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A novel method for adjusting CCD camera in geometrical calibration based on a two-dimensional turntable

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Abstract

In order to ensure the accuracy of the collimator viewing angles in geometrical calibration of the CCD camera, a novel method for adjusting CCD camera with wide field of view based on a two-dimensional turntable was presented. The method involves two steps: the first is to adjust collimator parallel to a rotation axis of turntable by estimating a fixed point image of collimator on the CCD when the camera is orientated around this rotation axis; the second step is to adjust the camera axis parallel collimator by estimating the symmetry of point images when the camera is orientated around another rotation axis of turntable. As an example, the adjustment accuracy of the wide field of view radiometer developed by us is analyzed and discussed in the article.

Keywords: Geometrical calibration; Two-dimensional turntable; Collimator

1. Introduction

Over the last decade, many techniques and some studies concerning camera geometrical calibration have been presented [1–3]. Calibration is basically performed by observing a reference object whose geometry is precisely known; moreover, the measurements are usually performed by means of collimator for the CCD camera with wide field of view lenses [4,5]. The geometrical calibration consists in determining the mathematical model relating each viewing direction within the instrument field of view to a pixel location in the focal plane, and many geometrical calibration models have also been developed to accommodate various applications [6,7]. But to the models whether they consider image plane distortions or not, the viewing angles of the reference object should be calibrated accurately.

It is a good method to calibrate the collimators by means of two theodolites in some references [8,9]. To obtain accurate viewing angles, however, the CCD camera needs be adjusted in order to make the camera axis parallel to the center collimator. In this paper, a simple method for adjusting CCD camera based on a two-dimensional turntable is presented and the adjustment accuracy is discussed.

2. Analysis on point images on the CCD

The schematic diagram of CCD camera geometrical calibration is shown in Fig. 1. The *ox* and *oz* are the rotation axes of a two-dimensional turntable and the parallel light provided by collimator is parallel to the *z*-axis. The entrance pupil of the CCD camera is

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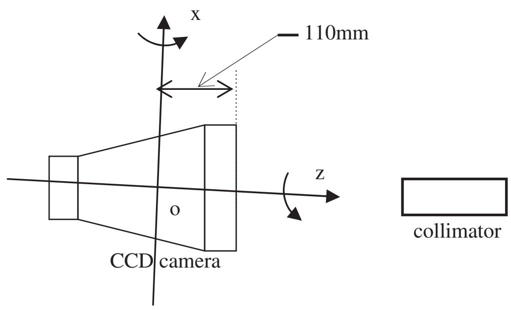

Fig. 1. Schematic diagram of camera geometrical calibration.

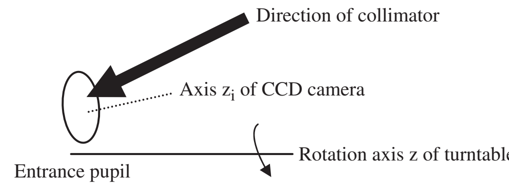

Fig. 2. The relations of three axes.

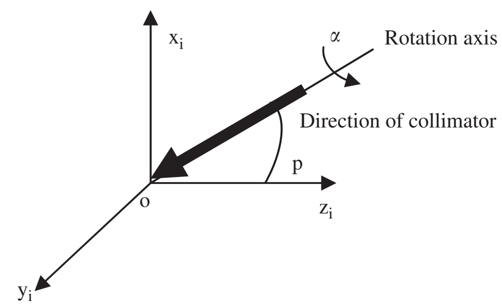

Fig. 3. Condition of fixed point image position.

fixed on the point of intersection of two rotation axes, and the distance from the first surface of the optics to the entrance pupil is about 110 mm though the wide field of view optics of camera has different entrance pupil positions that range from 100 to 123 mm for different spectral bands and different viewing directions. The collimator can be imaged at different positions on the CCD by the rotation axes of high-precision two-dimensional turntable.

2.1. Relations of three axes

In the ideal geometrical calibration, there are three axes, which should be parallel: the axis z_i of CCD camera, the rotation axis z of a two-dimensional turntable and the direction of collimator. However, the initial position of the camera and collimator does not meet the ideal calibration condition, i.e. three axes are not parallel, as shown in Fig. 2.

The axis z_i of CCD camera intersects the direction of collimator at the entrance pupil of the camera as long as the collimator is imaged on the CCD camera. In general, the rotation axis z of a two-dimensional turntable does not pass through the entrance pupil of the camera, but the collimator can always be imaged on the CCD when entrance pupil revolves round the rotation axis z of a two-dimensional turntable as long as the diameter of collimator has enough size. In that case, the image position of collimator on the CCD does not vary if the rotation axis z of a two-dimensional turntable is moved parallel. So we can assume that these three axes intersect at the entrance pupil of the CCD camera.

2.2. The condition of fixed point image position on the CCD

Let us examine under what conditions there is a fixed point image position of collimator on the CCD camera. We can imagine collimator is parallel to the rotation axis z of a two-dimensional turntable and the angle made by them and the axis z_i of CCD camera is p, as shown in Fig. 3. The direction of collimator and the rotation axis z of a two-dimensional turntable lie in the plane which is made by axes x_i and z_i of camera coordinates if the camera is orientated around the rotation axis z of turntable.

The direction numbers of the direction of collimator and the rotation axis z of turntable in the initial position can be written

$$\vec{l}_o = \begin{pmatrix} \sin p \\ 0 \\ \cos p \end{pmatrix} \tag{1}$$

When the camera is orientated around the rotation axis z of turntable at an angle α, the rotational change of basis matrix for Mueller matrices is

$$m_z = \mathrm{inv}(R_x)\mathrm{inv}(R_y)R_zR_yR_x \tag{2}$$

where

$$R_x = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}, \quad R_z = \begin{pmatrix} \cos\alpha & -\sin\alpha & 0 \\ \sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{pmatrix},$$

$$R_y = \begin{pmatrix} \cos p & 0 & -\sin p \\ 0 & 1 & 0 \\ \sin p & 0 & \cos p \end{pmatrix}$$

The direction numbers of the direction of collimator in new coordinate system can be given by

$$\vec{l}\,'_o = m_z \begin{pmatrix} \sin p \\ 0 \\ \cos p \end{pmatrix} \tag{3}$$