Calibration Platform for Modularized Robot Arm Joint Torque Sensor

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Abstract. Torque sensor is an important sensing element of modularized robot arm joint and its accuracy is influenced by calibration test significantly. In this paper, a new torque sensor calibration platform was introduced. It solved the existing problem of ordinary platform requiring extra radial force at calibration, and can be used in any torque sensors with inner and outer rim characteristics. Firstly, the torque sensor receives accurate torque effect through a reasonable structural design. Secondly, possible error of the proposed platform was analyzed. Finally, a calibration test of torque sensor was carried out. Results demonstrated that the proposed calibration platform achieved outstanding absolute measurement accuracy, repeated accuracy and sensitivity.

Introduction

Currently, torque sensors are mainly designed in spoke structure (Figure 1). It is mainly composed of outer rim, inner rim and strain beam where strain gauges stick on. When the relative torque is produced between the outer rim and inner rim, the resistance value of strain gauges is changed and the output voltage of the bridge circuit which is composed of strain gauges is input into the computer through the A/D converter. Finally, the strain signal is transformed into the corresponding torque through the calibration test and the relation curve between torque and output voltage is acquired from computer. This relation curve is used as the standard of sensor perceived torque. Therefore, whether the high-accuracy calibration curve can be gained determines the accuracy of torque sensor directly. Existing associated studies often focus on structural optimization and accuracy improvement of torque sensor, but despise the influence of calibration experiment on accuracy of torque sensor.

Since torque is difficult to be measured, it is generally calculated indirectly by multiplying the measuring force by the corresponding arm of force. The force value is adjusted by placing different quantities of mass blocks. Shenyang Institute of Automation applied torque to the sensor by suspending weight at single end of steel wire rope and found that extra radial force is inevitable. Nicolay et al. hung equal loads at two ends of the testing sensor. Only torque was generated, but the loading was inconvenient. Dong-Lin Tsai replaced suspending weights by two symmetrically placed motors, and found that the output forces were only equal when movement positions of two motors were completely consistent. Harbin Institute of Technology (HIT) connected the torque sensor with the weighing sensor through the steel wire rope during calibration for leg joint, and adjusted torque by...
driving the joint rotation. However, this was difficult to control the torque change piece by piece in the expected interval. Zhejiang University assembled the loading device by hand wheel and decelerator unit. The decelerator unit was connected with steel wire rope, tension detector and the sensor to be tested, while the hand wheel adjusted force. Such method brought unstable loading. The calibration platform developed by the Beijing University of Posts and Telecommunications connected one end of the sensor with the torque motor and the other end with the testing device for calibration. The load was only 20Nm and the calibration accuracy was influenced by the detection device.

The designed calibration platform in this paper was based on the principle of pulley block to transform external loads into torque completely and applied it on the torque sensor. Based on this principle, it could calibrate any torque sensors with outer and inner rim characteristics. The system errors of the calibration platform were analyzed and influences of system were reduced from the source. The average strain on the gauge was analyzed by ansys to discuss influences of partial load on calibration test. Finally, a practical calibration experiment was carried out to one model of torque sensor. It proved that the proposed platform achieved high absolute measuring accuracy, repeated accuracy and sensitivity.

Methods

The joint working of modularized robot arm is shown in Figure 2. The green part is the input shaft driven by the motor and yellow part is the output terminal connected to the next joint. The torque sensor connects the input to output and measures the torque at the same time. It is expected that the torque sensor can measure torque accurately during working, and eliminate interferences of partial load, radial force and other factors. The designed calibration platform shall meet above requirements and be close to the actual working state of torque sensor for the purpose of accurate torque calibration.

![Figure 2. Connections of modularized joint and torque sensor.](image)

![Figure 3. Principle of calibration test.](image)

Based on the principle of pulley block, the proposed calibration platform makes the sensor perceive torque only (Figure 3). The hang weight at the right end is G(N). Two movable pulleys on the horizontal beam generate two opposite tensile force (2G) to the horizontal beam. For the convenient calculation, the axial distance between two movable pulleys is set 0.5m and the sensor is put in the middle of the horizontal beam. The arm of torque force is 0.5/2 = 0.25m, so the torque size is:

\[ M = 4G \times 0.25 = G \text{ (Nm)} \] (1)

The gravity value of weight is the torque value perceived by the sensor.

Based on the above principle, a calibration platform model is designed (Figure 4). A blue flange plate is installed in the middle of the flexible horizontal beam. The flange plate has installation holes on different diameters of circumference, which can be used to fix different sizes of outer rim of sensor. This is convenient for disassembly and assembly. The installation way of the torque sensor is shown in Figure 5. The inner rim of the sensor is connected with the yellow installation part which is then inserted into the fixed seat. The blue baffle and the yellow installation part clamp the fixed seat tightly through 2 bolts, thus finishing the fixation of sensor. The seat is fixed on the aluminum profile framework and pulleys are fixed on the aluminum profile by the pulley seat. Auxiliary holes are
processed on the aluminum profile for the convenience of running through of steel wire rope. The tray with known weight is hung on the steel wire rope on the right side. Therefore, the torque perceived by the sensor can be calculated directly by placing a known weight.

![Figure 4. Calibration platform model.](image4.png)  ![Figure 5. Explosion diagram of the fixed device of sensor.](image5.png)

This calibration platform is designed to be applied with 200Nm torque and 0.1Nm of sensitivity. The system error of this calibration platform is mainly the installation error of the distance from the movable pulley axis to the sensor axis. 1mm deep positioning slots was processed on the aluminum profile in order to assure that the distance from the movable pulley axis to the sensor axis is 0.25m. According to the given tolerance requirement, there’s a 0.012mm error from the axis of pulley seat on the locating slot to the sensor axis. When the platform is applied with 200Nm torque, the error caused by robot arm is ΔM=0.0096Nm. Therefore, the system error caused by calibration platform can be neglected.

The tensile forces at two ends of the horizontal beam by the steel wire rope can be equivalent to a torque. Due to the dead load of the horizontal beam, a constant partial load will be generated to the torque sensor. The influences of partial load are negatively correlated with the calibration torque. If the horizontal beam is too heavy, a bearing is needed to overcome partial load. Meanwhile, the added parts will induce some uncertain factors, such as friction. As a result, it is necessary to analyze influences of unbalance loading caused by the horizontal beam on the calibration accuracy of torque sensor. In Figure 6, influences of horizontal beam dead load on simulation results are analyzed. The calibration torque range 0-200Nm. To simulate deformation of strain gauges, surface bodies are constructed on the strain beam to express the average strain. Since the strain gauge measures the strain along the beam, the strain along the x-axis in Figure 6 has to be analyzed. Influences of partial load are mainly manifested in the small loading stage. The relation curve between strain and torque under 0-5Nm load is shown in Figure 7, where the x-axis is the torque and the y-axis is the strain of torque sensor. The red line is the result under no partial load and the blue line is the result with considerations to dead load of beams. Since the primary thing after installation of the torque sensor on the calibration platform is resetting, it is equal to translate the blue line downward to overlap with the origin. At this moment, the blue line almost overlaps with the red line. The deviation between two lines after the translation is smaller than 1X10^{-9} and the minimum strain is 2.17X10^{-7}. Therefore, influences of the unbalance load after resetting can be neglected.
Experiments

The physical image of the assembled model is shown in Figure 8. A calibration experiment on a model of torque sensor was carried out. Output voltage data of the sensor were collected and processed. The red calibration straight line was fitted by the least square method (Figure 9). The x-axis is the loading moment and the y-axis is the output voltage of the sensor processed by the amplifier. It can be seen from Figure 9 that large error is produced in the large loading measurement stage. The nonlinear error and the delay error of the sensor were calculated ±0.94% and ±0.39% respectively. To measure sensitivity of the sensor, smaller loads were applied continuously for loading and deloading test. Results are shown in Figure 10, where the x-axis is the load torque and the y-axis is the torque corresponding to the output voltage of the sensor. The red line is the loading process and the blue line is the deloading process. When 10g load is applied, the sensor read changes significantly, indicating that the sensor can perceive 0.1Nm torque load. It is equal to that a 1m long robot arm still can obtain force perception information when it catches a dime.

Based on above test data, the proposed torque sensor calibration platform can achieve the absolute measurement accuracy lower than 1% and good linearity. The repeated accuracy is lower than 0.4% and the sensitivity is lower than 0.1Nm. Moreover, the acquisition circuit used in the test is a single channel, which has not offset disturbance of differential signals. Therefore, two-channel differential treatment can offset the composite disturbances and improve performance parameters of the sensor significantly.
Conclusions

In this paper, a torque sensor calibration platform for modularized robot arm joint is designed based on the principle of pulley block. It transforms the load into torque completely and applied onto the torque sensor, thus increasing the calibration accuracy. Applying loads through the steel wire rope is cheaper and occupies smaller space than loading by extra motor and detection device. The whole framework is easy to be installed and can be used to calibrate different sizes of torque sensor. Experimental results demonstrated that the proposed calibration platform can achieve the absolute measuring accuracy lower than 1%, repeated accuracy lower than 0.4%, and sensitivity lower than 0.1Nm. The designed load is 200Nm. It is applicable to calibrate sensors with larger torque by changing the whole size. In future, the two-way channel differential processing can be added to offset composite disturbances and improve the performance parameters of sensors significantly.

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