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A two-step calibration method of a large FOV binocular stereovision sensor for onsite measurement

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ABSTRACT

As there are some shortages with using both standard calibration method and self-calibration method to calibrate a large Field of View (FOV) binocular stereovision sensor, a two-step calibration method of a large FOV binocular stereovision sensor for onsite measurement is proposed. Furthermore, in order to improve the calibration efficiency, a novel method of corner detection based on region of interest (ROI) is also proposed to quickly detect the chessboard corner in the image of a small calibration target. Compared with the other two methods, the proposed method is more suitable for rapid onsite structure–parameter calibration of a large FOV binocular stereovision sensor. The experiments show that the onsite calibration process is efficient, and the average value of 10 measurements for a distance of 1071 mm is 1071.03 mm with a RMS less than 0.1 mm. Moreover, the application results indicate that the measurement accuracy of the stereovision prototype system calibrated by this method is improved by 13.56% compared with the other from standard calibration method.

1. Introduction

Nowadays, Binocular stereovision is broadly applied in the field of a large dimension measurement due to its fast measurement speed, high accuracy and large measurement range [1–5]. Before initial measurement, stereovision parameters, which consist of intrinsic parameters and structure parameters of cameras, should be calibrated firstly. Generally, there are two common calibration methods [6]. One is standard calibration method based on control points of known 3D coordinates. The other is self-calibration method based on control points of unknown 3D coordinates. The standard calibration method calibrates cameras by using careful distribution known 3D control points with high precision. The self-calibration method is mostly based on the correspondences between points in different views.

The three most representative techniques of standard calibration method are those of Direct Linear Transformation (DLT) [7], Tsai [8] and Zhang [9]. DLT [7] method can solve the basic camera perspective model with 3D metric space points. Generally, DLT method does not consider the lens distortion. Tsai's [8] method is a versatile two-step calibration. A radial alignment constraint is used to derive a closed-form solution for most of the camera parameters. Then, an iterative scheme is used to calculate other remaining parameters, including radial distortion coefficient. Zhang [9] proposed a flexible technique to calibrate a camera with a freely moved planar pattern. Zhang's method consists of a closed-form solution, followed by a

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non-linear refinement based on the maximum likelihood criterion. With a great flexibility and adaptability, Zhang's method becomes the most popular. Currently, a lot of work of binocular stereovision calibration has been done based on standard calibration method. Chen [10] and Xu et al. [11] used DLT method to calibrate a stereovision sensor respectively. Chen [10] used random spatial points of accurate known 3D coordinates given by CMM to calibrate the stereovision sensor. However, this method requires a high-precision positioning equipment, which limits its application. Xu et al. [11] adopted a 3D target to calibrate a binocular stereovision sensor. However, a 3D target, especially a large-size one, is not suitable for onsite calibration of a large FOV stereovision sensor because of its low shape accuracy and inconvenience of maintenance and use. Rovira-Más [12] and Li et al. [13] calibrated a large FOV stereovision rigs respectively in their research papers by using Zhang's method. As uniformly distributed spatial control points can benefit calibration accuracy of camera parameters, the size of both calibration targets adopted by R.-Más and Li is relatively large. However, as it is not convenient to be operated and maintained for a large size, a large-size target is also not appropriate for rapid onsite calibration in a complex production workshop.

In order to get an online calibration for a camera, self-calibration method has aroused many scholars' attentions ([6,14,15] to cite a few). Faugeras [6,14] estimated the camera parameters from the Epipolar transformations associated with displacements of the camera. The Epipolar transformation was obtained from point correspondences between images taken before and after the displacement. The method does not require a calibration object with a known 3D shape but require only point matches from image sequences. Hartley [15] gave a new method to calibrate a camera with unknown rotations. The calibration is based on the image correspondences only. For avoiding using complex 3D calibration structures, self-calibration methods for binocular stereovision also appear [16,17]. Assuming that the coordinates of the principal point of each camera were known, Zhang et al. [16] calibrated a stereo rig by moving it in an environment without using any reference points. The method calculates the initial estimate of unknowns for non-linear optimization by using the method proposed by Faugeras et al. [14]. Agapito et al. [17] further specified a ground plane for the motion of stereo head. He supposed that the intrinsic parameters of the camera were fixed, and only the focal length was unknown parameter. Although self-calibration method has some advantages, it is always unstable and inaccurate. Moreover, the Epipolar geometry employed by the method can not provide enough constraints to estimate all camera parameters, particularly the principal points and the distortion parameters of a lens [18,19]. To get a complete calibration, self-calibration has recently been extended to the determination of the principal points by Borghese [20,21]. However, the method does not give a solution for the distortion parameters. Starting from pairs of matched points, self-calibration method usually determine the relative orientation and position, up to a scale factor, of one camera with respect to the other through a linear algorithm, such as 8-point algorithm [22,23], assuming that part or all of the camera intrinsic parameters have been known or have been calibrated by other procedures. Mass [24] and Borghese [21] took a rigid bar as an image target to calibrate the structure parameters of cameras. The bar has two features, and the distance between the two features has been precisely verified, which will be used to determine the scale factor. The rigid bar is easier to be fabricated and operated by users compared to complex calibration target. Inspired by this, Xu et al. [25] and Sun et al. [26] respectively calibrated the structure parameters of a large FOV binocular stereovision sensor by using a modified bar. However, with less feature points on the bar, a user should capture many more images of the bar during a whole calibration process to get an accurate result. The number of the pairs of corresponding points needed by Xu's method is no less than 16, and the number of placement of the bar used by Sun is 22, which decreases the calibration efficiency. Additionally, as Borghese and Cerveri [21] pointed out, the self-calibration method had a very strict requirement on the accuracy of the distance between the bar's two features, which affects its application.

With the improving measurement requirements of large-size workpieces, onsite measurement becomes increasingly important. Sometimes, the structure size of a large FOV binocular stereovision sensor should be large to meet the measurement demand, and the stereovision sensor often needs to be onsite assembled for being easily transported, maintained and used. In addition, structure parameters of stereovision, in particular, are prone to change with an effect of working conditions such as temperature, vibration and so on, resulting in lowering measurement accuracy [27], so an onsite calibration of a stereovision rig is often needed. To improve the standard calibration method, Xiao et al. [28] proposed an onsite calibration method of binocular stereovision with a large FOV, using a non-coplanar cross target with ring coded points as feature information. The 3D coordinates of these ring coded points do not need to be known and the only necessary information is the distance between two points as a scale, which simplifies the target structure and reduces its weight. But the image recognition of the ring coded points is sensitive to illumination conditions, and the volume occupied by the cross target is still large, which reduces the calibration flexibility.

With the purpose to improve the deficiencies of two calibration methods mentioned above in calibration of a large FOV binocular stereovision sensor, we propose a two-step calibration method of a large FOV binocular stereovision sensor for onsite measurement, according to the calibration parameter's characteristic that camera intrinsic parameters do not change as the geometry of the two cameras relative to one another, described by structure parameters, varies. At the first step that is offline procedure, we calibrate the camera intrinsic parameters using a large precise rig. At the second step that is onsite procedure, we set up the binocular stereovision sensor and calibrate the structure parameters using a small accurate 2D target. The method proposed in this paper has some advantages as follows. Firstly, compared to self-calibration method, it can completely calibrate all the camera intrinsic parameters including distortion coefficients