Extending Depth of Field for Iris Recognition

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Abstract: Iris recognition has become popular in recent years due to its rich textures and high accuracy. However, a major constraint in current iris recognition systems is the very shallow depth-of-field (DOF) that limits system usability and increases system complexity. In this paper, we used a spatial light modulator in place of the traditional cubic phase mask to dynamically optimize the wavefront coding in real time with different depth ranges. Proposed scheme will certainly has a promising impact on the development of computational imaging for iris recognition due to its rapidity and versatility.

1. Introduction

Using biometric signatures for identity recognition has been practiced for centuries. Recently, biometric technology has becoming an important research topic. The personal attributes used for a biometric identification system can be physiological, such as facial features, fingerprints, iris texture, retinal scans; or behavioral traits of an individual, such as voice, signature and keystroke style. Among these methods, iris recognition is the most attractive one to the researchers because of the nature of randomness of iris texture. Moreover, recognition based on iris texture has many advantages such as high entropy density, stability of the iris texture over a lifetime, and the high independency across individuals (even for the twins). According to the research from Prof. J. Daugman, we can see that the probability of false identification can be the order of 10^{-10}[1-3].

There are several steps in iris recognition, including image acquisition, iris localization, feature extraction, signature encoding, and matching the iris codes to the stored database for recognition. Iris recognition has been applied to many fields, such as airport security, computer security and bank transactions, but existing iris recognition systems have disadvantages. One of them is that the depth of field is very small, and subjects' eyes must be positioned carefully inside the focus range to capture qualified images, or the user will not be identified successfully. This issue becomes particularly important when we want to build a more unconstrained iris recognition system. Thus the focus of this paper is how to build a system with large DOF for capturing iris images.

Several research have used wavefront coding [4] technology to extend the depth of field of the iris recognition system [5, 6]. Wavefront coding is the approach which employs a phase mask to modify the incoherent optical system, and makes the point spread function (PSF) insensitive to defocus. And in the previous referenced papers, all of them use a fixed phase mask which is optimized according to the desired depth of field and the trade-off between acceptable signal-to-noise ratio of the iris recognition system. But the fixed phase mask is only effective within the desired DOF range, which means that if the subject located out of the range then the phase mask must be redesigned to acquire good results. In this paper, we use the spatial light modulator (SLM) as a programmable phase mask, so the phase mask can be optimized in real time varying with different depth ranges.

2. Method for extended the depth of field

The limitation of the DOF is the main problem of the traditional iris recognition system. Stopping down the aperture can increase the DOF, but the light gathering capability and resolution will decrease. And because of eye safety concerns, increased power from the illumination source (which is infrared in our case) is not preferred as we know that high power IR may be harmful for human eyes.

2.1 The concept of wavefront coding technology

The phase mask modulates the phase of incoming light, so the pupil function in the pupil plane can be expressed as:

$$\mathrm{p}(\mathrm{x},\mathrm{y}) = \exp\,[\mathrm{i}\alpha(x^3 + y^3)] \tag{1}$$

The form of the mask is a cubic function, the spatial coordinates x and y are representative of the normalized distance from the center of the mask, where the constant α controls the phase deviation. The phase mask is designed for a specific optical aberration, such that the image looks blurry, and the blurring degree is proportional to the parameter α, so the image captured by the sensor is the optical coded intermediate image and needs to be decoded by a digital filter.

2.2 Using LC-SLM as a programmable phase modulator

The spatial light modulator we used in this paper is a twisted-nematic liquid crystal LC2002 from Holoeye [7]. The resolution of the LC-SLM is 800×600 pixels with 8 bits depth, and the pixel pitch is 32μm×32μm. The principle of liquid crystal is that the birefringence will change according to different external electric field, and for LC-SLM, the birefringence is controlled by the input video signal. Because the LC-SLM modulates the amplitude and phase simultaneously, in order to minimize the amplitude modulation, the LC-SLM must be calibrated by using a pair of polarizer and analyzer, placing the LC-SLM between them and choose the appropriate orientation angle of the polarizer and analyzer then a phase modulator with small amplitude modulation can be acquired.

We used the free program, called phase cam from Holoeye [8], which can measure the phase and amplitude modulation. The software can address the gray level from 0 to 255 onto the active half of the gray level window automatically. We set up a Mach-Zender interferometer in the experiment setup (Fig. 1), and the gray level in the right window keeps 0 while the gray level in the left window is varying per 5 steps, in such case the amplitude modulation of the interference induced by different gray level can be calculated. We chose 36 orientations of the polarizer and found the respective orientations of the analyzer will cause the shape of the PSF more similar to the ideal situation when we use the mask with cubic form. The amplitude of the interference pattern in the left window are different due to different input gray level, and the pattern was consist of 6 cycles, we calculated the amplitude modulation compared to the largest amplitude and then averaged the results. Finally, we found that the amplitude modulation at different gray levels is less serious (Fig. 2) when the orientation of the polarizer and analyzer equals to 124° and 168° respectively. Fig.2 shows that the gray level from 140~180 have the amplitude modulation larger than 10%, and the worst one is 14% at gray level 180..

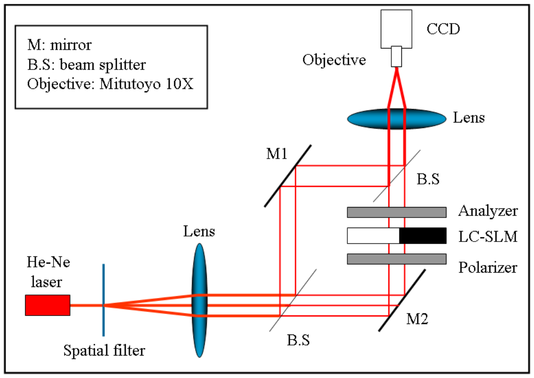


Fig. 1 Experiment setup. Mach-Zender interferometer: light passing through M1 and M2, PSF measurement: light passing through M2 only

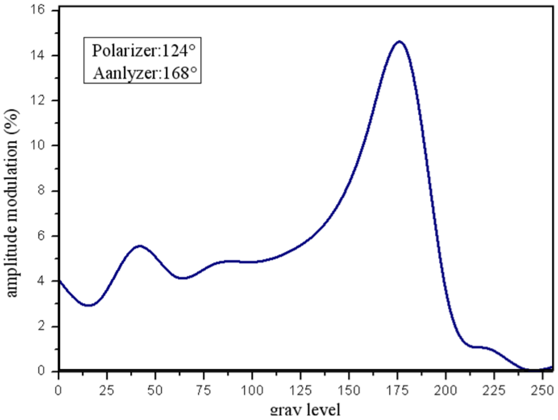


Fig. 2 Amplitude modulation of input gray level from 0~255

3. Experiment results

When the left mirror is blocked, the experiment setup (Fig. 1) can be used to measure the PSF of the system. The value of α we used in the work was 40 and the wavefront of the mask is illustrated in Fig. 3(a). Using this figure as the input video signal and Mitutoyo 10X objective with monochromatic CCD to capture the PSF, the results are shown in Fig. 4. The right column is the system without cubic phase modulation and the left column is the system with cubic phase modulation. The PSFs from top to the bottom represent defocus -2.5mm, onfocus and defocus 2.5mm, respectively. The geometrical size and energy distribution of the PSFs in the right column are varying with different levels of defocus while the PSFs in the left column can be kept almost constant. In other words, the cubic phase modulation makes the PSF insensitive to defocus.

Fig. 5 shows the simulated image which is calculated by the convolution of the captured PSFs in Fig. 4 and a iris picture, reminding that the PSFs must be magnified by the factor of 1/10 because they were captured by the objective with 10X magnification, and the Fig. 5(a)、Fig.5(b) represent the iris images without and with cubic phase modulation respectively. We can figure out the irises are sensitive to the defocus in Fig. 5(a) while the irises in Fig.5 (b) have high similarity between each other.

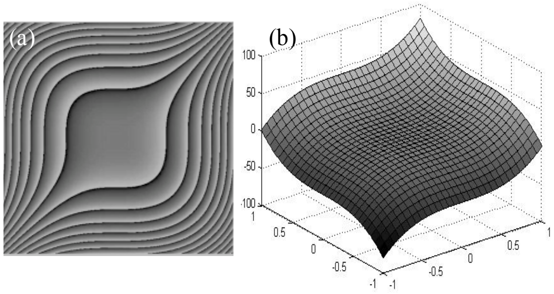
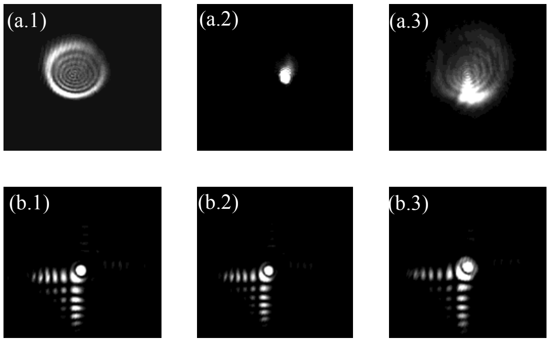


Fig. 3 (a) Phase modulation of cubic phase mask in Fresnel lens form (b) Phase profile of the pupil function



defocus -2.5mm on focus defocus 2.5mm

Fig. 4 (a) The PSF of the system without cubic phase modulation (b) The PSF of the system with cubic phase modulation

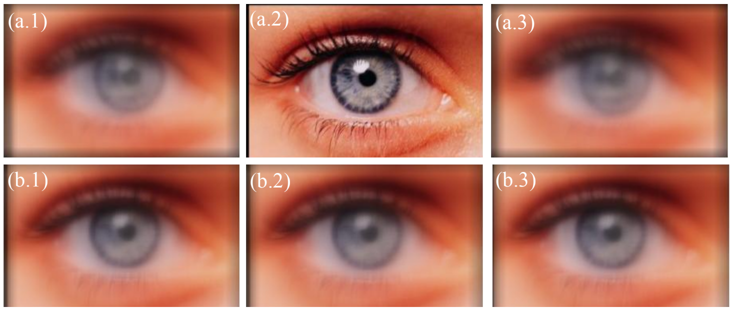


Fig. 5 (a) The simulated iris without cubic phase modulation (b) The simulated iris with cubic phase modulation

4. Conclusion

In the paper, we use the LC-SLM as a programmable device for extending the depth of field of the iris recognition system and the result shows that the image is insensitive to defocus but also becomes blurry due to the large size of PSFs. Our future work will focus on the decoding of the blurred iris image, and calculate the Hamming distance to measure the dissimilarity between two irises for the recognition stage and then implementing this method to a real iris recognition image capturing system.

5. Acknowledgment

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6. References

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