A High-Definition Imaging System Utilizing Single Lens And Double Monochromatic Light Sources

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Abstract: With reverse thinking, based on the phenomenon of chromatic dispersion, double monochromatic light sources scheme was used to solve the phenomenon of defocus in large-depth-field single lens digital imaging system. Two specific narrow bandpass filter was employed to filter the LEDs into two monochromatic light sources. The self-made circuit based on FPGA, LabView and Matlab hybrid programming software were well designed to fulfill the digital image processing. Experimental results show that such a single-lens digital imaging system can greatly reduce the chromatic aberration, extend the depth of field imaging and improved the image quality. This system can be extensively used in the fields of machine vision and medical microscopic imaging.

Introduction

In the territory of photoelectronic imaging, the spatial filter method (SFM) and the extend depth of field (EDOF) was used widely as the method to solve the defocus phenomenon in large EDOF imaging system. In fact, we found that SFM and EDOF both can not completely solve the phenomenon of chromatic dispersion in the optical imaging system, For this reason, we came up with an idea that , in physical, one can exploit chromatic dispersion to compensate the defocus resulted from the large depth of field by means of illuminating two objects in different depth of field with different wavelength monochromatic lights. In order to demonstrate this idea, a single-lens imaging system was constructed with given single lens and CMOS image sensor. A pair of monochromatic light sources with quite different wavelength were used to illuminate objects in different depth of filed. The self-made circuit based on FPGA, LabView and Matlab hybrid programming software were well designed to fulfill the digital image processing. Experimental results show that such a single-lens digital imaging system can greatly reduce the chromatic aberration, extend the depth of field imaging and improved the image quality. This imaging system can be used to take high-definition picture for two object in large depth of field. Thanks to the original operation principle and its simple designs , this imaging system and can be extensively used in the fields of machine vision and medical microscopic imaging.

Theoretical analysis

Figure 1 shows principle diagram of the system. Two ISO-12233 test charts with different object distances are illuminated by two different light sources with center wavelength at 396nm and 651nm(or 615nm), respectively. A lens with the focal length f =35mm is employed to focus the light to the

CMOS, then, the image information is read in with the help of a self-designed circuit based on FPGA , and then be processed by a personal computer.

Given refractive index n=1.516, according to Eq. 1

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f} \quad (1) \qquad (1)$$

where u is the object distance, v is the image distance, we can figure out the image distance of the test chart at 500mm[800mm] is 37.634mm[36.601mm], and the distance between the two test charts' images is about 1.033mm.

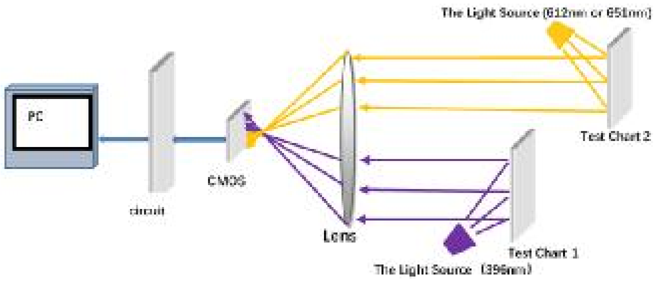

Fig.1 The principle diagram of the device

In fact, as is shown in Fig.2, different-wavelength lights will be characterised with different refractive index when they are transmitting in the k9 glass. In other words, according to Eq. 2,

$$\frac{1}{f}=(n-1)^{*}\left(\frac{1}{r_1}-\frac{1}{r_2}\right)-\frac{(n-1)*d}{n*r_1 r_2} \qquad (2)$$

where n is the refractive index of specific wavelength light in the k9 glass , d is the thickness of lens, both and is the radius of curvature of the lens, the test chart fixed with a certain object distance will image at different image distance if it was illuminated by different wavelength lights. So we can custom design the combination of two different-wavelength lights to illuminate two test charts fixed in different object distances in different depth of filed, making sure their image distances are exactly identical. For instance, Given that the test chart 2 of object distance 800mm is illuminated by the light of wavelength 651nm, the refractive index of the lens should be 1.514, and the focal length should be 31.737mm as we can figure it out with the following Eq. 2. Further, substituting those parameters into Eq. 1, the image distance of this test chart 2 is ready to figure out, and the result is 33.048mm. For the test chart 1 of object distance 500mm, to focus it at the same image distance of 33.048mm, the focus length should be 30.999mm, which is figured out according to Eq. 1. Once the focus length, r1 and r2 is given, the refractive index of the lens can be derived from Eq. 3.

$$n=\frac{\left(\frac{r_2-r_1}{r_1 r_2}+\frac{d}{r_1 r_2}+\frac{1}{f}\right)+\sqrt{\left(\frac{r_2-r_1}{r_1 r_2}+\frac{d}{r_1 r_2}+\frac{1}{f}\right)-\frac{4d(r_2-r_1)}{(r_1 r_2)^2}}}{\frac{2(r_2-r_1)}{r_1 r_2}} \qquad (3)$$

where r1=-r2= 34.86mm. Hence, the result is 1.531 . At last, with the help of Fig. 2, the ideal wavelength of the light to illuminate the test chart 1 is finely figured out to be 396 nm, which is quite different from the wavelength of the light to illuminate the test chart 1. All in all, when test chart 1 and test chart 2 are illuminated by 396 nm light and 651nm light, respectively, the single lens imaging system should present best performance.

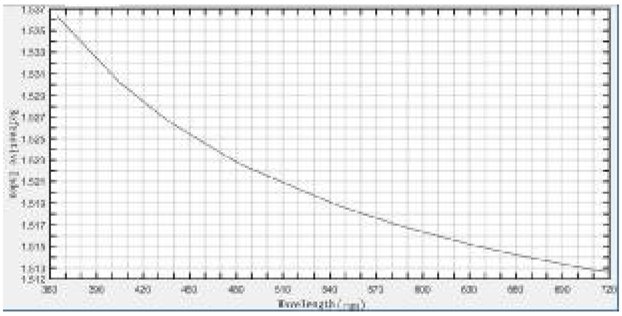

Fig.2 **T**he relationship between the wavelength and the refractive index of k9 glass.

The experiment setup

The experimental setup is shown in Fig. 3. In this experiment, the test chart 1 of 500mm object distance was lighted by violet LED with the central wavelength of 396nm , while the test chart 2 of 800mm object distance was lighted by red LED with the central wavelength of 651nm. In order to narrow the spectrum of LED light source and provide the ideal monochromatic light source, the specific narrow-band filter with narrow FWHM bandwidth (<10nm) and specific peak value wavelength was installed in every LED light to tailor the spectrum. Further, to reduce the influence of cross illumination of two different wavelength lights, a light blocking device that can adjust height and orintation was self-designed and effectively employed to reduce this influence.

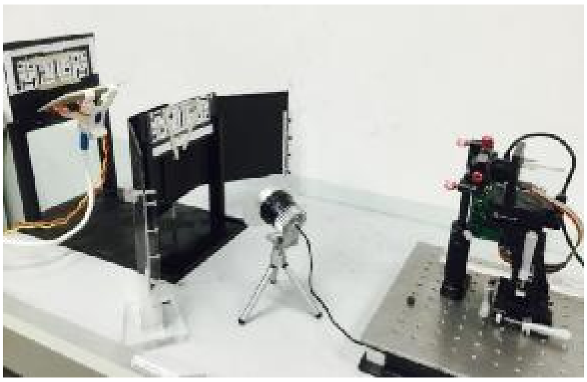

Fig.3 The Experiment Setup

As is shown in Fig. 4, the adjustment system is composed of a six dimensional adjustable platform, a three-dimensional adjustable bracket and a CMOS fixing device produced by 3D printer. With this system, the centers of the test card, the lens and the CMOS are easy to be adjusted, which makes the coaxial adjustment easier and faster.

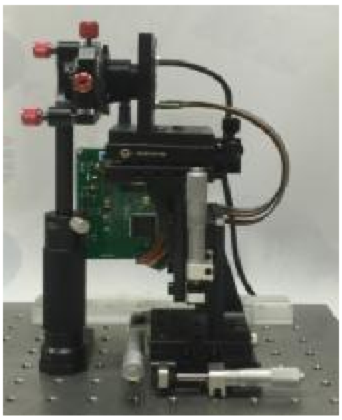

Fig. 4 The adjustment system

Experimental results and discussion.

To experimentally demonstrate the high-definition imaging system with single lens and double monochromatic light sources is feasible, without loss of generality, we used violet LED with the central wavelength of 396nm and red LED with the central wavelength of 651nm to conduct the experiment. Based on this method, the image which we have got is shown in Fig.5. Both the clarity and the comfort of this image is higher. In order to quantitatively analyze the image quality, we use Imatest software to evaluate the image. Fig. 6 shows the software evaluation results. The value of LW/PH is 1619. It means that the contrast and clarity of this image reach a fairly high level.

In order to demonstrate the theoretical designed results, we designed another experiment which used violet LED with the central wavelength of 396nm and orange LED with the central wavelength of 615nm to conduct the experiment. In this case, the image and its software evaluation results are shown in Fig.7 and Fig. 8, respectively. Compared Fig.8 with Fig.6, we could find the value of LW/PH of Fig.8 is greater than that of Fig.6, it proved that the theoretical designed results are correct.

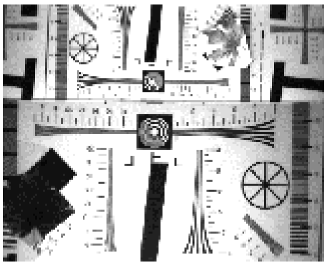

Fig.5 Image with Lights(396nm and 651nm)

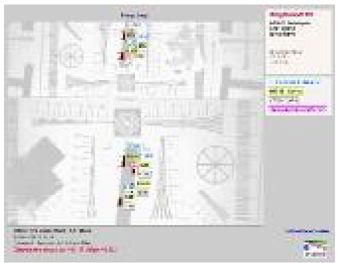

Fig.6 Imatest evaluation results of Fig.5

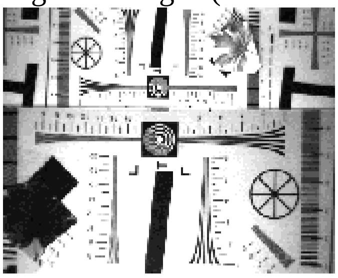

Fig.7 Image with Lights(396nm and 615nm)

Fig.8 Imatest evaluation results of Fig.7

conclusion

We have proposed and experimentally demonstrated the high-definition imaging system with single lens and double monochromatic light sources. In the case of large-depth-field imaging , we could use the phenomenon of chromatic dispersion to solve the defocus phenomenon, at the same time it can well improve the image quality. Operating principle of the reported scheme is very original, and this system is simple and low in the cost, so it can be extensively used in the fields of machine vision and medical microscopic imaging.

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