

Evaluating Harris Method in Camera Calibration

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Abstract - In this paper, we focus on the performance of Harris feature point extraction method (Harris Method) and evaluate its characteristic in some aspects. We propose a set of criteria for the evaluation: Detection, Accuracy, Consistency, and Efficiency. All of these criteria are defined theoretically and measured with different kinds of images. Especially, to verify the localization accuracy of Harris Method, we synthesize a series of chessboard images in which the real coordinates of feature points could be computed. Therefore, the criteria proposed here are objective and believable.

Keywords – feature extraction; Harris corner detector; sub-pixel accuracy Harris corner detector; performance evaluation.

I INTRODUCTION

In the research of computer vision, camera calibration is a procedure to assess camera parameters in order to deal with a camera mathematically according to an assumed model. A set of 3D points' perspective projections to an image plane is usually applied as the input data for camera calibration [5]. World coordinates of 3D points are known in advance, which are called "feature points" or "control points". Effective detection and precise localization of the feature points in the image are very important in camera calibration, which is broadly applied in human motion detection, 3D circumstance visualization and so on.

A wide variety of corner detectors by which feature points are extracted exist in the literature. In this paper, we focus on Harris Method [2] and evaluate this method by applying 4 criteria: Detection, Accuracy, Consistency, and Efficiency.

Section II introduces the theory of Harris Method which includes the basic Harris Corner Detector (HCD) method and the Improved Harris Corner Detector method, which is also called the Sub-Pixel Accuracy Harris Corner Detector (SHCD). In Section III, we illustrate the evaluation

procedure and results before offering concluding remarks in Section IV.

II THEORY

A. Harris Corner Detector

Harris Corner Detector was developed in [2] by Harris, C. and Stephens, M (1988). The problem of detecting corners was analyzed in terms of the local image intensity autocorrelation function. A version of the intensity spatial change function for a small shift (u, v) can be written as follows:

$$E(u, v) = \sum_{x,y} w(x, y)[I(x+u, x+v) - I(x, y)]^2 \\ = [u, v]M \begin{bmatrix} u \\ v \end{bmatrix}$$

$$M = \sum_{x,y} w(x, y) \begin{pmatrix} I_x^2, & I_x I_y \\ I_x I_y, & I_y^2 \end{pmatrix} \quad (1)$$

$I(x, y)$ denotes the image intensity. $E(u, v)$ is the average change of image intensity. $w(x, y)$ is a smoothing window. Let λ_1 and λ_2 be the eigenvalues of matrix M . Then HCD is given by the following operator where a large value of R signals the presence of corner in (2) [2].

$$R = \det M - k(\text{trace}M)^2 \quad (2)$$

$$\det M = \lambda_1 \lambda_2 \quad \text{trace}M = \lambda_1 + \lambda_2 \quad k \in [0, 0.04] \quad (3)$$

It has been shown that Harris Method yields a precision only a few pixels in the positioning. This conclusion is proved by our experiments (Tab.2). To get sub-pixel accuracy position, the improved Sub-Pixel Accuracy Harris Corner Detector is introduced.

B. Sub-Pixel Accuracy Harris Corner Detector

In order to concentrate on the area where they might be feature points, we first applied Harris Corner Detector at

pixel level, and then we interpolated image gray values in the areas near detected corners. A 2D Gaussian filter was chosen for the interpolation:

$$g(x, y) = \frac{1}{k_1} e^{-\frac{(x-x_0)^2+(y-y_0)^2}{2\delta^2}} \quad (4)$$

Where (x_0, y_0) is the center of the filter.

After the interpolation, the corners were detected again at these interpolated areas. This procedure is called Sub-Pixel Accuracy Harris Corner Detection, and the corner position up to the sub-pixel accuracy can be detected.

III EVALUATION METHOD

Extracting feature points was the first step in camera calibration, which would crucially affect the whole performance of calibration. We summarized 4 criteria to evaluate the performance of Harris Method used in our camera calibration; meanwhile, we synthesized a set of images through Perspective Projection Transform (Fig.1), with the accuracy of corner position up to 0.3 pixels. Then, we could evaluate the performance of Harris Method and test our criteria by comparing the real information of feature points, such as the image size, corner numbers, and coordinates of feature points, with the extracted features. This might be an objective and credible way to assess the quality of corner detectors.

A. Detection

In camera calibration, a chessboard (Fig.1) is usually served as a model plane. The corners in the chessboard are feature points. Let N_C be the real corner number, N_D number of detected corners by Harris Method. We define the criterion of Detection as follows:

$$\text{Detection} = \frac{N_D}{N_C} \quad (5)$$

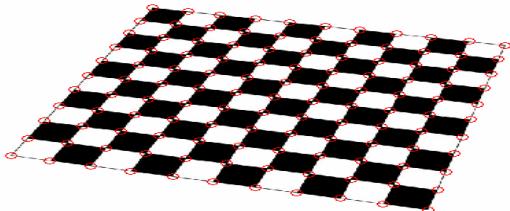


Fig. 1 Extracted Corners

A Detection equal to 100% is what we expect.

B. Accuracy

Besides good Detection mentioned above, precise localizations of the feature points in images are also important in camera calibration. We define Accuracy as follows:

$$\text{Accuracy} = \frac{\sum |P_T - P_D|}{N_C} \quad (6)$$

where P_T stands for the real position of feature points; P_D the detected position; So Accuracy is the average position error between real corners and detected ones (Prerequisites: $N_D = N_C$). A low value of Accuracy is expected.

C. Consistency:

The consistency of HCD has been evaluated by different methods [3~4, 6~7]. In this paper we define our criterion of Consistency theoretically as follows:

$$\begin{aligned} \text{Consistency} &= (C_N, C_P) \\ &= (CCN, 100 \times 1.1^{-10 \times P_{\text{error}}}) \end{aligned} \quad (7)$$

Where $CCN = 100 \times 1.1^{-|N_D - N_C|}$ is defined the same as consistency in [7]. In the expression of C_N and C_P , the use of the scale factor “1.1” aptly shows the results, which makes the coefficient C_N and C_P not too big or too small. This scale factor can be changed under different situations.

$$P_{\text{error}} = \frac{\sum |P_{T,i} - P_{D,i}|}{\text{sum}(N_C \cap N_D)}, \quad i \in \{N_C \cap N_D\} \quad (8)$$

P_{error} is the average position error of common corners between real corners and detected ones (note that N_D may be not equal to N_C here). The criterion of Consistency is composed of 2 elements: one is C_N which stands for the consistency of corner number; and the other is C_P which stands for the consistency of corner position. Since stable corner detectors do not miss any real corner or mistake non-corners for corners, the value of C_N for stable corner detectors should be close to 100%; meanwhile, the value of C_P is expected close to 100% for good consistency of corner

position.

D. Efficiency

The efficiency is evaluated using MatlabTM command interactive platform with a PC computer, equipped with an Intel P-IV CPU at 3.0G Hz. We define the Efficiency as follows:

$$\text{Efficiency} = \left(\frac{\text{Size}}{T_H}, \frac{\text{Corners}}{T_S} \right) \quad (9)$$

where *Size* and *Corners* stand for the size and corner numbers of detected images respectively. T_H stands for the time cost by HCD; T_S the time cost by SHCD. Efficiency here illustrates how many pixels and feature points could be processed by Harris Method in a second.

IV RESULTS

We tested our evaluation method in many different kinds of images, including our synthetic images (Fig.1), real pictures from Zhang's website [9], and a series of real pictures taken by ourselves (Table 4:Index 1,2,3). These experiments were performed as follows:

A. Implementation of Detection:

In some planar methods of camera calibration, a few images of the chessboard model plane should be taken under different orientations [5]. Therefore, we first apply Affine and Projective Transform to the chessboard (Fig.1). When considering lens distortion of a camera, we apply Barrel and Pin Cushion Transform to the chessboard. Real images are always affected by noise, and we contaminate the chessboard with Gaussian noise ($\delta=0.1$) (Fig.2); at last, we use 5-levels grey to simulate the change of lightning conditions. We apply Harris Method after each change.

B. Implementation of Accuracy

TABLE I

DETECTION OF HARRIS METHOD

Transformation	Affine and Projective	Barrel and Pincushion	Gaussian Noise	Illumination
Detection	100%	100%	100%	100%

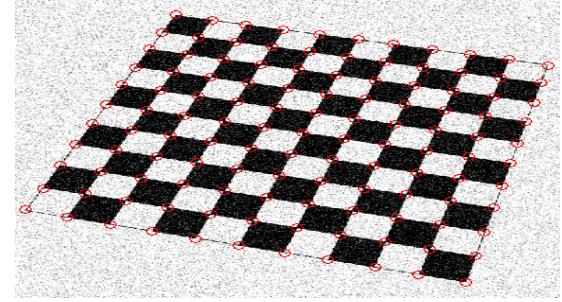


Fig. 2 Extracted Corners with Gaussian Noise

Synthetic images with different resolutions are used to evaluate the accuracy of Harris Method. The results are shown in Table II.

C. Implementation of Consistency

We take the images Zhang had used in his article [5, 9] to evaluate the Consistency of Harris Method. We compare the original images with the ones contaminated with Gaussian Noise.

D. Implementation of Efficiency

We use 3 kinds of chessboard images with different size and corner numbers. The results are compared in Table IV.

Table I shows that Harris Method can detect all corners in the chessboard images. From Table II, we verify that HCD and SHCD could detect corners at pixel and sub-pixel level respectively. By the way, due to the 0.3 pixel accuracy of our synthesized images, the Accuracy of SHCD could only be up to 0.5 pixels. This can also explain the results of P_{error} in Table III. Table III shows that Harris Method is not sensitive to the noise effects while noise is low. From Table IV, we estimate that HCD could calculate about 400000 pixels and that SHCD could deal with about 300 feature points in a second.

TABLE II
ACCURACY OF HARRIS METHOD WITH DIFFERENT IMAGE SIZE (PIXELS)

Accuracy	1200X1200	1000X1200	1000X1000	600X800
Corner Number	63	49	49	64
HCD	1.42120	1.3087	1.0909	1.0445
SHCD	0.50135	0.59962	0.5321	0.5161

TABLE III

CONSISTENCY OF HARRIS METHOD WITH GAUSSIAN NOISE

Noise(δ)	$ N_D - N_C $	$P_{\text{error}}(\text{pel})$	$(C_N\%, C_P\%)$
0	0	0.5300.	(100, 60.34)
0.01	0	0.5473	(100, 59.36)
0.02	4.3	0.5530	(66.38, 57.90)
0.08	10	0.5711	(38.55, 55.24)

TABLE IV

EFFICIENCY OF HARRIS METHOD

Image Index	1	2	3
Size (pixel)	200x200	640x480	1280x960
Corner Num.	9	256	140
TH	0.093s	0.671s	2.562s
TS	0.109s	0.704s	0.375s
Efficiency	(430107,82)	(45784,364)	(479625,373)

V CONCLUSION AND DISCUSSION

In this paper we have introduced 4 novel evaluation criteria mathematically: Detection, Accuracy, Consistency, and Efficiency and then proposed a series of experiments to assess the performance of Harris Method. These criteria and experiments present several advantages, especially in the application of camera calibration. First, we simulate different situations in camera calibration, for instance, when testing Detection of Harris Method, we applied several changes to the chessboard to simulate the real procedure. Second, our results accord with conclusions of others, for example, it was reported that Harris Method was invariant to plane rotation, change in views, and change in lightning conditions, excluding large scale changes [1, 3, 6]. And Table I shows accordant conclusions. Further, the results in Table II prove once again that HCD yields a precision of pixel level and that SHCD could detect the corner position up to the sub-pixel accuracy. Due to their good qualities, our 4 criteria could be directly applied to evaluating

performances of corner detectors when calibrating cameras.

However, the evaluation procedures and results also reveal the limitation of our evaluation method. For example, the localization accuracy of corners in the synthesized images is not accurate enough. This leads to the incompletely estimation of SHCD Accuracy of Harris Method.

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