A Deformed Chessboard Pattern for Automatic Camera Calibration

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Abstract

Chessboard pattern is popular in most of state-of-the-art camera calibration toolboxes. However, because of its geometric symmetry, it results in ambiguous extrinsic parameters or requires manual intervention to select the correct correspondences of extracted corners in image. In this paper a deformed chessboard pattern is designed to automatically accomplish camera calibration and metric rectification. We mainly utilize the cuboid bound of optical center to automatically obtain the correct correspondences of four extreme corners. The real experiments are shown to verify the correctness of the proposed technique.

Keywords: camera calibration, chessboard pattern, homography, points correspondence

1. Introduction

Camera calibration is a very common task in computer vision, especially as a preliminary step before 3D reconstruction and poses estimation. Its computation often includes two aspects: the optical properties of a lens (named the intrinsic parameters) and the relative rotation and translation between the camera frame and the world coordinate system (named the extrinsic parameters). The technology of camera calibration [1] [2] is very mature now and there are two state-of-the-art camera calibration toolboxes: *Matlab Camera Calibration Toolbox* [3] and *OpenCV*. In both of these two toolboxes, the chessboard is the only choice of planar calibration pattern. Compared to other planar calibration patterns, the biggest advantage of the chessboard is that it can provide many accurate corners by the individual corner detection method (e.g., Harris corner detection). However, these two toolboxes still possess some disadvantages which results in inconvenience in practical use. For example, *Matlab Camera Calibration Toolbox* requires people to manually select the four extreme corners one by one for each image of a chessboard pattern to obtain the correct extrinsic parameters. Thus this progress is boring and time-consuming as the number of the images grows. Although *OpenCV* could automatically extract all corners, the extrinsic parameters will have a two-fold ambiguity because of 180 degrees symmetry. Thus some vision tasks, such as metric rectification, stereo calibration and hand-eye calibration, cannot be accomplished automatically by these two toolboxes.

In this paper, we design a deformed chessboard pattern shown in Fig. 1 to overcome the above shortcomings. The basic idea is to slightly change the symmetry of the chessboard pattern so that the four extreme corners could be recognized. See Fig. 1. We tilt the chessboard so that the rectangle formed by four extreme corners becomes a right-angled trapezoid. Owing to the Centre Circle

constraint [4] and the cuboid bound of optical center [5], this right-angled trapezoid can be automatically obtained. Therefore the correct corresponding relationship of corners and the world coordinate system can be established without any ambiguity. Note that our solution is based on the theoretical problem of points correspondence while another enhancement toolbox [6] which need chessboard pattern use odd*even number of squares to avoid the symmetry is only an engineering improvement.
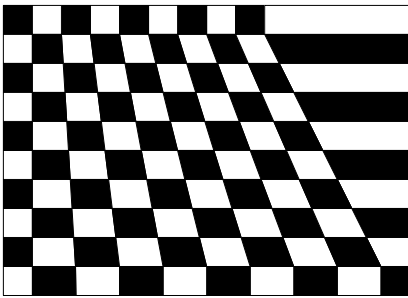

Fig. 1: The deformed chessboard pattern.

The paper is organized as follows. Section 2 includes some preliminaries. The details of how to design this deformed chessboard pattern is described in Section 3. Section 4 provides our initial experimental results with simulated and real data. Conclusion and future works are given in Section 5.

2. Preliminary

In this section we simply depict the core algorithm of automatically obtaining the correspondences of four extreme corners: the Centre Circle constraint and the cuboid bound of optical center.

Gurdjos et.al [4] utilized a computed 2D homography to obtain the equation of a spatial circle (named Centre Circle) where the optical center must lie. Thus for an un-calibrated camera, the Centre Circle imposes a geometric constraint on the intrinsic parameters. Based on this theory, Cai et.al [5] set a cuboid bound for optical center to verify the correctness of each possible correspondences of four coplanar points. The schematic is depicted in Fig. 2 and the detailed process of computation is omitted here. Generally, the Centre Circle computed by the wrong homography from the wrong points correspondence does not intersect with this cuboid bound. Thus the wrong homograhphies can be removed.
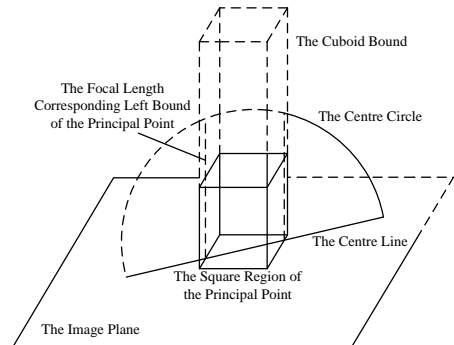

Fig. 2: Center Circle and the cuboid bound.

3. Design of Deformed Chessboard Pattern

In this section we will represent how to utilize the cuboid bound for camera center to erase the disadvantages of the original chessboard pattern. Our main goal is to design a new chessboard pattern to distinguish ambiguity of the extrinsic parameters under the precondition of preserving the merits of the original chessboard. As described before, the symmetry of the chessboard generates the ambiguous extrinsic parameters and the world coordinate system. Thus we deform the chessboard slightly to form a non-symmetric pattern as shown in Fig. 1.

The corners on the deformed chessboard are depicted in Fig. 3 and four extreme corners forming a right-angled
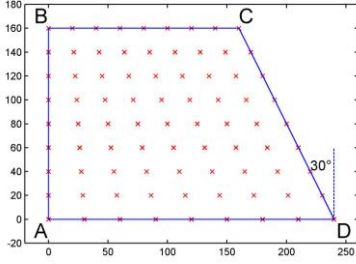
Fig. 3: Corners on the deformed chessboard.

trapezoid are denoted by A, B, C, and D. Assume their corresponding image points are denoted by a, b, c, and d. The four possibilities of correspondences (PoC) are expressed as

$$
\begin{bmatrix} A \\ B \\ C \\ D \end{bmatrix} \rightarrow \begin{bmatrix} a \\ b \\ c \\ d \end{bmatrix} \begin{bmatrix} b \\ c \\ d \\ a \end{bmatrix} \begin{bmatrix} c \\ d \\ a \\ b \end{bmatrix} \begin{bmatrix} d \\ a \\ b \\ c \end{bmatrix} \quad (1)
$$

From these four PoC, we compute their homographies and then judge whether if the Centre Circle intersect the cuboid bound for the optical center. Finally the only one correct PoC can be obtained followed by the unambiguous extrinsic parameters and the world coordinate system (e.g. set A as origin of coordinates and line AD and AB as *x* axis and *y* axis respectively).

All the above statements only introduce the basic principle of automatic corners detection and camera calibration. In practice, we should consider more detailed requirements of deforming the chessboard as follows.

- There should still have a rectangular coordinate system.
- Deform the chessboard as slightly as possible to make sure there are many ordered corners spreading all over the image.

- Deformation must suffice to ensure that all ambiguous PoC can be removed by using the cuboid bound.
- The coordinate value of every corner should be an integer to make the printer produce the high-precision pattern.

Based on all these requirements, the deformed chessboard not only inherits the advantages of original chessboard but also can automatically approach many vision tasks, especially in multi-camera calibration and metric rectification.

It is worth noting that this deformed chessboard pattern will generate the very approximate calibration results to the original one in theory even if the lens distortion is taken into account. The reason is that, although there may be fewer corners in small parts of images than the original chessboard, the symmetry of lens radial distortion will make this difference be ignored.

4. Experiments

To verify the correctness of the proposed algorithm, we did a simple real experiment to automatically rectify a chessboard image. An industrial camera (Point Grey FL2-08S2M-C) with a 4 mm fixed focal lens (uTron FV0420) is used to capture the deformed chessboard. The image resolution is 1024×768. One real photograph is shown in Fig. 4. Set the range parameter of the focal length to 20% and the region parameter of the principal point to 100. The results of applying the cuboid bound constraint are shown in Fig. 5 and Table 1. In Fig. 5, there are three Centre Lines (from PoC 1, 3 and 4) intersected by the square region of the principal point. Then compute the range of the focal length for each PoC. Only the result from PoC 1 satisfies the prior information of focal length (about 900).
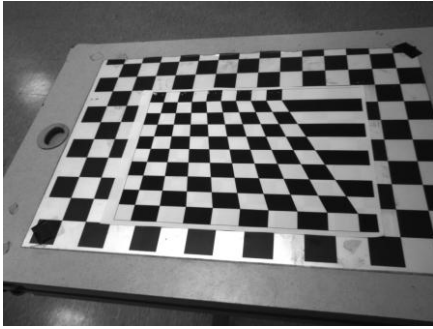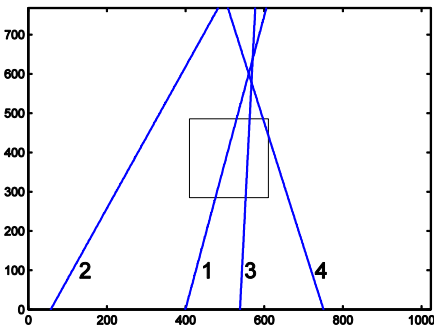
Fig. 4: One real image.

Fig. 5: Centre Lines computed from 4 PoC and the square region of the principal point.

Table 1: Range of the focal length computed from three PoC.

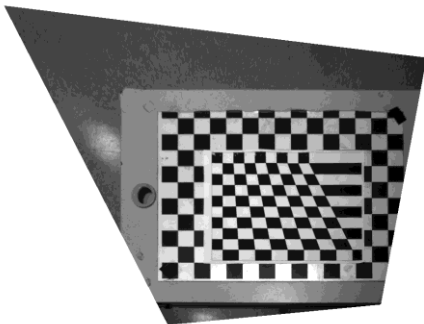| PoC	1	3	4
Focal length	0-1223	0-296	0-576

Fig. 6: The rectified image.

5. Conclusions

In this paper we depict a deformed chessboard pattern to automatically accomplish camera calibration. Compared to two state-of-the-art calibration toolboxes, our method overcomes their shortcomings by recognizing the four extreme corners which form a right-angled trapezoid. Our method will provide the great convenience in metric rectification, multi-camera calibration, etc. The next work is to do more specific experiments to verify the precision and the robustness of the proposed algorithm.

6. References

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