Calibration system of six-axis force sensor based on the Stewart platform

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Abstract. Calibration accuracy of the six-axis force sensor directly affects the measurement accuracy. In this work, we designed a calibration system of six-axis force sensor based on the Stewart platform. The device has the advantages of automation control, accuracy positioning, and large loading range. The important components of the calibration system are analyzed. The electric cylinder is utilized as the driving device to apply the force. The camera and the single-axis force sensor are employed to feedback the position and force. The six-axis force sensor is fixed with the fixture composed of the T-shaped stage and the rotation table. The calibration principle and loading process of the force/moment are proposed.

1. Introduction
Six-axis force sensors are widely utilized in aerospace, robotics, precision manufacturing, and other fields. Calibration of six-axis force sensor is an important part of sensor development because the calibration accuracy directly affects the measurement accuracy of sensors. Then the research on calibration machine of six-axis force sensor has attracted extensive attention.

Wu [1] invented a decoupled calibration system of six-axis force sensor. Weight is utilized as the calibration force source, and lever principle and pulley group are employed to realize the force-increasing effect. Wu [2] developed a six-axis force sensor calibration system using spring as the energy storage element of loading unit, so that the loading unit can accurately apply the required load in both loading and unloading. Shen [3] developed a kind of six-axis force sensor calibration system, which is suitable for calibration of medium-range and large-range. The device requires manual loading reducer and adjusting lifting pulley. Yin [4] proposed a lifting six-axis force calibration system. The device used a turbo-worm reducer to exert load. The load is measured by a weighing sensor installed at the end of the rope. Sun [5] invented a six-axis force sensor calibration system by changing the position of the force source. The device can load forces in all directions separately and circularly, using weights as the calibration force source. Lin [7] designed a six-axis force calibration system based on closed-loop feedback control system. The force feedback control system was used to load the calibration force accurately, and the grating ruler installed on the positioning mechanism was used to realize the accurate positioning of the linear displacement and rotation angle of the six-axis force sensor. But it is not suitable for the calibration of medium-range and large-range six-axis force sensors. The above calibration systems of the six-axis force sensor have different advantages, but these devices don’t have the advantages of precise continuous automatic loading and large loading range simultaneously. Therefore, it is an urgent requirement to develop a calibration system of six-axis force sensor which can realize high-precision continuous automatic loading and a large loading range.
Here, we proposed a calibration system of six-axis force sensor with automation control and large lording range. We use the Stewart platform as the motion device to improve the loading range. The camera and single-axis force sensor are utilized as feedback of the position and force. The general drawing of the calibration system is proposed. The T-shaped stage and the rotation table are employed as the fixture of the sensor. The calibration principle and loading process of the force/moment are presented.

2. Composition of calibration system for six-axis force sensor

The calibration system of six-axis force sensor is composed of motion mechanism, positioning device, force loading device, relevant control software, and data acquisition and calculation software. Figure 1 shows the relationship of the different composed parts.

2.1 Motion mechanism

Parallel mechanism has the advantages of high precision, high stiffness and structural stability. These advantages just meet the requirements of the calibration system of six-axis force sensor. In all parallel mechanisms, the theory of Stewart mechanism is relatively mature, so the Stewart mechanism is used as the loading mechanism of the calibrator. Stewart platform will move the loading head fixed on the force loading device to the loading point of the sensor loading board.

2.2 Force loading device

Figure 2 shows the force source, which consists of a servo electric cylinder, a single-axis force sensor, and a spherical loading head. Motor is utilized as the actuator of the servo electric cylinder to obtain the accurate force or moment. Single axis force sensor is used to feedback the magnitude of loading force. The three force sources are arranged orthographically with each other, and the load/moment in each direction can be realized by controlling the magnitude and position of the load force.

2.3 Fixture

The fixture is composed of a T-stage and a rotary table, which is shown in figure 3 and figure 4. The rotary table is assembled on the T-stage with T-shaped bolts. The rotation angle of the rotary table is controlled by the crank handle, and the six-axis force sensor is installed on the rotation table.
2.4 The entire structure of the calibration system
Stewart platform, vision system, force loading device, and sensor fixture are assembled together. Then the general assembly drawing of the new six-axis force sensor calibration system is obtained in figure 5.
3. Calibration process of the six-axis force sensor calibration system in different direction

Figure 6 shows the calibration process of different directions. Figure 6 (a) is the case of calibration in X-axis. The axis of the force-source coincides with the X-axis of the six-axis force sensor axis. Then the force increases from the minimum to the maximum in the measurement range. The output of the six-axis force sensor for calibration is sent to the industrial computer. The relationship between the input standard force and the output force is obtained. The loading type of Y-axis and Z-axis are the same as the X-axis, as shown in figure 6 (b) and (c). Figure 6 (d) is the case of loading the moment around the X-axis. Here, the loading head of Z-axis is moved H along Y-axis, then the moment $M_x$ can be generated by $F_z$ and the distance H. The calibration principle of $M_y$ and $M_z$ are the same as $M_x$, and figure 6 (e) and (f) propose the detailed loading type.

4. Conclusions
In summary, we present a novel calibration system of six-axis force sensor based on the Stewart platform. The important components of the calibration system are analyzed. The Stewart platform is selected as the motion device of the calibration system. The electric cylinder is utilized as the driving device. The T-shaped stage and the rotation are employed as the fixture of the sensor. The camera is used to feedback the position of the sensor. The whole structure of the calibration system is proposed. Finally, the calibration process and loading mode of force/moment in each characteristic direction are described. The calibration system has the advantage of accuracy positioning, automation loading, and loading without moving sensor, which will make it suitable for many engineering applications.

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