

Camera calibration using automated identification of checkerboard patterns

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Abstract—Camera calibration is needed in all applications where geometric measurements from images are desired. In camera calibration the intrinsic and extrinsic parameters of a camera are determined. First a reference pattern with known dimensions is imaged from different views and control points on the pattern are extracted with sub-pixel accuracy. Then the extracted pixel coordinates and corresponding world coordinates are used to estimate the camera parameters by optimisation. Checkerboard patterns are common as reference pattern in camera calibration. In this paper, we present a method for automated identification of checkerboard patterns in images. The method is applied as a first step before camera calibration using one of the available online toolboxes for Matlab to facilitate a fully automated calibration procedure. The method has been evaluated in a validation study of camera calibration using real image data recorded with a stereo camera and has provided reliable results.

I. INTRODUCTION

In camera calibration, the internal properties of the camera and the position of the camera in the world are determined. In the case of stereo cameras the positions of the two cameras relative to each other is also included in the calibration. The internal parameters of the camera, e.g., principal point, focal length, and lens distortion coefficients, are denoted intrinsic parameters. They answer the question - *What kind of camera is it?* The external parameters, e.g., camera rotation and translation relative to a given world coordinate system, are denoted extrinsic parameters. They answer the question - *Where is the camera?* We refer to calibration in two different settings, static and dynamic calibration. In static calibration, the environment can be controlled and the necessary measurements are usually obtained using known calibration patterns or reference objects. In dynamic calibration the camera is in operation, the environment cannot be controlled, and the necessary measurements must be obtained from the given camera data. In this work we only consider static camera calibration.

Static camera calibration can be divided into the following steps:

- 1) Camera measurement of a well specified reference pattern or object from a number of views.
- 2) Localisation of pre defined control points on the pattern or object in the recorded images using a subpixel corner detector.
- 3) Optimisation of intrinsic and extrinsic camera parameters using the control point coordinates from

the different views and the geometry of the reference pattern.

The result of the static camera calibration is the intrinsic and extrinsic camera parameters that can be used to rectify or warp the images, e.g., remove lens distortion and be able to obtain accurate measurements from the images. In the stereo case the extrinsic parameters, which include the rotation and translation of one camera with respect to the other, are used to align both images before a stereo image can be calculated.

Camera calibration based on [1] and [2] is implemented by Jean-Yves Bouguet in the Camera calibration toolbox for Matlab [3]. The toolbox provides camera calibration for both for a single camera and stereo camera. However, the calibration procedure in the camera calibration toolbox is not automated and the user must mark the position of the calibration pattern manually in each image by clicking four specific points. The calibration pattern is a checkerboard pattern, which is common in image calibration. In this paper we present a method for automatic identification of checkerboard patterns in images and rough estimation of all corner points on the board to facilitate an automated calibration procedure together with the camera calibration toolbox. The rough estimate is refined to subpixel accuracy as a post processing step before the points are sent to the main calibration function.

First, we give a brief overview of the main references in the area of camera calibration in Section II. Second, we detail the method in Section III. In Section IV the performance of the method in a validation study of camera calibration methods is illustrated, and in Section V we provide a discussion and conclusion.

II. RELATED WORK

Camera calibration has been a research topic since cameras were first used for measurement purposes. There are different requirements on the calibration accuracy depending on the application. The traditional camera calibration procedure in metrology applications is bundle adjustment [4], which is a precise calibration method. However, it has been regarded as a computationally heavy method using full scale non-linear optimisation to solve for all parameters. In the area of computer vision the calibration methods have been focused on speeding up the calibration process by using simplifications and linearisation of the optimisation problem. As the commonly available computing capacity has increased, there is also

an increasing interest in solving the calibration problem more accurately.

Some of the main contributions to the area of camera calibration are the papers by Tsai [5], Heikkilä [2] and [6], and Zhang [1] and [7]. Other interesting papers in the field are Weng [8], Kannala [9], and Sun [10]. A good introduction to camera models and camera calibration can be found in the book by Hartley and Zisserman [11]. In addition, an interesting method for stereo self calibration is presented by Dang et. al [12]. In the paper they use the camera calibration toolbox for Matlab [3] as ground truth to compare to the self calibration and consider the toolbox to be an “excellent off-line camera calibration toolbox”.

There are only a few papers which describe automatic control point extraction from calibration patterns. One example for checkerboard patterns is presented by Ha [13]. The method examines each potential corner point to see if it matches criteria to be an inner point on a checkerboard. Here we use features of the pattern on a larger scale to obtain the correct points by their arrangement and automatic ordering of the points to relate to world coordinates. Another example is a method for circular patterns presented by Douxchamps [14].

III. METHOD

The method is detailed in the following step-wise description:

- 1) Identify areas of interest using a simple corner detector filter mask which is [white, black; black, white]. The filter response using a 13×13 mask is shown in Figure 1.
- 2) Extract the areas with high filter response as regions of interest. The regions of interest are overlaid on the original image in Figure 2.
- 3) Apply the Radon transform (or Hough transform) to the filter response (1) masked by the regions of interest from (2).
- 4) Identify the N largest maxima in the image from (3) in the range from $-\theta_V$ to θ_V degrees around the vertical axis of the image. (N is the number of corners expected in the horizontal direction.) Figure 3 shows an illustration of the lines corresponding to the largest maxima in the Radon transform.
- 5) Pick out a subset of the binary image in (2). Regions which lie on lines corresponding to the N maxima are kept. See Figure 4.
- 6) Apply the Radon transform to the image from (5).
- 7) Identify the M largest maxima in the image from (6) in the range from $-\theta_H$ to θ_H degrees around the mean angle of the maxima from (4) minus 90 degrees. (M is the number of corners expected in the vertical direction.) Figure 5 shows an illustration of the lines corresponding to the largest maxima in the Radon transform.
- 8) Pick out a subset of the binary image in (5) that lie on lines corresponding to the M maxima. Figure 6 shows the regions that are the output from this step.
- 9) Check if the remaining regions from (8) correspond to a checker board in the image by comparing the

filter response sign to the expected sign from the board. If the expected sign matches the arrangement of the points the extracted corner points and the corresponding physical grid coordinates is passed along to the camera calibration.

If the expected sign from the filter response is a full match for the entire checkerboard pattern, the image can be passed automatically to the stereo camera calibration. Partial matches can be used for single view calibration.

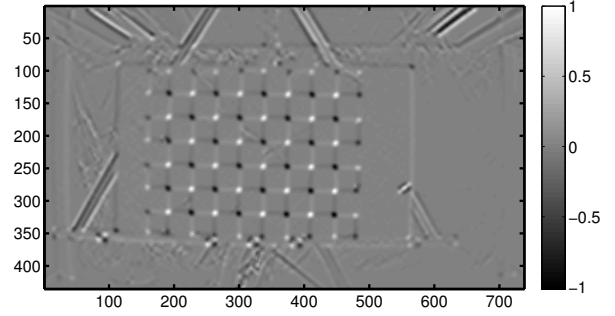


Fig. 1. The filter response from a simple corner detector filter.

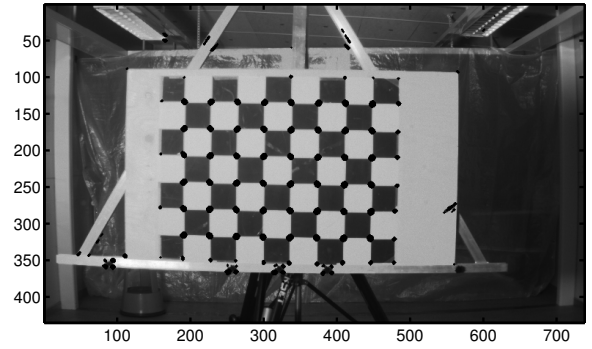


Fig. 2. The interest points found by the filter overlaid on the original image.

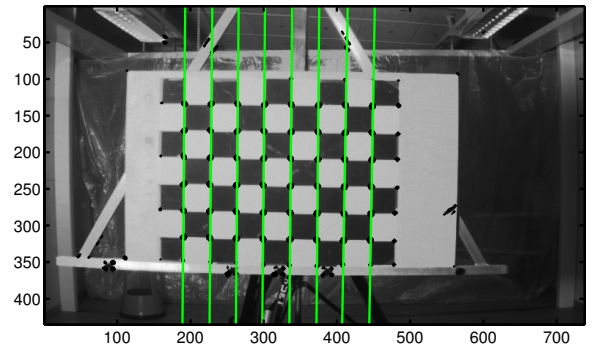


Fig. 3. The lines corresponding to the eight highest peaks in the Radon transform.

IV. EXPERIMENTS AND RESULTS

The presented method is used as the first step in a calibration procedure together with parts of the camera calibration toolbox. After the method has identified the neighbourhoods where the control points are located their

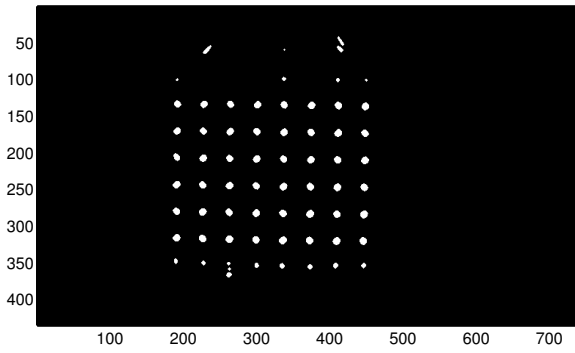


Fig. 4. The interest points that correspond to the eight highest peaks in the Radon transform.

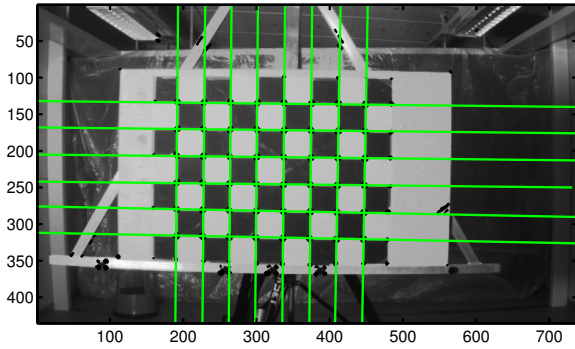


Fig. 5. The horizontal lines correspond to the six highest peaks in the Radon transform of the image in Figure 4.

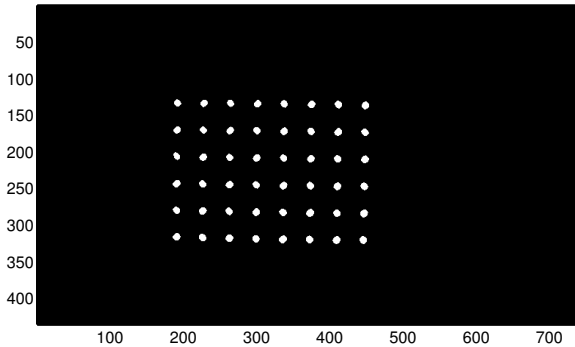


Fig. 6. The interest points that correspond to the six highest peaks in the Radon transform of the image in Figure 4.

subpixel positions are found using the method provided in the toolbox. After this, the pixel coordinates and the corresponding world coordinates are passed to the main calibration function in the toolbox, which perform optimisation of the intrinsic and extrinsic parameters of the camera.

The method was evaluated during a validation study of camera calibration methods for a single camera and stereo. Examples of results are shown in Figure 7. The method performs well for different sizes of the calibration board in the image and is able to find the pattern up to large view angles. However, the simple corner detector fails to find the corners for large rotations. If the calibration board is at close distance to a camera with visible lens distortion all points on the same line may not be

identified since the lens distortion displace the points and they do not contribute to the same maxima in the Radon transform.

V. DISCUSSION AND CONCLUSION

In this paper we have presented a method for automatic detection of checkerboard patterns in images and the approximate position of the corresponding control points on the pattern. The method was developed to facilitate a completely automated calibration procedure together with the Camera calibration toolbox [3].

The method performs well for real world images from a stereo camera and has been used in a validation study of camera calibration methods. The method fails to detect the checkerboard pattern for large rotations of the calibration board due to the simple filter which is not rotation invariant. If larger rotations are needed in a particular application, additional filters or rotation invariant corner detector filters may be applied to find the best initial rotation. Another possible approach is to estimate a rough rotation of the board from the image gradient and select a filter for corner detection from this. In many applications using camera calibration it is enough with large yaw and pitch angles of the calibration pattern as seen by the camera, therefore this has not been implemented here.

The method fails to find some control points for patterns close to a camera with visible lens distortion. This problem is not severe since the loss of a single point on the board in the calibration is small. In addition, this can be overcome in several ways. An example is to calibrate the camera using the first set of points and then use the estimated lens distortion parameters to find all points in the images in a second iteration. Such a two step approach can also be used to find corresponding points for stereo calibration in stereo images of calibration boards that are not fully visible in the images.

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REFERENCES

- [1] Z. Zhang, "Flexible camera calibration by viewing a plane from unknown orientations," in *IEEE International Conference on Computer Vision*, vol. 1, 1999, p. 666.
- [2] J. Heikkilä and O. Silvén, "A four-step camera calibration procedure with implicit image correction," in *CVPR*, 1997, pp. 1106–1112.
- [3] J.-Y. Bouguet, "Camera calibration toolbox for Matlab," http://www.vision.caltech.edu/bouguetj/calib_doc/.
- [4] B. Triggs, P. McLauchlan, R. Hartley, and A. Fitzgibbon, "Bundle adjustment – a modern synthesis," in *Lecture Notes in Computer Science*, vol. 1883, 2000, pp. 153–177.
- [5] R. Tsai, "A versatile camera calibration technique for high-accuracy 3D machine vision metrology using off-the-shelf tv cameras and lenses," *IEEE Journal of Robotics and Automation*, vol. 3, no. 4, pp. 323–344, 1987.
- [6] J. Heikkilä, "Geometric camera calibration using circular control points," in *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 22, no. 10, 2000, pp. 1066–1077.
- [7] Z. Zhang, "A flexible new technique for camera calibration," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, pp. 1330–1334, 2000.

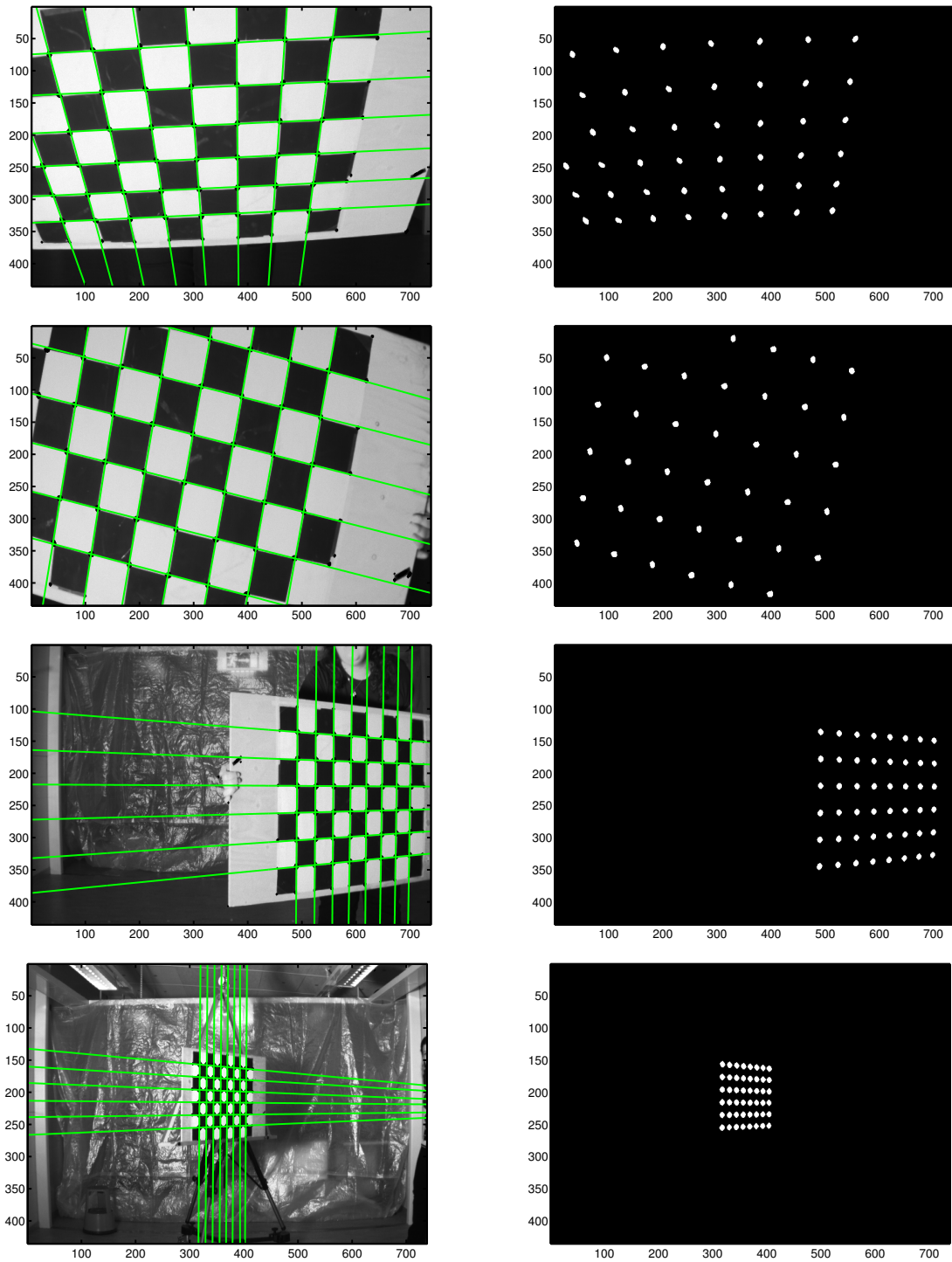


Fig. 7. (Left column) The original images with overlaid lines corresponding to the maxima in the Radon transform. (Right column) The identified interest points in the image.

- [8] J. Weng, P. R. Cohen, and M. Herniou, "Camera calibration with distortion models and accuracy evaluation," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 14, no. 10, pp. 965–980, 1992.
- [9] J. Kannala and S. S. Brandt, "A generic camera model and calibration method for conventional, wide-angle, and fish-eye lenses," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 28, no. 8, pp. 1335–1340, 2006.
- [10] W. Sun and J. R. Cooperstock, "An empirical evaluation of factors influencing camera calibration accuracy using three publicly available techniques," *Machine Vision and Applications*, vol. 17, no. 1, pp. 51–67, 2006.
- [11] R. Hartley and A. Zisserman, *Multiple View Geometry in computer vision*, 2nd ed. Cambridge University Press, 2003.
- [12] T. Dang, C. Hoffmann, and C. Stiller, "Continuous stereo self-calibration by camera parameter tracking," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 18, no. 7, pp. 1536–1550, 2009.
- [13] J.-E. Ha, "Automatic detection of calibration markers," *Optical Engineering*, vol. 46, no. 10, 2007.
- [14] D. Douchamps and K. Chihara, "High-accuracy and robust localization of large control markers for geometric camera calibration," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 31, no. 2, pp. 376–383, 2009.