A Practical Camera Calibration System on Mobile Phones

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Abstract. We propose a practical camera calibration system on mobile phones to calibrate the camera’s intrinsic parameters, based on the geometrical property of the vanishing points. This system only requires the camera to observe a rectangular card shown in a few (at least four) different orientations. The experimental results of real images show that the proposed calibration system is robust, simple, and practicable.

Keywords: Camera Calibration, Vanishing Point, k-means, Line detection

1 Introduction

Camera calibration is a valuable process in the field of computer vision. With the development of the mobile phones, there has been extensive research into the technology of AR in mobile phones in recent years. Owing to these developments, it is necessary to develop a calibration system that is suitable for mobile phones.

In general, camera calibration techniques can be divided into three categories: the traditional method, the method based on the active vision technique, and the camera self-calibration method. The traditional method [1] requires an accurate three-dimensional or two-dimensional calibration target; the method based on the active vision method [2], a particular movement of the camera is necessary, and a relatively high accuracy of experimental equipment is required; the camera self-calibration method makes use of the self-constraints of the camera for calibration. This method can further be divided into the technique based on Kruppa’s equations [3], and that of the absolute quadric method [4], both of which can work without a reference calibration target. Both these methods require high computational complexity. Therefore, particularly in low-performance mobile phones, the process is extremely time-consuming.

In our system, in order to avoid such high computational complexity, we implement a camera calibration method based on the geometrical properties of the vanishing points that are determined by two perpendicular groups of parallel lines [5]. The vanishing points can be obtained from an arbitrary rectangular card, which can be a card used in everyday life (e.g., credit card, business card) and is therefore easy to obtain. In comparison with other methods, our method is robust, easy to use, and requires less computation.
2 Related Work

The pinhole camera model is a widely used model in the field of computer vision. Let the image point $p(\upsilon, \nu)^T$, which is located in the image coordinate frame, be the projection of the three-dimensional point $P_w(x_w, y_w, z_w)^T$ located in the world coordinate frame. Then, the projection equation can be written as:

$$
\begin{bmatrix}
\frac{1}{\upsilon} \\
\frac{1}{\nu}
\end{bmatrix}
= 
\begin{bmatrix}
\frac{f}{d_x} & s & \varepsilon_x \\
0 & \frac{f}{d_y} & \varepsilon_y \\
0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
x_w \\
y_w \\
z_w
\end{bmatrix}
- 
K \cdot 
\begin{bmatrix}
R & T
\end{bmatrix}
\begin{bmatrix}
x_w \\
y_w \\
z_w
\end{bmatrix}
$$ (1)

Where $K$ is the intrinsic parameters matrix of the camera, and $R$ and $T$ are the rotation matrix and translation matrix, respectively. In the intrinsic parameters matrix $K$, $f$ is the camera's focal length, $d_x, d_y$ are the CCD/CMOS sensor pixel's length and width, respectively, $(c_x, c_y)^T$ is the principal point, and $s$ is a factor accounting for the skew due to non-rectangular pixels.

![Fig. 1. Geometry model of the ideal projection of two perpendicular groups of parallel lines](image)

A set of parallel lines in the three-dimensional world is projected onto a set of converging lines in the image plane; these lines converge at a common point known as the vanishing point. The line that joins the camera center and the vanishing point of the parallel lines in the world is parallel to these parallel lines. If there are two perpendicular groups of parallel lines in the world, as illustrated in Fig.1, then: $L_1, L_2, L_3, L_4$ are parallel lines; $L_1 \perp L_3$; $L_2$ and $L_3$ 's projection $l_1, l_2$ intersect at vanishing point $A$ in image plane $\Omega$, and $L_3$ 's projection $l_3$, $l_4$ intersect at vanishing point $B$. Based on the property of the vanishing point, it is known that the lines joining the optical center $O$ and the vanishing points $A$ and $B$ are parallel to the
respective lines corresponding to these in the world: \( OA \parallel L_1, OB \parallel L_2 \), then, \( OA \perp OB \), and \( O \) is on a sphere with a diameter of \( AB \).

We conclude that, if two perpendicular groups of parallel lines exist, the optical center \( O \) is on the sphere of which the diameter is the line joining the two vanishing points obtained by those parallel lines.

3 Proposed calibration algorithm for mobile platform

3.1 Pre-processing

The first step in this stage is Gaussian smoothing, for reducing the noise that is generated by camera's sensor, as well as reducing bad lighting conditions to a certain extent. Following this, we enhance the edge details of the image by increasing the global contrast by means of Histogram equalization; however, as this may increase the contrast of background noise, in the third step, we again use Gaussian filtering again to minimize the little edge's influence. Thereafter, we detect the edge using the Canny algorithm, and finally, we detect the lines by means of Hough lines detection.

3.2 Vanishing point detection

In this stage, we use the k-means algorithm to classify the lines into four groups, based on the line's angle and intercept. Thereafter, we compute the average line of each line group. In the last step, we use the average lines to calculate the vanishing points.

3.3 Camera calibration based on vanishing points

In the image coordinate frame, the vanishing point coordinates obtained by the projection of the parallel lines are \( A(t_{A}, v_{A})^T \), \( B(t_{B}, v_{B})^T \). Then, the vanishing point coordinates in the camera coordinate frame are:

\[
A(t_{A} - e_{X})ld_{x} + (v_{A} - e_{Y})ld_{y}, b^T + B(t_{B} - e_{X})ld_{x} + (v_{B} - e_{Y})ld_{y}, b^T
\]

The equation of the sphere of which the diameter is \( AB \):

\[
\left\{\begin{array}{c}
\left(t - \frac{t_{A} + t_{B}}{2}d_{x}, v - \frac{v_{A} + v_{B}}{2}d_{y}\right)^2 + (z - f)^2 = \left(\frac{t_{A} - t_{B}}{2}d_{x}\right)^2 + \left(\frac{v_{A} - v_{B}}{2}d_{y}\right)^2
\end{array}\right.
\]

Based on the conclusion of section 2, the optical center \( O(0,0,0)^T \) is on the sphere with a diameter of \( AB \), and therefore, we substitute \( O(0,0,0)^T \) into equation (2), then:
Simplifying equation (3):

\[
\left( \frac{c_y - v_A}{f_x^2} \right) \left( c_x - v_A \right) + \left( \frac{c_y - v_A}{f_y^2} \right) \left( c_x - v_A \right) = I = 0
\]

Equation (4) is a function of the intrinsic camera parameters \((f_x, f_y, c_x, c_y)\) and has four unknowns. It is necessary to obtain at least four images (each rectangular card image get 2 vanishing points) from different orientations. In Hun's method [5], the lens distortion coefficient is considered, and a non-linear optimization based on Nelder-Mead simplex algorithm is used to optimize the intrinsic parameters. Because the distortion of a mobile camera lens is very small, we used the method of least squares to solve the intrinsic parameters.

### 4 Experiments

We took four images, shown in Fig. 2, using the rear camera of a Galaxy Note 2 moving it around a card so that different vanishing points could be obtained. The calibration results of the images in Fig. 2’s are listed in Table 1’s data1. In order to evaluate our method objectively, we also tested two other image data sets obtained from the same device and the results are shown in Table 1. We used Zhang's chessboard method [1] to calibrate the camera as a reference. In this test, each test data set is obtained by capturing the chessboard in 20 different orientations using the same device(Fig. 3). Three data sets were tested, and the results are shown in Table 2. When we compare the results of our system with the results of Zhang's method, there are no significant differences between two; however, our system is more flexible.
4 Conclusion

In this paper, in accordance with the low computing performance of mobile phones, we have presented a camera calibration system with low computational complexity. This system can be used to obtain the vanishing points in the image of an arbitrary rectangular card and to calibrate the intrinsic camera parameters based on these vanishing points. Our experiments show that this system is flexible and effective.

References