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A New Method of Camera Self-calibration Based on Relative Lengths

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Abstract: A new camera self-calibration approach is presented by considering the relative lengths of the scene. There exists a homographic matrix whose elements partly depend on the intrinsic parameters to upgrade the projective reconstruction to the metric one. Relative length is an invariant property of the similarity transformation. An error function according to the invariance of relative lengths is formulated. Hence, camera calibration and 3D structure recovery can be achieved by minimizing the error function. For the homographic matrix is uniquely determined by every views of the scene, the proposed method can effectively deal with the case with varying intrinsic parameters of camera. In addition, the complete 3D recover procedures based on relative lengths are put forth. An experiment is implemented to demonstrate the validity and the performance of the presented approach. The results show that it is accurate and the accuracy of the proposed method is obviously improved compared with the Bougnoux's methods.

Key words: Self-calibration, relative lengths, homographic matrix, intrinsic parameters, method

INTRODUCTION

Now-a-days many methods of uncalibrated structure from motion are proposed and they already have well reconstructed effect (Hartley, 1992). But if the information from image sequences is known and the constraint is employed to reconstruct 3D model again, the reconstructive effect would be improved. Relative lengths are a very beneficial constraint to metric 3D reconstruction. It can be easily acquired from geometrical shape such as circle and cubic. In this study, an algorithm for the camera self-calibration is present based on the relative lengths. The proposed method computes the intrinsic parameters of camera using the invariance of relative lengths under the similarity transformation. The homographic matrix between the projective structure and metric structure using relative lengths is set up. Since this matrix is unique in the given set of image sequences, the problem of varying intrinsic parameters of the camera can be coped with easily.

THE PROPOSED SELF-CALIBRATION ALGORITHM USING RELATIVE LENGTHS

Metric Reconstruction by the Homographic Matrix: the process of projection of points in 3D to the image plane can be represented as a linear matrix operation in the homogeneous coordinates. First, there is a rigid motion transformation between world coordinates x and camera centered coordinates x_c. The next step is the perspective projective projection of x_c onto x in the image plane. In the end, the image coordinates x are transformed into the pixel coordinates m = (u, v, 1). The process can be expressed as:

$$m_j^i = P_{euc}^i X_j \tag{1}$$

where, m_j^i is jth image point in the ith view, P_{euc}^i is Euclidean projection matrix, x_j is jth scene point.

Here, we assume that the skew factor γ in the camera is negligible:

$$\gamma = 0 \tag{2}$$

Among lots of nonsingular 4×4 matrix Q, there exists the unique Q matrix that transforms the projective structure to Euclidean structure. We can calibrate each camera and reconstruct a 3D scene up to similarity transformation from it. A Q matrix satisfies the following relations:

$$\begin{aligned} P_{euc}^i &\approx P_m^i = P_{proj}^i Q \\ X_{euc}^j &\approx X_m^j = Q^{-1} X_{proj}^j \end{aligned} \tag{3}$$

where, X_m^j is a metric structure of a 3D point under the similarity transformation Q. If the world coordinate system is at the optical center of first camera, the projective projection matrix and Euclidean projection matrix can be get. Hence Q is defined up to a scale, it can be expressed as:

$$Q = \begin{bmatrix} a_u & 0 & u_0 & 0 \\ 0 & a_v & v_0 & 0 \\ 0 & 0 & 1 & 0 \\ q_1 & q_2 & q_3 & 1 \end{bmatrix} \tag{4}$$

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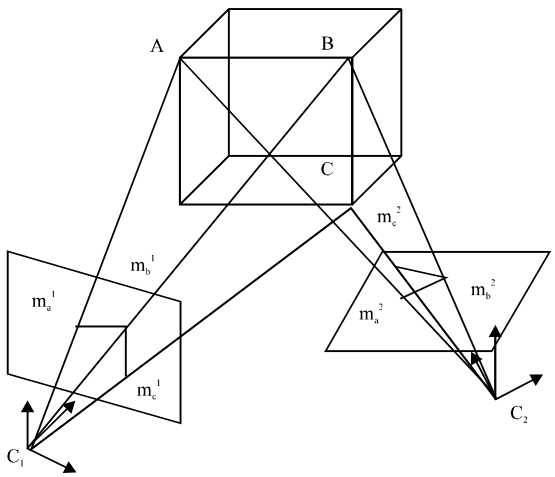

Fig. 1: The configuration of imaging system

Camera calibration: Let's assume that four points A, B, C and D are specified with their world coordinates X_m^A, X_m^B and X_m^C as shown in Fig. 1.

Hence the Metric structure is obtained and the relative lengths formed by the three points are invariant under the similarity transformations as follows:

$$\frac{AB}{BC}=\frac{A'B'}{B'C'}=\frac{\left|X_m^A-X_m^B\right|}{\left|X_m^B-X_m^C\right|} \tag{5}$$

The Q^{-1} and the projective structure of jth point are assumed as:

$$Q^{-1}=\begin{bmatrix}Q_1^{-T}\\Q_2^{-T}\\Q_3^{-T}\\Q_4^{-T}\end{bmatrix}=\begin{bmatrix}\frac{1}{a_u} & 0 & -\frac{u_0}{a_u} & 0\\ 0 & \frac{1}{a_v} & -\frac{v_0}{a_v} & 0\\ 0 & 0 & 1 & 0\\ -\frac{q_1}{a_u} & -\frac{q_2}{a_v} & -q_3+\frac{q_1u_0}{a_u}+\frac{q_2v_0}{a_v} & 1\end{bmatrix}$$

$$X_{proj}^j=\begin{bmatrix}\alpha_j\\ \beta_j\\ \chi_j\\ \delta_j\end{bmatrix}\quad\left(j=A',B',C'\right) \tag{6}$$

Q_i^{-T} notes the ith row of Q_i^{-1}. Substitute Eq. 6 into Eq. 3, 7 can be received:

$$X_m^j=\begin{bmatrix}\frac{Q_1^{-T}X_{proj}^j}{Q_4^{-T}X_{proj}^j}\\ \frac{Q_2^{-T}X_{proj}^j}{Q_4^{-T}X_{proj}^j}\\ \frac{Q_3^{-T}X_{proj}^j}{Q_4^{-T}X_{proj}^j}\end{bmatrix}\quad\left(j=A',B',C'\right) \tag{7}$$

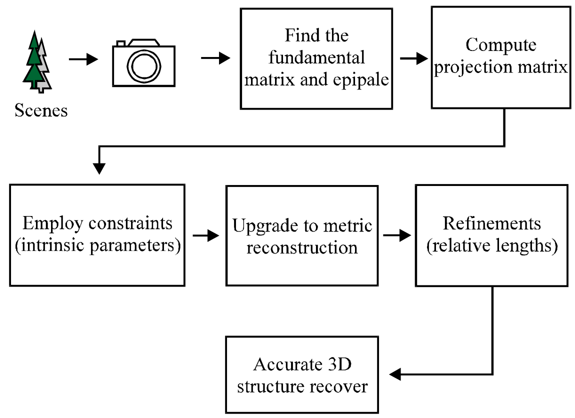

Fig. 2: The flow chart of complete 3D reconstruction

Using Eq. 7:

$$\frac{A'B'}{B'C'}$$

can be expressed as the function of parameters of Q:

$$\frac{AB}{BC}=\frac{A'B'}{B'C'}=\frac{\left|X_m^A-X_m^B\right|}{\left|X_m^B-X_m^C\right|}=f\left(a_u,a_v,u_0,v_0,q_1,q_2,q_3\right) \tag{8}$$

So, scene constraints are the relative length invariance under similarity transformation that can be translated to constraints on the intrinsic parameters. Equation 8 is used to get the metric projection matrix from the projective one. We can minimize the error function to approximate the solution as follows:

$$\min\sum_{n=1}^{N}\left(\frac{\overline{D_n}}{\overline{D'_n}}-\left(\frac{\left|X_m^A-X_m^B\right|}{\left|X_m^B-X_m^C\right|}\right)\right)^2=\min\sum_{n=1}^{N}\left(\frac{\overline{D_n}}{\overline{D'_n}}-f\left(a_u,a_v,u_0,v_0,q_1,q_2,q_3\right)\right)^2 \tag{9}$$

where:

$$\frac{\overline{D_n}}{\overline{D'_n}}$$

is nth set of relative lengths. Here, the nonlinear minimization problem can be solved by the Levenberq-Marquardt method (Lera and Pinzolas, 2002). An initial estimate of unknowns is completed by the method represented in literature (Bougnoux, 1998). We can obtain the better 3D reconstruction of object in metric stratum according to the following procedures (Fig. 2).

EXPERIMENTAL RESULTS

To verify the validity of proposed method and compare it with the Bougnoux's method, we test the proposed algorithm on some real data. We take four different views with a digital camera around a toy-chair as shown in Fig. 3a-d, respectively.

Table 1: The estimated homographic matrices

	a_u	a_v	u_0	v_0	q_1	q_2	q_3
View 1-2 (Bougnouxs' method)	3365.0823	3365.0823	1279.439	963.0138	0.3034	0.0195	-0.2524
View 1-2 (proposed' method)	3365.0827	3365.0824	1279.4439	963.0138	0.285	0.013	-0.3741
View 1-3 (Bougnouxs' method)	2766.1459	2766.1459	1078.2945	965.6074	0.3011	0.0095	-0.1425
View 1-3(proposed; method)	2766.1458	2766.1459	1078.325	965.6074	0.2049	0.0198	-0.4743

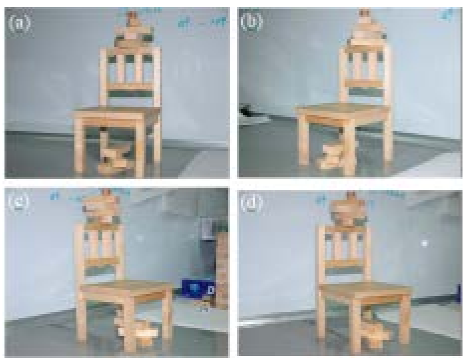

Fig. 3(a-d): The four pictures taken with a camera

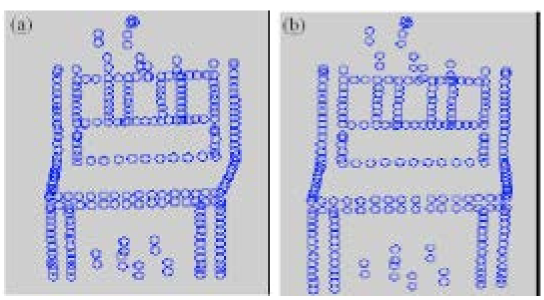

Fig. 4(a-b): Estimated 3D structure of coordinating points using Bougnouxs' method and the proposed method (by view 1-2)

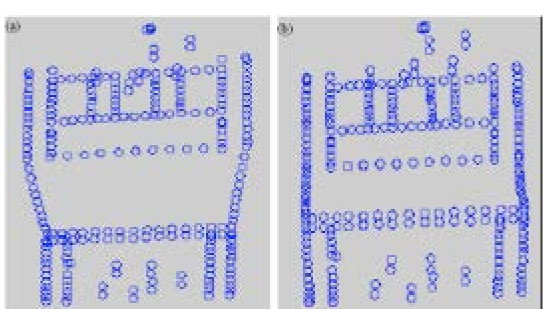

Fig. 5(a-b): Estimated 3D structure of coordinating points using Bougnouxs' method and the proposed method (by view 1-3)

We reconstruct the projective 3D structure from the two views and upgrade them to metric stratum. The homographic matrix Q is computed by the 12 relative lengths and 225 corresponding points are taken to reconstruct 3D structure. The reconstructed results using Bougnoux's and our method are shown in Fig. 4. Where, Fig. 4a represents the result get from Bougnouxs' method and Fig. 4b represents the result get from the proposed method.

Utilizing different views to reconstruct the projective structure, we can get different results due to the different noises in images. The reconstructed metric structure by the first and third views is shown in Fig. 5. Figure 5a represents the result get from Bougnouxs' method and Fig. 5b represents the result get from the proposed method.

From all these figures, one can see that our method produce a better visual effect than Bougnoux's method. The estimated homography matrices Q for previous experiments are listed in Table 1.

From the experimental results, we can certainly know that, the proposed method can actually improve Bougnoux's method to achieve a much better 3D structure recovery.

CONCLUSION

In this thesis, we presented a camera self-calibration and 3D structure recovery algorithm by using the relative lengths which is an invariant property under the similarity transformation. From the studying of 3D geometry and camera model, it can be shown that there exists a homographic matrix with its elements partly depending on the intrinsic parameters to be able to upgrade the projective reconstruction to the metric one. Based on the particular form of homographic matrix, we can formulate an error function according to the invariance of relative lengths under the similarity transformation and hence camera calibration and 3D structure recovery can be achieved by minimizing this error function. In this way, the recovered structure will automatically satisfy the invariance constraint of metric stratum. Thus, a metric reconstruction of the scene is also achieved. In addition, the proposed method can effectively deal with the case with varying intrinsic parameters of camera for the homographic matrix is uniquely determined for every views of the scene. However, our method requires a priori

3D scene information for some relative lengths of the scene. In this thesis, we have tested the proposed method on some synthetic and real data. The results are encouraging and the reconstructed 3D structures are visually perfect.

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