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Automatic distortion measuring system with reticle positioning for enhanced accuracy

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Abstract

In this paper an automatic measuring system for lens distortion is presented. The system consists of a screen showing reticle-type target moving inward automatically and a camera to capture the image for analysis. The computer plots the center coordinate groups of the cross and obtains the distortion result of the testing camera lens. A new computation method of reticle positioning is used in this research with linear regressions. In the compensation process, we cancel the large deviation points, then transforms the coordinates of the original sampling points from a vertical sampling point group to a horizontal one with a 90° rotation around the original point. The experimental results, including system calibration, alignment calculation, mark locations, and statistical functions of inspection are presented and evaluated. The speed and accuracy of this imaging system are supported by the available experimental observations.

Keywords: Automatic measuring; Lens distortion; Reticle positioning

1. Introduction

Distortion can be classified into "barrel distortion" (also known as negative distortion) and "pincushion distortion" (also known as positive distortion). Suppose the original width of the square is h_0 and it becomes h_0' after distortion, as shown in Fig. 1a, and b. The distortion ratio is defined by the following formula. The standard lens requires a distortion ratio of $\leqq \pm 3\%$.

$$\text{Distortion } (\%) = \frac{|h_0' - h_0|}{h_0} \times 100\% \tag{1}$$

To discuss the distortion produced by a single refracting surface [1], we consider that the object surface is flat and normal to the axis at L (Fig. 2). H is the height of an object on the flat object surface. The image plane is conjugated to L at L' for paraxial rays. H' is the image depicted by the primary ray from H through O to the image screen.

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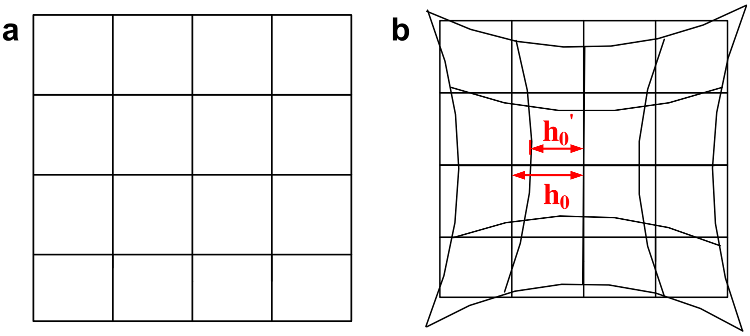

Fig. 1. The definition of distortion.

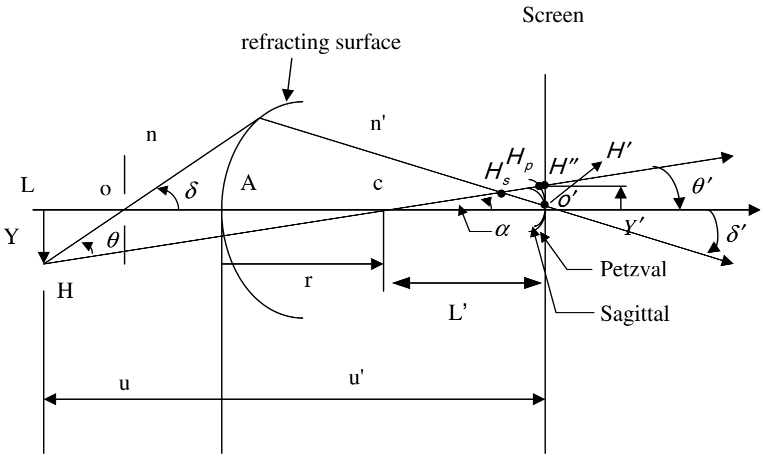

Fig. 2. The distortion of a refracting surface.

The auxiliary axis from H through C penetrates the image screen at H''. If there is no distortion, H' must at the same position with H''. It can be clearly detected when the aperture-stop is placed at the center of curvature, all of the primary rays would pass through the refracting surface normally to the center of curvature. Therefore, we get a perfect projection image from the object. The primary ray from H coincides with the auxiliary axis at H' and also coincides with H''; contrarily, distortion occurs. The amount of distortion is the displacement from H' to H''. The chief ray crosses the auxiliary axis at H_s and H_p, which is the sagital image and Petzval image of each H. The equation for distortion can be derived as

$$\text{Distortion} = \overline{H'H''} = -(\overline{H''H_p} + \overline{H_pH_s})\frac{\sin\theta'}{\cos\delta'} \tag{2}$$

For small angles, the sine is equal to the radian value and the cosine is equal to unity, and Eq. (2) reduces to Eq. (3). The error can be minimized when we select suitable E (distortion coefficient) to calculate the amount of distortion.

$$\text{Distortion} = \overline{H'H''} = -(\overline{H''H_p} + \overline{H_pH_s})\theta' \tag{3}$$

Let n be the index in object-side medium, and n' be the index of image-side medium. The distortion equation can be derived as

$$\text{Distortion} = E(Y')^3 \tag{4}$$

where

$$E = \left(\frac{u'}{u}\right)^2\left(\frac{\overline{CO'}}{\overline{O'L'}\cdot\overline{CL'}}\right)^3\overline{A} - \left(\frac{\overline{CO'}}{\overline{O'L'}\cdot\overline{CL'}}\right)\left(\frac{n'-n}{2nr}\right) \tag{5}$$

r is the equivalent curvature of the lens, E is the distortion coefficient, Y' is the height of image-side ray.

We can infer that distortion increases in proportion to the cube of Y'. But, in the real world the