Advances in Engineering Research, volume 181

International Conference on Electronical, Mechanical and Materials Engineering (ICE2ME 2019)

A Geometric Distortion Rectification Method for Wide Field of View Camera

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***Abstract*—In large-size, high-resolution LCD measurement systems, images acquired by wide field of view (WFOV) cameras exhibit significant geometric distortion. To solve this problem, this paper presents a global parameter guided camera geometric distortion rectification method, which estimates the local geometric rectification parameters of the camera by a calibrating image and corrects the subsequent measured images. Firstly, the global parameters of the camera are initially estimated in coarse-grained, and the approximate position of the feature points in the distorted calibrating image. Secondly, using the method of finding centroid with threshold to calculate the exact position of feature points in the neighborhood of the estimated position. Finally, the local geometric rectification parameters of the camera are calculated in fine-grained. The experimental results show that the measurement accuracy of the WFOV camera for LCD can reach sub-pixel level after rectification by this method, and it can be easily implemented in parallel, reduce computing time. It can meet the requirements of LCD inspection, quality assessment, de-Mura and so on.**

***Keywords*—CCD; LCD; geometric distortion; geometric rectification**

I. INTRODUCTION

LCD (Liquid Crystal Display) has become the leading panel display technique with excellent display performance. The uniformity of LCD display is an important factor affecting its quality level. CCD camera can quickly measure the brightness, chromaticity and other information of each pixel in LCD, which is widely used in the field of LCD measurement [1]. In recent years, with the rapid development of LCD, the size and resolution of LCD is becoming larger and larger. So it is necessary to use wide field of view (WFOV) CCD camera to measure it [2]. However, because of aspects such as the production process of the optical lens, the camera image may have large geometric distortion, so geometric distortion rectification must be done for WFOV camera [3][4].

Geometric distortion rectification technology of image originated from the lens rectification in the 20th century [5]. It is used to solve the matching problems of measured object between the 3D world coordinates and the 2D image coordinates, such as the direct linear transformation (DLT) method proposed by Abdel-Aziz YI and Karara HM and the two-step calibration method proposed by Tsai R Y [6][7]. Many improved algorithms have been proposed based on these methods, such as Zhang's calibration method proposed by Zhang Z, the automatic geometric distortion rectification method proposed by Zhang Sen, the image reconstruction technology proposed by LU CH J and so on [8][9][10]. In these methods, for geometric distortion phenomenon in measurement, some feature points need to be detected and matched before estimating rectification parameters. After using the global parameters of the camera to rectify the distort image, the image accuracy stays low, and the image details acquisition with low contrast and low SNR is still insufficient. For the local geometric rectification method, since the vignetting and geometric distortion of the WFOV camera are large, the error of the feature point detection is also large, resulting in the rectification accuracy being poor.

Aiming at the inadequacies in existing technologies, on the basis of previous studies, this paper presents a new local rectification method for geometric distortion guided by global parameters of WFOV CCD camera. Firstly, the global parameters of the camera are initially estimated in coarse-grain, and then the local feature points detection and local rectification parameters estimation are guided by them. Finally, the gray level of each pixel in the image after geometric distortion rectification is determined by bilinear interpolation method.

II. PRINCIPLE AND METHOD OF GEOMETRIC CORRECTION

The mathematical model of the camera is usually a pinhole camera model. Assuming that there is a point M in the world coordinates. After shooting through the camera, its image is the point m. The relationship between the coordinate systems is shown in Figure I.

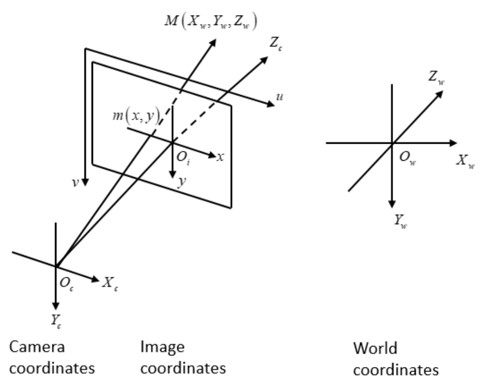


FIGURE I. CORRESPONDENCE RELATIONS IN THREE COORDINATES

In the measurement of LCD, because of the measured object is plane, the world coordinates can be constructed on the plane. The following formula can be obtained:

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \mathbf{H} \bullet \begin{bmatrix} X \\ Y \\ 1 \end{bmatrix} \quad (1)$$

where $\mathbf{H}$ is the homography matrix, which can be solved by a set of feature points in the world coordinates and image coordinates, and then rectify the image by using the following formula:

$$\begin{bmatrix} X \\ Y \\ 1 \end{bmatrix} = \mathbf{H}^{-1} \bullet \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} \quad (2)$$

This method is called global rectification method, but because of the radial distortion and other conditions of the lens, the mapping obtained by this method exhibit some errors, resulting in a poor correction accuracy. Therefore, the local geometric rectification method is proposed, which divides the image into many small areas. In each area, the distortion parameters are estimated by using feature points and applied to the rectification of pixels in the area.

Compared with the global rectification method, this method improves the accuracy of rectification. However, when WFOV camera collects images, the pixels far away from the principal point not only suffer from serious geometric distortion, but also suffer from the influence of camera vignetting, resulting in a serious attenuation in brightness. Thus, the position detection of feature points in the image is inaccurate, which results in the rectification accuracy being poor.

III. GEOMETRIC RECTIFICATION OF WFOV CAMERA

A. Geometric Rectification for WFOV Camera

When measuring the display of LCD, the steps of measurement and correction are as follows:

1) *Place the LCD and camera in a darkroom to reduce the effects of external light.*

2) *Pre-calibrate the spatial position of the LCD and camera, try the best to ensure that the optical axis passes through the center of LCD and the scale is approximately 1:1.*

3) *Let the LCD to display geometric feature images and control the camera to shoot the LCD.*

4) *Use the method in Section III.B to detect the coordinate position of more than three feature points near the center of the LCD in the image coordinates, and then find the homography matrix* $\mathbf{H}$.

5) *Use the homography matrix* $\mathbf{H}$ *to predict the coordinates of the remaining feature points in the image coordinates, then use the method in Section III.B to detect and estimate the exact coordinates of the remaining feature points.*

6) *The geometric feature image is devided into several small blocks based on four adjacent feature points:* And then the geometric correction parameters of each block are obtained. Finally, use the bilinear interpolation or other methods to rectify the subsequently measured image.

B. Detection and Position Estimation of Feature Points

Assuming that the neighborhood of a feature point (u_0, v_0) in the distorted image is $\mathrm{N}\left(u_0, v_0\right)$, find the mean $\boldsymbol{\mu}$ and the standard deviation $\boldsymbol{\sigma}$ of the gray values of all the pixels in the neighborhood N, set the threshold th as:

$$th = \boldsymbol{\mu} + k \bullet \boldsymbol{\sigma} \quad (3)$$

where k is a preset constant, assuming that x and y be the horizontal and vertical coordinates of the pixels in N, $f(x, y)$ is the gray level of pixel $\left(x, y\right)$. Threshold $f(x, y)$ by th as follows

$$I(x, y) = \begin{cases} f(x, y) & , \quad f(x, y) \geq th \\ 0 & , \quad f(x, y) < th \end{cases} \quad (4)$$

By calculating the centroid of $I(x, y)$, the coordinates of the current feature point in the image coordinates can be obtained as follows:

$$x = \frac{\sum_{(i,j)\in\mathrm{N}} i \bullet I(i, j)}{\sum_{(i,j)\in\mathrm{N}} I(i, j)} \qquad y = \frac{\sum_{(i,j)\in\mathrm{N}} j \bullet I(i, j)}{\sum_{(i,j)\in\mathrm{N}} I(i, j)} \quad (5)$$

C. Global Parameter Estimation of Camera

Through the above method, the exact coordinates of several feature points with less distortion in the image coordinate system can be estimated. The homography matrix $\mathbf{H}$ can be calculated. By taking four feature points as examples, let H be:

$$\mathbf{H} = \begin{bmatrix} A & B & C \\ D & E & F \\ G & H & 1 \end{bmatrix} \quad (6)$$

The coordinates of these four feature points in the world coordinates are set as follows:

$$P_1 = \left(0, 0\right), \quad P_2 = \left(1, 0\right)$$
$$P_3 = \left(0, 1\right), \quad P_4 = \left(1, 1\right) \quad (7)$$

Their coordinates in the image coordinates are:

$$m_1 = (u_1, v_1) \ , \ \ m_2 = (u_2, v_2)$$
$$m_3 = (u_3, v_3) \ , \ \ m_4 = (u_4, v_4) \tag{8}$$

The homography matrix $\mathbf{H}$ can be obtained by using (1). Ideally, the image coordinates of the camera image can be mapped to the coordinates of the world coordinates, which can be used to guide the location of the remaining feature points.

D. Local Geometric Rectification Guided by Global Parameters

Using homography matrix $\mathbf{H}$ and coordinates in (7), the coordinates of other feature points in image coordinates can be predicted. Assuming that the coordinates of each feature point in the world coordinates are $(X_i, Y_i),\ i = 1, 2, ..., N$ and the predicted coordinates in the image coordinates are (u_i', v_i'), the relationship can be established by using (1):

$$\begin{bmatrix} u_i' \\ v_i' \\ 1 \end{bmatrix} = \mathbf{H} \bullet \begin{bmatrix} X_i \\ Y_i \\ 1 \end{bmatrix} \tag{9}$$

By using the method Section III.B, the precise coordinates (u_i, v_i) of every feature points in image coordinates can be estimated in neighborhood N (u_i', v_i'), and then the mapping relationship between feature points in image and world coordinates can be used to guide the local rectification of geometric distortion.

Assuming that the coordinates of each four adjacent feature points obtained by the above method in the world coordinates are as follows:

$$P_1 = (x_1, y_1) \ , \ \ P_2 = (x_2, y_2)$$
$$P_3 = (x_3, y_3) \ , \ \ P_4 = (x_4, y_4) \tag{10}$$

The corresponding coordinates in the image coordinates are shown in (8). A set of rectification parameters $c_1 \sim c_8$ can be solved by using the blocks enclosed in the four feature points. The solution is as follows:

$$\begin{cases} u_1 = c_1 x_1 + c_2 y_1 + c_3 x_1 y_1 + c_4 \\ v_1 = c_5 x_1 + c_6 y_1 + c_7 x_1 y_1 + c_8 \\ \vdots \\ u_4 = c_1 x_4 + c_2 y_4 + c_3 x_4 y_4 + c_4 \\ v_4 = c_5 x_4 + c_6 y_4 + c_7 x_4 y_4 + c_8 \end{cases} \tag{11}$$

After calculating the geometric rectification parameters, assuming that the coordinates of the (x, y) pixel in the measured image after geometric distortion are (u, v), the following formula can be obtained:

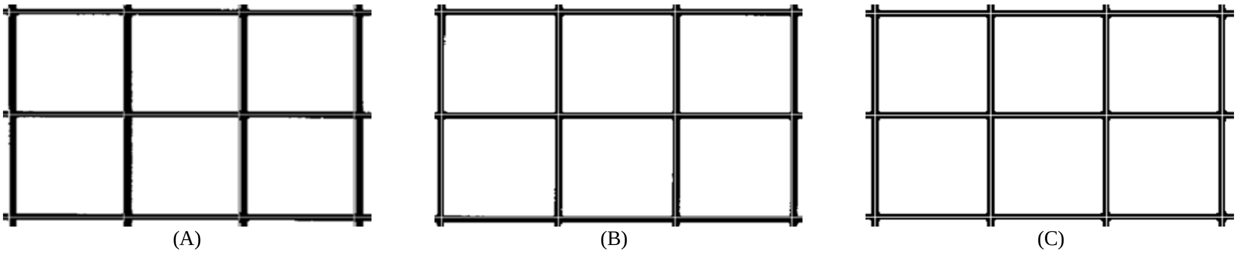
$$\begin{cases} u = c_1 x + c_2 y + c_3 xy + c_4 \\ v = c_5 x + c_6 y + c_7 xy + c_8 \end{cases} \tag{12}$$

The proposed method combines global parameters calibration and local parameters rectification to rectify the geometric distortion of the camera. It can not only solve the problem of large deviations in calibration results when only using global parameters, but also solve the problem of inaccurate or undetectable feature points when only using local parameters for rectify. The calculation is easy to be realized by GPU, which can significantly improve the speed of image geometric rectification.

IV. Experimental Results and Analysis

In the experiment, a 16 mega pixel mono camera and a 28mm fixed focus lens were used. The image taken was 4896×2752 in resolution. The measured object is a 55 inches and 3840×2160 LCD panel. Two computers with different GPU are used to process the data.

Figure II shows the rectification results of equally spaced grid. Figure II(a) is the result by global rectification, Figure II(b) is the result by local method, and Figure II(c) is the result by the proposed method. Table I shows the correction errors of three methods.



(A) (B) (C)

FIGURE II. OUTPUT IMAGES RECTIFIED BY DIFFERENT METHODS: (A) GLOBAL RECTIFICATION METHOD (B) LOCAL RECTIFICATION METHOD (C) THE METHOD IN THIS PAPER

TABLE I. RECTIFICATION DEVIATIONS OF DIFFERENT METHODS

Rectification Method	**Rectification Deviations(pixel)**			
	Maximum deviation	***Minimum deviation***	***Average deviation***	***Mean square deviation***
No rectification	6.42	3.18	4.30	4.77
Global rectification	4.02	1.79	2.75	1.83
Local rectification	0.61	0.06	0.30	1.00
The proposed method	0.04	0.02	0.03	0.10

As seen in Figure II and Table I, the proposed method can rectify the geometric distortion of the image accurately, and the error can be controlled at sub-pixel level.

To test the parallelization performance of the proposed method, experiments with I5-6500 and different types of GPU are carried out. The results are shown in Table II, which shows that the proposed method can be speeded up by GPU while keeping good rectification performance.

Rectification PSNR in brightness of low, medium and many detail images (as shown in Figure III) is given in Table III, which shows that the proposed method is more accurate than the other two methods in rectify the geometric distortion of images.

TABLE II. RECTIFICATION DEVIATIONS OF DIFFERENT METHODS

Platform	***Average deviation***	***Mean square deviation***	***Running time(s)***
I5-6500	0.03	0.10	22.37
GTX1060	0.03	0.10	0.78
TITAN V	0.03	0.10	0.73

TABLE III. PSNR BY DIFFERENT RECTIFY METHODS

Rectification method	***Few Features***	***Medium Features***	***Many Features***
No rectification	23.90	21.83	12.29
Global rectification method	29.67	27.01	26.47
Local rectification method	32.96	30.99	29.67
The proposed method	34.95	33.15	31.34


(A)


(B)


(C)

FIGURE III. INPUT IMAGES WITH DIFFERENT DETAIL FEATURES: (A) FEW FEATURES (B) MEDIUM FEATURES (C) MANY FEATURES

V. CONCLUSION

Aiming at the geometric distortion caused by camera in large-size and high-resolution LCD measurement system, this paper presents a global parameter guided camera geometric distortion rectification method. The comparative experiments show that the geometric distortion of the image can be relatively rectified by the proposed method. The measurement accuracy can reach sub-pixel level with less time, which can meet the requirements of LCD inspection, quality assessment, de-Mura and so on.

ACKNOWLEDGMENT

This work was supported by the Science and Technology Project of Guangdong (2016B090918084), and the Science and Technology Project of Shenzhen (JCY2017030215011535).

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