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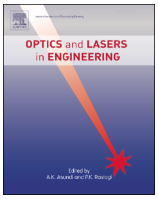

On-site calibration method for outdoor binocular stereo vision sensors

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ABSTRACT

Using existing calibration methods for binocular stereo vision sensors (BSVS), it is very difficult to extract target characteristic points in outdoor environments under complex light conditions. To solve the problem, an online calibration method for BSVS based a double parallel cylindrical target and a line laser projector is proposed in this paper. The intrinsic parameters of two cameras are calibrated offline. Laser strips on the double parallel cylindrical target are mediated to calibrate the configuration parameters of BSVS. The proposed method only requires images of laser strips on the target and is suitable for the calibration of BSVS in outdoor environments. The effectiveness of the proposed method is validated through physical experiments.

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1. Introduction

Stereoscopic vision inspection is widely utilized in industrial measurement [1–4]. And there always exist complicated conditions in outdoor environments such as complex light condition, bad weather condition, and strong vibration and so on. In order to be adaptive for these conditions, binocular stereo vision sensors (BSVS) usually have protections, including rugged protective shells and optical protective equipment to remove external inference of light, such as optical filters. Meanwhile, many users ask for simple and fast method to calibrate BSVS. For example, BSVS installed on the both sides of railway lines for detecting the size and fault of vehicle, are requested for working all days. The less time maintenance and calibration occupy, the more time BSVS can work. Besides, the high calibration accuracy is not particularly demanded. The calibration accuracy of 0.05 mm is good enough to meet measurement requirements. As a result, the fast and simple calibration with moderate accuracy is required for this kind of BSVS. Existing online calibration of BSVS in outdoor environments under strong or weak light often presents difficulties. Thus, exploring the high-precision calibration of BSVS in outdoor measurement environments is significant.

BSVS calibration is divided into two parts, namely, calibration of the intrinsic parameters of two cameras and calibration of the coordinate transformation matrix between two cameras; the latter is also called configuration parameter calibration of BSVS. Intrinsic parameter calibration of a camera is relatively mature, and existing methods for this type of calibration rely on different types of targets, such as 3D [5,6], 2D [7,8], 1D [9,10], and sphere [11–13] targets. Among these methods, the calibration method proposed by Zhang [7] using a 2D target is the most popular. The method has high flexibility, high accuracy, and several other advantages. When 3D, 2D, and sphere targets are utilized for the calibration of the two cameras intrinsic parameters of BSVS, the two cameras capture the images of the target at the same time, and the transformation matrix between coordinate frames of the two cameras can be obtained. For 3D and 2D targets, the accuracy of the calibration of camera intrinsic parameters and configuration parameters of BSVS is relatively higher than that of other targets. However, for sphere targets, none of the existing methods satisfy the high-precision measurement requirements. Reference [10] shows that a single 1D target without constraints cannot realize intrinsic parameter calibration of a camera; however, the configuration parameters of BSVS can be obtained [14] with known intrinsic parameters of two cameras of BSVS and the known distance between characteristic points of the 1D target. A 1D target is suitable for configuration parameter calibration of a wide-field BSVS.

As for the camera calibration in outdoor environments, some methods have been brought forward. In references [15,16], Dawson and Zheng utilize vanishing points and vanishing lines to calibrate practical traffic cameras. This method can be applied to practical traffic cameras well, because features of vanishing points and vanishing lines such as parallel road boundaries and walking human, can be obtained from traffic surveillance images. Tian [17] proposes a calibration method for large field vision in outdoor environments. In the experiments, three independent targets

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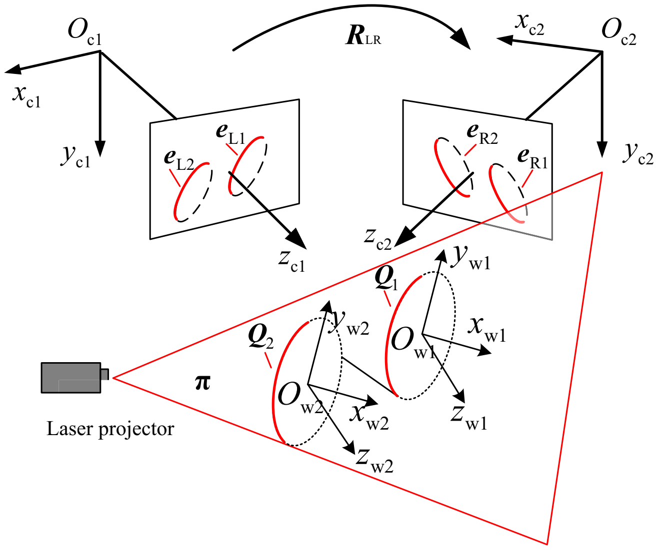

Fig. 1. Configuration parameter calibration of BSVS.

which have the same height are set in the field to calibrate cameras. And Liu [18] introduces an outdoor binocular camera calibration method for a multi-GPS apparatuses and multi-cameras. To calibrate the binocular camera in an outdoor environment, the Scale Invariant Feature Transform (SIFT) descriptor is used to compute the features in images. In purpose of avoiding the impacts of the sun light, all the cameras in experiments should be fixed at a proper position. Also, an adaptive optical band pass filter is designed for the measurement system in reference [19] to get clear images under complex background light conditions. However, adding an optical filter in front of the camera lens increases the difficulty of online calibration. Optical filters should be removed before calibrations. All the above methods require clear features in images to complete calibrations, and the calibration accuracy of them is not high. When it comes to situations, however, such as foggy weather, reflect sunlight, strong sunlight and so on, their performances have been affected. Rodríguez [20] proposes a method based on laser line imaging and also uses Genetic Algorithm (GA) to calibrate and recalibrate the binocular setup without references and physical measurements. The laser projector has a stable light source and is actively irradiated on objects, which can solve the problem of obtaining clear features efficiently. In addition, this method has an advantage of high calibration accuracy without references and physical measurements. But, two cameras are supposed to keep parallel with the surface while the laser line projector is projected perpendicularly to the surface. Besides, the laser line projector and both two cameras are fixed on a high precision slider during the process of calibration and measurement. According to these experimental conditions, this method is more suitable for BSVS working in the indoor environments rather than in the outdoor environments.

As a result, a novel online calibration method that only requires images of laser strips on a double parallel cylindrical target is proposed in this paper. Zhang's method is adopted to calibrate intrinsic parameters of two cameras offline, and configuration parameter calibration is achieved with the proposed method. The contents of this paper are structured as follows: Section 2 describes the basic principle of the algorithm in detail; Section 3 contain the information about physical experiment; and Section 4 presents the conclusion.

2. Algorithm principle

As shown in Fig. 1, $O_{c1}x_{c1}y_{c1}z_{c1}$ and $O_{c2}x_{c2}y_{c2}z_{c2}$ denote the coordinate frames of cameras 1 and 2, respectively. $\boldsymbol{Q}_j\,(j=1,2)$ denote two space ellipses of two laser strips on the target. $\boldsymbol{e}_{Lj}$ and $\boldsymbol{e}_{Rj}$ are images of two space ellipses on the image planes of the left and right cameras, respectively. The long axis of $\boldsymbol{Q}_1$ is defined as the x-axis of $O_1x_1y_1z_1$, and the short axis is defined as the y-axis. The center of $\boldsymbol{Q}_1$ is the origin of $O_1x_1y_1z_1$. Through a similar method, the coordinate frame of $\boldsymbol{Q}_2$, $O_2x_2y_2z_2$, can be obtained. We assume that $O_1x_1y_1z_1$ is the target coordinate frame$O_Tx_Ty_Tz_T$. $\boldsymbol{R}_{L1}$ and $\boldsymbol{t}_{L1}$ denote the rotation matrix and the translation vector from $O_1x_1y_1z_1$ to $O_{c1}x_{c1}y_{c1}z_{c1}$, respectively. $\boldsymbol{R}_{R1}$ and $\boldsymbol{t}_{R1}$ denote the rotation matrix and the translation vector from $O_1x_1y_1z_1$ to $O_{c2}x_{c2}y_{c2}z_{c2}$, respectively. $\boldsymbol{R}_{LR}$ and $\boldsymbol{t}_{LR}$ denote the rotation matrix and the translation vector from $O_{c1}x_{c1}y_{c1}z_{c1}$ to $O_{c2}x_{c2}y_{c2}z_{c2}$, respectively.

Given that the two cylinders of the target are parallel to each other and have the same diameter, the following conclusions can be obtained: the long and short axes of $\boldsymbol{Q}_1$ and $\boldsymbol{Q}_2$ are parallel and similar, and the short axis is equal to the diameter of the cylinder. Zhang's method [7] is adopted to calibrate the intrinsic parameters of two cameras offline. Eq. (1) is the camera model.

$$\rho\boldsymbol{p} = \rho\begin{bmatrix}u\\v\\1\end{bmatrix} = \boldsymbol{K}_L[\boldsymbol{r}_1\ \ \boldsymbol{r}_2\ \ \boldsymbol{t}_j]\begin{bmatrix}x\\y\\1\end{bmatrix} = \boldsymbol{H}_{Lj}\boldsymbol{q} \tag{1}$$

where ρdenotes a nonzero constant, $p=\begin{bmatrix}u & v & 1\end{bmatrix}^T$ denotes the undistorted homogeneous coordinate under the image coordinate frame of the left camera, $\boldsymbol{q}=\begin{bmatrix}x & y & 1\end{bmatrix}^T$ denotes the 2D coordinate on $O_Tx_Ty_T$, $\boldsymbol{K}_L$ denotes the intrinsic parameter matrix of the left camera, and $\boldsymbol{R}_{Lj}=[\boldsymbol{r}_1\ \ \boldsymbol{r}_2\ \ \boldsymbol{r}_3]$ and $\boldsymbol{t}_{Lj}$ denote the rotation matrix and translation vector from $O_jx_jy_jz_j$ to $O_{c1}x_{c1}y_{c1}z_{c1}$, respectively. Since $O_1x_1y_1z_1$ and $O_2x_2y_2z_2$ is parallel, $\boldsymbol{R}_{L1}=\boldsymbol{R}_{L2}$. $\boldsymbol{e}_{Lj}$ and $\boldsymbol{Q}_j$ can be expressed by Eq. (2).

$$\begin{cases}\boldsymbol{p}^T\boldsymbol{e}_{Lj}\boldsymbol{p}=0\\ \boldsymbol{q}^T\boldsymbol{Q}_j\boldsymbol{q}=0\end{cases} \tag{2}$$

where $\boldsymbol{Q}_j=\begin{pmatrix}1/b^2 & 0 & 0\\ 0 & 1/a^2 & 0\\ 0 & 0 & -1\end{pmatrix}$ and $2b$ denotes the long axis of the

Fig. 2. Images of different targets captured by the vision sensor under good light conditions.

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