Misalignment error calibration of faro retro probe for laser tracker system

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A technique to calibrate faro retro probe using laser tracker system (LTS) is presented. The deep-access retro probe enables LTS to perform three-dimensional (3D) measurements of surface hidden features. It has been shown that misalignment errors are the key contributor to measuring errors of retro probe. A device for measuring misalignment errors of retro probe is invented. Theoretical analysis and experiment show that using this technique to calibrate retro probe, the misalignment errors of retro probe can be eliminated effectively and quickly.

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Laser tracker system (LTS) is a portable three-dimensional (3D) large-scale-size measuring system. It measures 3D coordinates with laser beam by following a spherical mirror reflector (SMR). The tracker follows a SMR in the range of 35 m, tracking features at 1000 points per second with accuracy of 1×10^{-6}. Among the large-scale size measuring technologies, such as measuring arm, theodolites, and total station systems, laser trackers possess many advantages, such as broad range, high speed, and high accuracy. LTS has been implemented in a wide range of applications spanning a large number of industries including aerospace, automobile, heavy equipment, shipbuilding, etc.[1].

Figure 1 shows the measuring principle of the laser tracker, which is used as a portable coordinate measuring machine (CMM) to measure a bus body. The measuring laser beam emitted from the laser tracker tracks the SMR and then is reflected to the laser tracker. The laser tracker can measure the distances by two laser interferometers and the angular locations by two angular encoders. An operator moves the SMR on the measured object to get required measured points for the whole-body measurement.

Generally, SMR is used as the main measurement device for LTS, but because of its large diameter and small receiving angle, it cannot measure in holes or in hidden features. However, the deep-access retro probe enables laser trackers to perform 3D measurements of small pockets, holes, corners, punch marks, and other surface hidden features that are difficult to access using SMR[2]. The misalignment errors are the key contributor to measuring errors of retro probe. There have not been any standard device and method to measure misalignment errors of retro probe, the key for a successful calibration is to measure misalignment errors accurately and effectively. The purpose of this paper is to present an applicable and low cost technique, including the calibration method and device, to measure misalignment errors of retro probe using LTS[3,4].

A faro retro probe mainly includes corner reflector, reflecting mirror, probe, and base as shown in Fig. 2. Figure 3 shows the working principle of retro probe. The measuring laser beam emitted from LTS and directed at the probe would be reflected into the corner reflector by the reflecting mirror. The laser beam incident on the corner reflector would then be reflected back to LTS via the reflecting mirror. The perpendicular distance of O_1O equals O_2O on either side of the reflecting mirror. Provided these components are accurately positioned in this way, the measuring location of the corner reflector is equal to the location of the probe. Therefore, the deep-access retro probe enables laser trackers to perform 3D

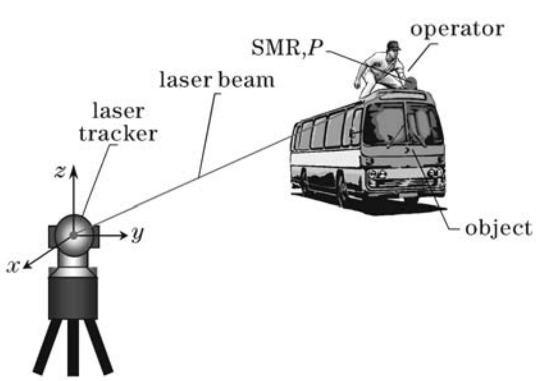

Fig. 1. Working principle of the laser tracker.

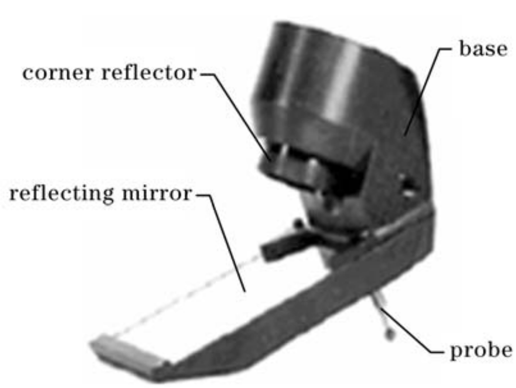

Fig. 2. Faro retro probe.

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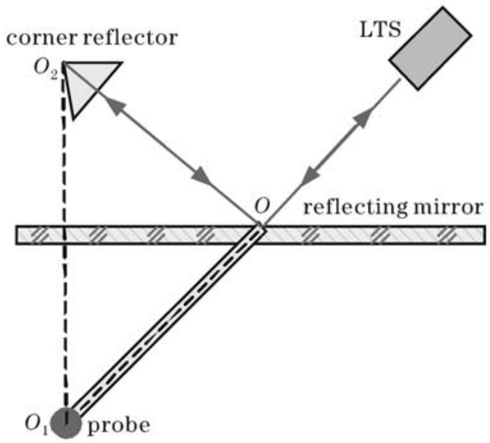

Fig. 3. Working principle of retro probe.

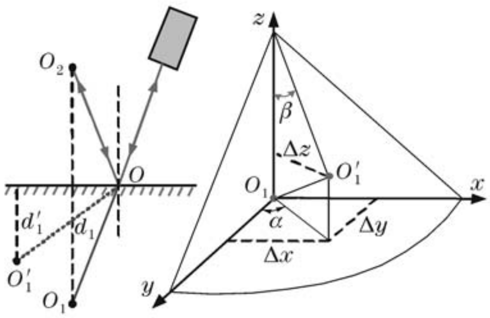

Fig. 4. Misalignment errors of retro probe.

measurements of surface parts hidden features[5].

A significant cause of systematic errors in retro probe is the misalignment of the corner reflector relative to the reflecting mirror plane and the probe. As shown in Fig. 4, when misalignment error exists in retro probe, Δx, Δy, Δz are the misalignment errors along the coordinate axes, respectively[6],

$$\begin{aligned}\Delta x &= (d_1 + d_1') \cdot \tan\beta \cdot \cos\alpha, \\ \Delta y &= (d_1 + d_1') \cdot \tan\beta \cdot \sin\alpha, \\ \Delta z &= (d_1 - d_1'),\end{aligned} \tag{1}$$

where d_1 and d_1' respectively represent the distances between O_1, O_1' and the reflecting mirror, α is the angle between probe and y axis, β is the angle between probe and z axis.

The total misalignment error is determined by the misalignment components Δx, Δy, Δz as

$$\begin{aligned}\Delta M &= \sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2} \\ &= \sqrt{(d_1 - d_1')^2 + (d_1 + d_1')^2 \tan^2\beta}.\end{aligned} \tag{2}$$

Equation (2) and experiments have shown that the misalignment errors are the main cause to decrease the measuring accuracy of retro probe. One of the applicable techniques to improve the accuracy of retro probe is geometric calibration, which measures and compensates the misalignment errors.

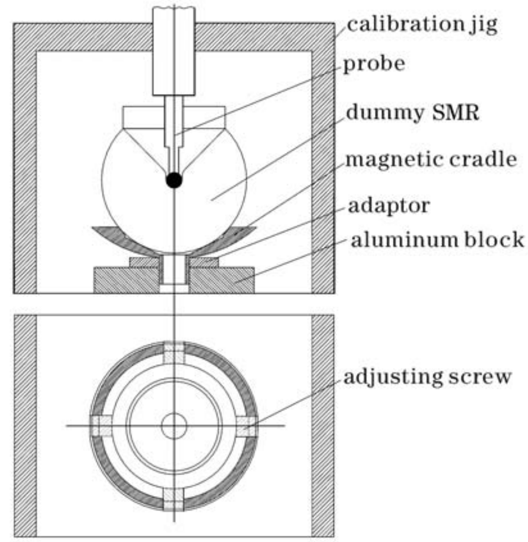

Fig. 5. Calibration device of retro probe.

The purpose of calibrating the retro probe is to accurately position the corner reflector with respect to the reflecting mirror plane and the probe. As shown in Fig. 3, the desired location of the corner reflector is at a distance from the reflecting mirror plane that is equal to that of the probe, and on an axis that is perpendicular to the reflecting mirror plane, which passes through the probe.

A special device is developed for this purpose. As shown in Fig. 5, the proposed calibration device includes calibration jig, probe, dummy SMR, magnetic cradle, adaptor, aluminum block, and adjusting screws. The calibration jig is used to hold the retro probe so that the probe is seated in the SMR, and to align the coordinate axis of the LTS with the adjustment axis of the retro probe. In order to accurately measure the misalignment errors of retro probe, a device known as the dummy SMR (the position of the probe fit into the SMR equals the position of SMR) is used. The probe of the retro probe accurately fits into the dummy SMR and the latter accurately fits into the magnetic cradle.

A prototype calibrating device was built. This device was used to calibrate the faro retro probe, and the calibration procedure includes: using CMM to measure the position of dummy SMR, and using the result as nominal values; accurately seating the retro probe in the dummy SMR; using LST to measure the position of retro probe, and using the result as reference values; calculating the corresponding misalignment errors of retro probe; building the misalignment error database of retro probe; using the database to compensate misalignment errors of retro probe. All of these can eliminate the misalignment errors of retro probe effectively and quickly.

Figure 6 shows the results of using LTS to measure the misalignments errors of retro probe. It can be easily seen that after calibration with the proposed technique, the misalignment error is significantly reduced. The maximum errors before and after calibration are 102 and 29 μm, respectively.

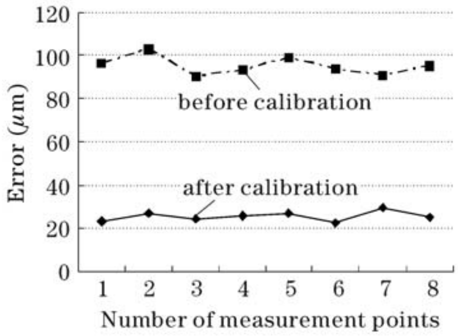

Fig. 6. LTS measurement results.

In conclusion, a technique to calibrate the misalignment errors of faro retro probe using LTS has been presented. After calibration by a newly invented calibration device, the misalignment errors of retro probe can be eliminated effectively and quickly. Using this technique to calibrate the retro probe, the maximum measuring error of the calibrated retro probe has been decreased sharply from 102 to 29 μm. We are working on further improvement to make this technique be used in industries easily.

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