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A New Method of Camera Calibration for Large Field Videometrics

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Abstract: A new method of camera calibration is proposed for high-precise videometrics in large field. The camera to be calibrated and the control points used in the new method are both close to the ground. In the condition that the control points and the optical center of the camera are approximately coplanar, the principle point position, focal length, lens distortion coefficients and the camera's position and attitude parameters are calibrated precisely by the method. Two calibration images are taken by the camera to be calibrated in measurement state and vertical rotation state respectively. If the vertical tangent lens distortion can be neglected or the movement field of the targets to be measured are close to the ground, only the measurement state calibration image is needed to calibrate the camera's parameters except the vertical tangent lens distortion coefficients. By the new method, to calibrate the camera's intrinsic parameters in laboratory in advance is not needed. The new method breaks the localization for the traditional camera calibration methods in large field videometrics which require the control points must be distributed in space rationally.

Keywords: videometrics in large field, camera calibration, control points close to the ground

1 Introduction

Videometrics is to estimate objects' structure or movement parameters from their images or videos taken by cameras. Videometrics has advantages in precise, real time, automatization, untouchment, dynamic and conveniency for movement and distortion measurement[1]. To calibrate the cameras's parameters precisely is the basic work for videometrics[2,3,4]. 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 extrin-

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sic parameters to describe the camera's position and attitude, and the coefficients to describe the lens distortion. There are two kinds of camera calibration methods. One is to use the special instrument such as autocollimator etc. The other is to take a reference object's images and calculate the camera's parameters by analyzing the images[2,4]. The first kind of calibration methods need to calibrate the intrinsic parameters and lens distortion in laboratory, and calibrate the extrinsic parameters outdoors. While by the second kind of calibration methods, to calibrate all of the camera's parameters by analyzing the reference images in field, is more applicable to the condition that the camera's focal length, installation position and attitude are required to be adjusted in field. The classical camera calibration methods in precise videometrics include Tsai's[5], Weng's[6] and Zhang's[7] methods etc., which are based on images of some control points with exactly known coordinates. If the control points are coplanar, images taken from different position are needed. Most recent researches belong to the second kind of calibration methods which expands to calibrate a camera's partial parameters based on coplanar control points or lines[8,9] and methods of camera calibration based on restriction movement control points aligned on a line[10,11,12] are presented. Another kind of camera calibration methods is self-calibration which do not need control points or lines. Self-calibration is the hot research topic in the field of videometrics recent years [13,14,15,16]. Self-calibration methods usually used in low-precise tasks such as the robot vision navigation etc are scarcely applied to precise measurement.

For traditional camera calibration methods, the reference points or lines must be distributed in space rationally to get stable and precise results. Such condition is easy to be constructed in laboratory or if the view field is not large. Figure 1 shows several kinds of reference object for camera calibration with crosses, cirques or chessboard corners as control points. For the large field measurement task outdoors that the camera is installed close to the ground, if there are high buildings in view, structure character on the building can be used as calibration symbols. While, if the view field is void, a few or tens of meters high shelf may be needed to be builded to construct symbols distributed in space and images rational which are required for traditional calibration methods. This will bring extremely high engineering cost.

To fulfill the high-precise camera calibration requirement in videometrics task in large outdoors field, a method to calibrate cameras' parameters based on control points close to the ground is presented in this paper. In such condition, the control and the camera to be calibrated are coplanar approximately, and the image projections of the control points are distributed close to a line parallel to the image's landscape orientation shown as Figure 2, where G is the ground level, S is the camera's optical center, the dashdotted line is the optical axis, I is the image, $P_0 \sim P_3$ are control points close to the ground, $p_0 \sim p_3$ are the corresponding image projections.

Figure 1: Reference objects for camera calibration usually used in laboratory

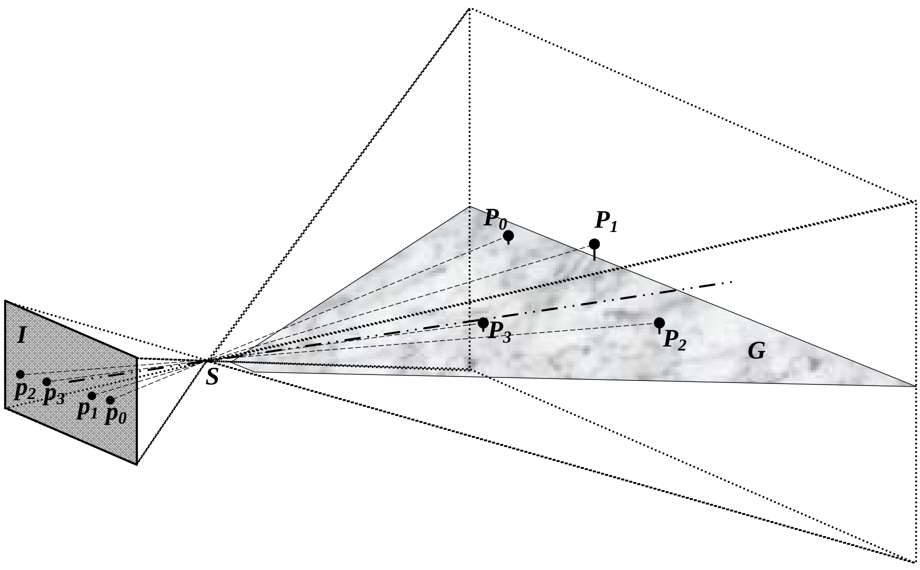

Figure 2: Imaging progress that the camera to be calibrated and the control points are both close to the ground in large outdoors field

For the traditional calibration methods based on coplanar or noncoplanar reference symbols, the calibration will be invalidation or bring large errors in above condition. While a new method to calibrate the camera's parameters precisely in the condition that the control points and the camera are approximately coplanar in field is presented in this paper. By the new method, the initial values of parameters are calculated and then the precise results obtained through optimizing the values. The calibration can be tested just using one calibration image taken by the camera in measurement state with its landscape orientation approximately horizontal. What's more, if another calibration image can be taken by the camera in vertical rotation state, i.e. the state of rotating the camera about 90 degrees around its optics axis from the state that the landscape orientation is approximately horizontal, the images in measurement state and in vertical rotation state respectively will be used together in the calibration.

If only one calibration image in measurement state is used, because the control points' image projections are approximately parallel to the image's landscape orientation, the horizontal tangent lens distortion coefficients will not be calibrated in the new method. In fact, the horizontal tangent lens distortion can be neglected in most conditions, the calibration results can be used in measurement in the full view field. For the few conditions that the horizontal tangent lens distortion can not be neglected, the calibration results also can be used in measurement in the field close to the ground. While, if another calibration image can be taken by the camera in vertical rotation state, all of the parameters consisted of the horizontal tangent lens distortion coefficients can be calibrated.

2 The principle of the new calibration method

2.1 The camera model

A central projection camera model with nonlinear lens distortion is used in this paper[4]. The imaging model can be described as following

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

Where (X,Y,Z) is a world point's coordinates in the norm system, (x,y) is the corresponding image projection's coordinates in the image system. (C_x,C_y) is the camera's principle point, i.e. the image coordinate of the cross point of the optical axis and the imaging plan. f_x and f_y are the transverse and longitudinal equivalent focal length respectively, i.e. the ratio value of the real focal length and a single pixel's transverse or longitudinal physical width. (X_S,Y_S,Z_S) is the camera's optical center's coordinate in the norm system. $r_{00} \sim r_{22}$ are the elements of the camera's rotation matrix R

$$R = \begin{bmatrix} r_{00} & r_{01} & r_{02} \\ r_{10} & r_{11} & r_{12} \\ r_{20} & r_{21} & r_{22} \end{bmatrix} \tag{2}$$

The elements of R are the camera's rotation angles A_X, A_Y and A_Z's trigonometric functions' combinations [4]. R is an unit orthogonal matrix, i.e., the sum of squares of the three elements in the same row or line is 1, and the sum of products of the corresponding elements in different row or line is 0, a vector constructed by the elements in a row or line is the cross product of the two vectors constructed by the elements in the other two rows or lines. The rotation angles A_X, A_Y and A_Z are the three Euler angles that the norm system rotates around the three axes in turn to the state that the axes are parallel to the camera system's corresponding axes respectively. The optical center is defined as the camera system's origin and the optical axis as axis Z with the shoot orientation positive. The X axis is parallel to the image landscape orientation with rightward be positive. The Y axis is defined by the right hand rule.

δ_x andδ_y are the transverse and longitudinal image errors brought by the lens distortion. If the lens distortion can be neglected, the image error will be 0 and the imaging model will be a linear relationship that the space point, the corresponding image projection and the optical center is on the same line. Then the image projection $(\tilde{x}, \tilde{y})$ is called ideal image projection. The image errors' values are calculated as

$$\begin{cases} \delta_x = (k_0 x_d + k_1)\left(x_d^2 + y_d^2\right) + k_3 x_d^2 + k_4 x_d y_d \\ \delta_y = (k_0 y_d + k_2)\left(x_d^2 + y_d^2\right) + k_3 x_d y_d + k_4 y_d^2 \end{cases} \tag{3}$$

Where (x_d, y_d) is the ideal image projection's unitary coordinates

$$\begin{cases} x_d = (\tilde{x} - C_x)/f_x \\ y_d = (\tilde{y} - C_y)/f_y \end{cases} \tag{4}$$

$k_0 \sim k_4$ are lens distortion coefficients. k_0 is radial distortion coefficients which describe the distortion centrosymmetric about the principle point. $k_1 \sim k_4$ are tangency distortion coefficients which describes the distortion along the image's transverse or longitudinal orientation.

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

The camera calibration method for outdoors large field videometrics in this paper is presented in the following condition. The control points' coordinates in norm system (X, Y, Z) are precisely known. The corresponding image projections have been extracted precisely. And the optical center's coordinates in norm system (X_S, Y_S, Z_S) are approximately known. Then the camera's parameters including the optical center's position (X_S, Y_S, Z_S) are to be calibrated precisely. In fact, the optical center exists actually, but it's very hard to measurement the optical center's precise position in space directly. While the optical center's approximate position used as initial values can be measured by the same method when we measure the control points' precise position.

2.2 Calculation of the camera parameters' initial values

Approximate but not precise initial values are needed. The method in this paper is to take the image's center as principle point and take the distortion coefficients as 0. Then to calculate the initial values of the equivalent focal length and the rotation angles.

Firstly, the method of calculating the initial values of the equivalent focal length and the rotation angles is introduced by taking one image in measurement state calibration as an example.

1) Calculation of the equivalent focal length's initial values in measurement state

The camera and calibrated makers are close to the ground relatively, so approximatively as two-dimensional problem for solving the equivalent focal length's initial values. As usual, set the norm system Z axis vertical to the ground, the image in measurement state transverse axis parallel to ground level, then calibrated makers, camera position X, Y axis, imaging points x axis should just be considered. In Figure 3, the position coordinate of optical center S is (X_S, Y_S), the principle point coordinate is C_x, the image transverse equivalent focal length is f_x. Choose two makers unlinear to optical center$P_0(X_0, Y_0)$ and $P_1(X_1, Y_1)$ to correspond to imaging points $p_0(x_0)$ and $p_1(x_1)$, the angle of optical axis and line-of-sight SP_0, SP_1 is α and β respectively.

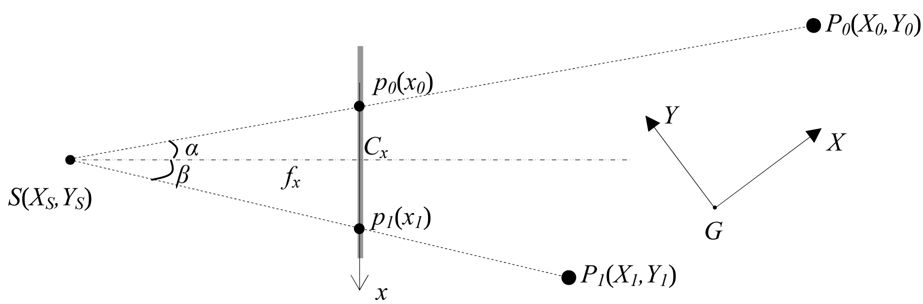

Figure 3: Diagram of equivalent focal length's initial values calculation

Mark $x'_0 \cong |x_0 - Cx|$, $x'_1 \cong |x_1 - Cx|$, the result is retrieved from using angle formulas and triangle in fig.3.

$$\tan(\alpha + \beta) = \frac{\tan\alpha + \tan\beta}{1 - \tan\alpha\tan\beta} = \frac{f_x\,(x'_0 + x'_1)}{f_x^2 - x'_0 x'_1} \tag{5}$$

Based on the cosine theorem, then

$$\tan(\alpha+\beta)=$$
$$\tan\left[\arccos\frac{(X_0-X_S)^2+(Y_0-Y_S)^2+(X_1-X_S)^2+(Y_1-Y_S)^2-(X_1-X_0)^2-(Y_1-Y_0)^2}{2\sqrt{\left[(X_0-X_S)^2+(Y_0-Y_S)^2\right]\left[(X_1-X_S)^2+(Y_1-Y_S)^2\right]}}\right] \tag{6}$$

So the calculation of initial values about transverse equivalent focal length is obtained.

$$f_x=\frac{(x_0'+x_1')+\sqrt{\left(x_0'+x_1'\right)^2+4x_0'x_1'\tan^2(\alpha+\beta)}}{2\tan(\alpha+\beta)} \tag{7}$$

In the condition that calibrated image be taken only in measuring state, set transverse and longitudinal equivalent focal length the same according to cameras, and take **initial values** of longitudinal equivalent focal length f_y equal to $f_{x.}$

2) The calculation of rotation angle's initial values in measurement state

Mark$x'' \cong \frac{x-C_x-\delta_x}{f_x}$,$y'' \cong \frac{y-C_y-\delta_y}{f_y}$ the imaging principle in formula (1) is

$$\begin{cases} x''=\frac{r_{00}(X-X_S)+r_{01}(Y-Y_S)+r_{02}(Z-Z_S)}{r_{20}(X-X_S)+r_{21}(Y-Y_S)+r_{22}(Z-Z_S)} \\ y''=\frac{r_{10}(X-X_S)+r_{11}(Y-Y_S)+r_{12}(Z-Z_S)}{r_{20}(X-X_S)+r_{21}(Y-Y_S)+r_{22}(Z-Z_S)} \end{cases} \tag{8}$$

Which can be rewritten as

$$\begin{cases} \frac{r_{00}}{r_{22}}(X-X_S)+\frac{r_{01}}{r_{22}}(Y-Y_S)+\frac{r_{02}}{r_{22}}(Z-Z_S)-\frac{r_6}{r_{22}}x''(X-X_S)-\frac{r_{21}}{r_{22}}x''(Y-Y_S) \\ =x''(Z-Z_S) \\ \\ \frac{r_{10}}{r_{22}}(X-X_S)+\frac{r_{11}}{r_{22}}(Y-Y_S)+\frac{r_{12}}{r_{22}}(Z-Z_S)-\frac{r_{20}}{r_{22}}y''(X-X_S)-\frac{r_7}{r_{22}}y''(Y-Y_S) \\ =y''(Z-Z_S) \end{cases} \tag{9}$$

To solve this linear equations, then can get $\frac{r_{00}}{r_{22}},\frac{r_{01}}{r_{22}},\frac{r_{02}}{r_{22}},\frac{r_{10}}{r_{22}},\frac{r_{11}}{r_{22}},\frac{r_{12}}{r_{22}},\frac{r_{20}}{r_{22}},\frac{r_{21}}{r_{22}}$.
Each element of rotation matrix can be calculated based on unit orthogonality of rotation matrix:

$$\begin{bmatrix} r_{00} & r_{01} & r_{02}\end{bmatrix}^T=\begin{bmatrix}\frac{r_{00}}{r_{22}} & \frac{r_{01}}{r_{22}} & \frac{r_{02}}{r_{22}}\end{bmatrix}^T\Big/\sqrt{\left(\frac{r_{00}}{r_{22}}\right)^2+\left(\frac{r_{01}}{r_{22}}\right)^2+\left(\frac{r_{02}}{r_{22}}\right)^2} \tag{10}$$

$$\begin{bmatrix} r_{10} & r_{11} & r_{12} \end{bmatrix}^T = \begin{bmatrix} \frac{r_{10}}{r_{22}} & \frac{r_{11}}{r_{22}} & \frac{r_{12}}{r_{22}} \end{bmatrix}^T / \sqrt{\left(\frac{r_{10}}{r_{22}}\right)^2 + \left(\frac{r_{11}}{r_{22}}\right)^2 + \left(\frac{r_{12}}{r_{22}}\right)^2} \tag{11}$$

$$\begin{bmatrix} r_{20} & r_{21} & r_{22} \end{bmatrix}^T = \begin{bmatrix} r_{00} & r_{01} & r_{02} \end{bmatrix}^T \times \begin{bmatrix} r_{10} & r_{11} & r_{12} \end{bmatrix}^T \tag{12}$$

Furthermore, each rotation angle is analyzed on the basis of the definition of rotation matrix[4]. Thus initial values of parameters in measurement state are successfully obtained.

If the camera is fixed before measuring, a calibration image can be taken by the camera in vertical rotation state, to calculate initial values of longitudinal equivalent focal length and the rotation angles. While in vertical rotation state, longitudinal mode is parallel to ground level, the imaging of calibrated makers is distributed closed to a line in longitudinal mode on the whole. So only take calibrated makers, $\boldsymbol{X}$, $\boldsymbol{Y}$ coordinate showing camera's position and imaging point $\boldsymbol{y}$ coordinate into consider, to calculate the initial values of transverse equivalent focal length in measurement state corresponding to initial values of longitudinal equivalent focal length $f_{y.}$As transverse and longitudinal equivalent focal length are almost consistent, we can assume the initial values of longitudinal equivalent focal length f_y equal to$f_{x.}$ After calculating the initial values of equivalent focal length, the initial values of the rotation angles in vertical rotation state can be calculated correspondingly in measurement state.

The position and attitude of the camera after vertically rotating are also to-be-calibrated parameters by the calibration method introduced in this paper, so during vertical rotating it is demanded that calibrated makers are districted in longitudinal mode instead of strictly demanded 90°rotating as self optical axis in the original position.

2.3 To calculate precise values of camera's parameters

Consider calibrated makers as control points, grab imaging coordinates of each control point and do adjustment optimization treatment after getting initial value of every parameter, minimize the windage of overlapped projection of control points separately based on camera's calculated parameters and actual imaging, then the best calibration parameter result of the camera is obtained.

In the condition that calibrated images be taken separately in measuring state and in vertical rotation state, link of each control points' imaging relations in two images, use the camera's principle point coordinate, equivalent focal length, coefficients, and position of each optical center in measuring state and in vertical rotation state, rotation angles as optimize parameters to do bundle adjustment. Full imaging model as (3) is introduced in the bundle adjustment.

If calibration with only one image taken in measurement state, considering the parallel of image transverse and the ground level, as a result of every calibrated control points' image distributed close to a line parallel to the image's landscape orientation, the calculation of longitudinal equivalent focal length f_y and the horizontal tangent distortion parameter k_2, k_4 that only has longitudinal effect can't be controlled perfectly. In the circumstance, set transverse and longitudinal equivalent focal length the same to optimize calculation, the rationality of that will be discussed in the following. While most of lens are vertical tangent lens distortion, the effect of the horizontal tangent lens distortion can be neglected usually. As a result, imaging model is simplified as (3) when the longitudinal image tangent lens distortion unconsidered now.

$$\begin{cases} \delta_x = (k_0 x_d + k_1)\left(x_d^2 + y_d^2\right) + k_3 x_d^2 \\ \delta_y = k_0 y_d \left(x_d^2 + y_d^2\right) + k_3 x_d y_d \end{cases} \tag{13}$$

Meanwhile, k_0 is the radial distortion coefficients, k_1, k_3 is the transverse angency distortion coefficients. Here set only k_0, k_1, k_3 as refined distortion coefficients. In the condition that the motion scale of the object is close to the ground or the horizontal tangent lens distortion can be neglected, it will not bring significant effect on measurement precision.

In fact, the parameters acting on processing of imaging are coupled and compensated each other neither of self-independent. Based on this principle, some parameters can be set as fixed values, or optimize the calculation of other parameters. The calibration also can be used for high precision measurement[17]. The prevailing simplification is to take the image's principle points in the center of image [18,19]. Detailed analysis on this issue and simulation validation in literature [17]verify that overlapped projection error of imaging compared with overlapped projection error based on intact model calibration and image characteristics extraction error in application is little, so introducing these simplified camera imaging model to calibrate and measure in application is without precision loss. The effect produced by using simplified camera imaging model to calibrate and measure in large field in the text has little prominent difference compared with using intact camera imaging model. In this paper, take the image's principle points in the center of image, and set transverse and longitudinal equivalent focal length the same, then the calculation process can be simplified and the number of the calibrated makers needed can be reduced without influencing calibration and precision.

2.4 The implementation of calibration

A representative implementation of the camera calibration for outdoors large field videometrics in this paper is presented as follows:

1). Put some control points in the camera metrical view.

2). Build the norm system to meet the need of measurement, and confirm the precise coordinates of every control points in the norm reference frame, then ascertain the glancing position coordinate of the camera in this norm reference frame; total station or theodolite can be used during the process.

3). If the condition of the measurement allowed, put cameras to-be-calibrated in vertical rotation state relatively to measuring state, and images of the control points are taken.

4). Adjust the camera to-be-calibrated to measuring state and install it, the image of calibrated point can be taken. If it is impossible for image grabbing under the camera in vertical rotation state, then we can change to take calibrated image in measurement state .

5). Grab calibrated makers in the calibrated image, analyze and calculate the parameters of the camera.

3 Verifying experiment in large field

3.1 The condition and process of the experiment in large field

In the experiment in large field, an area coverage of about fifty meters multiplied meters is shooted and intersection measured by two cameras. The type of the camera is Adimec-4050m, image size is 2352×1728pix, the transverse field of vision's angle is about 30^o.The camera is set up about 1 meter height from the ground. The distance of the camera and observation coverage center is about 80 meters. The angle of two camera's optical axis is about 50^o.

Set up some makers in the observation coverage. Establish the norm reference frame to attain the experiment, measure every maker's precise coordinate in the norm reference frame and the camera's position coordinate in the norm reference frame by total station. Use some of the makers as calibration makers to calibrate two cameras' parameter. Then choose other makers as to-be-measured object, do intersection measurement to these makes' position coordinate based on camera's parameter calibration result, and compare with the result measured by total station. Compare both results from the experiment data processing separately between the whole parameter camera model adopted when the horizontal tangent lens distortion be neglected and simplified camera model introduced in this paper. The type of total station used is Leica NTS312, under the circumstance of the experiment observation allowed, the measured precision of the makes' position is within 5mm estimately. The image characteristic is extracted in the way that part enhanced and amplified then manual point-take-out, the extraction precision is within 0.5pix estimately.

The norm reference frame, the position of cameras, the position of the maker planform in the experiment is as fig.4. Where *W-XYZ* is the norm reference frame, C_0, C_1 are the cameras. The triangle position 00∼12 are the makers which are hollow aluminum alloy balls set up casually and branched by pole, where about 1m height from the ground. Every maker and camera C_0, C_1 are approximately coplanar. In Figure 4, solid triangle makers sign calibration makers, while hollow triangle makers sign to-be-measured object.

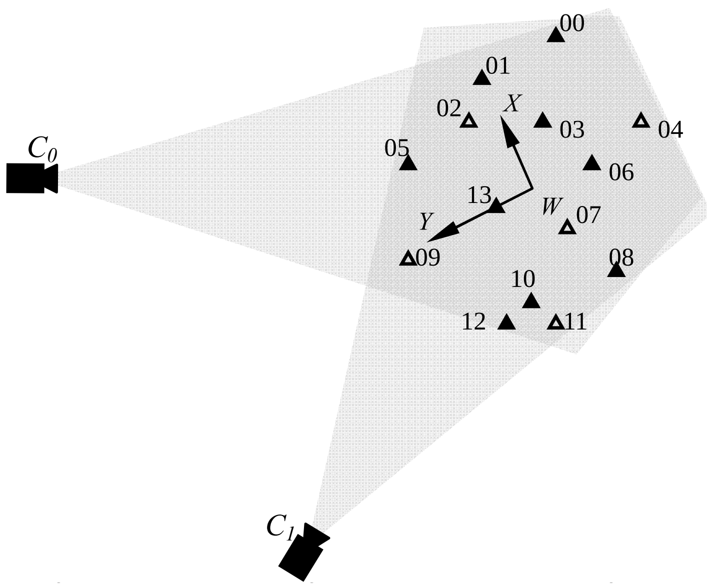

Figure 4: The norm reference frame, the position of cameras, the position of the maker planform in the verifying experiment in large field

During the experiment, two calibration images are taken by the camera to be calibrated in measurement state and vertical rotation state respectively, to calibrate camera in two ways introduced in this paper, one is based on two calibrated images in measurement state and in vertical rotation state; another is based on calibrated image only in measurement state. the whole parameter camera model is used for two calibrated images in measurement state and in vertical rotation state, while simplified camera model is used for calibrated image only in measurement state, take the image's center as principle point, assume the transverse and longitudinal equivalent focal length same, and only consider radial distortion coefficients and image transverse tangency distortion coefficients, while image longitudinal tangency distortion coefficients dismissed.

Figure 5 is a part of one calibration image taken by camera C_0 in the experiment. The imaging position of each maker coplanar approximately with the camera is distributed close to a line parallel to the transverse image.

Figure 5: A part of one calibration image shot by camera C_0 in the experiment large field

3.2 Experimental results

To be calibrated by some makers close to the ground in Figure 4, then based on calibration results, do intersection measurement in each points untapped during the calibration. Meanwhile, compare with these makers' position coordinates in the norm system measured by total station as the actual value to verify the calibration effect. Use two modes above-mentioned respectively to calibrate the camera's parameters and do intersection measurement on to-be-calibrated points. The result of error is listed in Table 1.

It shows that using the method proposed in this paper to do camera calibration based on condition that the cooperative control points and the camera are approximately coplanar, the observation distance about 80 meters, observation field of vision about 50 meters multiply 50 meters and to-be-calibrated points are close to the ground, the precision of double camera intersection measurement in large field is in centimeter scale; separately use two images of measuring state and vertical rotation state and based on whole parameter imaging model to calibrate camera, and only use one image in measuring state and based on simplified parameter imaging model to calibrate camera, these methods have no significant intersection measurement precision difference to target close to the ground. Every cooperative point's measuring result indicates the majority of Y element error is bigger than other coordinates element error, that's because the measuring angle of double-camera intersection measurement is less, viz ratio less than one, so as to the intersection measurement error is bigger in the direction of eyeshot depth. [20]

Table 1: Camera calibration intersection measurement result of error in large field

Point number	As the actual position values of to-be- calibrated points by Total Station (m)			After calibrating parameters of camera using two images in measuring state and vertical rotation state based on whole parameter imaging model, the intersection measurement error of to-be- calibrated points(cm)			Only use one image in measuring state and calibrate parameters of camera based on simplified parameter imaging model, the intersection measurement error of to-be- calibrated points(cm)		
	X	*Y*	*Z*	*X*	*Y*	*Z*	*X*	*Y*	*Z*
02	19.377	6.254	0.912	-1.0	2.4	0.7	-1.1	2.6	0.5
04	5.521	-24.852	1.263	1.2	-3.1	-1.3	1.5	-3.2	-1.5
07	-11.002	-1.853	1.291	1.5	-2.7	1.6	1.6	-2.5	1.7
09	-0.967	26.241	1.224	-0.9	2.0	-1.2	-1.2	2.4	-1.3
11	-24.655	9.201	1.039	1.4	-1.5	1.3	1.6	-1.8	1.5

4 Conclusions

Based on the condition that the calibrated makers and the position of the camera are approximately coplanar, a camera parameter calibration method is proposed in this paper. Two calibration images are analyzed using the camera in measurement state and vertical rotation state respectively. While in the condition that the motion scale of to-be-calibrated object is close to the ground, then one image taken in measurement state is needed to be analyzed. This method is easy and convenient to be applied in the field, and it is not needed to calibrate the camera's intrinsic parameters in laboratory in advance. The new method is of great value in theory and applications, and it breaks the localization for the traditional camera calibration methods in large field videometrics which require the control points must be distributed in space rationally. The verifying tests taken in large field proves that the method of camera calibration presented in this paper can be used effectively for high-precise videometrics in large field.

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