Research on Camera Calibration method Based on Eight Parameter Model

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Abstract

Camera calibration is the basis for realization of image distortion correction. Because the causes of image distortion are very complex, it has become a difficulty to correct image distortion with calibration results. In order to reduce the complexity of the existing distortion correction method, an eight parameters camera calibration model was proposed in this paper. In this model, eight parameters were used in describing radial distortion and tangential distortion. The experimental results show that the proposed method can be easily solved and correct distortion accurately.

Keywords: Image distortion, Camera calibration, eight-parameters model, radial distortion

1. Introduction

Image distortion correction is a key technology in the field of computer [1]. Because of the influence of lens manufacturing precision, the image of the computer vision system would appear different degrees of distortion, the distortion can be divide into radial distortion and tangential distortion [2]. If we don't need too high precision, and because of the influence of tangential distortion is far less than the radial distortion, so We can only consider the radial distortion [3-5]. The influence of tangential distortion is often ignored for another reason, a correction model with radial distortion is a fifth-order polynomial, and it is difficulty in obtaining its iterative solution [6].

So we put forward a kind of implicit image distortion method. The method is that we can use an implicit distortion correction model to take place of the traditional fifth-order polynomial correction model, in the same way, we use the correction factor λ_n ($1 \leq n \leq 8$) with no any physical meaning to take the place of radial distortion coefficient (k_1, k_2) and tangential distortion coefficient (p_1, p_2). then the implicit parameter of model could be achieved by the least square method.

2. Explicit Correction of Image Distortion

Assuming that (u', v') is the ideal coordinates of pixels, (u, v) is the image pixel coordinate with radial distortion and tangential distortion. The following two relationships:

$$\begin{aligned} u &= k_u (k_2 u'^5 + 2k_2 u'^3 v'^2 + k_2 u' v'^4 + k_1 u'^3 \\ &\quad + k_1 u' v'^2 + 3p_2 u'^2 + 2p_1 u' v' + p_2 v'^2 + u') + u_0 \\ v &= k_v (k_2 u'^4 v' + 2k_2 u'^2 v'^3 + k_2 v'^5 + k_1 u'^2 v' \\ &\quad + k_1 v'^3 + p_1 u'^2 + 2p_2 u' v' + 3p_1 v'^2 + v') + v_0 \end{aligned} \quad (1)$$

In the formula, k_u is the level pixel unit of image, k_v is the vertical pixel unit of image, obtained by camera calibration. k_1 and k_2 are the radial distortion coefficient; p_1 and p_2 are the tangential distortion coefficient.

Formula (1) is a classic one of the explicit correction model, it is a fifth-order polynomial, including k_1, k_2, p_1 and p_2 . It isn't difficult that we use the calibration data from the formula (1) to obtain k_1, k_2, p_1 and p_2 , but even if we know what is the value of k_1, k_2, p_1 and p_2 , a distortion of the pixel coordinates (u, v) restore the true pixel coordinates (u', v') is a very difficult work in the whole image plane. And the method of literature reference is also very little at the present. Wei [6] had put forward a method to solve this problem, finally the method didn't get the promotion because of poor precision.

Therefore, the researchers consider correcting the image distortion by the implicit parameter model with no any physical meaning.

3. Implicit Correction of Image Distortion

Implicit correction, that is, the building of distortion correction model doesn't use the distortion factor of radial distortion and tangential distortion, but will use some correction factor with no any physical meaning to realize the purpose of simplified correction algorithm. Wei and Ma [6] proposed the implicit calibration method is one of representative.

3.1 Implicit Correction Methods of Wei and Ma

The literature proposed implicit calibration model is as follows:

$$\begin{aligned} u' &= \frac{\sum_{0 \leq j+k \leq N} \lambda_{jk}^{(1)} u^j v^k}{\sum_{0 \leq j+k \leq N} \lambda_{jk}^{(3)} u^j v^k} \\ v' &= \frac{\sum_{0 \leq j+k \leq N} \lambda_{jk}^{(2)} u^j v^k}{\sum_{0 \leq j+k \leq N} \lambda_{jk}^{(3)} u^j v^k} \end{aligned} \quad (2)$$

In the formula, $N = 3$, $\{\lambda_{jk}^{(n)}\}$ is the implicit calibration factor with no any physical meaning. After camera calibration, we can use the internal reference of video camera to get $\{\lambda_{jk}^{(n)}\}$, then a distortion of the pixel coordinates (u, v) restore the true pixel coordinates (u', v') becomes a simple work. The reason is that we already know (u, v) and $\{\lambda_{jk}^{(n)}\}$.

It can be seen from the formula (2), the literature could only use a cubic polynomial distortion correction model to get the value of $\{\lambda_{jk}^{(n)}\}$, so its precision is not high.

Therefore, we would try to use the fifth-order polynomial model of formula (1) in literature [6] to improve the correction accuracy (in the formula (2), $N = 5$). But now, there are as many as sixty-three parameters in $\{\lambda_{jk}^{(n)}\}$, using the results of the calibration are difficult to calculate the complete $\{\lambda_{jk}^{(n)}\}$. In order to solve this problem, we put forward a kind of implicit 8 parameter implicit calibration model.

3.2 A Model of 8 Parameter Implicit Calibration

This new implicit calibration model is as follows:

$$\begin{bmatrix} u' \\ v' \end{bmatrix} = \begin{bmatrix} \frac{u + u(\lambda_1 r^2 + \lambda_2 r^4) + 2\lambda_3 uv + \lambda_4(r^2 + 2u^2)}{H} \\ \frac{v + v(\lambda_1 r^2 + \lambda_2 r^4) + \lambda_3(r^2 + 2u^2) + 2\lambda_4 uv}{H} \end{bmatrix} \quad (3)$$

In the formula, $H = (\lambda_5 r^2 + \lambda_6 u + \lambda_7 v + \lambda_8) r^2 + 1$,

$r^2 = u^2 + v^2$. $\lambda_n (1 \leq n \leq 8)$ doesn't have any physical meaning in this model, but λ_1 、 λ_2 、 λ_3 、 λ_4 and k_1 、 k_2 、 p_1 、 p_2 approximate into corresponding relation, and we can achieve radial and tangential distortion of image correction at the same time.

It isn't hard to see, this model is compared with model in literature [6], the number of implicit correction factor is only eight, the difficulty is reduced greatly if we use the least square method to work out.

After 8 parameters implicit calibration model was established, you can use this model to correct the distortion of image.

3.3 Method of 8 Parameter Implicit Calibration

Assumption, we extract n points from the camera, and measure that the image coordinates value are $(u_i, v_i) (1 \leq i \leq N)$. After calibration, we could use the back calculation of interior and exterior parameters to calculate the value of image coordinates is $(u'_i, v'_i) (1 \leq i \leq N)$. We are given three vector U_i 、 V_i 、 T as follows:

$$U_i = \begin{bmatrix} -u_i r_i^2 \\ -u_i r_i^4 \\ -2u_i v_i \\ -(r_i^2 + 2u_i^2) \\ u'_i r_i^4 \\ u'_i u_i r_i^2 \\ u'_i v_i r_i^2 \\ u'_i r_i^2 \end{bmatrix} \quad V_i = \begin{bmatrix} -v_i r_i^2 \\ -v_i r_i^4 \\ -(r_i^2 + 2v_i^2) \\ -2u_i v_i \\ v'_i r_i^4 \\ v'_i u_i r_i^2 \\ v'_i v_i r_i^2 \\ v'_i r_i^2 \end{bmatrix} \quad (4)$$

$$T = [U_1, V_1, \dots, U_i, V_i, \dots, U_N, V_N]^T \quad (5)$$

In the formula (4), $r_i^2 = u_i^2 + v_i^2$.

Assumption, the vector P is made up of 8 correction factor vector, the following formula:

$$P = [\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, \lambda_6, \lambda_7, \lambda_8]^T \quad (6)$$

Assumption, the vector e as follows:

$$e = [u_1 - u'_1, v_1 - v'_1, \dots, u_N - u'_N, v_N - v'_N]^T \quad (7)$$

According to the formula (3), the vector e 、 T 、 P should satisfy the following relations :

$$e = TP \quad (8)$$

Finally, we use the least square method to get the vector P :

$$P = (T^T T)^{-1} T^T e \quad (9)$$

In other words, we know that the vector P also know the eight implicit calibration $\lambda_n (1 \leq n \leq 8)$ of formula (3).

Then we use model of formula (3) to achieve it, namely the distortion correction is that a distortion of the pixel coordinates (u, v) restore the true pixel coordinates (u', v') in the whole image.

4. Implicit Correction of Image Distortion

In order to verify the validity of the algorithm in this paper, we select 20 images of literature (8) to process camera calibration and image distortion correction experiment.

a) Distorted image.

b) Corrected image.

Figure 1. Experimental Results

The main body of camera calibration experiments is Zhang Zhengyou calibration method, image distortion correction experiments adopt 8 parameter implicit calibration method. All twenty images for the correction, in order to compare the difference between

the front and back distortion correction more intuitively, so we give the following images, the figure 1 is image before correcting distortion, the figure 1(b) is image after correcting distortion.

The figure 2(a) shows the influence of radial distortion, and the influence of tangential distortion is shown in figure 2(b).

Figure 2. Radial Distortion and Tangential Distortion

We can see from figure 4 and figure 5, the influence of radial distortion in the image edges reach twenty-five pixels, but the tangential distortion most affect three pixels, so the influence of radial distortion is bigger on the PC of Pentium 1.7G and in the Matlab environment, the whole process of the correcting distortion takes 0.5 seconds, and after correction, the errors of horizontal and vertical coordinates are 0.11 and 0.09 pixel unit.

5. Conclusion

In this paper, we analyze the formation of image distortion, in order to correct the image of the radial and tangential distortion at the same time, this paper proposes a new method of 8 parameters implicit calibration. The method is compared with the method of Wei and Ma, solving process is greatly simplified. The experimental results show that the proposed method performs fast and has high precision, can effectively eliminate the influence of the radial and tangential distortion image.

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