Automatic Control Point Segmentation and Localization for Online Camera Calibration

Chunrong Yuan
Fraunhofer FIT
Schloss Birlinghoven
53754 Sankt Augustin, Germany

yuan@computer.org

ABSTRACT

Camera calibration is an essential step for 3D object recognition and reconstruction. In this work, we propose a novel method for the automatic localization of control points and present a simple and yet robust online camera calibration system. First a planar calibration pattern with circular control points is designed. These points are then automatically segmented and localized by integrating information resulted from two complementary segmentation methods: region extraction and contour detection. After the calibration pattern has been shown to the system at a few locations, both the intrinsic and extrinsic camera parameters can be determined. The main advantage of this approach is that the metric measurement of the calibration pattern in the image plane is done purely automatically. We have implemented the whole system on a windows platform. Tests with USB cameras in different configurations and applications show the efficiency as well as the accuracy of the proposed approach.

Keywords

Camera calibration, image segmentation, contour detection, automatic point localization, parameter estimation

1. INTRODUCTION

Camera calibration is the process of determining the set of unknown parameters of a certain camera. It is generally done by using a suitable calibration pattern. The set of parameters can be computed by inferring the relationship between the 3D world coordinate of some reference points on the calibration pattern and their 2D image coordinate. The whole calibration procedure includes the definition of a camera model, the design of a calibration pattern with a definite geometric configuration of control points, the acquisition of a few images of the calibration pattern to obtain the locations of the control points in the images, the determination of the camera parameters by fitting the extracted points to the camera model and solving a system of equations.

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There are numerous methods for camera calibration presented in the literature [Tsai87a, Hei97a]. While many of them focus on modeling the image formation process and solving the camera projection matrix, we discuss the whole pipeline of camera calibration and pay particular attention to the measurement procedure of the 2D image coordinate of the reference points. Unlike [Zha00a], where squares are used as control points, we use circles for the purpose of more robust localization of the control points under unfavorable lighting conditions and heterogeneous backgrounds.

2. AUTOMATIC LOCALIZATION OF CONTROL POINTS

A calibration pattern with some circular points on it that act as control points has been designed, as is shown in Fig. 1. Altogether there are 70 circular points whose diameter is equal to 23 mm. An input image $\mathbf{f}$ of the calibration pattern is first segmented separately using two different approaches, namely threshold based region extraction and contour detection. Then an algorithm has been developed to integrate the information resulted from the two segmentation approaches. Illustrated in Fig. 2 is the output image with the extracted control points shown as white points in the centre of each circular contour. As can be seen, all the circular points have been segmented properly despite the fact that the background of image $\mathbf{f}$ is heterogeneous.

3. CAMERA MODEL & ESTIMATION

Using a pinhole camera model, A 3D point $\mathbf{P} = [x_w, y_w, z_w, 1]^T$ is mapped to its 2D image point $\mathbf{p} = [x_i, y_i, 1]^T$ with $\lambda\mathbf{p} = \mathbf{MP}$, where $\mathbf{M} = \mathbf{K}[\mathbf{R} \quad \mathbf{t}]$, and $\mathbf{K} = \begin{bmatrix} f_x & 0 & cc_x \\ 0 & f_y & cc_y \\ 0 & 0 & 1 \end{bmatrix}$.

Matrix $\mathbf{M}$ has 10 unknowns, 4 intrinsic parameters f_x, f_y, cc_x, cc_y and 6 extrinsic ones (three embedded in $\mathbf{R}$ and three in $\mathbf{t}$). To model lens distortions, we use five parameters (three radial and two tangential distortion coefficients) $k_i, i = 1,...5$.

From the 3D and 2D correspondences, a linear solution can be obtained for the 4 intrinsic camera parameters. Using the Levenberg-Marquardt algorithm, k_i and the 6 extrinsic camera parameters that are associated with each input image of the calibration pattern can be estimated.

4. EXPERIMENTAL RESULTS

The proposed approach has been implemented on a PC operated under windows XP. The algorithm is tested with a pair of Logitech USB cameras, which are placed parallel on a stereo rig. Calibration of the two cameras (one left camera and one right camera) can be done simultaneously within a few minutes.

After obtaining the intrinsic and extrinsic camera parameters, we project the 3D world coordinate of the control points back to the image plane. The deviation is within 0.25 pixels in the image frame.

With the extrinsic camera parameters of both cameras estimated, the relative pose of the right camera in the left camera coordinate system can be computed. It has been found out that the computed relative 3D pose is quite stable and agrees with the actual configuration of the two cameras.

The calibration algorithm has also been integrated into an object tracking system. The goal is to calculate the 3D pose of some marker objects observed by the calibrated cameras. A satisfying tracking accuracy has been achieved (the deviation of the reconstructed markers in 3D is within 1 cm by translation and 3 degrees by rotation).

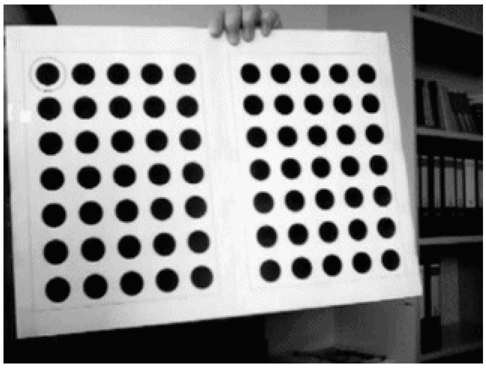

Figure 1. Input image of the calibration pattern.

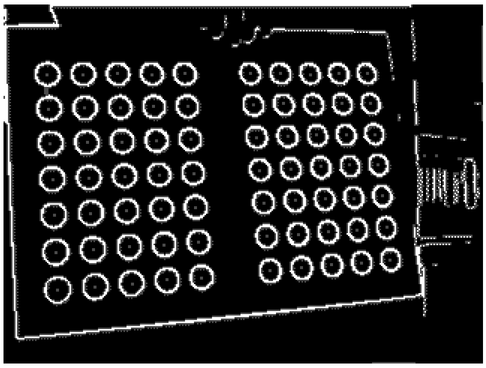

Figure 2. Results with control points localized.

5. CONCLUSIONS

We have presented a new and easy online camera calibration technique based on a planar calibration pattern with circular control points. The proposed approach concentrates mainly on the automatic extraction of 2D control points. By analyzing the calibration images in an unsupervised way, a precise measurement of the reference points can be achieved. The calibration system has been implemented on a windows platform and tested with USB cameras. The efficiency and accuracy of the proposed methodology have been demonstrated by examples.

6. REFERENCES

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