A New Approach for Nonlinear Distortion Correction in Computer Vision Images

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Abstract

The nonlinear distortion is the crucial problem that affects the procession of computer vision images. In this paper, the mathematics model of nonlinear distortion is established. After combining the merits of standard straight-line method and camera calibration method, a new way to computing nonlinear distortion coefficient is put forward. And also, a new nonlinear distortion correction approach based on the concentric circle principle is brought forward. In testing the proposed methods, satisfactory results are achieved in real data experiments.

Keywords: nonlinear distortion, distortion model, distortion coefficient, correction and computer vision.

1. Introduction

The main information carrier of computer vision is the image, so the quality of image has direct influence on the process effect of computer vision images. There are two factors leading to this. One is the clarity degree of image, which has influence on gray scale or color of image. The other is nonlinear distortion of image. The main factor that affects computer vision process (such as image recognition, 3D reconstruction and visual inspection etc.) is nonlinear distortion. Much work has been conducted in this area [1-3]. However, most of the existing methods require either complicated modeling and computing or less of accuracy, which causes difficulties in practical use. To overcome these limitations, a new nonlinear distortion correction approach is presented. It includes a new way to computing nonlinear distortion coefficient and a concentric circle method that is used to correct nonlinear distortion along radial direction in image. Compare with traditional methods, this new approach not only simplify the correction computation but also improve the correction accuracy.

This paper is structured as follows. Section 2 deals with nonlinear distortion modeling. Section 3 describes the principle of correction approach. Then, a new way to computing nonlinear distortion coefficient, a gray scale interpolation method used for processing empty pixel and the description of whole approach are presented in section 4. Finally, a testing experiment is carried out, and some results are obtained.

2. Nonlinear distortion modeling

The nonlinear distortion actually is the error between real pixel point and theoretical pixel point, so this distortion error can be divided into radial distortion, decentering distortion and thin prism distortion according to their future.

The radial distortion can be modeled by equations (1), which consider only k_1 the first term of the radial distortion series. It has been proven that the first term of this series is sufficient to model the radial distortion in most of the applications [4]. In equation (1), superscript c denotes camera coordinate system; subscript d denotes distortion point.

$$\begin{aligned} \delta_{xr} &= k_1 {}^{C}X_d ({}^{C}X_d^2 + {}^{C}Y_d^2) \\ \delta_{yr} &= k_1 {}^{C}Y_d ({}^{C}X_d^2 + {}^{C}Y_d^2) \end{aligned} \tag{1}$$

The decentering distortion is due to the fact that the optical center of the lens is not correctly aligned with the center of the camera [5]. This type of distortion introduces a radial and tangential distortion [6], which can be described by the following equations,

$$\begin{aligned} \delta_{xd} &= p_1 (3{}^{C}X_d^2 + {}^{C}Y_d^2) + 2p_2 {}^{C}X_d {}^{C}Y_d \\ \delta_{yd} &= 2p_1 {}^{C}X_d {}^{C}Y_d + p_2 ({}^{C}X_d^2 + 3{}^{C}Y_d^2) \end{aligned} \tag{2}$$

The thin prism distortion arises from imperfection in lens design and manufacturing as well as camera assembly. This type of distortion can be modeled by adding a thin prism to the optic system, causing radial and tangential distortions [5]. This distortion is modeled by,

$$\delta_{xp} = s_1 ({}^{C}X_d^2 + {}^{C}Y_d^2) \quad \delta_{yp} = s_2 ({}^{C}X_d^2 + {}^{C}Y_d^2) \tag{3}$$

The total distortion will be the sum of these three distortions. Equations (4) transform the undistorted point ${}^{C}p_u$ to the distorted point ${}^{C}p_d$, where δ_x and δ_y represent the total distortion involved.

$${}^{C}X_u = {}^{C}X_d + \delta_x \qquad {}^{C}Y_u = {}^{C}Y_d + \delta_y \tag{4}$$

Usually, tangential distortion can be reduced by adopting high quality camera and lens, which has been proved by test experiments. In addition, for most application, the accuracy obtained by only considering radial distortion is sufficient. At the same time, with the increasing of model complexity, the correction algorithm will become less stability, and new error will be introduced. Therefore, radial distortion will be paid more attentions in our approach, that is,

$$\delta_x = \delta_{xr} \qquad \delta_y = \delta_{yr} \tag{5}$$

3. Principle of correction approach

The effect of radial distortion is the radial displacement of image point in distortion, not the tangential displacement of it. The main reason for this distortion is flawed radial curvature of lens. There are two trends of radial distortion: one is the distortion of image point deviating from the center, so that the rectangle frame is saddle-shaped; the other is the distortion of image point gathering towards the center, so that the rectangle frame is drum-shaped [7], as shown in Fig.1.

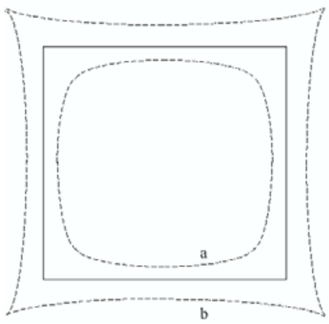

Fig. 1: radial distortion effect (a: negative, b: positive)

Perspective projection has one important feature, that is, the straight line in three-dimensional space still has the quality of being straight after it turned into two-dimensional picture by perspective projection. Among all the images that are non-linearly distorted, the radial straight line from light center stays straight both before and after the distortion, which shows all non-radial straight lines will be distorted. The optical lens in capturing images is centrosymmetric in theory. The nonlinear distortion of image also has the centrosymmetric feature [7]. Therefore, under the condition of ignoring tangential distortion, the circle with light center (that is also the center of image) as the center of circle will keep the circular shape both before and after the distortion, only the radius changes. This conclusion can also be proven by equation (1). Based on this principle, move these points at same circle (its center is the light center) a distance towards the reverse direction of radial distortion, and they will come back to the position that they ought to be. This is also shown in fig. 2.

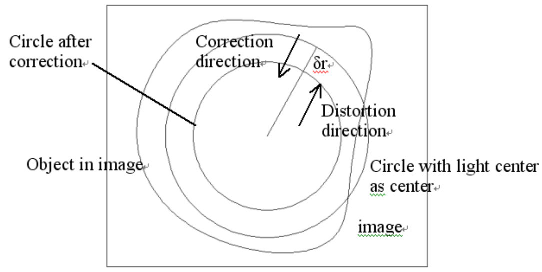

Fig. 2: Illustration of correction principle

When there is positive radial distortion, the empty pixel points will appear after applying nonlinear distortion correction to distorted image. In order to keep continuity of image feature after correction, a gray scale interpolation must be applied to these empty pixel points.

4. Description of correction approach

Nonlinear distortion correction of image includes two respects: one is some movements of pixel point position, which must accord with the model of nonlinear distortion and keep gray scale value of pixel point not changing at the same time. It is also called as geometry correction of nonlinear distortion. The other is about applying gray scale interpolation to empty pixel.

4.1. Nonlinear distortion coefficient computing

In order to apply geometry correction to nonlinear distortion, some relevant parameters, such as nonlinear distortion coefficient, must be given at first. At present, there are two methods used for computing nonlinear distortion coefficient. One is camera calibration method; the other is standard straight-line method. These two kinds of methods both have their own advantages and weak point, the calculating course of former is complicated, but the precision is relatively high, the solution of latter is easy, but the precision is relatively low. By combining the merits of this two methods, a new method for nonlinear distortion coefficient computing is put forward, that is, the approximation of nonlinear distortion coefficient is worked out by using standard straight-line method firstly, and then, bring it into the camera model with non-linear distortion, utilize the nonlinear camera calibration method to optimize the approximation, and get the exact value of distortion coefficient.

Fig. 3 shows the relative position relation between the pinhole projection and real camera projection of standard straight-line in nonlinear distorted image. By comparing pinhole projection with real camera projection, the approximation of radial distortion, δ_{xr} and δ_{yr}, which is related to some points on standard straight-line, can be measured out; and then, by using equation (1), the approximation of nonlinear distortion coefficient k_1 can be obtained; at last, calculate out the average of k_1, and input it into nonlinear camera calibration model, acting as the initial value of iteration optimizing computation.

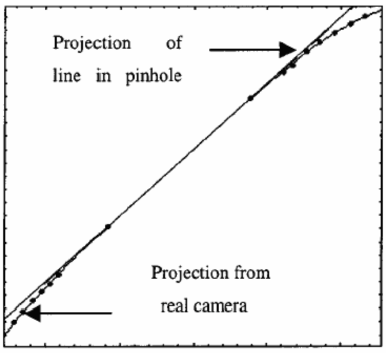

Fig. 3: Pinhole projection and real camera projection of standard straight-line

Equation (6) describes the camera model including nonlinear distortion [8]. In equation (6), superscript *C* denotes camera coordinate system; superscript *W* denotes world coordinate system; subscript *d* denotes distortion point; subscript *w* denotes real points in world coordinate system.

$$
\begin{aligned}
{}^{C}X_d + {}^{C}X_d k_1 r^2 &= f\,\frac{r_{11}\,{}^{W}X_w + r_{12}\,{}^{W}Y_w + r_{13}\,{}^{W}Z_w + t_x}{r_{31}\,{}^{W}X_w + r_{32}\,{}^{W}Y_w + r_{33}\,{}^{W}Z_w + t_z} \\
{}^{C}Y_d + {}^{C}Y_d k_1 r^2 &= f\,\frac{r_{21}\,{}^{W}X_w + r_{22}\,{}^{W}Y_w + r_{23}\,{}^{W}Z_w + t_y}{r_{31}\,{}^{W}X_w + r_{32}\,{}^{W}Y_w + r_{33}\,{}^{W}Z_w + t_z} \qquad (6) \\
r &= \sqrt{{}^{C}X_d^{\,2} + {}^{C}Y_d^{\,2}}
\end{aligned}
$$

Here, r_{ij} is the element of rotation matrix ${}^{C}R_W$, i=1,2,3, j=1,2,3, and t_x, t_y and t_z is the element of translation vector ${}^{C}T_W$, that is,

$$
{}^{C}R_W = \begin{pmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{pmatrix} \quad {}^{C}T_W = \begin{pmatrix} t_x \\ t_y \\ t_z \end{pmatrix} \qquad (7)
$$

The entire computing process of nonlinear distortion coefficient is explained in Figure 4.

4.2. Gray scale interpolation to empty pixel point

In order to keep continuity of image feature after correction, a gray scale interpolation must be applied to these empty pixel points. Utilizing gray scale value of these points around empty pixel point, the gray scale value of empty pixel can be obtained by adopting linear inner interpolation, and the empty pixel will be well jointed to neighboring pixels [7]. Denotes (x,y) as the coordinate of empty pixel, denotes (0,0), (0,1), (1,0) and (1,1) as the coordinates of four pixels around empty one, their gray scale value are f(0,0), f(0,1), f(1,0) and f(1,1); and the interpolation course can be described by equation (8) and Fig. 5.

$$
\begin{aligned}
f(x,y) &= [f(1,0) - f(0,0)]x + [f(0,1) - f(0,0)]y \\
&\quad + [f(1,1) + f(0,0) - f(1,0) - f(0,1)]xy + f(0,0)
\end{aligned} \qquad (8)
$$

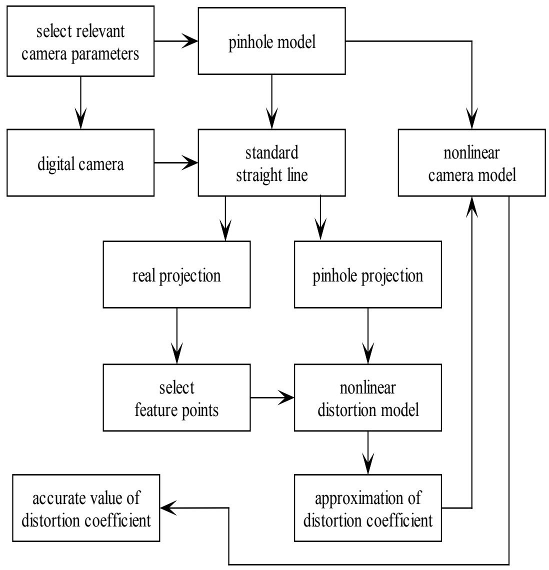

Fig. 4: Flowchart of computing process of nonlinear distortion coefficient

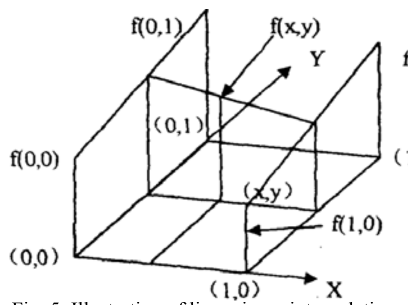

Fig. 5: Illustration of linear inner interpolation

4.3. Flowchart of whole correction approach

After completing calculation of nonlinear distortion coefficient and confirming gray scale interpolation method of empty pixel points, the correction process is carried out. The flow chart of the whole course is shown in Fig. 6.

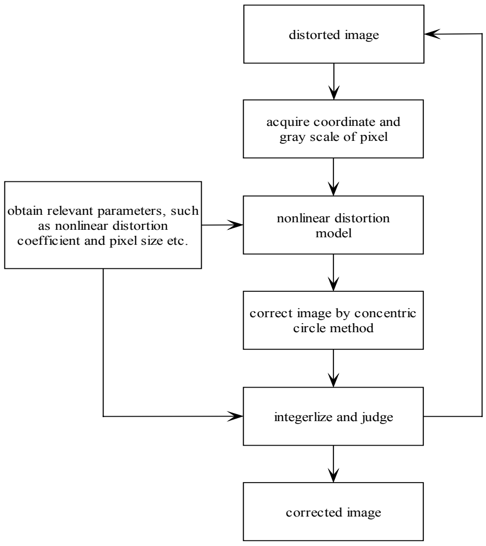

Fig. 6: Flowchart of whole approach

5. Experiment results

In experiment, two-dimension barcode that was captured by digital camera is chosen as testing image. The experiment result is shown in Fig. 7.

(a) Distorted barcode image

(b) Corrected barcode image

Fig. 7: Image before and after correction

6. Conclusion

There are some nonlinear distortions in testing image before correction, which can be seen in Fig.7a. After correction, these distortions are corrected, as shown in Fig.7b, and satisfactory distortion correction result is achieved. But there is still something unsatisfactory in the process of empty pixels, the gray scale interpolation course should be improved in future work.

7. Acknowldgment

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8. References

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