ENHANCED USABILITY OF IRIS RECOGNITION VIA EFFICIENT USER INTERFACE AND IRIS IMAGE RESTORATION

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ABSTRACT

In this paper, we investigate the possibility of enhancing the usability of iris recognition via exploration of the specular spots in iris images. Firstly, the spatial configuration of the specular spots in iris images is utilized to estimate the distance between the user and the camera. Based on this a friendly user interface is established to assist users for their range adjustment. Furthermore, the estimated distance is used by an adaptive image restoration scheme to restore the blurred iris image, thereby increasing the depth of field of the iris camera. Experimental results show that the proposed method significantly enhances the usability of iris recognition without noticeable computation cost.

***Index Terms*—** User Interface, image restoration, iris biometrics

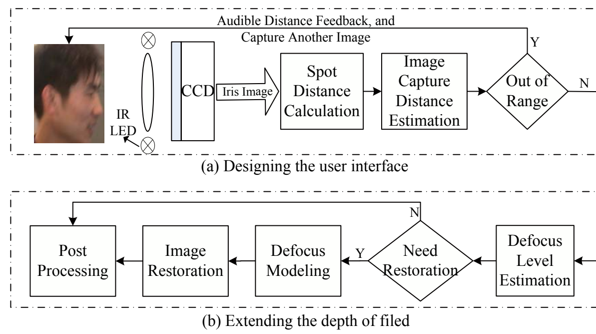

Fig. 1. A system overview of the proposed method.

1. INTRODUCTION

Recently, iris recognition, as a promising biometrics, has received more and more attention for its unique, stable and non-invasive properties [1]. However, its usability has been greatly limited by the difficulty of acquiring a clear iris image. That is partly because of the unfriendly user interface and partly because of the image defocus. Therefore, for enhancing the usability of iris recognition two important issues remain unsolved and deserve more effort. One is to design a friendly user interface to assist users for positioning themselves at a suitable distance from the camera. And the other is to restore the defocused images to make them clear enough for recognition.

Several methods have been developed to tackle these problems. For the former problem, one straightforward solution is to use a distance sensor to measure the image capture distance (ICD) and then provide audible feedbacks [2]. However, such a sensor may be inaccurate and increases the hardware cost of the system. An alternative is to guide the user by estimating the focus scores of consecutive frames [1]. Although no special hardware is required, at least two frames are needed in order to give a correct instruction, which inevitably increases the total recognition time. For the later problem, J. van der Gracht et al. [3] and Ramkumar et.al. [4] adopted the so-called Wavefront Coded imaging technique to reduce the system's sensitivity to defocus, and the results are promising. However, they required special hardware design and traded focusing for phase blur. Recently, Kang and Park [5, 6] proposed an iris image restoration scheme based on image focus assessment, but focus assessment methods are sensitive to noise and appearance of individual iris texture.

In this paper, we propose a novel method, which requires no additional hardware while addressing each of the above problems. The basic approach is developed based on the exploration of the specular spots in iris images. In order to get proper illumination, most iris systems have at least one infrared (IR) illuminator, which results in the specular spots in iris images. For example, our imaging system has two IR LEDs fixed on the left and right sides of the iris camera, and hence results in two specular spots in the iris images (see Fig. 3). As demonstrated later, the distance between the two spots is approximately inversely proportional to the image capture distance. Therefore the spot distance can be utilized to estimate the image capture distance of the user, based on which a friendly user interface is established. Furthermore, benefited from the derived distance information, current defocus level (which is directly related to the image capture distance) can be estimated. If the current defocus level is within a certain extent, an image restoration scheme will be invoked to restore the blurred image.

A system overview of our method is depicted in Fig. 1. In Fig. 1(a), the image capture distance is estimated according to the calculated spot distance in the iris image, and a corresponding audible feedback is provided when necessary. In Fig. 1(b), the defocus level of the input image is first estimated according to its image capture distance, and then the system decides whether to invoke the image restoration scheme to restore the defocused image.

2. DESIGNING THE USER INTERFACE

2.1. From Spot Distance to Image Capture Distance

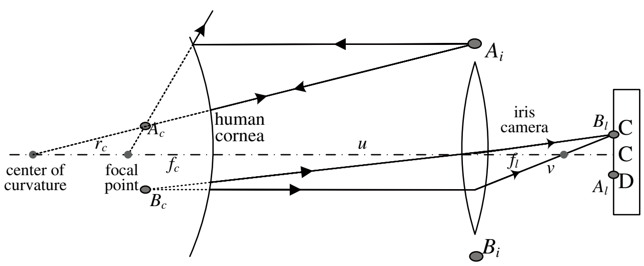

Fig. 2. The formation of the specular spots in iris images.

In this subsection, we describe how we can estimate the image capture distance via the spot distance in iris images. For the simplicity of description the human cornea and the iris camera are modeled as a convex mirror and a convex lens respectively.

As illustrated in Fig. 2, the formation of the spots in iris images involves three steps. In the first step, the IR-LEDs (A_i, B_i) form a virtual image (A_c, B_c) on the user's cornea. In the second step, the virtual image generates a real image (A_l, B_l) through the iris camera. Finally, the CCD sensor captures (A_l, B_l) and results in the specular spots in iris images.

Based on the optical imaging theory of convex mirror [7], the distance between A_c and B_c is derived as:

$$\overline{A_c B_c} \simeq \frac{f_c}{u + f_c} \cdot \overline{A_i B_i} \quad (1)$$

where f_c is the focal length of the human cornea, and u is the image capture distance. Similarly, by applying the optical imaging theory of convex lens, the length of $A_l B_l$ is derived as:

$$\overline{A_l B_l} = \frac{v}{u + f_c} \cdot \overline{A_c B_c} \simeq \frac{f_l f_c}{(u + f_c - f_l)(u + f_c)} \cdot \overline{A_i B_i} \quad (2)$$

where v is the image distance, f_l is the focal length of the iris camera lens. Noticing f_l, f_c, $\overline{A_i B_i}$ are constant in our fixed focal length imaging system, and f_l (about 30mm), f_c (about 4-5mm) are relatively small with respect to u (about 270mm), Eq. 2 can be rewritten as $\overline{A_l B_l} \simeq a_0/u^2$ (here $a_0 = f_l f_c \overline{A_i B_i}$ is constant), from which we can conclude that the spot distance (proportional to $\overline{A_l B_l}$) is approximately inversely proportional to the image capture distance u.

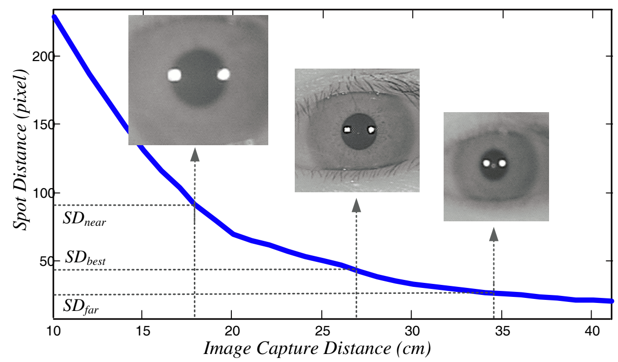

Fig. 3. The relationship between specular spot distance and image capture distance, with three illustrative image examples.

This analytical result provides important cues for estimating the image capture distance via the spot distance. Figure 3 shows an empirical plot of the spot distance with respect to the image capture distance established in our practical application. From Fig. 3, we can see that although the empirical result does not strictly adhere to the analytic equation, the spot distance keeps being strictly monotonic to the image capture distance. That is, the image capture distance can be uniquely determined by the spot distance. In addition, this method is also capable of off-angle iris images. When off-angle occurs, there will be a slightly change of f_c, however, the change is relatively too small to spoil this distance relationship.

Noticeably, Park and Kim [8] also used the specular spots for distance estimation. However, they only examined the appearance (i.e. the size and shape) of a single spot. In contrast, our method utilizes the structure information of two spots, and therefore is more stable and accurate. Moreover, they required the assistance of special hardware operations, while our method requires none but just utilizes the existing hardware configuration.

2.2. User Interface Establishment

The next question is how to derive the spots (and spot distance) in an iris image. An interesting property of the spots is that their contrast with the background (e.g. pupil or iris) is always high. Therefore, we adopt the *Mexican hat* function (MHF) [9] to detect the spots. MHF method is better than direct thresholding because it considers the isotropic contrast structure of the spots rather than merely the brittle intensity. In addition, we use the pair-wise characteristic of the two spots to validate the detection result (i.e., the two spots should form an amphiastral structure [8]).

Once the spot distance is extracted, a friendly user interface can be easily established according to the relationship depicted in Fig. 3. In order to generate a correct distance feedback, the user interface only needs two thresholds ($\mathcal{SD}_{far}$, $\mathcal{SD}_{near}$ as shown in Fig. 3). For instance, if the spot distance is smaller (larger) than $\mathcal{SD}_{far}$ ($\mathcal{SD}_{near}$), it implies that the user is too far (near) from the camera and he/she should move closer (farther) to the camera.

The effect of this user interface is twofold. First, real-time distance feedback is provided so that the user can move to a proper position more easily. Second, the current defocus level, which is directly related to the image capture distance, can be evaluated simultaneously, which paves the way for the image restoration in the next section.

3. IRIS IMAGE RESTORATION

Even with the help of the above user interface, there inevitably exist several defocused iris images that, after proper image restoration, can be appropriate for recognition.

3.1. Constrained Least Square Filter

Our goal is to recover a 'well focused' image $\hat{I}(x, y)$ from the defocused (observed) one $I(x, y)$. In this work, the constrained least squares filter (CLSF) method [9] is adopted. The frequency domain solution of CLSF method to this image restoration problem is given by [9]:

$$\hat{I}(u,v) = \left[\frac{H^*(u,v)}{|H(u,v)|^2 + \gamma|P(u,v)|}\right] I(u,v) \qquad (3)$$

where $I(u, v)$, $H(u, v)$ and $\hat{I}(u, v)$ are the frequency representations of $I(x, y)$, $h(x, y)$ (i.e. the 2-D point spread function (PSF) of defocus), and $\hat{I}(x, y)$ respectively; γ is a constant that controls noise regularization, and $P(u, v)$ is the Fourier transform of a 3×3 Laplacian mask.

3.2. Estimating $H(u, v)$ and γ

Before applying Eq. 3, we have to know $h(x, y)$ and γ. In our work, $h(x, y)$ is modeled as a circular spot [9].

$$h(x,y) = \begin{cases} 1/\pi R^2, & \text{if } x^2 + y^2 \le R^2; \\ 0, & \text{others.} \end{cases} \qquad (4)$$

where R is the defocus radius of $h(x, y)$. The larger the defocus radius is, the higher the defocus level will be.

Typically, it is difficult to blindly estimate $h(x, y)$ without any prior knowledge. To address this problem, we turn to the spot distance again. The insight is that the defocus level is directly related to the image capture distance, which, as demonstrated in Section 2, can be reflected by the spot distance. Based on this idea, different defocus parameters (R and γ) are adaptively determined based on the spot distance. In detail, the spot distance in the input iris image is compared with that of the best focused image. And the bigger the difference is, the larger the defocus radius of $h(x, y)$ will be. In our work, an iterative search scheme [9] is adopted and pre-performed to learn appropriate R and γ at each image capture distance.

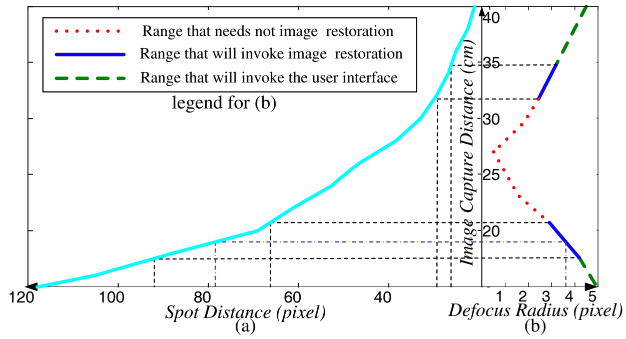

Fig. 4. The empirical relationships between the spot distance, the image capture distance and the defocus radius.

The jointly empirical relationships between the spot distance, the image capture distance and the defocus radius learned in our experiment are depicted in Fig. 4. For example, when the spot distance in a defocused image is 79 pixels, we can estimate that the corresponding image capture distance is about 19 cm. Then according to Fig. 4 the defocus radius of this image should be 3.6 pixels. By substituting R into Eq. 4 and Eq. 3, the defocused image can be restored and becomes more suitable for recognition, and hence the depth of field (DOF) is extended equivalently.

An important issue for improving the usability of iris recognition is the trade-off between requesting users to adjust their position and the application of the image restoration scheme. It is evident that the image restoration scheme should not be invoked when (1) the image defocus level is too low to spoil the recognition result and (2) the image defocus level is too high to be appropriate for recognition even with restoration. As shown in Fig. 4, only the images whose spot distance is within [27, 30] pixels and [66, 93] pixels can invoke the image restoration scheme. Images with a spot distance above 93 pixels or below 27 pixels will be excluded by the user interface with a distance feedback provided for the user.

4. EXPERIMENTAL RESULTS

A database was collected to evaluate the usefulness of the proposed method. This database contains 38 eye sequences from 19 subjects. For each eye sequence, 190 iris images at 19 different positions were captured (from 10 cm to 46 cm with an increment of 2 cm, and the best focus position is about 27cm from the camera lens). Based on this database, two experiments were conducted.

In the first experiment, we measure the efficiency of the proposed user interface. For each image, the image capture distance is estimated via its spot distance according to the

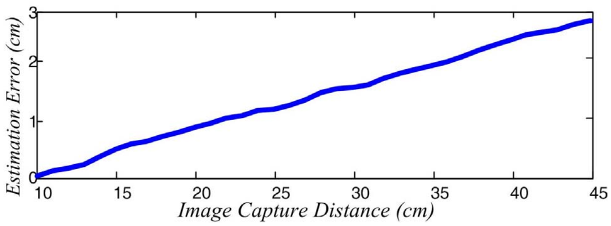

Fig. 5. The estimation error of our user interface.

empirical relationship curve shown in Fig. 3. The average estimation error at each capture distance is depicted in Fig. 5. We can see that the estimation is quite accurate, almost always within 5% error rate with respect to the genuine value. This means the proposed user interface can provide a correct distance feedback to users for their range adjustment.

In the second experiment, we test the efficiency of the proposed image restoration scheme via recognition performance. For each eye sequence, three best focused original images are enrolled as the templates [10, 11]. All other images with and without restoration are compared with these templates to generate the intra and inter matching scores (Note that images which are out of range (ICD<18cm or ICD>35cm) are excluded from template matching by the user interface.). The corresponding ROC curves are shown in Fig. 6 (The method described in [6] is implemented for comparison since it also adopts the CLSF method for iris image restoration with a Gaussian defocus model). From Fig. 6, we can see that the recognition performance is significantly improved by image restoration. Moreover, the proposed method slightly outperforms [6] because [6] tries to estimate the PSF of defocus via image focus assessment, which, as mentioned above, is often sensitive to noise and appearance of individual irises. More encouragingly, the computation cost of our restoration method is very small (about 5ms on a PC with 3.2GHz processor and 512M SDRAM).

5. CONCLUSION

This paper has made two contributions to enhance the usability of iris recognition. The insight is that the spot distance in an iris image is approximately inversely proportional to its image capture distance. Based on this observation, a friendly user interface and an adaptive iris image restoration scheme are developed, which, as demonstrated by our experimental results, brings significant improvements to image acquisition convenience and iris recognition performance. As a result, the usability of iris recognition is greatly enhanced.

6. ACKNOWLEDGE

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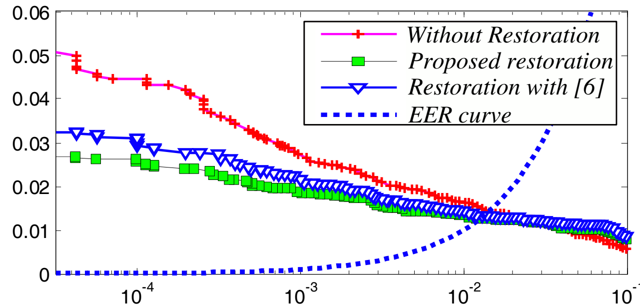

Fig. 6. ROC curves with different restoration methods.

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