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A camera calibration method for large field optical measurement

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ABSTRACT

A camera calibration method is presented for large field optical measurement, where the camera is close to the ground and the control points can only be located close to the ground, too. In such conditions, the camera's optical center and the control points are approximately coplanar. Only a single image of these control points captured by the camera in measurement state is used in the method. Neither to distribute the control points in space rationally nor to calibrate the camera's intrinsic parameters in laboratory in advance is needed. By the presented method, the camera's principal point position, focal length, radial and transverse tangency lens distortion coefficients, and the camera's position and attitude parameters can be estimated precisely. Then the calibration results can be used for precise large field optical measurement in the conditions that the camera's longitudinal tangency lens distortion can be neglected or the objects' movement field is close to the ground, which is usually factual in practical applications. The presented camera calibration method has been successfully used in applications, such as automatic landing of UAV (Unmanned Aerial Vehicle) based on optical measurement guidance, to calibrate the cameras precisely.

1. Introduction

To estimate objects' structure or movement parameters from their images or videos captured by cameras is an important task of optical measurement. To calibrate the cameras' parameters precisely is the basic work for precise optical measurement. Camera calibration is to estimate a camera's parameters by experiments and calculation. The parameters to be calibrated include the intrinsic parameters consist of principle point and focal length, etc., the extrinsic parameters which describe the camera's position and attitude, and the coefficients which describe the lens distortion [1]. Classical camera calibration methods in precise optical measurement include Tsai's [2], Weng's [3] and Zhang's [4] methods, etc., which are based on images of some control points with exactly known coordinates. Such control points even can be provided by novel crossed fringe pattern [5]. Some recent research expands to calibrate a camera's parameters by using a single image of coplanar control points or lines [6,7]. And methods of camera calibration by using restriction movement control points aligned on a line are presented in recent years [8]. Another kind of camera calibration methods is self-calibration which does not need control points or lines and is the hot research topic in recent years [9,10].

For traditional camera calibration methods, the reference points or lines must be distributed in space or in the calibration image rationally to get stable and precise results. Such condition is easy to be constructed in laboratory or if the view field is not large. Fig. 1 shows several kinds of reference objects with control points for camera calibration. For the large outdoors field optical measurement that the camera is installed close to the ground, if there are high buildings in the view field, structure characters on the buildings can be used as control points. While, if the view field is void, a few or even tens of meters high shelves may be needed to be built to construct control points distributed in space and images rational. This will bring extremely high engineering cost.

To fulfill the precise camera calibration requirement in optical measurement in large outdoors field, where control points in space rationally are difficult to be built, a new camera calibration method is presented in this paper. As shown in Fig. 2, the presented method is used in the condition that the control points and the camera to be calibrated are coplanar or approximately coplanar (both close to the ground in a large view field). In Fig. 2, G is the ground surface, S is the camera's optical center, the dashdotted line is the optical axis, I is the image, P_0–P_3 are the control points close to the ground and p_0–p_3 are their corresponding projections.

In the presented method, the initial values of the camera's parameters are calculated first. Then, the precise results are obtained by optimization. Only a single calibration image captured by the camera in measurement state is used, where the control points and the camera's optical center are coplanar or approximately coplanar. As shown in Fig. 2, because the control

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(a) novel crossed gridding (b) chess board (c) novel crossed fringe pattern [5]

Fig. 1. Several reference objects for camera calibration usually used in laboratory.

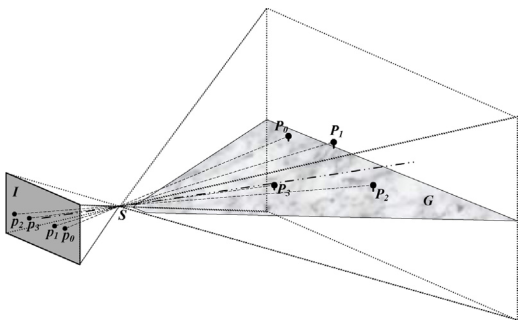


Fig. 2. The projective relationships that all of the control points and the camera to be calibrated are close to the ground in large outdoors field.

points' projections are approximately on a straight-line parallel to the image's landscape orientation, the longitudinal tangency lens distortion coefficients will not be calibrated. Other parameters including the radial and transverse tangency lens distortion coefficients will be calibrated. In fact, the tangency lens distortion is usually so small that it can be neglected in many application conditions [1,11]. While, if the tangency lens distortion cannot be neglected, such calibration results still can be used when the objects to be measured are close to the ground, because the transverse tangency lens distortion coefficients are calibrated precisely.

2. Principle of the presented method

2.1. Camera model

A central projection camera model with nonlinear lens distortion as follows is considered [11].

$$\begin{cases} x = f_x \dfrac{r_{00}(X - X_S) + r_{01}(Y - Y_S) + r_{02}(Z - Z_S)}{r_{20}(X - X_S) + r_{21}(Y - Y_S) + r_{22}(Z - Z_S)} + C_x + \delta_x \\ y = f_y \dfrac{r_{10}(X - X_S) + r_{11}(Y - Y_S) + r_{12}(Z - Z_S)}{r_{20}(X - X_S) + r_{21}(Y - Y_S) + r_{22}(Z - Z_S)} + C_y + \delta_y \end{cases} \quad (1)$$

where (X,Y,Z) are an object point's coordinates in the reference system, (x,y) are the corresponding projection's coordinates, (C_x,C_y) are the camera's principle point's image coordinates, f_x and f_y are the transverse and longitudinal equivalent focal length, respectively, and (X_S,Y_S,Z_S) are the camera's optical center's coordinates in the reference system. The camera's rotation angles A_X, A_Y and A_Z's trigonometric functions' combinations, r_{00}–r_{22}, are the elements of the camera's rotation matrix R. δ_x and δ_y are the transverse and longitudinal lens distortion, respectively. If the lens distortion can be neglected, the imaging model will be a linear relationship that the object point, the corresponding projection and the optical center are on the same line of sight.

The lens distortion's values are calculated as

$$\begin{cases} \delta_x = (k_0 x_d + k_1)(x_d^2 + y_d^2) + k_3 x_d^2 + k_4 x_d y_d \\ \delta_y = (k_0 y_d + k_2)(x_d^2 + y_d^2) + k_3 x_d y_d + k_4 y_d^2 \end{cases} \quad (2)$$

with

$$\begin{cases} x_d = (\tilde{x} - C_x)/f_x \\ y_d = (\tilde{y} - C_y)/f_y \end{cases}$$

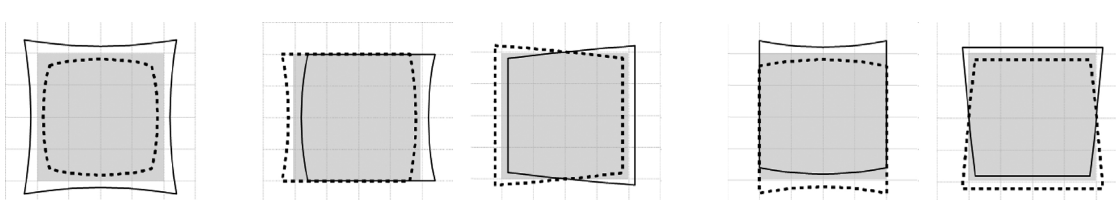
where $(\tilde{x}, \tilde{y})$ are the ideal projection's coordinates without lens distortion. k_0–k_4 are the lens distortion coefficients. k_0 is a radial distortion coefficient which describes the distortion centrosymmetric about the principle point. k_1–k_4 are tangency distortion coefficients which describe the distortion along the image's transverse or longitudinal orientation. Where k_1 and k_3 are transverse tangency distortion coefficients, and k_2 and k_4 are longitudinal tangency distortion coefficients. These lens distortion coefficients' actions on the image are shown in Fig. 3. Where the shadow squares are the images without distortion, the solid line frames or the dashed line frames are the distortion images with corresponding positive or negative lens distortion coefficients, respectively.

For camera calibration, the parameters to be calibrated are the principle point's coordinates (C_x,C_y), the transverse and longitudinal equivalent focal length f_x and f_y, the lens distortion coefficients k_0–k_4, the optical center's coordinates (X_S,Y_S,Z_S) and the rotation angles A_X, A_Y and A_Z.

In this paper, the camera calibration method for large outdoors field optical measurement is presented in the following conditions. The control points' coordinates (X,Y,Z) are precisely known. Their corresponding projections have been extracted precisely from the calibration image. The camera's optical center's coordinates (X_S,Y_S,Z_S) are approximately known as initial values. In fact, the camera's position coordinates are treated as the optical center's approximate coordinates. They are measured by the same method when we measure the control points' positions in the reference system. All of the control points and the camera are coplanar or approximately coplanar.

2.2. Calculation of the camera parameters' initial values

Approximate but not precise initial values are needed. We take the image's center as the principle point's initial position and 0 as the distortion coefficients' initial values. Then we calculate the equivalent focal lengths and the rotation angles' initial values.



(a) actions of k_0 (b) actions of k_1 (c) actions of k_3 (d) actions of k_2 (e) actions of k_4

Fig. 3. The lens distortion coefficients' actions on the image.