Enhancement of alignment-technologies for lenses used in high-end optics

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In high-end optics now a days manufacturing tolerances below one micron are well-established. Common alignment techniques fail to achieve this precision on many lens types. In this paper we present a way to circumvent these by using digital image processing. We show results of lenses centered within ±0.25 µm.

1 Introduction

To satisfy the increasing demand for high-end optics, alignment lathe turning machines are used. While the current system uses a half covered photo-detector, we use digital image recognition to overcome some of the major problems of this system, allowing us to align a broader range of various lenses.

2 Current system

To gain the necessary precision in turning the lens mounts we use the alignment lathe "JDM 200 CNC", which has a granite cast machine body, a spindle with a run out smaller than 0.5 µm and an accuracy for diameter turning smaller than 1 µm (for a more detailed description see [1]). Centering is done using two mechanical pushers utilizing the stick-slip effect [2]. These move an alignment chuck with a plane- and calotte surface to center the optical axis to the machine axis. Afterwards the lens mount is turned accordingly.

To get the necessary information how to control the pushers a reflex imaging system is used. A measuring pinhole is projected onto the position of the radius of curvature of the lens surface. The reflex of the surface is projected to a half covered photo-detector (see Fig. 1). As long as the optical axis of the lens has a lateral offset or is tilted, the reflex describes a circuit. Thus the photo detector generates an AC signal, which is evaluated by a lock in amplifier. When the lens is aligned the photo detector only yields a DC signal, the centering process is finished.

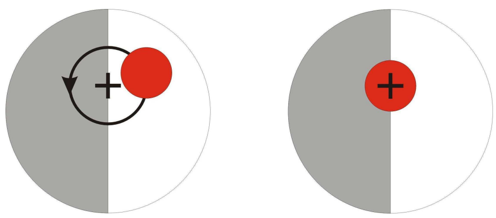

Fig. 1 *Reflex on the half-covered photo detector. Left: tilted lens, right: aligned lens*

Problems occur since in principle there are always two reflexes. For ordinary lenses this is solved, since the distance between the radii of curvatures Δz is big enough, so that the corresponding reflex planes can easily be distinguished and only one spot is visible on the photo detector (see Fig. 2 left). For meniscus or microscope lenses this distance gets too small (see Fig. 2, right), so that both reflexes are visible on the detector leading to a failure of the common process. The resulting detector signal is shown in Figure 5.

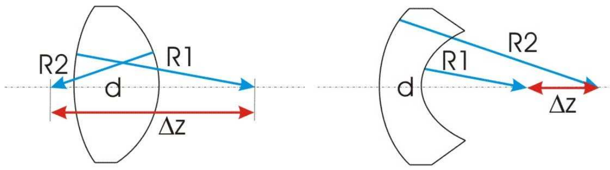

Fig. 2 *Distance between radii of curvature Δz. Left: ordinary lens, right: meniscus or microscope lens*

3 Adaptive image recognition

The reflex imaging system held an 8-bit CCD-camera, which we used to monitor and control the alignment process. This process consists of four steps: (a) record a short series of video frames (b) automatically finding the region of interest (ROI) (c) choose appropriate algorithm (d) start live capturing and drive pushers according to the recognized reflex position.

While selecting a manual ROI is still possible, a short series of frames can be used to locate moving objects. This is done by subtracting subsequent frames to get their difference. These differences are summed up for the whole series to get an area where movement takes part. To eliminate small brightness fluctuations a threshold criteria is used to convert the grayscale image to a binary one. In post processing a circle is matched to the maximum circumference of the binary image, which defines the wanted ROI.

After this the part of the initial series within the ROI is reprocessed to find the appropriate algorithm to convert the grayscale images to binary ones. Therefore each frame is converted to a binary image, with gradually rising threshold level. For each level the gravitational pixel center is determined and stored. After the whole series is processed the algorithm searches for a local minimum within the variance. A typical result is depicted in Fig. 3. One can see that there is a threshold level (over all frames), where the reflex position has a very small variance. In this case threshold conversion will be used as algorithm, with the corresponding level of the minimum, otherwise a gradient technique is used.

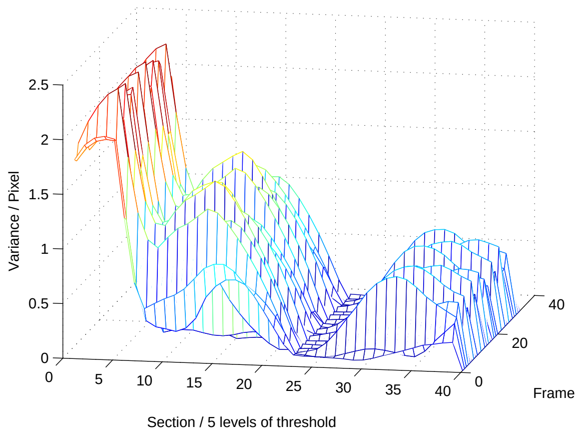

Fig. 3 *Variance of center position for different sections of threshold levels for a given series of frames.*

For edge detection and to be able to distinguish between reflexes we use the exact gradient value:

$$g(x,y) = \sqrt{(\Delta_x b(x,y))^2 + (\Delta_y b(x,y))^2}$$

where $b(x,y)$ is the brightness of a certain pixel [3]. With this technique we can select the wanted reflex by applying a threshold for the gradient, resulting in a very precise image recognition. Fig. 4 (top) shows an artificial constructed image with a sharp reflex on the left half and a brighter defocused reflex on the right. The post processed recognized image is below.

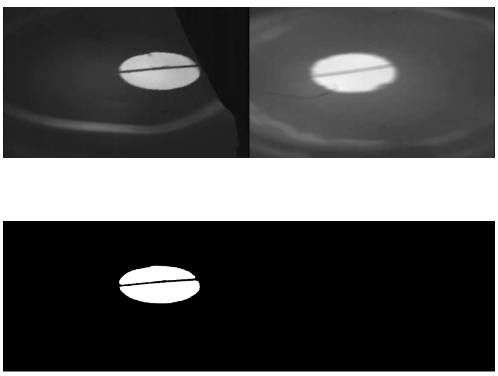

Fig. 4 *Top: image with two reflexes, bottom: binary image after gradient algorithm*

4 Comparison and results

To compare the new system directly to the old one, a lens with a small second reflex (Fig. 6 left) was used and evaluated by the current system and the image recognition. The left part of Fig. 5 shows the signal from the photo detector, on the right side the position of the recognized reflex is shown. One can see the nearly perfect sinusoidal result of our method, which can be proven by a Fourier transformation.

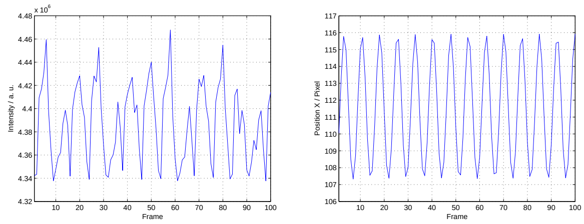

Fig. 5 *Comparison of the current system vs. image recognition. Left: signal of half-covered photo detector, right: lens position with image recognition*

The alignment process is finished, when the lens reaches an alignment of ±0.25 µm (see Fig. 6 right).

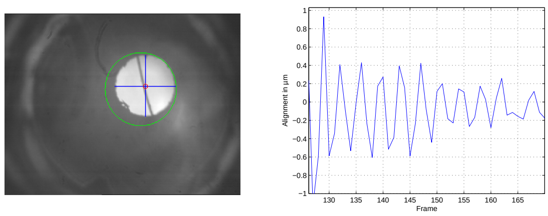

Fig. 6 *Left: Common lens with a small second reflex. Green: recognized ROI, blue: size of reflex, red: center of reflex. Right: Achieved precision of alignment with digital image acquisition*

Acknowledgment

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References

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