Automatic inspection system for measurement of lens field curvature by means of computer vision

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This paper proposed an automatic inspection system for field curvature in order to replace the present lens measurement device for curvature of field and manual adjusting of screen distance. The system utilizes a screen equipped with automatic driving system and computer vision technique, along with DLP projection and computer software to capture data from image area by scanning, and then obtains the average and threshold values of its pixels. The analysis is based on 8 adjoining points to conduct contractive algorithm between bright spot and dark spot, and automatically measure the figure projected on a screen and provide real-time measuring results. The drawbacks of traditional manual measurement can be completely avoided by this system. When comparing the measured result with that of the optics emulating software, the accuracy and time effect of this automatic inspection measurement for the lens aberration of field curvature are significant.

Keywords: Automatic inspection system, Curvature of field, Computer vision

1 Introduction

When light penetrates the optical element and focuses, according to different conditions, it will produce different out-of-focus phenomena so that the focal point is no longer merely a point but a round spot producing aberration. There are several kinds of lens aberrations and the types that afflict an imaging system depend entirely on the type of hardware¹. The aberration of an optical system is not only the function of structural parameter, but also the function of object height, field angle, aperture of light beam and angular aperture. In optical design, under certain conditions, the relation between aberration and system structural parameter is expressed by a power series. Aberration with the lowest power is called primary aberration and the aberration with higher power is called higher-order aberration.

The third-order Seidel aberration includes spherical aberration $S_1$, coma $S_2$, astigmatism $S_3$, curvature of field $S_4$ and distortion $S_5$. The automatic measuring system for lens distortion aberration $S_3$ consists of a screen showing reticle-type target moving inwards 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 lens². When a plane is placed in front of the imaging plane to obtain an image, the image may not be always clear when compared to that obtained from curving the plane near the imaging plane to a spherical surface, which is caused by the curvature of field phenomenon. Due to the curvature of field problem, it is normal to see some instamatics with the curvature of field phenomenon. Its negative film is designed to be curly and it can also be seen that some large scale movie screens are designed to be cambered on purpose. The measurement of lens aberration images by taking images using a CCD imaging system has been proposed in the past few years³. In this paper, we propose a modified algorithm that determines the position of a moving reticle-circle-type target on the screen for automatic field curvature measuring system.

The projector was used to project the picture preset through the lens onto the screen, capture picture with CCD and use this system to restrict the limit on the picture, namely the image center (optical axis) and the corner of image (far optical axis). In the automatic inspection system for lens field curvature measurement (Fig. 1), this computation device is used to carry out the following steps:

(1) The computer connected with DLP projects concentric circle of former figure. (2) Adjust the depression angle and elevation angle of DLP and drive the linear automatic slide-rail to bear the translucent screen. The center of the image is at the same point on the screen all the time. (3) Mount the...
lens to be measured, drive the linear automatic slide-rail to bear the translucent screen and image capturing device to move behind lens, reconfirm that the center of figure projected through the lens is located at the same point. (4) Adjust the position of the linear automatic slide-rail, confirm that the image captured by the image capturing device is a clear figure and suitable for analysis. (5) Input the moving range of motor and measuring distance, so as to start carrying out the movement.

When a projector projects the figure to be measured (Fig. 2), it will capture the image information on the screen through CCD and shows the real-time measuring process on the computer. The inspection system is designed to measure the contrast of the image center and the outer ring’s contrast to obtain the field curvature.

2 Algorithm of Image Processing Methods for Lens Field Curvature Measurement

2.1 Lens field curvature

Generally, the high order terms for object height and the aperture of light beam are mostly ignored by optical system’s aberration, which is also the primary approximation of actual aberration. The relations among the curvature of field and object height ($y$) as well as aperture ($h$) are as follows (Fig. 3):

Primary meridian curvature of field:
$$X'_i = a_i y^2$$  

Primary sagittal curvature of field:
$$X'_s = a_s y^2$$

where $a_i$ and $a_s$ are the factors.

From the Seidel theory, we can derive the fourth coefficients in the expansion of the aberration function $\Phi$ for any centered system. The canonical expansion of the fourth-order geometry can be expressed as in the following:

$$\varphi^{(4)} = -\frac{1}{4}Bp^4 - C\kappa^4 - \frac{1}{2}Dr^2p^2 + Er^2\kappa^2 + Fr^2\kappa^2$$  

where $p$, $r$, and $\kappa$ are the related geometric variations. B-, C-, D-, E-, and F-type aberrations are related with the spherical aberration, astigmatism, field curvature, distortion, and coma, respectively. In the absence of astigmatism ($C=0$), the radius of the common focal surface may then be calculated from a simple equation.

2.2 Noise compression technology

Since the actual image captured has uneven optical field phenomenon, during the brightness algorithm, the target zone can be set to grey scale, and the average value of grey scale is taken as the threshold value of grouping, then the pixels is averaged to less than threshold value to obtain $I_d$. Similarly, the pixels can be averaged for the value larger than the threshold value to obtain $I_b$. In Eqs (4) and (5), $I(x,y)$ is the
brightness value in different coordinates, \( m, n \) are the size of calculating area, \( V_b \) is the reference threshold value calculated.

\[
V_b = \frac{1}{mn} \sum_{x=1}^{m} \sum_{y=1}^{n} I(x, y) \quad \ldots(4)
\]

\[
\begin{align*}
I_b &= \frac{1}{ij} \sum_{x=1}^{m} \sum_{y=1}^{n} I(x, y) & \text{if} \quad I(x, y) > V_b + \Delta_1 \\
I_d &= \frac{1}{(n - j)(m - l)} \sum_{x=1}^{m} \sum_{y=1}^{n} I(x, y) & \text{if} \quad I(x, y) > V_b + \Delta_2
\end{align*}
\]

\[
\Delta_1 \quad \text{and} \quad \Delta_2 \quad \text{are constants used for noise filtering.}
\]

In the target zone, the point \( P(x, y) \) is taken as the pixel to scan and 8 adjoining pixels \( K_0-K_7 \) (Fig. 4) are taken into the determinant equation for analysis, in order to compute the number and total point brightness of all core bright spots. Finally, the optimum bright and dark spots are obtained. Here, we use the 8 adjoining points method with two new algorithms to segment bright and dark spots and automatically measure the figure projected on the screen to be measured and draw real-time measuring results.

**Algorithm (I):**

If \((\forall K_g > I_b) \land (P(x, y) > I_b) \land g = 0-7 \quad \ldots(6)\)

Then \(S_b = P(x, y) + S_b, \; l_b = l_b + 1 \quad \ldots(7)\)

\[
I'_b = \frac{S_b}{l_b} \quad \ldots(8)
\]

where \( P(x, y) \) is the center point; \( K_g \) the 8 adjoining points, \( g = 0-7; \; l_b \) the point number of all core bright spots; \( S_b \) the total point brightness of all core bright spots and \( I'_b \) is the grey level of bright spot.

**Algorithm (II):**

If \((\forall K_g < I_b) \land (P(x, y) < I_b) \land g = 0-7 \quad \ldots(9)\)

Then \(S_d = P(x, y) + S_d, \; l_d = l_d + 1 \quad \ldots(10)\)

\[
I'_d = \frac{S_d}{l_d} \quad \ldots(11)
\]

\( K_1, K_2, K_3 \)

\( K_4, P(x, y), K_0 \)

\( K_5, K_6, K_7 \)

\( I_d \) is the point number of all core dark spots; \( S_d \) the total point brightness of all core dark spots; \( I'_d \) is the grey level of dark spot.

Within each range, the pixels of optimum bright and dark spots are analyzed and computed statistically for comparison. The mathematical expressions for the contrast of image center and edge are given by:

\[
C_c = \frac{I'_cb - I'_ed}{I'_cb + I'_ed} \quad \ldots(12)
\]

\[
C_e = \frac{I'_eb - I'_ed}{I'_eb + I'_ed} \quad \ldots(13)
\]

where \( C_c, \; I'_cb, \; I'_cd \) are contrast values between brightness and darkness of image center, grey scales of brightness and grey scales of darkness, respectively. While \( C_e, \; I'_eb, \; I'_ed \) are contrast values between brightness and darkness of edge of image and value of grey scales of optimum brightness and darkness, respectively.

### 3 Experimental Details

We use a DLP projector for projection and a computer to control the CCD and screen on the Servo Slider. For each movement of 0.1 mm, real-time measurement and analysis are conducted on images captured by CCD. The image captured by CCD is the major device for measuring the curvature of field. Because of the distance of curvature of field is in the unit of millimeter, a relative large error occurs if there is a slight movement. Therefore, it is not feasible to move the screen manually to adjust the image distance. A computer, projector, and linear automatic slide-rail were needed in this experiment. Translucent screen, image capturing device and lens module were used to measure the aberration of the lens module.

A Servo Slider-DS-SA5M-150 was used to drive the movement of the screen and it was controlled by the computer. According to the computer data, the moving distance of screen can be affirmed and the CCD video camera was used to affirm the position of images and then captured the picture. Since this motor had no ultimate sensor, it was reset when the skid platform bumps the primary end and the stress is greater than a value for a certain period, which was then considered as an origin point. This model Servo Slider can move a distance of 200 mm forwards and backwards with a precision of ±0.02 mm.

The inspection system for field curvature is divided into three types of measurement. Real-time analysis of the image center and the outer ring’s contrast grade

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**Fig. 4** — Measurement of pixel and its 8 adjoint points
is taken at the real time area. Real-time ordering of image center and outer ring’s contrast grade are taken at the bmax data area and the highest contrastive value and the position of the value passed back by slider are also shown in this area. The real-time record of each contrast grade and its position in the diagram for the analysis of the curvature of field are taken. Horizontal axis is the moving distance of slider; its unit is 0.1 mm. Longitudinal axis is the contrast grade and its unit is per cent. When the contrast grade is larger, the distance between bright and dark pixels is larger; in other words, when the contrast grade is larger, the black and white in the image are clearer and more distinct.

Since visible light has different wavelengths, the positions of field curvature formed by them are different. This study changed the base colour of image in Fig. 5 to three primary colours (red, green, blue), and the analytical diagrams for the field of curvature are shown in Figs 6-8. Among the analytical data for the field of curvature projected with red base, its image center corresponds to the value of the highest position of 15.906 mm, its outer ring corresponds to the highest value’s position of 19.195 mm and the field of curvature value is 3.289 mm. Among the analytical data for the field of curvature projected with green base, its image center corresponds to the position of the highest value of 22.593 mm, its image’s outer ring corresponds to the highest value’s position of 26.085 mm and the field curvature value is 3.492 mm. Among the analytical data for field of curvature projected with blue base, its image center

![Image of inspection system for the curvature of field](image)

Fig. 5 — Inspection system for the curvature of field
corresponds to the highest value’s position of 27.085 mm, its image’s outer ring corresponds to the highest value’s position of 30.195 mm and field of curvature’s value is 3.110 mm.

In order to prove the accuracy of the automatic inspection measurement for the aberration of field curvature proposed by this study, optical simulation software ZEMAX was used for comparative
simulation. Three wavelengths (0.656273 microns (red light), 0.587562 microns (green light) and 0.486133 microns (blue light)) were simulated to obtain the analytical data (Table 1).

Based on comparison with the measurement proposed by this study (Figs 9-11), the differences between the curvature of field produced by the experimental results and theoretical values were all in the reasonable range. Therefore, the measurement and framework proposed in this study can achieve the same practicability and reliability as the simulation software.

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<th>Wavelength</th>
<th>V angle (deg)</th>
<th>Tan shift</th>
<th>Sag shift</th>
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<th>Ref. Height</th>
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<td>-5.46160521</td>
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<td>-5.9252892</td>
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<tr>
<td>0.656273</td>
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<td>-6.49501752</td>
<td>21.68954352</td>
<td>21.68958215</td>
<td>0.017104%</td>
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</tbody>
</table>

Table 1 — Emulating data for the curvature of field layout

Fig. 9 — Field curvature of theoretical value and experimental results produced by blue base pattern

Fig. 10 — Field curvature of theoretical value and experimental results produced by green base pattern
5 Conclusions

This study designed an automatic inspection system for the lens field curvature measurement using Servo Slider with CCD video camera for capturing images continuously. Automatic measurement of computer software was used to find the center point of continuous images, in order to obtain the comparative value of each image within specific range. It can deduce the value of field curvature produced by the image through this lens. The measured results are saved in the table form and stored with the author. This measured data is accurate when compared with the ZEMAX simulation. In addition, a comparison with manual measurement reveals that the automatic method has the advantage of reliability, speed and accuracy.

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References