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An Improved QPSO Algorithm Based on EXIF for Camera Self-calibration

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***Abstract* - Binocular vision technology is an important branch of computer vision technology, which is widely used in robot motion, navigation, surgical treatment and many other fields. As is a crucial link, it is the basis of binocular vision technology to obtain the internal parameters of a digital camera. Traditional calibration methods, such as Zhengyou Zhang's method needs a calibration board, while the self-calibration method based on active vision needs to strictly control a camera to move in a designated way. Based on that, those methods can't be applied to simple and convenient occasions. In this paper, we aim to propose a new method of camera self-calibration by improving an existing QPSO algorithm with the EXIF information of digital camera photos. The method only needs to shot one object twice on different angles. We derive the conversion formula of equivalent focal length and pixel focal length and use it to initialize the algorithm. It is to find the optimal solution of the cost function transformed from the Kruppa equation by using the QPSO method. The experiment results proved that the improved method is better than the initial one and using the EXIF information to initialize the algorithm is feasible.**

Index Terms - Camera self-calibration, QPSO, KRUPPA equation, EXIF information

I. INTRODUCTION

Binocular vision technology is an important branch of computer vision technology, which imitates the principle of human binocular imaging to obtain the surrounding environment information. In recent years, the development of binocular vision technology is booming. The application of binocular vision technology in robot motion [1-3], navigation [4-5], three-dimensional reconstruction [6], surgical treatment, VR, target detection [7], bionic design [8-10] and other fields is prevalent. That is, the prospect of binocular vision technology is extremely broad.

Camera calibration aims to calculate the camera's internal parameters from the image information obtained by a digital camera. Since the mapping relationship between the spatial position of an object and its projected pixels in the image is determined by the geometric model of camera imaging, obtaining these geometric model parameters, that is, camera internal and external parameters, is the premise of image measurement or binocular vision technology.There are three kinds of calibration methods these years. Traditional camera calibration methods, such as Zhengyou Zhang's method [11-12], need to use precisely processed calibration blocks to calculate the camera's internal and external parameters by establishing the corresponding relationship between image points and points on known-sized calibration blocks. This method is of high accuracy and the results are often seen as a camera's true value, while the main disadvantage is that ten to twenty photos need to be taken with the calibration board to ensure the reliability of the results. The calibration process is time-consuming and laborious. So it is not suitable for real-time monitoring calibration online and is also restricted to the situation where it is impossible to use a calibration board.

Compared with the traditional calibration method, self-calibration methods have already reduced the number of photos. Although the calibration method based on active vision does not need a calibration board, it needs to control a digital camera to do some special movements, such as rotation around the optical center or pure translation and so on [13]. According to the image information and known displacement changes, the internal and external parameters of the camera can be solved out. The advantage of this method is that the algorithm is simple and the linear solution can always be solved out[14]. Besides, this calibration method needs to be equipped with an accurate control platform, so the cost is high. And the disadvantage is that it is not suitable for the situation where the camera motion is unknown or uncontrollable.

And other self-calibration method, such as Kruppa equation [15], multi-vision [16], geographical information fusion [17], lidar system [18], additional parameter model [19] and so on. In the early 1990s, from the perspective of projective geometry, Faugeras. proved that there are two quadratic nonlinear constraints between every two images and the internal parameters can be obtained by directly solving the Kruppa equation [20]. It is extremely complex to solve this equation directly, so people put forward the idea of layering step-by-step. The length of the image sequence will affect the stability of the algorithm, which can not guarantee the infinite plane in the projective space.

Therefore, this paper aims to improve an existing parallel particle swarm optimization algorithm(QPSO) algorithm for a camera self-calibration based on EXIF information of photos, which uses only two photos of different angles. We specifically convert the known equivalent focal length hidden in the EXIF information into pixel focal length, which is the focal length value in the camera's internal parameter and use it as the initial value of the algorithm. It is proved by the camera calibration experiment that it can effectively improve the accuracy of the existing QPSO self-calibration algorithm [21].

The paper is mainly composed of three chapters. Chapter II discuss the method of camera self-calibration. In part *A*, we give the internal parameter model of a digital camera and simplify it. In part *B*, we introduce the EXIF information of a photo and explain the meaning of the equivalent focal length. In part *C,* we deduce the conversion relationship between equivalent focal length and pixel focal length. In part *D,* the solution of internal parameters is transformed into the solution of Kruppa equation and is further transformed into the optimization of the cost function. In part *E,* we introduce the QPSO algorithm. In chapter III, we do experiments to assess the accuracy of the original QPSO algorithm and the improved QPSO algorithm and discuss the two methods in chapter IV.

II. Camera self-calibration method

A. Internal Parameter model

Matrix K is the transformation matrix, which can transform camera coordinate system to image coordinate system. It is called camera internal parameter matrix and the purpose of camera self-calibration is to obtain matrix K (1):

$$K = \begin{bmatrix} \alpha f_u & s & u_{0i} \\ 0 & f_v & v_{0i} \\ 0 & 0 & 1 \end{bmatrix} \tag{1}$$

Here, α represents aspect ratio, s represents skew factor, f_i represents effective focal length, (u_{0i}, v_{0i}) represents principle point.

Besides, the image formation of digital camera is related to charge coupled devices (CCD), which can convert optical image into digital signal. And the diagonal length of CCD is the size of photosensitive element, which determines the size of imaging. The skew factor is caused by manufacturing errors of CCD devices. Because the manufacturing process of the CCD component of digital cameras is relatively exquisite, the value of skew factor s is very close to 0. At the same time, the focal length values of the two directions are approximately equal. That is, $s = 0$, $\alpha = 1$.

Therefore, the internal parameter matrix of digital camera can be simplified as follow(2):

$$K = \begin{bmatrix} f_u & 0 & u_{0i} \\ 0 & f_v & v_{0i} \\ 0 & 0 & 1 \end{bmatrix} \tag{2}$$

B. EXIF Information of a photo

EXIF information is a set of photographing parameters embedded in JPEG/TIFF image file format, mainly including aperture, shutter, isolation(ISO), time, equivalent focal length and other information related to photographing conditions at that time. Fig. 1 is an example of EXIF information of a photo.

When calculating the focal length in parameter matrix K, it is necessary to convert the imaging angles of different-sized photosensitive elements into standard-sized photosensitive elements camera. This standard is 135 full frame camera, which has a 43.27mm CCD device when imaging and a 35mm physical focal length. Therefore, the equivalent focal length in Fig. 1 means it is equivalent to the 27mm focal length value of 135 full frame camera.

Fig. 1 An example of a photo's EXIF information

C. Conversion between equivalent focal length and pixel focal length

As the focal length in the camera internal parameter is pixel focal length, so we need to convert the known equivalent focal length into pixel focal length. Apparently, we can obtained the following equations according to the definition of physical focal length and pixel focal length.Thus(3),

$$k_u = f_u \times dpu \tag{3}$$

Where k_u (mm)represents the physical focal length on direction *u*, f_u (pixel) represents the pixel focal length on direction *u*, *dpu* (mm/pixel) represents the effective pixel size on direction *u*.

Generally, the ratio of a photo is 3:4, that means width: diagonal = 4:5. As to a general CCD digital camera, the size of the photosensitive element is 25.4mm in one inch, while in the calculation of the handheld CCD digital camera, it is 16mm in one inch because of the glass cover outside the vacuum tube does not participate in the imaging process. Thus(4),

$$dpu = \frac{ccdSize \times 16 \times 0.8}{Nfu} \tag{4}$$

Thus(5),

$$k_u = \frac{ccdSize \times 16 \times 0.8}{Nfu} \times f_u \tag{5}$$

Where *Nfu* represents the number of effective pixel on direction *u* and *ccdSize*(inch) represents the diagonal length of photosensitive element.

The diagonal length of 135 full frame camera is 43.27mm. Thus(6),

$$\frac{43.27}{\text{ccd}Size \times 16} = \frac{f_{equal}}{k_u} \tag{6}$$

$$f_1 = \frac{(\sigma_1^F)^2[k_1\upsilon_{11}^2 + k_4\upsilon_{21}^2 + \upsilon_{31}^2 + (k_2\upsilon_{11}\upsilon_{21} + k_3\upsilon_{11}\upsilon_{31} + k_5\upsilon_{21}\upsilon_{31})]}{(k_1\mu_{12}^2 + k_4\mu_{22}^2 + \mu_{32}^2) + 2(k_2\mu_{11}\mu_{21} + k_3\mu_{12}\upsilon_{32} + k_5\mu_{22}\mu_{32})} \tag{12}$$

$$f_2 = \frac{(\sigma_1^F)^2\left[k_1\mathrm{v}_{11}\mathrm{v}_{12} + k_4\mathrm{v}_{21}\mathrm{v}_{22} + \mathrm{v}_{31}\mathrm{v}_{32} + k_2(\mathrm{v}_{11}\mathrm{v}_{22} + \mathrm{v}_{21}\mathrm{v}_{12}) + k_3(\mathrm{v}_{11}\mathrm{v}_{32} + \mathrm{v}_{31}\mathrm{v}_{12}) + k_5(\mathrm{v}_{21}\mathrm{v}_{32} + \mathrm{v}_{31}\mathrm{v}_{22})\right]}{-\left[k_1\mathrm{u}_{11}\mathrm{u}_{12} + k_4\mathrm{u}_{21}\mathrm{u}_{22} + \mathrm{u}_{31}\mathrm{u}_{32} + k_2(\mathrm{u}_{11}\mathrm{u}_{22} + \mathrm{u}_{21}\mathrm{u}_{12}) + k_3(\mathrm{u}_{11}\mathrm{u}_{32} + \mathrm{u}_{31}\mathrm{u}_{12}) + k_5(\mathrm{u}_{21}\mathrm{u}_{32} + \mathrm{u}_{31}\mathrm{u}_{22})\right]} \tag{13}$$

$$f_3 = \frac{(\sigma_1^F)^2[k_1\upsilon_{12}^2 + k_4\upsilon_{22}^2 + \upsilon_{32}^2 + (k_2\upsilon_{12}\upsilon_{22} + k_3\upsilon_{12}\upsilon_{32} + k_5\upsilon_{22}\upsilon_{32})]}{(k_1\mu_{11}^2 + k_4\mu_{21}^2 + \mu_{31}^2) + 2(k_2\mu_{11}\mu_{21} + k_3\mu_{12}\mu_{31} + k_5\mu_{21}\mu_{31})} \tag{14}$$

Therefore we can obtain formula(7) ,

$$f_u = \frac{f_{equal} \times Nfu}{34.616} \tag{7}$$

Equally we can derive formula(8),

$$f_v = \frac{f_{equal} \times Nfv}{25.952} \tag{8}$$

So far, we have concluded the handheld digital camera conversion relationship between equivalent focal lengths and pixel focal length .

In the same way, we can conclude the general digital camera conversion relationship between equivalent focal lengths and pixel focal length. Units are reduced in calculation and the conversion relationship is the same as formula (7) and (8).

D. KRUUPA Equations and Solutions

In image plane *e* of the camera, there are two polar lines[17]. l_1 and l_2 are tangent to the curve ω on the plane. In image plane *e'*, there are two polar line l_1' and l_2'. They are tangent to ω' . According to the principle of epipolar geometry, l_1 and l_2 , l_1' and l_2' are respectively corresponded to two lines tangent to the absolute conic on the infinite plane [22]. The point sum can be regarded as a projection point on the infinite plane e, image plane *e* and image plane *e'*, and the two points are the principle points of the two planes respectively [23].

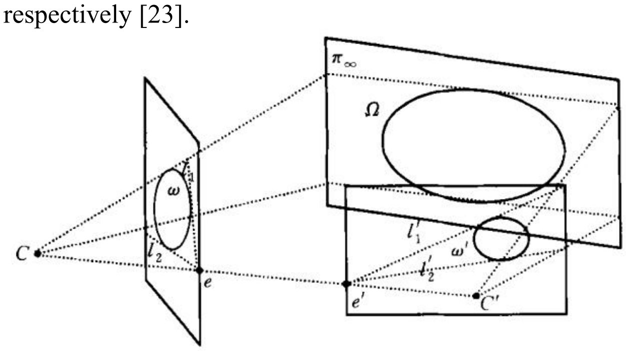


Fig. 2 An epipolar geometry diagram

Obviously, we can obtain formula(9),

$$F\mathrm{e}' = 0 \tag{9}$$

As the rank of the fundamental matrix is 2. Therefore, the equation can be transformed into(10),

$$[e']^T KK^T[\mathrm{e}'] = \lambda F^T KK^T F \tag{10}$$

Do SVD decomposition on matrix F and obtain formula (11),

$$F = UDV^T = \sum_{i=1}^{2} \sigma_i^F \mu_i v_i^F \tag{11}$$

Expansion the formula (12-14),

And, $k_1 = f_u^2 + u_{0i}^2$, $k_2 = u_{0i}v_{0i}$, $k_3 = u_{0i}$, $k_4 = f_\mathrm{v}^2 + u_{0i}^2$, $k_5 = \mathrm{v}_{0i}$. The cost function based on Kruppa equation can be obtained formula(15):

$$f_{cost} = (f_1 - f_2)^2 + (f_1 - f_3)^2 + (f_2 - f_3)^2 \tag{15}$$

So far, we have transformed the problem of solving the Kruppa equation into finding an optimal solution of the cost function [24].

E. Solution by using QPSO Algorithm

QPSO algorithm imitates the intelligent behavior of group animals and is widely used in optimization problems. QPSO algorithm defines a group of random particles through nonlinear optimization to get the optimal solution of a problem [25]. Its main idea is to let the particles to find the most suitable position through updating, so as to get the solution of the equation. The evaluation of the final solution is mainly determined by the fitness value of particles. The smaller the fitness value is, the more accurate the result is.

III. EXPERIMENT

A. Photos Collection

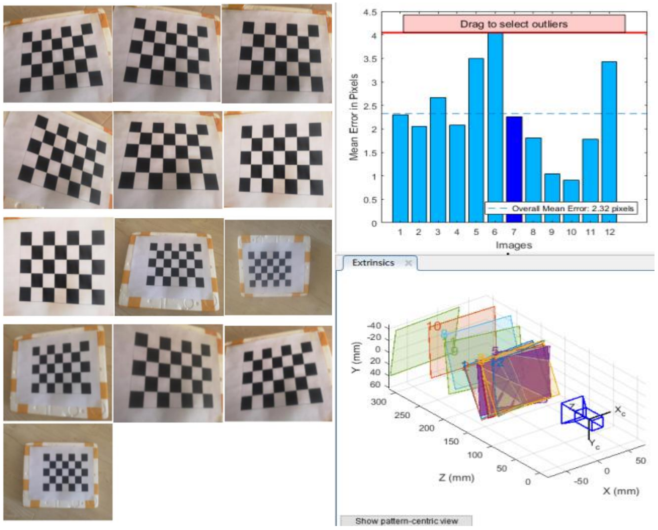
We take two photos of the same surface marker from different angles, and get the original two photos as a pair. In the process of shooting, try to ensure that the main body of the mark is in the center of the picture, so as to prevent the deformation of the mark.

B. Results of Zhengyou Zhang's Method

We use a calibration board to take 13 photos of different angels and then use the calibration toolbox in Matlab to calculate. The results obtained are considered as the true value of the camera's internal parameters. Data is shown in TABLE I and pictures are shown in Fig. 3.

TABLE I
RESULTS OF ZHENGYOU ZHANG'S METHOD

Series	Appearance		
	fv	*fu*	Intrinsic points
0	2992.5	2979.5	(1811.1,1356.4)



(a)Thirteen pictures for calibration (b)Analysis by Matlab

Fig. 3 Thirteen pictures and calibration process by Zhengyou Zhang's method

C. *Results based on EXIF Information*

The photo's EXIF information is shown in Fig. 1 and according to the transformation formula (7) and (8), we can calculate the value of each parameter, which is shown in TABLE II .

TABLE II
RESULTS OF CALCULATION

Series	Appearance		
	fv	*fu*	Intrinsic points
1	2845.4	2846.5	(1824.0,1368.0)

D. *Results of initial QPSO algorithm*

According to the principle of QPSO method, we can obtain the results of three pairs [26]. The focal length, intrinsic points and fitness value are shown in Fig. 4 and TABLE IV.

TABLE IV
RESULTS OF INITIAL QPSO ALGORITHM

Series	Appearance			
	fv	*fu*	Intrinsic points	Fitness
2	2301	2301	(1824,1368)	$8.68119\,e^{-15}$
3	3139.55	3139.55	(1824,1368)	$3.17651\,e^{-17}$
4	2140	2140	(1824,1368)	$1.73472\,e^{-18}$

E. *Results of improved QPSO method*

When we obtain the EXIF information of a photo ,we can then use the information to initialize the QPSO algorithm. And the results are shown in Fig. 5 and TABLE IV.The fitness value is smaller than the fitness value obtained from the initial QPSO method.

TABLE IV
RESULTS OF IMPROVED QPSO ALGORITHM

Series	Appearance			
	fv	*fu*	Intrinsic points	Fitness
5	2972.5	2972.5	(2063.91,1311.75)	$1.54021\,e^{-21}$
6	3243.64	3243.64	(1813.94,1280.52)	$1.38966\,e^{-22}$
7	2846.34	2846.34	(1857.32,1356.23)	$8.0468\,e^{-21}$

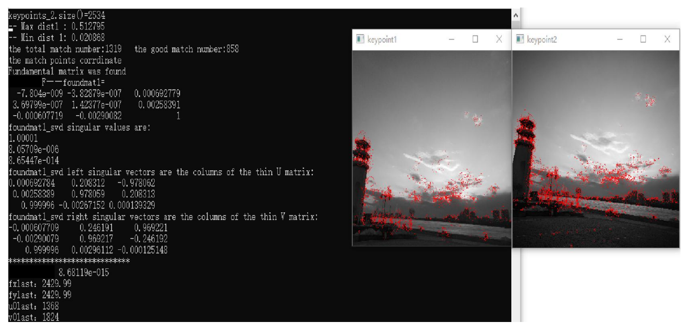
F. *Accuracy Analysis*

We use the results of Zhengyou Zhang's method as the camera's true value and use the quotient between the observed value and the true value as each method's average accuracy and show them in TABLE V.

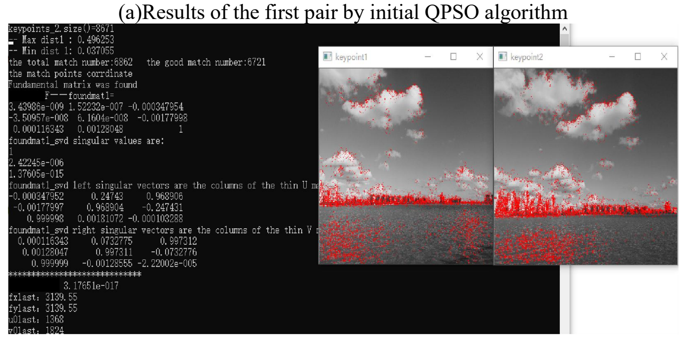
TABLE V
ACCURACY ANALYSIS

Method	Series	Accuracy		
		fv	*fu*	Intrinsic points
Initial QPSO	2	76.89%	77.23%	(99.29%,99.14%)
	3	95.09%	94.63%	(99.29%,99.14%)
	4	71.51%	71.82%	(99.29%,99.14%)
	Average	**81.16%**	**81.23%**	**(99.29%,99.14%)**
Improved QPSO	5	99.31%	99.75%	(86.04%,96.71%)
	6	91.13%	94.61%	(99.84%,99.4%)
	7	95.11%	95.53%	(97.45%,91.15%)
	Average	**95.18%**	**96.63%**	**(94.44%,95.75%)**

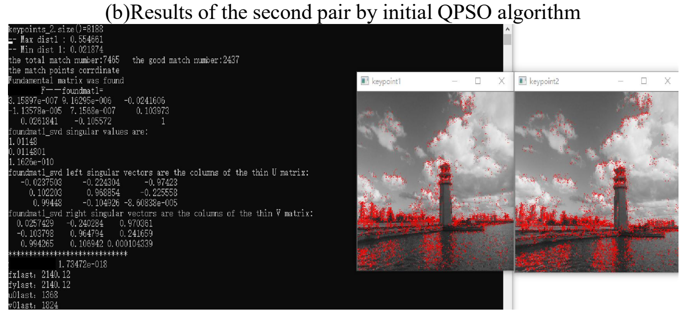
The prediction accuracy of the four parameters is above 94%, as well as the prediction accuracy of the camera's focal length is above 95%. The fitness of the initial QPSO algorithm is is larger than that of the improved QPSO algorithm, and the difference is more than two orders of magnitude. According to the QPSO method, the smaller the fitness is, the more accurate the result is. The experiments and the fitness value both proved that the improved QPSO algorithm have a better performance compared with the initial QPSO algorithm. And it also proved that using EXIF information to initialize the algorithm is feasible.



(a)Results of the first pair by initial QPSO algorithm

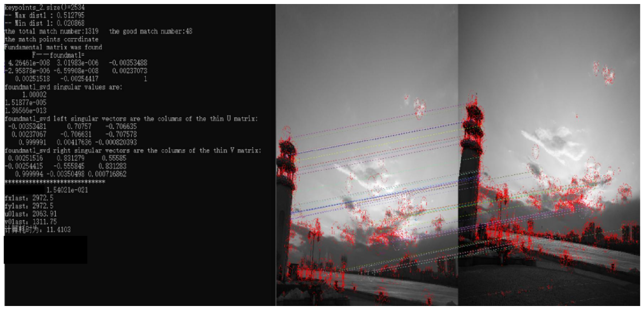


(b)Results of the second pair by initial QPSO algorithm

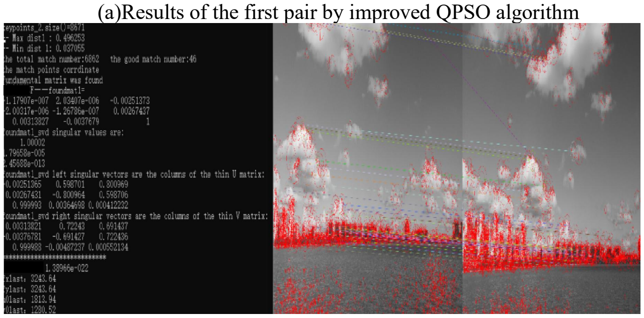


(c)Results of the third pair by initial QPSO algorithm

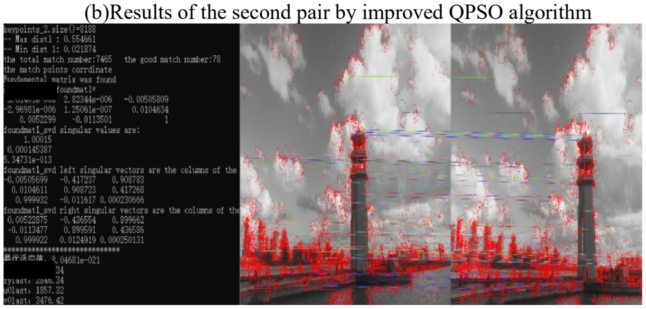
Fig. 4 Three results of initial QPSO algorithm



(a)Results of the first pair by improved QPSO algorithm



(b)Results of the second pair by improved QPSO algorithm



(c)Results of the third pair by improved QPSO algorithm

Fig. 5 Three results of improved QPSO algorithm

IV. CONCLUSION

The improved algorithm has an average accuracy of above 94%, which is significantly higher than the initial one. And the experiment results prove that the improved method is better than the initial one.

In this paper, internal parameters are first introduced at the beginning of the paper, and the parameters can be simplified due to the developing manufacturing skills. And secondly, the EXIF information of a photo is used to calculate the pixel focal length of the internal parameter. Then we derive the conversion formula of equivalent focal length and pixel focal length and use it to initialize the algorithm. Moreover, we discussed the principle of the KRUPPA equation and convert the problem of solving the equation into optimizing the cost function.

Above all, we carried out experiments to test our ideas. We collect three pairs of photos respectively and use the two methods to predict the internal parameter matrix. We use Zhengyou Zhang's method with a calibration board and obtain the results as the true value. The improved algorithm has an average accuracy of above 94% and the prediction accuracy of the camera's focal length is above 95%. The experiments and the fitness value both proved that the improved QPSO algorithm have a better performance compared with the initial QPSO algorithm. And it also proved that using EXIF information to initialize the algorithm is feasible.

Future work should further strengthen accuracy of the algorithm and do experiments in some extreme environment to observe the influence of unclear image or dark light or no clear mark on calibration results [27].

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