Computable Relation Graph Based Calibration Pattern Extraction Algorithm on Multiple Calibration Boards

Jiewei Sun
Key Laboratory of Machine Perception (MOE), Peking University
sunjw@graphics.pku.edu.cn

Yisong Chen
Key Laboratory of Machine Perception (MOE), Peking University
chenys@graphics.pku.edu.cn

Guoping Wang
Key Laboratory of Machine Perception (MOE), Peking University
wgp@graphics.pku.edu.cn

ABSTRACT
Calibration point extraction is an important step in camera calibration. Traditional methods work on single calibration board. In this paper, we propose a brand-new calibration point extraction algorithm that works on multiple calibration boards. In order to solve the world coordinate for every calibration point on multiple calibration boards, we propose a computable relation graph based algorithm. This algorithm constructs a computable relation graph with the computable relation between two calibration boards, and determines the computation order employing the classic minimum spanning tree algorithm. We use a triple parameter model to compute the position of one calibration board from another, and solve the problem by downhill simplex optimization. The proposed algorithm is fully automatic, and the precision is sufficiently high to fulfill the requirement of an image based modeling system.

Categories and Subject Descriptors
I.2.10 [**Vision and Scene Understanding**]; I.4.9 [**Applications**]

General Terms
Algorithms.

Keywords
Camera calibration, feature extraction, minimum spanning tree.

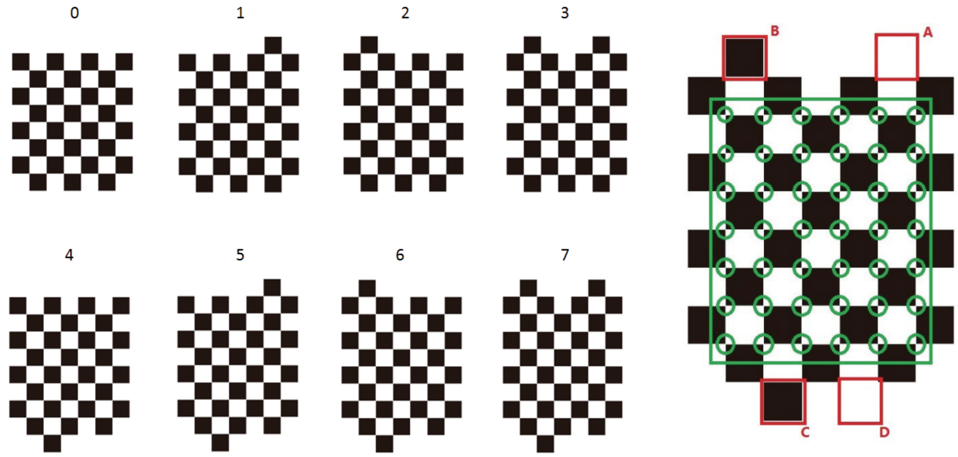
1. INTRODUCTION
Camera calibration is a critical step in vision tasks like an image base modeling system [1, 2]. Two parts of work need to be done for a calibration pattern based system: calibration point extraction and camera parameters optimization. In the first part, several calibration points are extracted from some specially designed calibration boards in the input pictures. In the second part, the extracted points are used to solve camera parameters. Many research efforts have been made in recent years [3, 4], among which the algorithms proposed by Tsai R. Y. and Zhang Z. Y. are most broadly used [1, 5]. This paper focuses on the work of the first part.

Most of the previous work uses a single calibration board. Soh *et al.* propose a black-white grid calibration point extraction algorithm [6]. Lucchese *et al.* treat checkerboard corners as saddle points on saddle surfaces [7]. Shu *et al.* find calibration patterns by triangulating the Harris corners found on the input image with Delaunay triangulation algorithm [8]. Fiala *et al*. propose a point correspondence extraction algorithm using a self-identifying pattern [9]. Sun *et al.* divide the neighborhood of a grid corner into 4 layers, and use the feature of the black-white segments on each layer to detect grid corners [10]. The chessboard corner detector in OpenCV finds chessboard pattern using an erosion based algorithm [11]. Rufli *et al.* analyze this algorithm and make some improvement [12]. Bouguet *et al.* release a calibration toolbox for Matlab [13]. This toolbox is used broadly, but its point correspondence extraction process requires manual clicks for 4 initial points.

The good side of using a single calibration board is the simplicity of computation, in which case computation for world coordinates is barely needed. However, when pictures have to be taken from various viewpoints, occlusion of the calibration board is inevitable, which brings difficulty to calibration point extraction. In addition, it suffers from the limited number of points concentrated in a small region of the picture, which weakens the constraint the points provide. More importantly, it often occurs that the target object is fixed in space and cannot be removed to add a single calibration board underneath the object. The above difficulties can be easily treated by placing multiple calibration boards around the 3D object. In this paper we propose a new calibration point extraction method using multiple calibration boards instead of a single one. The main challenge of multi-calibration board calibration is how to accurately obtain and correct the image coordinates of all calibration points and how to robustly estimate the corresponding world coordinates for randomly placed calibration patterns. We first use an improved erosion based algorithm to detect checkerboard patterns in input pictures, which solves the image coordinate part. Then we construct a computable relation graph between these patterns. By employing the minimum spanning tree algorithm, the computation order is determined, and the world coordinates of the patterns are solved one by one. Our method is completely automatic and the precision of the result is high enough to fulfill the requirements of practical systems.

2. COMPUTABLE RELATION GRAPH BASED ALGORITHM
Figure 1 shows the multiple calibration boards used in our algorithm. Figure 2 gives two example pictures with 8 and 4 calibration boards, respectively.

IVCNZ '12, November 26 - 28 2012, Dunedin, New Zealand



(a) Calibration boards numbered from 0 to 7 (b) Illustrated calibration board pattern No. 6.

Figure 1. The patterns of multiple calibration boards in this paper. There are 42 calibration points on each calibration board. The centers of the green circles of (b) are the calibration points. The 4 red squares A, B, C, D makes unique ID label with different color combinations. Here black means 1 and white means 0. For example, in (b), DCBA is 0110, which indicates a binary label of 6. This label system could support up to 16 calibration boards in total., and any number of calibration boards less than or equal 16 will work.

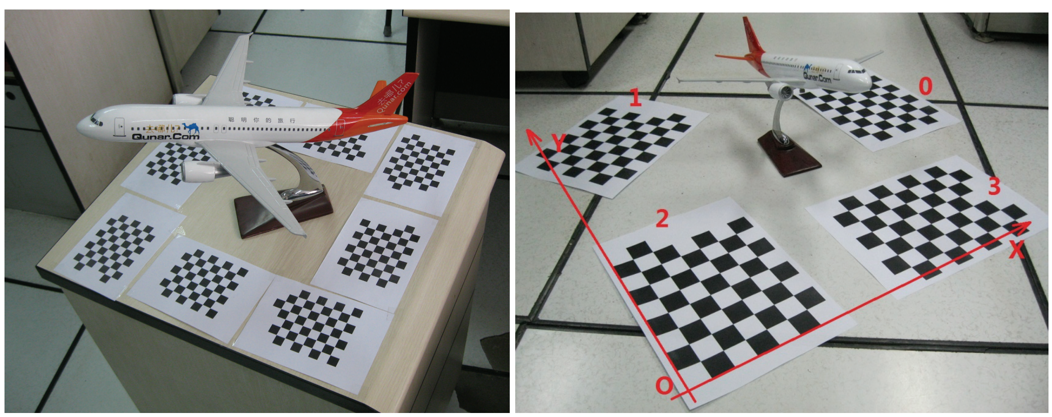


Figure 2. Two example pictures with 8 and 4 calibration boards respectively.

Unlike the single calibration board mechanism, in the situation where multiple calibration boards are used, not all calibration points' world coordinates are immediately known. In the following of this paper, we call the calibration board used to set the unique world coordinates system the reference calibration board. In Figure 2(b), calibration board 2 is chosen as the reference calibration board. All other calibration boards are called non-reference calibration boards. Although the world coordinates of the calibration points on the reference board are easily known, those on the non-reference boards have to be accurately estimated from the relations between different boards. This makes the major challenge of a multi-calibration board system.The input of our algorithm is a set of pictures. Each picture contains the target object and one or more calibration boards. The relative position of the target object and all calibration boards is invariant. We additionally assume that the multiple calibration boards are placed on the same plane. Our algorithm mainly contains 4 steps, which are described step by step in the following parts of this section.

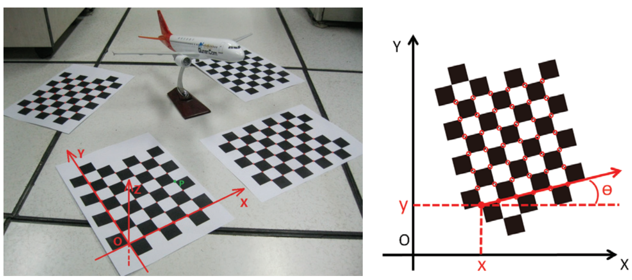
2.1 Detecting Calibration Board Patterns in Pictures

We use an improved erosion based feature detection method to identify calibration patterns in pictures [12]. The pictures are first binarized, and then iteratively eroded. The erosion operation makes the black squares on the calibration board separated from each other. The contours of these eroded black squares are extracted and fitted with quadrangles. Then the quadrangles are linked together with their neighbors and form quadrangle groups. After all quadrangle groups are detected, each of them is compared with the given pattern. The groups that match with the given pattern are recognized as a calibration board, and then identified by its ID label.

Once we detect a calibration board in a picture, we know the image coordinates of all calibration points on this board. The next work is to solve for the 3D positions of these calibration points in the unified world coordinate system.

2.2 World Coordinate Set of the Reference Calibration Board

The unified world coordinates system is defined based on the reference calibration board. An example is given in Figure 3(a), where we set a right-hand 3D coordinate system based on the lower left calibration board. The bottom-left calibration point of the board defines the origin and the square size defines the unit length. The x axis aligns with the bottom row and the y axis aligns with the left column. Consequently, all calibration points lie on the plane z=0. The edge length of a black square is 1 unit. The coordinates of all calibration points on the reference board are immediately known. For instance, the green point p in Figure 3(a) has the coordinate (5, 3, 0).



(a) (b)

Figure 3. The world coordinate of the reference board (a), and the non-reference calibration board (b).

2.3 World Coordinates of Non-reference Calibration Board

In this subsection, we discuss the algorithm for computing the position of a non-reference calibration board with respect to the reference calibration board when both boards are visible in one picture. That means estimating the 2D translation and rotation between the two boards, since they are on the same plane. This is a rigid motion that can be represented by a triplet (x, y, θ), where x is the X coordinate of the bottom-left calibration point, y is the Y coordinate of the same point, and θ is angle between the bottom line of the calibration board pattern and the x axis of the world coordinate. Figure 3(b) shows the 3 parameters. Based on the above triplet representation, the problem of estimating the position of a non-reference board providing the reference board can be treated as a 3-parameter optimization problem.

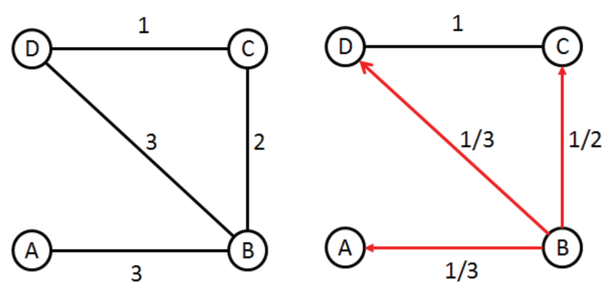
Given the image coordinate set of A and B, and the world coordinate set of A, our goal is to solve the world coordinate set of B. Our method first uses the image coordinates of A to fit an initial homograph H that rectifies board A to an orthogonal view. Then the image coordinates set of B and H are used to calculate an initial world coordinate set of B, which is represented by the aforementioned triplet (x, y, θ). A rough sampling is carried out in the local space centered at (x, y, θ) to get a better initial triplet. Searching for the optimal solution of the triplet from this initial value can be done by the classic optimization algorithms like Downhill Simplex and LM methods, which change the triplet little by little in each iteration round [14]. In each optimization step, we use the difference between the world coordinate set generated by the on-line updating triplet and the projected world coordinate set as the error function.

2.4 Computable Relation Graph

In previous subsection, we give an algorithm for estimating the position of a calibration board given the reference. In this subsection, we propose a method that determines the computing order of all calibration boards when multiple calibration boards are used.

Generally speaking, the positions of multiple calibration boards can be calculated one after another. When the position of board A can be calculated from that of board B, we say that there is a *computable relation* between A and B. Obviously, computable relation is bidirectional. If we put the computable relations in all pictures together, we get a *computable relation graph*. The nodes of the graph represent for the calibration boards, while the edges represent the associated computable relation. The same computable relation may appear in multiple pictures, so we use the weight on each edge to represent the times that the edge relation appears. For example, if we have 7 pictures, 3 of them contain calibration board A and B, 2 of them contain B and D, 1 of them contains B and C, and 1 of them contains B, C, and D, then the computable relation graph associated with these pictures can be represented as in Figure 4(a).

We choose the reference board with the most out-degrees as the source node of the graph because it evidently leads to least estimating error. Afterwards, the order in which we calculate the other calibration boards has to be determined. The computation path must be arranged carefully and cover all of the nodes, corresponding to a rooted spanning tree. In order to minimize the total error, we change the weight on each edge with their reciprocal and employ Prim minimum spanning tree (MST) algorithm to find the optimal path [15]. The computation order of Figure 4(a) determined by MST is shown as the red tree in Figure 4(b).

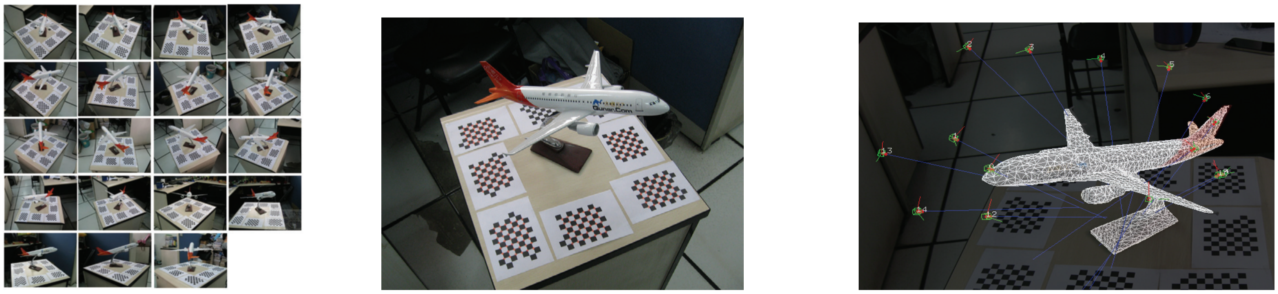


(a) Original graph. (b) Taking the reciprocal.

Figure 4. Computable relation graph

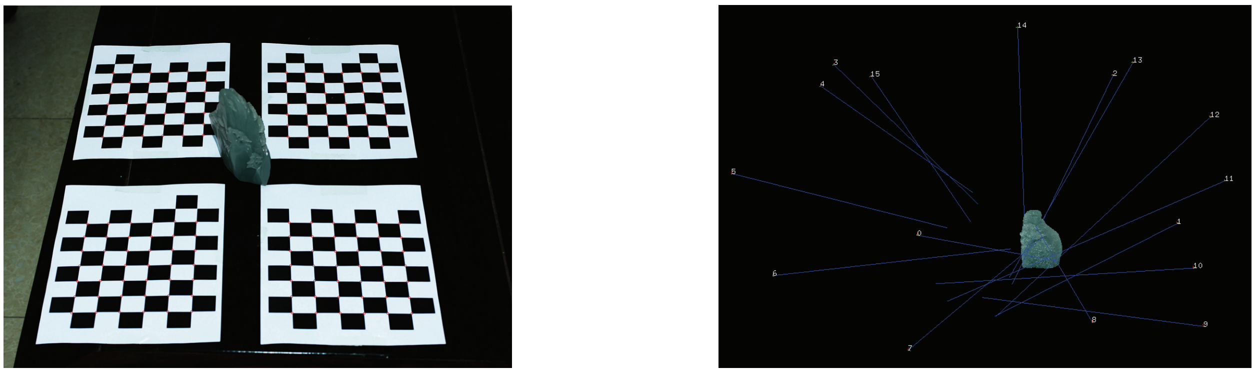
3. EXPERIMENTS

In this section, we give some experimental results. Figure 5 shows a 3D model reconstruction task using multiple calibration boards. From Figure 5(c) we can see that all camera positions are correctly estimated. The precision of the reconstructed 3D model is high with small details reserved. Figure 6 shows the result of another experiment. The experiments show that our feature extraction method for multiple calibration boards works well for 3D reconstruction system.



(a) (b) (c)

Figure 5. A model airplane reconstruction task. (a) 19 pictures of different viewpoints. (b) The extracted calibration points in one picture. (c) The reconstructed model and the calculated camera positions.



(a) The extracted calibration points in one image. (b) The reconstructed model and camera position.

Figure 6. Experimental result using a jade

4. CONCLUSION

In this paper, we propose a brand-new calibration pattern extraction method for multiple calibration boards. We construct a computable relation graph using the computable relation contained in input pictures, and employ Prim MST algorithm to determine the computation order of non-reference calibration boards. By doing this, the accumulated error is minimized during the computation from one world coordinate set to another. We employ a triplet representation of the world coordinate set and turn the world coordinate set computation problem between two calibration boards into an optimization problem, which can be solved by efficient optimization methods. Our method is fully automatic, and the extracted calibration points are with high precision. We also carry out experiments to prove that our method fulfill the requirement of 3D model reconstruction system. As possible future work, we can improve the erosion based calibration board detection algorithm and try to compute multiple world coordinate sets instead of just one to improve the accuracy further more.

5. ACKNOWLEDGMENTS

The work in this paper was supported by the 863 program grant (2011AA120301) and NSF of China (60973052, 61173080, 61121002).

6. REFERENCES

[1] Tsai, R. Y.: A Versatile Camera Calibration Technique for High-Accuracy 3D Machine Vision Metrology Using Off-the-Shelf TV Cameras and Lenses. IEEE J. Robotics and Automation 3, 4 (Aug. 1987), 323-344.

[2] Faugeras, O. D., Luong, Q. T., Maybank S. J.: Camera Self-calibration: Theory and Experiments. Lecture Notes in Computer Science; Vol. 588(1992), 321-334.

[3] Weng, J., Cohen, P., Herniou, M.: Camera Calibration with Distortion Models and Accuracy Evaluation. IEEE Transactions on Pattern Analysis and Machine Intelligence 14, 10 (Oct. 1992), 965-979.

[4] Heikkila, J., Silven, O.: A Four-step Camera Calibration Procedure with Implicit Image Correction. Computer Vision and Pattern Recognition (Jun. 1997), 1106-1112.

[5] Zhang, Z.: A Flexible New Technique for Camera Calibration. IEEE Transactions on Pattern Analysis and Machine Intelligence 22, 11(Nov. 2000), 1330-1334.

[6] Soh, L. M., Matas J., Kittler J.: Robust Recognition of Calibration Charts. In Proceedings of International Conference on Image Analysis and Processing (1997).

[7] Lucchese, L., Mitra, S. K.: Using Saddle Points for Subpixel Feature Detection in Camera Calibration Targets. In Proceedings of IEEE Asia Pacific Conference on Circuits and Systems (2002).

[8] Shu, C., Brunton, A., Fiala, M.: Automatic Grid Finding in Calibration Patterns Using Delaunay Triangulation. Technical Report of INRIA (August 2003).

[9] Fiala, M., Shu, C.: Self-identifying Patterns for Plane-based Camera Calibration. Machine Vision and Applications (2008), 209-216.

[10] Sun, W., Yang, X., Xiao, S., Hu, W.: Robust Checkerboard Recognition for Efficient Nonplanar Geometry Registration

in Projector-camera Systems. IEEE International Workshop on Projector-Camera Systems (Aug. 2008)

[11] Vezhnevets, V.: OpenCV Calibration Object Detection. http://graphics.cs.msu.ru/en/research/calibration/opencv.html

[12] Rufli, M., Scaramuzza, D., Siegwart, R.: Automatic Detection of Checkerboards on Blurred and Distorted Images. In Prceedings of International Conference on Intelligent Robots and Systems (2008).

[13] Bouguet, J. –Y., Strobl, K., Sepp, W., Paredes, C., Arbter, K.: Camera Calibration Toolbox for Matlab. (2008) http://www.vision.caltech.edu/ bouguetj

[14] Press, W. H. *et al.*, Numerical recipes in C: the art of scientific computing, 2nd ed., Cambridge, New York: Cambridge University Press, 1997.

[15] Prim, R. C., Shortest connection networks and some generalizations. Bell System Technical Journal, 36 (1957), pp. 1389–1401.