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Automatic Estimation of Spatially Varying Focal Length for Correcting Distortion in Fisheye Lens Images

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** Regular Paper*

***Abstract*:** This paper presents an automatic focal length estimation method to correct the fisheye lens distortion in a spatially adaptive manner. The proposed method estimates the focal length of the fisheye lens by generating two reference focal lengths. The distorted fisheye lens image is finally corrected using the orthographic projection model. The experimental results showed that the proposed focal length estimation method is more accurate than existing methods in terms of the loss rate.

***Keywords*:** Fisheye lens distortion correction, Focal length estimation

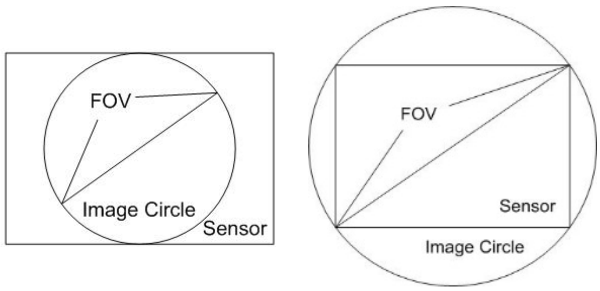
1. Introduction

Wide-angle lenses play important roles in modern computer vision-based imaging systems, such as vehicle rear view cameras and intelligent surveillance systems. Because a fisheye lens, which is the most popular wide-angle lens, inherently generates geometric distortion in the radial direction, an appropriate correction method is needed in the pre-processing step for fisheye lens imaging systems [1].

Fisheye lens images can be categorized by the ratio of the diameter of a circle inside or enclosing the image and the sensor format. Fig. 1 shows the two different types of fisheye lens [2].

Existing methods to correct fisheye lens distortion use either special patterns or distortion models. Pattern-based methods establish the relationship between a pair of distorted and undistorted points using a polynomial equation. The correction step is performed using that relationship. Fig. 2 shows an ideal pattern image, the distorted pattern image, and the distortion rate curve versus R_U, which represents the distance from the center of the image to the undistorted pixel point. R_D is the distance from the center of the image to the distorted pixel point.

The advantages of pattern-based methods are the high accuracy of correction and the wide field of view (FOV). On the other hand, inaccurately detected point pairs can reduce the reliability.



(a) Circular fisheye (b) Diagonal fisheye

Fig. 1. Two types of fisheye lens images.

Existing geometric models rely on a number of different projections including stereographic, equidistance, equisolid angle, and orthographic projection. In these geometric models, a user manually specifies the focal length prior to the correction. This process repeats until the desired result is obtained. This method, however, is inefficient, and its optimality is not guaranteed. Furthermore, the FOV should be limited by 180° because the perspective projection uses the trigonometric function [1, 2, 5].

This paper presents a novel fisheye lens distortion correction method using a spatially-adaptive focal length estimation. The proposed method calculated two reference

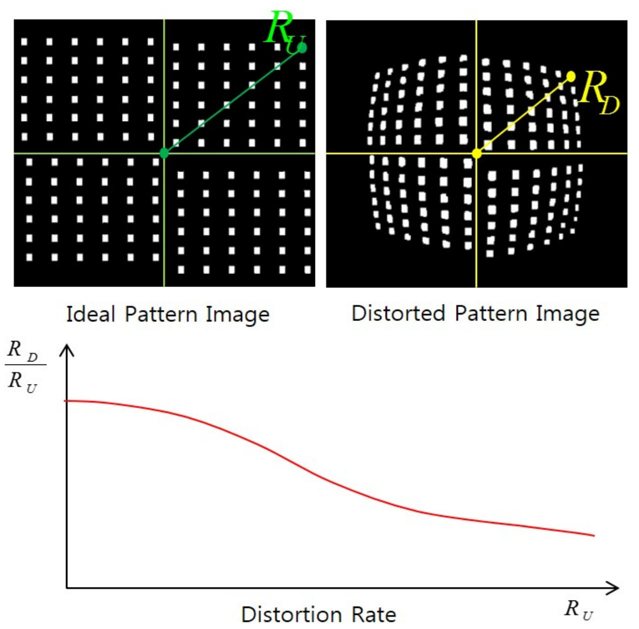


Fig. 2. Relationship between a pair of distorted and undistorted points (top) and the corresponding distortion rate (bottom).

focal lengths, and then divides the corrected crop image of the input image to 10 radially symmetric regions with different distances from the center of the image, called fields. Finally, the focal length of each field is estimated using the pre-determined reference focal lengths.

Fig. 3 shows a block diagram of the proposed algorithm.

2. Focal Length Estimation for Distortion Correction

For a fully automatic correction of the fisheye lens distortion, an orthographic projection based method was used to determine the focal length. As shown in Fig. 4(a), it was assumed that the incident ray to the lens center O from object A in the scene meets the lens surface at point P, and the orthogonal projection of P meets the image sensor at P'. If the image sensor is located at the top of the spherical lens, the distorted and undistorted points in the image sensor are found at R_D and R_U, respectively, as shown in Fig. 4(b).

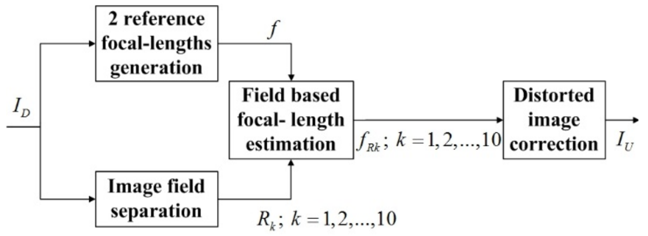


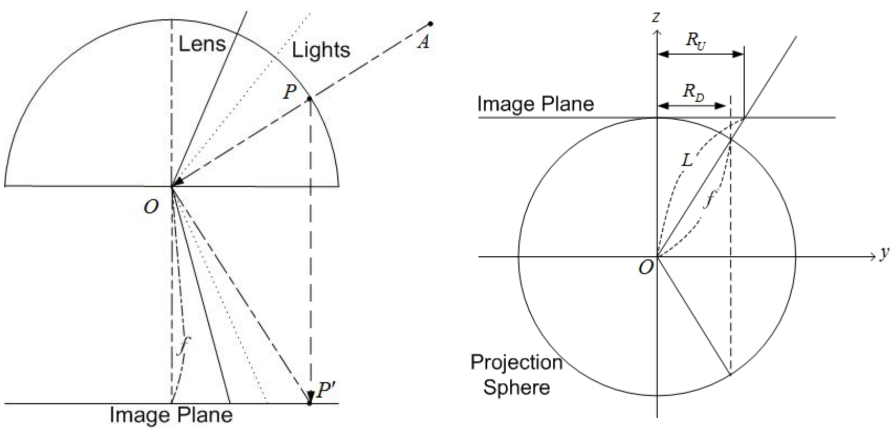
Fig. 3. Block diagram of the proposed fisheye lens distortion correction algorithm.

2.1 Focal Length Estimation Using Two References

Three temporary reference angles were calculated; i) angle of the inner circle, ii) angle of the outer circle, and iii) angle of view, as shown in Fig. 5. The focal length equation was solved using the relationship among the three angles and the trigonometric ratio. The focal length between the minor axis and viewing angle and the focal length between the major axis and viewing angle can be expressed as

$$f_1 = \frac{(\theta_{view} - \theta_{inner})}{R}, \quad f_2 = \frac{(\theta_{outer} - \theta_{inner})}{R}, \tag{1}$$

where θ_{inner} is the angle of the minor axis of the image, θ_{outer} is the angle of the diagonal direction of the image, and $R = d / \theta_{view}$. The focal length was finally calculated by averaging two reference focal lengths f_1 and f_2 as



(a) (b)

Fig. 4. (a) image formation model of the hemispherical lens, (b) relationship between the distorted and undistorted points via the focal length.

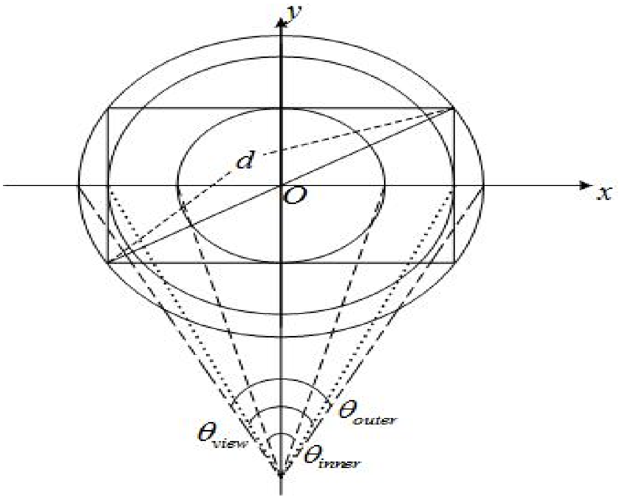
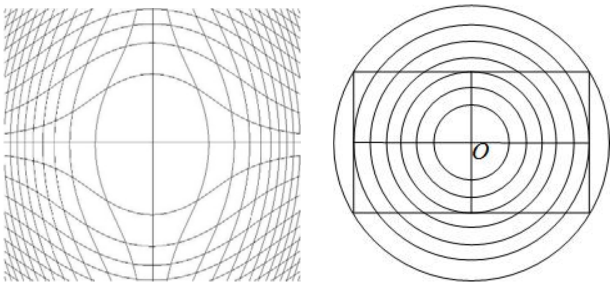


Fig. 5. Two reference focal lengths corresponding to the inner and outer angles.



(a) (b)

Fig. 6. Diagonal distance-based field separation (a) rectangular grid pattern with barrel distortion, (b) Fields of the fisheye lens proportional to the diagonal distance from the center.

$$f = \frac{(f_1 + f_2)}{2} \tag{2}$$

2.2 Diagonal Distance-Based Field Separation

In the fisheye lens image, the amount of distortion of a pixel is proportional to the distance from the center. Therefore, the distance-based field separation is needed for an accurate correction. Fig. 6(a) shows the distorted rectangular grid pattern and Fig. 6(b) shows the separated fields with the cropped imaging region. Fig. 7 shows various sizes of the image [3, 4]. In general, the corrected image is larger than the input image distorted by a wide-angle lens.

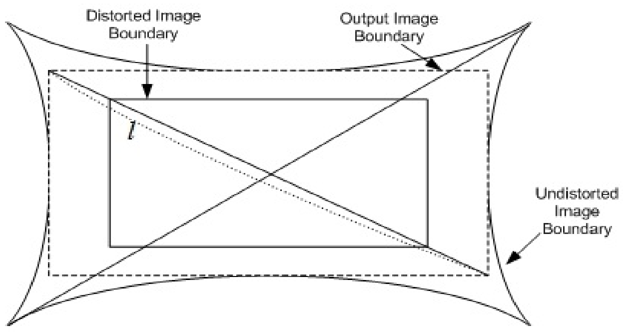


Fig. 7. Image size variation between the distorted and corrected images.

The corrected crop image of input distorted image was divided into 10 fields, each of which can be expressed as

$$R_k = \begin{cases} (0, 2l/10], & k = 1 \\ (kl/10, (k+1)l/10], & k = 2, \ldots, 9 \end{cases}, \tag{3}$$

where k represents the field number, and l is the diagonal distance from the image center. The focal length of the $k-th$ field can be expressed as

$$f_{R1} = f,\ f_{Rk} = f - \alpha(k-1),\ 0<\alpha \le 5, \tag{4}$$

where α is a weighting value. If α is larger than 5, the mismatch between two neighboring regions can become visible. Fig. 8 shows an enlarged part of a set of corrected images using different values of α .

2.3 Correction of the Fisheye Lens Distortion Using the Orthographic Model

The estimated focal length f_{Rk} was applied to the orthographic projection model to correct the distortion.

Fig. 9 shows the trigonometric ratio of between the distorted and corrected point. The ratio equation can be expressed as

$$\frac{R_d}{R_u} = \frac{f}{L}. \tag{5}$$

The ratio equation can be rewritten as

α =1 α =3 α =5 α =6 α =7

Fig. 8. Experimental results using different values of α .

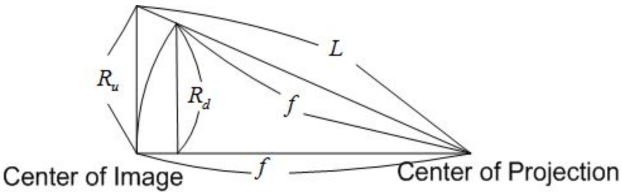


Fig. 9. Geometric relationship between R_d and R_u.

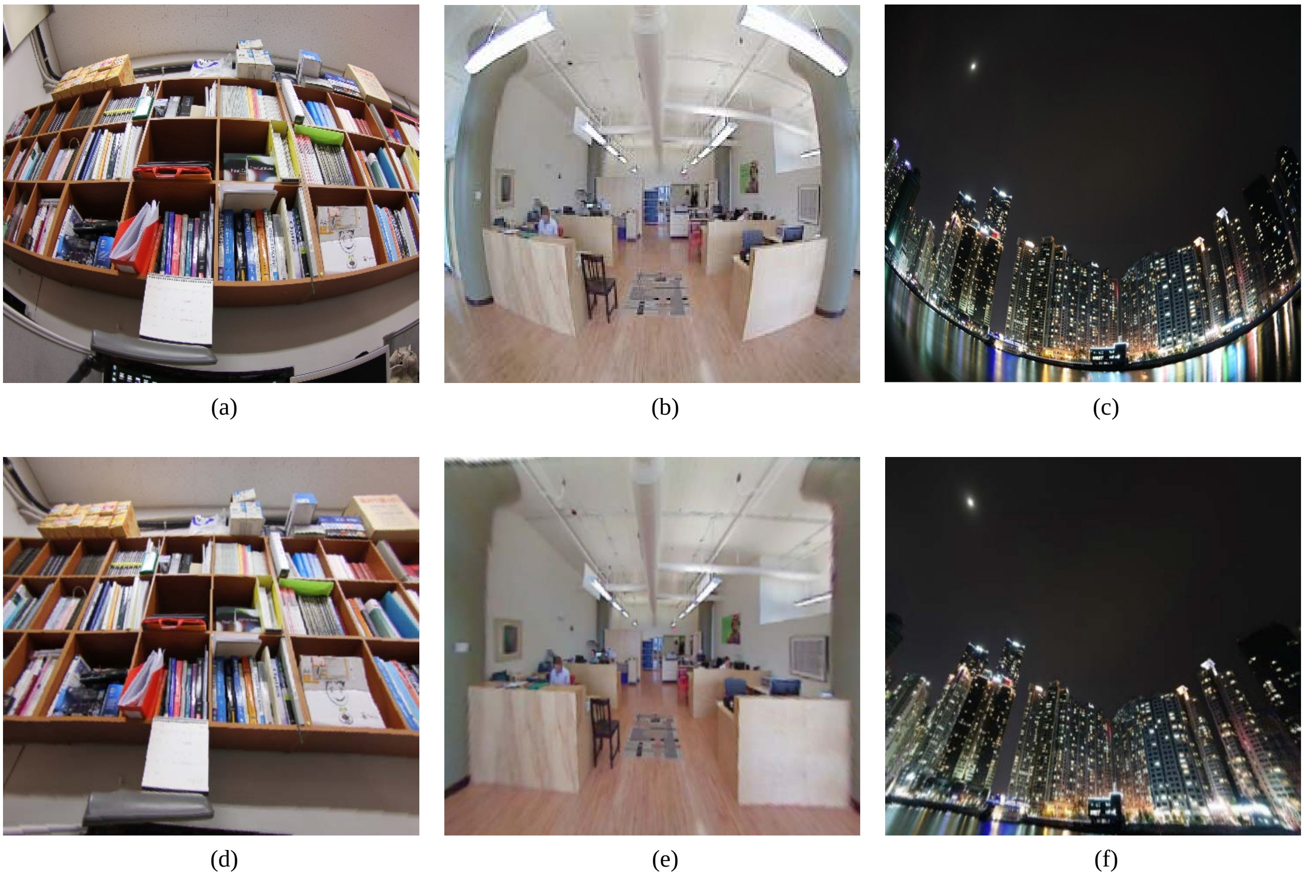


Fig. 10. Experimental results; (a), (b) and (c) are distorted images with FOV 120°, 140° and 180°, respectively. (d), (e) and (f) are resulting images of proposed method with FOV = 120°, 140° and 180°, respectively.

$$R_{dx} = R_{ux} \times \left(f_{Rk} / L \right),\ R_{dy} = R_{uy} \times \left(f_{Rk} / L \right), \qquad (6)$$

where $L = \sqrt{R_{dx}^2 + R_{dy}^2 + {f_{Rk}}^2}$. R_{ux} and R_{uy} represent the horizontal and vertical positions of the corrected pixel coordinates, R_U , respectively.

3. Experimental results

Test images were acquired using a Cannon EOS 550D DSLR camera with a Tokina Fisheye 10-17mm f3.5~4.5 DX Lens, whose FOV is 120°. A 120° distorted image was also made using an optical simulator to evaluate the performance of the proposed correction method.

As shown in Fig. 10, three input distorted images have slightly different levels of distortion. Fig. 10(a) contains major distortion in the horizontal direction, and Fig. 10(d) shows the corrected version. Fig. 10(b) contains major distortion in the vertical direction, and Fig. 10(e) shows the corrected result. Fig. 10(c) contains distortion in both horizontal and vertical directions, and Fig. 10(f) shows the corrected version.

Fig. 11 compares the correction performance of an existing orthographic model-based and the proposed methods. In the left column of Fig. 11, the distorted image (top) has six poles, but the corrected image (middle) using the existing method has only four poles. On the other hand, the corrected image using the proposed method (bottom) has six poles, which shows that the proposed method can provide a wider angle view than the existing method. In the remaining two real images, the proposed method shows a wider angle in the corrected images.

(a)

(b)

(c)

Fig. 11. Experimental result (a) input distorted image, (b) corrected results using the orthographic projection model, corrected results using the proposed method.

4. Conclusion

An automatic field-adaptive focal length estimation method is presented to correct the fisheye lens distorted images. The proposed method divides the corrected crop image of the input image into ten fields, and estimates the focal length to characterize the orthographic projection model. The proposed algorithm can accurately calibrate the distortion made by the wide angle lens, and can be applied to many imaging systems.

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