

## Automatic Evaluation of Lens Decentration\*

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**Abstract:** *A method is described for real-time automatic processing of images obtained from a lens decentration evaluation device. For the initial localization of the centers of the autocollimation blics produced by the upper and bottom lens surfaces the Hough's transform for gray level images is applied. Better center localization is achieved using maximal gradient direction. Lens decentration measurement is based on the radii of the circles described by the centers of the auto collimation crosses.*

**Keywords:** *lens decentration, autocollimation, optical quality assurance, image processing.*

### 1. Introduction

Quality evaluation of optical details is a precise and complicated process, which is usually carried out manually, therefore it is a result of a subjective estimation. There are different techniques for lens centration that differ in accuracy and complexity [4]. The most popular among them are the following: centration using light spot, centration with autocollimator, use of diffraction image and use of interferential image. The best accuracy of 3-5 mm is achieved with the autocollimator's approach. It is used in case of severe requirements for the quality of the lenses. Here the detail's centration is monitored via the image created by the reflection from the upper and bottom surfaces of the lens [1, 4].

The evaluation accuracy and the detail's quality as a result could be improved if the process is automated. This would be possible if the measuring device is coupled with a computer and the obtained images are processed automatically. The present paper is an attempt in this direction.

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## 2. Decentration evaluation device

The device for decentration evaluation based on the autocollimation principle is developed by the firm “Optix – Co” in Panagyurishte (Fig. 1). It consists of an autocollimator, focusing system allowing a reflection to be obtained from both surfaces of the lens, lifting, balancing and clamping mechanisms, motorized vacuum-holder rotation device, CCD camera and a PC.

The device is designed for double purpose operation: centration control of lenses during their blocking to the rods for rounding process, as well as for measurements of a centering errors of ready lenses.

The procedure of identifying the centring errors insist on rotation of the sample in reflected light [1, 4]. The autocollimator with additional optics is focussed to collect the light reflected from the top and bottom surfaces of the lens. The images are observed through the eyepiece of the microscope and registered by a CCD camera. When a centration error is present, both images describe circles while the sample is rotated around a reference or datum axis. The vector difference between the radii of the circles is proportional with the size of the centering errors.

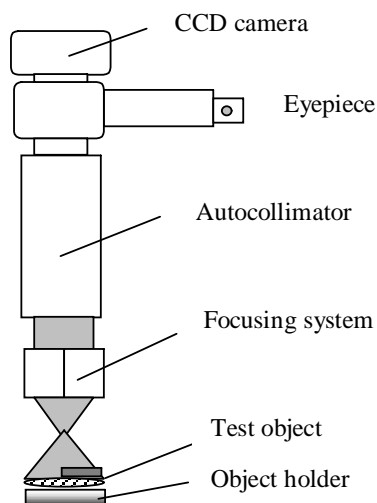


Fig.1. Block-scheme of the centering device

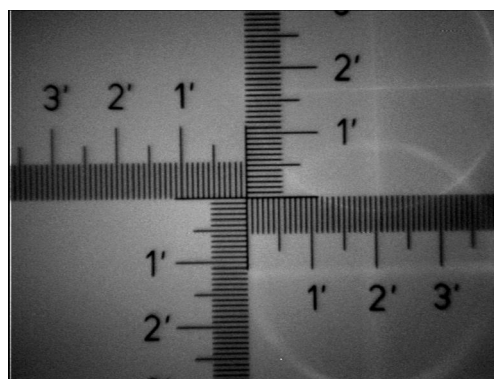


Fig.2. An image of the scale and autocollimation blinks

The initial adjustment of the focus is carried out on the basis of the sharpness of the measuring scale in the monochrome image (Fig. 2). Together with the scale two structures consisting of bright crosses encompassed by a circle that are created by the reflection of the light from lens' surfaces are registered. The illumination of the device field produces irregularities in the image brightness. Also, the image of the upper surface is brighter than the image of the lower surface and creates a diffraction which increases the local brightness. During the adjustment both autocollimation structures describe circles of different radius depending on the accuracy of the current centration

of the lens. Thus, the problem consists in a real-time evaluation of the vector-difference between the corresponding radii during the adjustment process.

### 3. Automatic localization of the autocollimation blics

#### 3.1. Hough approach for cross detection

The Hough's approach allows the detection and parameter evaluation of geometric lines and surfaces provided the coordinates of some points from them are known [2, 3, 7, 8]. In case of straight lines the equation (1) in polar coordinates  $\rho$ ,  $\theta$  (Fig. 3) is used:

$$(1) \quad l: x \cos\theta + y \sin\theta = \rho,$$

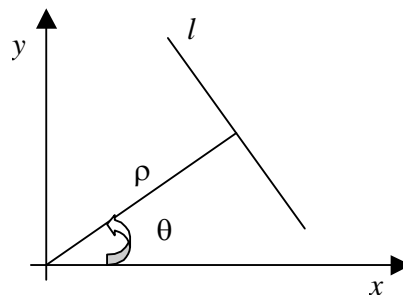


Fig. 3. Polar coordinates of the line  $l$

where  $\rho$  is the distance from the origin of the coordinate system to the line and  $\theta$  is the angle between the vector  $\rho$  and  $x$  axis.

At  $\theta = 90^\circ$ , the equation (1) turns to  $\rho = y$ , therefore the accumulator ( $\rho$ ,  $\theta = 90^\circ$ ) will contain all the pixels with coordinates ( $y = \text{const}$ ,  $0 \leq x < x_{\text{max}}$ ), i.e. the accumulator will contain the integral projection in  $x$  direction<sup>1</sup>.

Similarly at  $\theta = 0^\circ$ , the corresponding accumulators will contain the integral projections in  $y$  direction.

Despite the small difference in the brightness of the cross lines it could be expected that the total sum will be maximal there. An additional advantage of this approach is that the effect of the random noise will be diminished significantly.

#### 3.2. Brightness equalization and scale elimination

Two factors produce a strong negative effect on the integral projections: a) the presence of a measurement scale which may suppress local maximums if the cross lines goes through it, and b) the irregularity of the light source which results in difference of 50-60 gray levels in the brightness in different places of the field (Fig. 4). These factors could be neglected to some extent if an image containing only the scale is subtracted from the image with auto collimation blics. The result from such an operation is shown in Fig. 5. However, this will increase the noise two times but, as mentioned above, this will not affect the position of local maximums. Noise normalization will be of no effect since the signal will be decreased as well.

<sup>1</sup> In case of a half-tone image every pixel contributes to the accumulator with its gray level value.

Fig. 6 shows the integral projection in  $y$  direction for the image from Fig. 5. Thus, accepting that the brightness is equalized and the scale influence is diminished, one could expect that the global maximums in the integral projections will point out at the position of the lines of the brighter cross.

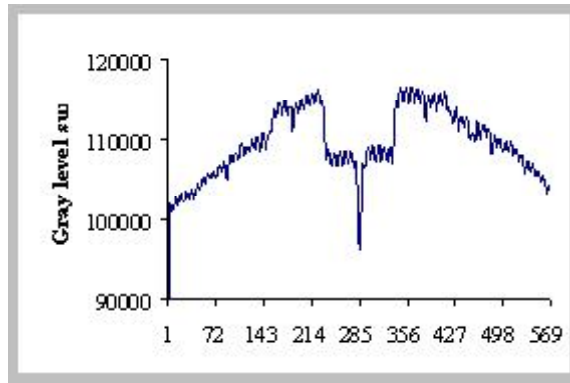


Fig. 4. Horizontal projection from the scale image

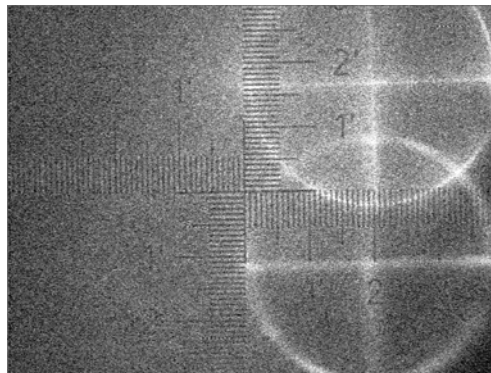


Fig. 5. Subtraction result

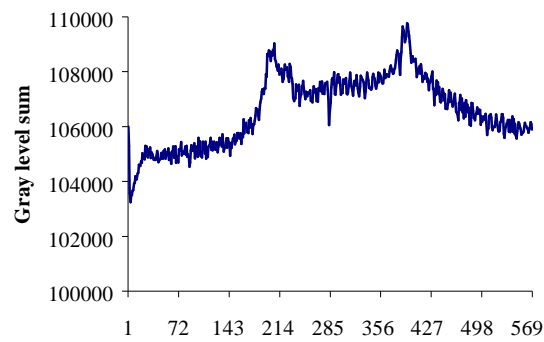


Fig. 6. Horizontal projection from the resulting image

### 3.3. Trend elimination

Fig. 6 of the horizontal projection shows that the brightness increases from left to right. The reason for this is explained in paragraph 2. This tendency may bring to a false maximum especially when the second cross is searched for. To avoid this, the trend must be taken away. Different techniques could be used to solve the problem. The following 2 of them have been tested.

**3.3.1. Linear regression.** The projection is approximated with a straight line  $y = ax + b$ , where the coefficients  $a$  and  $b$  are determined according to the mean square technique. Minimizing the expression:

$$(2) \quad S = \sum_i (y_i - (ax_i + b))^2,$$

the following formulae in  $a$  and  $b$  will be obtained:

$$(3) \quad a = \frac{n(\sum_i x_i y_i) - (\sum_i x_i)(\sum_i y_i)}{n \sum_i x_i^2 - (\sum_i x_i)^2}, \quad b = \frac{\sum_i y_i - a \sum_i x_i}{n},$$

where  $n$  is the number of points.

The result from the subtraction of the straight line from the original projection is shown in Fig. 7. This approach is fast and the result is quite satisfactory. A problem may occur if one or both crosses are close to the image border. Then a decrease in the maximum value may occur due to a significant trend. To avoid this, more flexible correction is required.

**3.3.2. Use of a smoothed curve.** Smoothed curve will be obtained if a Fourier transform is applied [8]. Preserving only a few initial coefficients and subtracting the obtained curve from the original one the trend will be eliminated. The result from this operation is shown in Fig. 8, where the first 5 Fourier coefficients are used. In that case no such significant declination at the ends of the projection line is observed.

Both approaches have been tested and no difference at the obtained results has been observed.

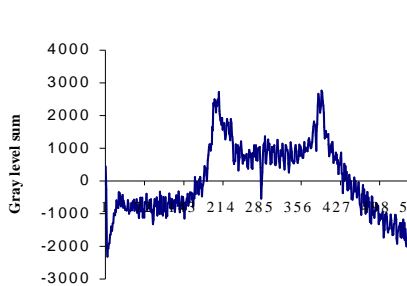


Fig. 7. Correction with a linear regression

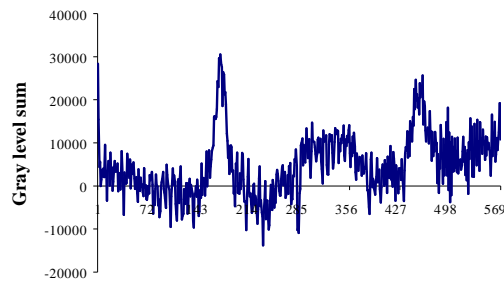


Fig. 8. Correction with Fourier transform

### 3.4. Cross position detection

The maximums in the integral projections will refer to the position of the cross lines in the image. The global maximum usually points out at the first cross, which is brighter. This allows its fast and comparatively reliable localization. Problems with the accuracy may arise when the cross is close to or lies in the scale area where the brightness is low and the actual maximum may be masked. This requires an additional specification of the cross center which could be accomplished in different ways.

**3.4.1. Neighborhood examination.** As mentioned above the integral projections are influenced from the scale on the one hand and from the bright circles around the crosses, on the other hand. This may compromise the maximum's localization. To avoid such a possibility, projections from the near neighborhood of the potential position of the center are investigated. For this the center's coordinates from the previous image and the information about the admissible offset is used<sup>2</sup>. Again the decision is based on the position of the global maximum.

**3.4.2. Locating the circle's center.** It is known [4] that the center of the encompassing circle coincides with the cross center. At this juncture and having in mind that the circle's line is brighter than the cross one we could precise the cross position looking for the position of the corresponding circle of known radius  $R$ . For this the integral brightness  $B$  alongside the circle about a center from the admissible neighborhood is evaluated. The search direction is determined by the maximal value of  $B$ . The procedure is repeated for the new center and continues until no larger  $B$  is found.

Since the scale's area will diminish  $B$  for the pixels that cross it it's recommended to not take them into account. In that case  $B$  must be normalized. Also, such a normalization is required if a part of the circle's line is outside the image.

The second cross is searched for in a similar way. Better results in terms of accuracy will be obtained if the pixels from the first cross and its surrounding circle are neglected during the projection evaluation. Either they may not be taken into account or their actual brightness may be replaced by a neutral value.

## 4. Decentration evaluation

Lens's decentration is evaluated as a difference between the radius-vectors of both crosses from the centers of circles that they follow. When processing manually the difference magnitude is measured according to the scale. In the automatic processing it is based on the length in pixels. In that case a scale in the screen is not required at all.

The major problem for the evaluation of decentration concerns the determination of the circles described by the cross centers. The motion of these centers changes due to the rotation of the lens in different planes at the beginning. Looking at the images on the screen the operator is searching for the plane of the smallest offset. From now on the rotation is in this plane and the cross centers lie on a circle. The problem that must be solved at that point is to find the center and radius of the corresponding circles on the basis of some points from them. However, it must be taken into account that depending on the accuracy of cross position evaluation its center will decline to some degree from the corresponding circle's line. This makes the problem undetermined. To overcome

<sup>2</sup> The operator points out at the cross centers in the first image.

this uncertainty, one may proceed in one of the following ways.

1. A circle is evaluated for every combination of 3 points such that the distance between them is maximal. The mean value of the coordinates of the centers and radii of those circles are taken as a center and radius of the required circle.

2. The average value of the  $n$  cross centers is used as an initial position of the circle. Also, the average value of the distances of the points from this center is used as an initial approximation of the unknown radius. Setting an experiment with these data [6] and varying them with steps  $\Delta x$ ,  $\Delta y$  and  $\Delta r$  respectively, a minimum of the function:

$$(4) \quad Q = \sum_{i=1}^n r(C_i, k(O_p, R_p)),$$

representing the sum of distances between the centers  $C_i$  of the crosses and the circle  $k(O_p, R_p)$  about the point  $O_p$  and radius  $R_p$ , obtained at the  $p$ -th step. Thus, a solution is found corresponding to the least square technique.

## 5. Software system

The described approach for the automation of the process for lens decentration evaluation is realized as a software system written in C/C++ in Windows. The functional block-scheme of the system is shown in Fig. 9. Fig. 10 shows the main window of the system. Some menus include standard functions like Open, Save and like. Some others are used for the equipment adjustment like Adjust, Tools, Test, Service. The buttons on the right side have the following meaning:

Init – loads a reference image of the scale;

Series – a series of images will be measured automatically;

Calibrate – opens a dialog window for series parameters specification. The entered values will be displayed in the upper right corner of the screen;

Save – allows a series of images to be saved;

Go – ends the previous measurement and starts a new one.

In the bottom part of the window the obtained results from the current measurement will be displayed including the radii of the circles described by the crosses, their difference and corresponding decentration.

## 6. Conclusion

The precise optics production implies severe requirements to the quality of optical elements. This means a diminished or even excluded role of the subjective evaluation. The developed approach is a solution to the problem of automated and objective evaluation of the lens quality using the autocollimation principle. The poor quality of the images and their peculiarities need a special attention to be paid to the reliability of the obtained results. The main difficulties stem from the weak difference between the autocollimation blics and background. In some images parts of the cross lines or even an entire line may not be visible. This requires the surrounding circles to be used for the detection. Thus satisfactory results may be obtained.

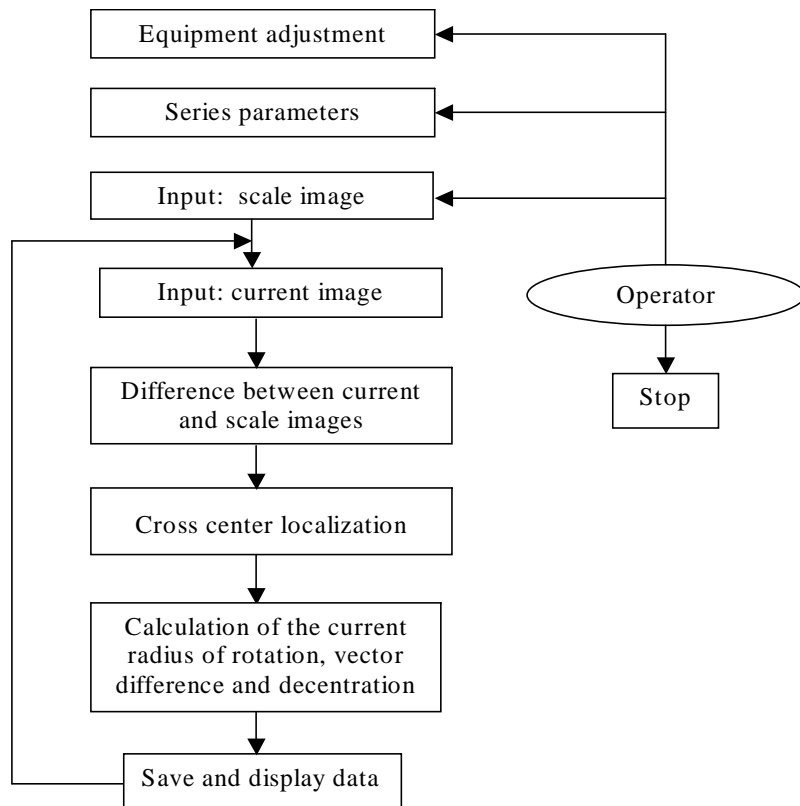


Fig. 9. A functional block-scheme of the system for automated evaluation of lens decentration

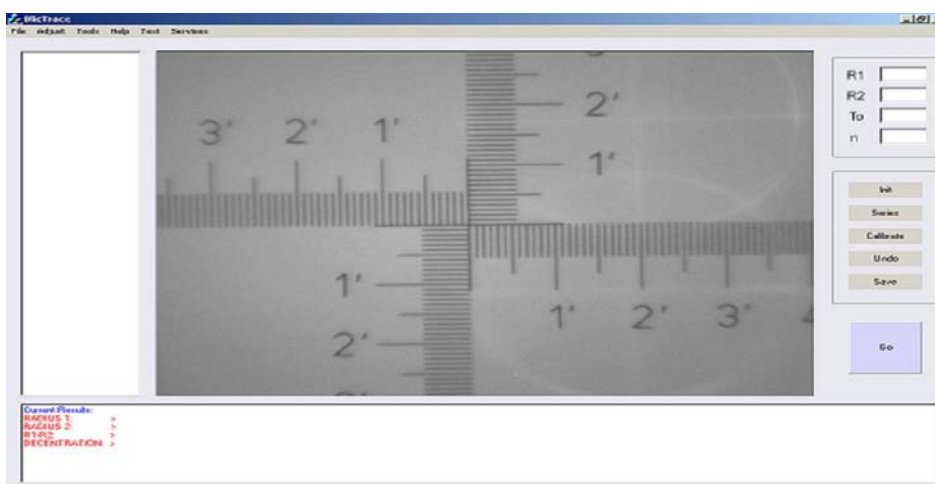


Fig. 10. Main window of the system



Another difficulty concerns the mutual position of the two crosses during the movement. They may overlap partially or entirely which will make them indiscernible. Except the small difference in their brightness it is not known how to distinguish them when both share a common admissible area. Additional investigations are required for the case where the crosses cross the scale's area. The significance of this problem may be diminished provided the scale's size is diminished.

Also, the evaluation of the parameters of the circles described by the cross centers is difficult. The case when the rotation is stopped by some reasons but the process has not yet finished requires additional investigation as well. Acceptance of a tolerance for the minimal deviation between two consecutive images may partially solve the problem.

The experiments with real and comparatively good images have shown that the suggested approach for the automatic evaluation of the lens decentration gives promising results. The required computational time is about 60 ms for a 1.7 GHz processor, which is quite satisfactory from a practical point of view.

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## Автоматично измерване на децентровката на лещи

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### (Резюме)

Описан е метод за автоматична обработка на изображения, получени от уред за оценка на децентровката на лещи. За първоначално определяне на центровете на автоколимационните бликове от горната и долната повърхност на лещата се използва трансформация на Hugh за полутонови изображения. По-точно определяне на центровете се постига с използване на посоката на максималния градиент. Измерването на децентровката на лещи се основава на радиусите на окръжностите, описани от автоколимационните кръстове.