multi-axis machine tool. Five-axis machine tool is composed of three linear axes and two rotating shafts, the machine has a multi-directional machining capabilities for continuous, smooth and complex surfaces such as molds or turbine blades.

However, the quality and precision of cutting tool machining has always been an important task to measure the performance of machine tool. The roots that affect the accuracy of machine tool can be divided into static and dynamic errors. The static error may come from the geometrical error of assembly structure or the deflection of work platform degree of error and thermal deformation, and dynamic error is generated during the movement error is caused by the servo motors, ball screw, encoder and lubrication system.

In order to improve the cutting tool machining accuracy, the basic measurement technology is particularly important. Since five-axis machine tool has in addition two election shaft compared to three linear axis, the calibration for achieving the standard accuracy is relative difficulties. There are many different methodologies for five-axis error detection equipment such as Probe-Ball, DBB, IBS R-test and others [1-10], these devices are effective for five-axis machine tool geometric error analysis and compensation, but the above-mentioned equipment are all contact system error is not easy to measure the separation and equipment erection, measurement time is also longer and more expensive. In this paper, an optical IOT based five-axis method calibration for cutting tool is presented, it combined Wi-Fi communication function at a low-cost DSP system for data calibration and calculation. It allows users to shorten the adjustment time of the cutting machine tool.

This paper is organized as: Cutting tool machine calibration algorithm will be introduced in Section 2. The architecture of the proposed sensor architecture and implementation results are shown in Section 3. At the end, Section 4 concludes this paper.

II. Calibration Algorithm

Since the proposed measurement device received the displacement characteristics of the laser beam through the four-quadrant photoelectric sensor, the laser beam penetrates the ball lens and is focused and imaged by the principle of optical imaging onto the four-quadrant sensor. The spot will be at four quadrants were irradiated to different sizes, and the quadrant will output the corresponding current signal as shown in Fig. 1. After that, the analog voltage is converted to a digital signal by 16-bit ADC, and finally calculated by the DSP. Light spot position calculated by the four-quadrant voltage value obtained in accordance with the Eq. (1) to calculate the x-axis and y-axis position, respectively. When the sensor and the laser and the machine tool X-axis vertical formula is the machine tool X-axis changes, when the sensor and the laser and the Y-axis machine tool perpendicular to the formula that is Y-axis machine tool changes, the Eq. (2) is the machine Z-axis variation.

$$x = \frac{(A+D)-(B+C)}{A+B+C+D} \quad (1)$$

$$y = \frac{(A+B)-(C+D)}{A+B+C+D} \quad (2)$$

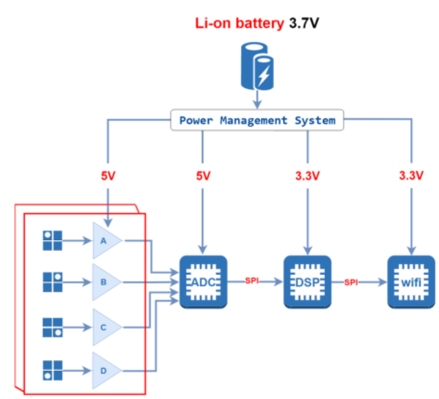
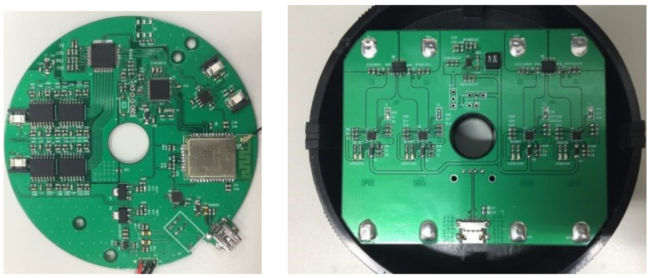


Fig. 1, The architecture of optical based non-contact machine tool calibration IOT system.

III. SYSTEM ARCHITECTURE

The proposed measurement IOT system, through the mutual coordination of optical components, for multi-axis machine tool dynamic / static detection, the system hardware includes two sets of laser light source, two sets of photoelectric sensors and spherical len, ball seat, digital signal processing unit. Signal processing unit consists of OPA amplifiers, 8-chanel synchronous ADC with 16-bit resolution, a 32-bit DSP micro-controller and Wi-Fi module, as shown in Fig. 2.



(a) Sensor Main Board (b) Power Mamagment Unit

Fig. 2, PCB Design of the presented IOT non-contact machine tool calibration kit [11-12].

When the laser light source emits a beam expander and penetrates the spherical lens, the laser spot will fall on the four-quadrant sensor. Through the signal processing unit, the photoelectric sensor signal is amplified by the OPA signal, and the analog signal is converted by 8-chanel synchronous ADC channel using SPI transmitted to 32-bit micro-controller to calculate the laser spot falls on the four-quadrant sensor position, the measurement results is forward to back-end server thought the Wi-Fi module, and finally processing the received signal in remote site to obtain multi-axis machine error for further calibration usage.

When there is no error in the machine tool, the laser beam penetrates the ball lens and is focused and imaged by the principle of optical imaging. The laser spot will fall on the center point of the four-quadrant sensor. If there is an error in the machine tool, Focusing and imaging by the principles of optical imaging, the laser spot will fall above or below the four-quadrant sensor's sensing range, as shown Fig. 3.

A multi-axis machine tool is obtained by receiving two sets of four-quadrant sensors to receive the displacement characteristics of the laser beam to sense the relative movement between the input beam and the sensed receiving surface, and calculating and analyzing the spherical lens center position of error, and then to provide a convenient assembly and low cost multi-axis machine tool detection device.

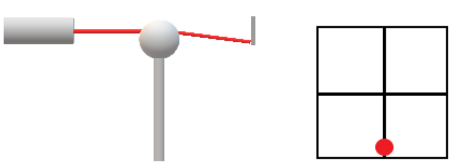


Fig. 3, Errors in y-direction.

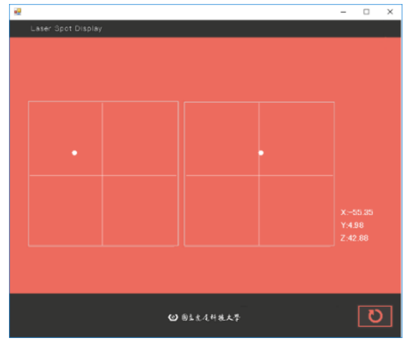


Fig. 3, Remote measurement results via wireless communication method.

IV. CONCLUSION

In this paper, an optical non-contact sensor system is developed. It performs a single-axis slow movement of small stroke, which can quickly and accurately detect the relative linear movement of the five-axis machine tool. The system has the following advantages: 1) The system is easy to set up. 2) Three-dimensional detection signal can be obtained at the same time, increase the detection speed 3) Low cost and different multi-axis machine tool error algorithm based on software calculation can be achieved.

REFERENCE

[1] J. Peters et. al., "*Contribution of CIRP to the development of metrology and surface quality evaluation during the last fifty years*", CIRP Annals Manufacturing Technology, vol.50, no.2, pp. 471-488, 2001.

[2] H. Schwenke, W. Knapp, H. Haitjema, A. Weckenmann, R. Schmitt and F. Delbressine, "*Geometric error measurement and compensation of machines—an update*", CIRP Annals Manufacturing Technology, vol.57, no.2, pp. 660-675, 2008.

[3] C.H. Liu, W.Y. Jywe, C.C. Hsu and T.H. Hsu, "*Development of a laser-based highprecision six-degrees-of-freedom motion errors measuring system for linear stage*", Review of Scientific Instruments, vol.76, no.5, 2005.

[4] W.Y. Jywe, C.H. Liu, B.J. Lin and T.H. Hsu, "*The development of a triple ball bar system for calibration of CNC machine tools, Proceedings of the Institution of Mechanical Engineers*", Journal of Engineering Manufacture, vol. 220, no. 5, pp. 759-766, 2006.

[5] Renishaw, "*New system greatly extends flexibility and ease for rotary axis calibration*", www.renishaw.com/en/new-system-greatly-extends-flexibility-and-ease-for-rotary-axis-calibration--15852, Mar. 2018.

[6] Automated Precision, "*Machine Tool Calibration: Swivelcheck*", https://apisensor.com/products/mth/swivelcheck, Mar. 2018.

[7] R. Donaldson, "*A simple method for separating spindle error from test ball sphericity error*", CIRP Annals, vol. 1, pp. 125-126, 1972.

[8] G.X. Zhang and R.K. Wang, "*Four-point method of sphericity and spindle error measurements*", CIRP Annals Manufacturing Technology, vol. 42, no. 1, pp. 593-596, 1993.

[9] C.H. Liu, W.Y. Jywe, L.H. Shyu and Chun-Jen Chen, "*Application of a diffraction grating and position sensitive detectors to the measurement of error motion and angular indexing of an indexing table*", Precision Engineering, vol. 29, no. 4, pp.440-448, 2005.

[10] C.J. Chen, P.D. Lin and W.Y. Jywe, "*An optoelectronic measurement system for measuring 6-degree-of-freedom motion error of rotary parts*", Optics Express, vol.15, no.22, pp. 14601-14617, 2007.

[11] European Patent 2340914, " Detecting assembly for a multi-axis machine tool".

[12] U.S. Pattern 7852478, "Detecting assembly for a multi-axis machine tool".