World Journal of Mathematics and Physics
ISSN: 2960-009X
DOI: 10.61784/wjmp3003

RESEARCH ON IMAGE PROCESSING IN LENS FOCAL LENGTH MEASUREMENT

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Abstract: In order to study lens focal length in detail, this paper uses image processing method to improve the research of lens focal length. The use of ruler, lens, lens to be measured and CCD to build an experimental system, the use of magnification method, the use of CCD to collect the lens to be measured focal plane image, using MATLAB digital image processing technology, through equalization, adding noise and other operations to measure the image height of the object, and then calculate the lens focal length size. The measurement of lens focal length is realized, and the feasibility of image processing in lens focal length measurement is verified.
Keywords: Magnification method; Focal length of lens; CCD acquisition system; MATLAB

1 INTRODUCTION

Lens is one of the most important commonly used optical components, and plays an important role in optical applications, such as light propagation, imaging and the design and use of optical instruments. In recent years, with the development of science and technology, people continue to combine lenses with modern science and technology. CCD is a kind of semiconductor device, which can convert optical image into digital signal, with low noise, low image distortion, high resolution, wide dynamic range, good linear curve [1] characteristics, large sensitive area and so on [1]. MATLAB has a relatively complete graphics processing function, which can realize the visualization of the image information obtained in the experiment, so as to clearly obtain the data information shown in the picture [2]. Using CCD data acquisition system and MATLAB to collect and process the experimental results, the experimental results can be obtained directly; And can feel the characteristics of lens focal length more directly, in the data extraction and processing has a better effect.

The commonly used measurement methods of lens focal length in experiments are as follows: object distance image distance method, autocollimation method, conjugate method, parallel light tube method [3]. The advantage of object distance image distance method is simple and universal, but due to the error caused by the resolution of the human eye, the position of the clear image formed by the lens is not completely accurate, and there are also measurement errors in the process of lens focal length measurement, which affect the accuracy of lens focal length [4]. The lenses used in the conjugate method are mostly thick lenses, which may cause the center deviation of the lens (the offset of the optical center axis and the mechanical center axis of the optical lens), resulting in the reduction of the accuracy of the lens focal length measurement. Autocollimation method measurement of interference image, will cause the lens focal length measurement is less than the actual value [5].

In several conventional experiments commonly used, the lenses used for measurement are mostly thin lenses or all are treated as thin lenses [6]. The focal length measured by calculation in this paper is the focal length from the center of light to the focal plane, which can be applied to non-thin lenses with a relatively wide range of application areas. Moreover, image information can be obtained directly by using MATLAB image processing in this paper, which is more convenient.

2 EXPERIMENTAL PRINCIPLE AND EXPERIMENTAL METHOD

2.1 Experimental Principles

Figure 1 is the magnification method to measure the lens focal length optical path, light through the parallel optical tube objective lens parallel out, it is easy to get △ and △ similar, can be obtained by the similar triangle rule Fyo $F_x y' o'$

$$f_x = -\frac{y'}{y} f_0 \tag{1}$$

Where is the focal length of the objective lens of the parallel light tube, y is the size of the object, is the size of the image, it is easy to see that the proportional relationship between the object and the lens focal length is proportional. f_0 y' The experiment uses the proportional relationship between the objects to determine the focal length of the lens to be measured, and the calculated result is the focal length of the lens to be measured, which is more accurate than other methods. [7]

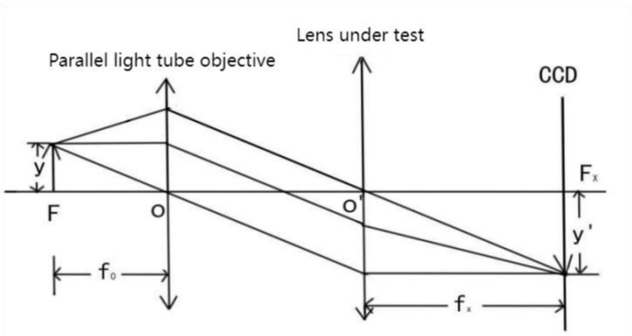

Figure 1 Magnification Method to Measure Lens Focal Length Optical Path

2.2 Experimental Method

(1) Coarse adjustment, the parallel light tube, the lens to be measured, and the plane mirror are placed on the light base in turn. Due to the lack of parallel light tubes in the experiment, there is also an overexposure problem in the use of Boro board, so the light source, transparent ruler and lens are used in the experiment. Visually adjust the experimental instrument to the initial coaxial height, and then further use the autocollimation method to adjust.
(2) Use the autocollimation method to measure the best position, the image is presented on the CCD, and the imaging effect is observed on the computer. And the image will be taken down, the obtained image for the ruler fragment image.
(3) Repeatedly adjust the lens under test and the CCD photoelectric device 4 times, capture 4 pictures, and use MATLAB for image processing.

3 EXPERIMENTAL RESULTS AND DATA PROCESSING

3.1 Experimental Results

After assembling the experimental instrument and saving the CCD image, five images with clearer images were obtained through repeated adjustment. The experimental image is shown in Figure 2. The clearer part of the obtained picture was captured and imported into MATLAB for data processing. The paper regards the picture as composed of the smallest unit pixel, and the data information can be obtained by obtaining the number of pixels.

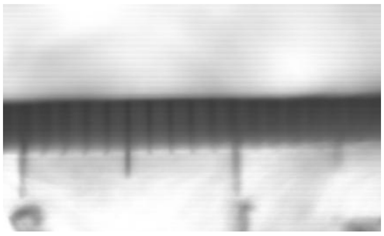

Figure 2 The Experimental Picture

3.2 MATLAB Data Processing Method

First, read the images obtained in the experiment into MATLAB, and use imread function to read JPG format images. Since the difference between low gray level and high gray level is small, the image is equalized first to enhance the image contrast. The left side of Figure 3 is the original image, and the right side is the effect image after equalization.

Figure 3 Image Reading and Equalization Processing

Since the horizontal fringe on the image is generated by clutter interference, the notch filter is used for filtering, and the filtered effect is shown in Figure 4. Notch filter refers to rapidly attenuating the input signal at a certain frequency point, so as to obtain the filtering effect of inhibiting the signal passing at that frequency [8].
Because the interference fringes of the image are very obvious, the picture is processed with sharpness. Poisson noise is added here to make the image more evenly disturbed [9], and the image after adding noise is shown in Figure 5.

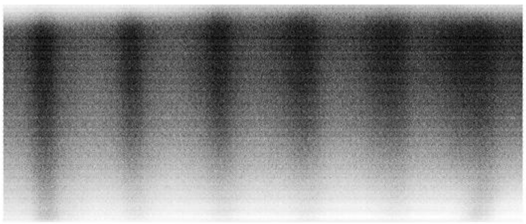

Figure 4 Image after Notch Filtering

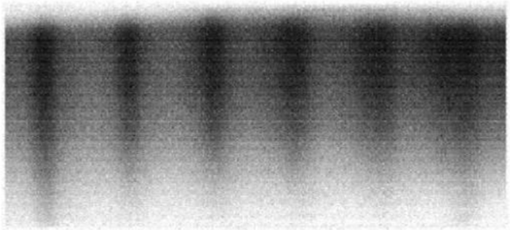

Figure 5 Image after Noise Processing

Image filtering is used to process the image. Firstly, the homomorphic filter is used for the initial processing of the image. The advantage of homomorphic filter is to convert the original complex operation into a relatively simple operation with the same efficiency to further improve the contrast and increase the detail information of the image [10]. Then, the Gaussian filter is further processed to transform the multi-dimensional convolution into multiple one-dimensional convolution, and then the image is smoothen without changing the direction of the image edge, ensuring the feature points and edge characteristics. Figure 6 and Figure 7 show the processing results of homomorphic filter and Gaussian filter respectively.

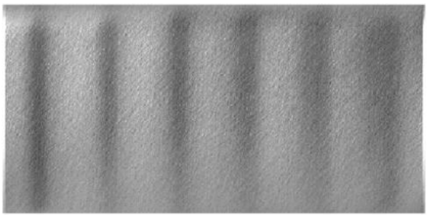

Figure 6 After Homomorphic Filtering

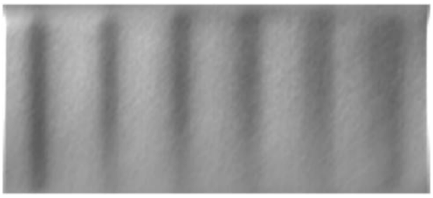

Figure 7 After Gaussian Filtering

Compared with the unprocessed image, the filtered image has no obvious interference fringe and granular noise, and it is judged that the processing effect after adding Poisson noise is better than that of adding Gaussian noise.
In order to better locate the image position, the global threshold segmentation is used to process the image. The global threshold method means that only one threshold is used in the binarization process, and the value of the pixel is compared with the threshold, if it is greater than black, less than white. By experimental comparison, the effect is best when the threshold is 0.5, as shown in Figure 8.
In order to better position, edge detection is used first. Edge detection is to find the location of drastic changes in the gray level of the image, which greatly reduces the amount of data, eliminates irrelevant information, and retains the important structure of the image.

Figure 8 Binarization Process

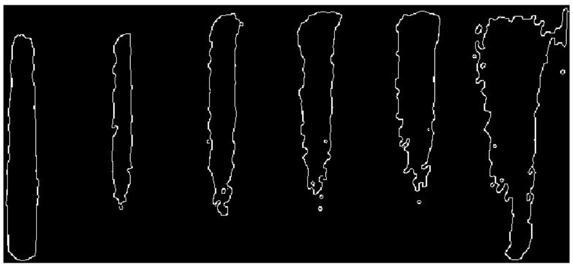

Figure 9 Threshold Transformation Diagram of Canny Operator

Canny edge operator, is a kind of edge operator that can not only filter the noise, but also maintain the edge characteristics. It adopts two-dimensional Gaussian function to filter by convolution with the image, and determines the image edge by positioning the local maximum value of the image. Canny not only has a low bit error rate and few positioning errors, but also can accurately locate the edge on the pixel with the largest gray scale, suppressing the occurrence of false edges [2]. In this paper, the image with a threshold value of 0.5 is taken for the next experiment. The result is shown in Figure 9.

The image with edge detection is segmented, and the floor function is used to take the maximum pixel of the image horizontally or vertically. y=floor(m/M), where y is the length of the cut subblock, m is the pixel value of the image X axis, M is the number of cut blocks, and the size of the subblock is the original m/M. The formula is used to segment the area blocks, and the results are shown in Figure 10 below.

The polyfit least square function can be used to get the straight line where the image is located, and the plot function can be used to plot the two-dimensional straight line. Let the line be, and the $y = kx + b$ fitting image is shown in Figure 11.

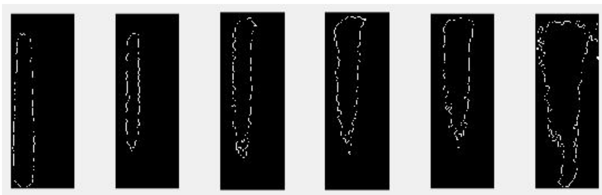

Figure 10 Segmentation after Edge Detection

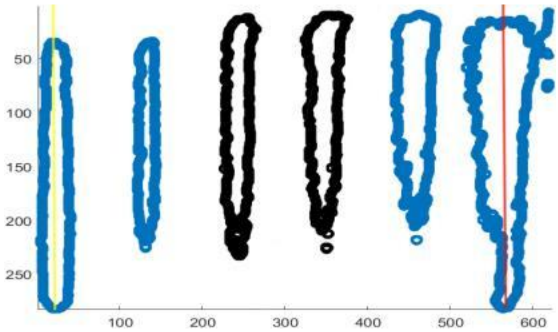

Figure 11 Linear Fitting Image

$$y_1 = -0.00066x_1 + 25.17, R^2 = 0.0012 \quad (2)$$

$$y_2 = 0.0488x_2 + 551.72, R^2 = 0.0255 \quad (3)$$

The position information of the image can be obtained by obtaining the pixel value of the image (unit is Px). The relationship between pixel value and centimeter is: The obtained value can be put $1Px = 0.00357cm$ into formula (1), and the focal length of the lens to $f_0 = 21cm$， $y = 5cm$ be measured can be calculated in formula 1. The Y ordinate and ordinate Y' in the table ΔY respectively represent the pixel value of article 1 and article 6 in the figure, indicating the distance between them, and the focal length f_x is the calculated focal length of the lens, the specific data is shown in figure [11] below

Table 1 Experimental Data Table

Ordinate Y/Px	ordinate Y'/Px	$\Delta Y/Px$	y' Values /cm	f_x /cm
15.726	525.339	509.612	1.82	7.64
14.224	528.908	514.684	1.84	7.72
13.811	526.059	512.248	1.83	7.69
16.397	527.657	511.260	1.82	7.64

$$\overline{y'} = 511.951 \times 0.00357 = 1.828\text{cm} \tag{4}$$

$$\overline{f_x} = \frac{\overline{y'}}{y} f_0 = \frac{1.828}{5} \times 21 = 7.68cm \tag{5}$$

$$s_{f_x} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(f_x - \overline{f_x})^2} = 0.0404cm \tag{6}$$

$$f_x = 7.68 \pm 0.0404cm \tag{7}$$

4 CONCLUSION

In this paper, magnification method combined with MATLAB image processing technology, through the original image equalization processing, notch filtering, adding Poisson noise and a series of processing technology, the last least square fitting can calculate the lens focal length. Through calculation, the lens focal length is 7.68cm, and the deviation is only 0.526%, which shows that the image processing is feasible in the measurement of focal length.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

REFERENCES

[1] Guo Zhenyu, Xie Na, He Pengju, et al. Design of experimental system for lens focal length measurement based on CCD. Computer Technology and Development, 2017, 27(05): 174-178.

[2] Liu Zhijian, Yan Yongfei, Sun Yingbi, et al. Research on transient stability verification of power grid black start. Electric Power Science and Engineering, 2019, 35(09): 1-8.

[3] Li Xiaolei. Focal length measurement of thin convex lens based on parallel optical tube method. Chinese Journal of Applied Optics, 2019, 40(05): 859-862.

[4] Li Wei, Liu Chao, Zhang Liwei, Liu Songjiang, Nie Ming. Research on focal length measurement of thin lens. Experimental Physics, 2014, 34(07): 27-29.

[5] YU Ying. Error analysis of focal length measurement of convex lens by autocollimation method. Physics Bulletin, 2015(09): 70-72.

[6] Tao Shufen, Zhou Xiaofeng. A simple method for measuring focal length and base point position of optical array. Experimental Science and Technology, 2009, 7(01): 59-60.

[7] SU Qiong. Measuring the focal length of thin lens by parallel light tube method. Journal of Qiandongnan Teachers College for Nationalities, 2006(06): 34-35.

[8] Yuan Lihua, Hong Huasong, Qi Xinmin. Design and Application of Notch Filter. Automation & Instrumentation, 2004(4): 20-22.

[9] Shahlin. Research and experimental analysis of image filtering denoising and edge detection technology. Jilin University, 2021.

[10] Gong Yun, Jie Xinyu. Research on image enhancement technology of underground coal mine based on homomorphic filter method. Coal Science and Technology, 2023, 51(03): 241-250.