Fake Iris Detection by Using Purkinje Image

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Abstract. Fake iris detection is to detect and defeat a fake (forgery) iris image input. To solve the problems of previous researches on fake iris detection, we propose the new method of detecting fake iris attack based on the Purkinje image. Especially, we calculated the theoretical positions and distances between the Purkinje images based on the human eye model and the performance of fake detection algorithm could be much enhanced by such information. Experimental results showed that the FAR (False Acceptance Rate for accepting fake iris as live one) was 0.33% and FRR(False Rejection Rate of rejecting live iris as fake one) was 0.33%.

1 Introduction

Counterfeit iris detection is to detect and defeat a fake (forgery) iris image. In previous research, Daugman proposed the method of using FFT (Fast Fourier Transform) in order to check the printed iris pattern [1][3][7]. That is, the method checks the high frequency spectral magnitude in the frequency domain, which can be shown distinctly and periodically from the print iris pattern because of the characteristics of the periodic dot printing. However, the high frequency magnitude cannot be detected in case that input counterfeit iris image is defocused and blurred purposely and the counterfeit iris may be accepted as live one in such case. The advanced method of counterfeit iris detection was introduced by iris camera manufacturer. They use the method of turning on/off illuminator and checking the specular reflection on a cornea. However, such method can be easily spoofed by using the printed iris image with cutting off the printed pupil region and seeing through by attacker's eye, which can make corneal specular reflection [6].

To overcome such problems, we propose the new method of detecting fake iris attack based on the Purkinje image by using collimated IR-LED (Infra-Red Light Emitting Diode). Especially, we calculated the theoretical positions and distances between the Purkinje images based on the human eye model and the performance of fake detection algorithm could be much enhanced by such information.

2 Proposed Method

2.1 The Overview of the Proposed Method

The overview of the proposed method is as following. At first, we capture an iris image and calculate the focus value of input image by the Daugman's method [7]. If the calculated focus value is bigger than the predefined threshold (as 50), we regard the input image as focused one and perform the iris recognition. However, the focus value is smaller than threshold, our system capture an iris image again until the well focused image is acquired enough to recognition. Then, if the user's identification is completed, our system turns on two 'collimated IR-LEDs', alternatively. The collimated IR-LED has the property of smaller illumination angle than the conventional IR-LED for iris recognition. One of the collimated IR-LEDs is used for measuring Z-distance between a camera and an eye, another is used for making the Purkinje image. Two 'collimated IR-LEDs' turns on, alternatively, synchronized with image frame and we can obtain two images. Then we capture a bright iris image with the 760nm + 880nm IR-LED and detect the regions of pupil and iris in image. At the next, we measure Z-distance between a camera lens and an eye. The measured Z-distance is used for calculating a theoretical distance between the Purkinje images. In detail, we define three 'the Purkinje image searching boxes' based on the measured Z-distance and the Purkinje image model (Fig. 1). The Purkinje image model is obtained by using the Gullstrand eye scheme [2]. Due to detecting Purkinje images in the searching boxes, we can reduce the processing time. Then we detect the 1st, 2nd and 4th Purkinje images in the searching boxes. From that, we check whether the 1st and 2nd Purkinje images exist in the searching box of the iris area (because of our system configuration of collimated IR-LED, the 1st and 2nd Purkinje images exist in iris region). If so, we also check whether the 4th Purkinje image exists in the searching box of the pupil area (because of our system configuration of collimated IR-LED, the 4th Purkinje image exists in pupil region). If so, we determine the input image as the live iris and accept the user. If not, we reject the input image as the fake iris.

2.2 The Proposed Iris Camera Structure

Our iris recognition camera (made by our Lab.) uses dual IR-LEDs for iris recognition and two collimated IR-LEDs. For camera, we use a conventional USB camera (Quickcam-Pro 4000 [9]) with CCD sensor (in which IR-cut filter is removed).

The wavelength of dual IR-LEDs for recognition is 760nm and 880nm. In this camera, we also use two collimated IR-LEDs. The illumination (divergence) angle of collimated IR-LED is about 2.9 degrees.

2.3 Detecting Purkinje Images

Conventional human eye has four optical surfaces, each of which reflects bright lights: the front and back surface of the cornea, and the front and back surface of the lens. In this case, the 4 reflected images of incident light on each optical surface are mentioned as Purkinje images. The positions of these four Purkinje reactions depend on the geometry of the light sources [5]. Fig.1 is the Purkinje image shaping model which is designed based on the Gullstrand eye model [2].

To overcome the vulnerable problems of the Daugman method using the Purkinje images [4], we consider the shaping model of the Purkinje image. Since this model is designed with the Gullstrand eye model, the theoretical distances between the Purkinje images can be obtained. Because such distances are determined by human eye model (such as refraction rate, diameter of cornea and lens, etc), the distances from live iris are different from those from fake one. So, it is difficult to make fake iris showing the Purkinje images having same distances to those of live eye, because the material characteristics (such as refraction rate, diameter of cornea and lens, etc) of fake iris is different to that of live iris. In Fig.1, we show the method of calculating the theoretical distances between the Purkinje images.

In Fig.1, the radius and the focal length of an each optical surface (anterior cornea, posterior cornea, anterior lens, posterior lens) are shown. C_{ac} is the center of an anterior cornea's curvature and the radius of anterior cornea is 7.7 mm. F_{ac} ($= 3.85$ mm) is a focal point (a half of radius). Similarly, C_{pc} is the center of a posterior cornea's curvature and the radius of anterior cornea is 6.8 mm. F_{pc} ($= 3.4$) is the focal point of posterior cornea's curvature. C_{pl} is the center of a posterior lens's curvature and the radius of posterior lens is -6.0 mm. F_{pl} ($= -3.0$ mm) is the focal point of posterior lens's curvature [2].

Fig. 1. The Purkinje image shaping model

Since the 1st, 2nd and 3rd Purkinje image are shaped by reflecting from a convex mirror, images are virtual and erect. But the 4th Purkinje image is real and inverted since it is shaped by reflecting from a concave mirror. Due to these facts, we can know the 1st and 2nd Purkinje images exist in symmetric position to 4th Purkinje image about the center of iris. Actually, there can be 3rd Purkinje image made from anterior lens. But, the 3rd Purkinje image is not seen in image. That is because the 3rd Purkinje image happens on the behind position of an iris from the camera. Generally, a diameter of pupil is reported to be 2mm~8mm [3] and its size is changed according to environmental light. The stronger the light is, the smaller the pupil size becomes. In our case, since we use collimated IR-LED and its light is entered into the pupil area,

the pupil size becomes the smallest (2mm). So, the iris area is enlarged consequently and the 3rd Purkinje image is hidden by an iris area in captured eye image (cannot be seen).

Now, we introduce the method of calculating the distances between the 1st, 2nd and 4th Purkinje images, theoretically. As seen in Fig. 1, we can suppose the surfaces of anterior and posterior corneas as convex mirror models. In addition, we can do the surfaces of posterior lens as concave mirror model. So, we can use the camera lens model [8].

The 1st Purkinje image :

$$y_{1st} = \frac{D \cdot F_{ac}}{D - F_{ac}} \quad x_{1st} = \frac{l \cdot (7.7 - y_{1st})}{D + 7.7} \quad (1)$$

(because the radius of anterior cornea is 7.7, D is the distance between camera lens and anterior cornea surface. l is that between camera lens and collimated IR-LED as shown in Fig. 1)

The 2nd Purkinje image :

$$y_{2nd} = \frac{F_{pc} \cdot (D + 0.5)}{(D + 0.5) - F_{pc}} + 0.5 \quad x_{2nd} = \frac{l \cdot (7.3 - y_{2nd})}{D + 7.3} \quad (2)$$

(because the depth of cornea is 0.5 and the radius of posterior cornea is 6.8.
7.3 = 6.8 + 0.5)

The 4th Purkinje image :

$$y_{4th} = 7.2 + \frac{F_{pl} \cdot (D + 7.2)}{(D + 7.2) - F_{pl}} \quad x_{4th} = \frac{l \cdot (y_{4th} - 7.2)}{D + 7.2} \quad (3)$$

(because the distance between the anterior cornea and the posterior lens is 7.2)

(In all cases, l is 50mm as shown in Fig. 1)

According to the similarity of triangle and equation (1), an each Purkinje image's axis values on coordinate x, y is as follows. By using x_{1st} , x_{2nd} , x_{4th} and the perspective transformation, we can obtain the corresponding position of the 1st, 2nd and 4th Purkinje images in input image as shown in Eq. (4)(5)(6). Experimental results (from 100 test images) show that the x image positions of the 1st, 2nd and 4th Purkinje images are 42.9, 38.1 and -33.7 pixels, respectively. And the measured x range of iris region is -37.7 ~ +37.7 pixels in image. From that, we can know that the 1st and 2nd Purkinje image exist in the iris area, but the 4th Purkinje image does in the pupil area in a captured image. And we can obtain the distance between the 1st and 4th Purkinje image in Eq.(7). Also, we can measure the distance between the 1st and 2nd Purkinje image in Eq.(8).

$$1^{st} \text{ Purkinje image in CCD plane} \quad : \quad p_{1st} = \frac{fc \cdot X_{1st}}{D + Y_{1st}} \quad (4)$$

$$2^{nd} \text{ Purkinje image in CCD plane} \quad : \quad p_{2nd} = \frac{fc \cdot X_{2nd}}{D + Y_{2nd}} \quad (5)$$

$$4^{\text{th}} \text{ Purkinje image in CCD plane} : p_{4th} = \frac{fc \cdot X_{4th}}{D + Y_{4th}} \quad (7)$$

$$d_1 = p_{1st} - p_{4th} \quad (8)$$

$$d_2 = p_{1st} - p_{2nd}$$

2.4 Finding the Purkinje Image in the Searching Box

Based on Eq.(7) and (8), we can know the theoretical distance between the 1st and 4th Purkinje image, and that between the 1st and 2nd Purkinje image. So, we first detect the 1st Purkinje image in input image by the information of p_{1st} in Eq. (4). Then, we define the 2nd and 4th Purkinje image searching boxes (for the 2nd Purkinje image, the size of searching box is 20*20 pixels. For the 4th Purkinje image, the size of searching box is 37*37 pixels.) by the information of d_1 and d_2 in Eq. (7)(8) and detect the 2nd and 4th Purkinje images in the searching boxes. To detect the Purkinje images in the searching box, we perform the binarization (threshold of 190), component labeling and size filtering [8]. The sizes of Purkinje images are largest in each searching box. From that, we can detect the exact positions of the Purkinje images excluding the noise by eyebrows, etc.

3 Experimental Result

For experiments, the live iris samples were acquired from 30 persons (10 persons without glasses (no contact lens), 10 persons without glasses (contact lens) and 10 persons with glasses (no contact lens)). Each person tried to recognize 10 times and total 300 eye images were acquired to test our algorithm. In addition, we acquired total 15 counterfeit samples for testing. They were composed of 10 samples for 2D printed iris image on planar or on / with convex surface. Also, 2 samples were acquired for 3D artificial eye. And 3 samples were for 3D patterned contact lens. With each sample, we tried to 20 times to spoof our counterfeit iris detecting algorithm.

At first test, we measure the accuracy of our fake detection algorithm with FAR and FRR. Here, the FAR means the error rate of accepting the counterfeit iris as the live one. And the FRR does the error rate of rejecting the live iris as the counterfeit one. Experimental result shows that the FAR is about 0.33% (1/300) and FRR is 0.33% (1/300), but the FRR becomes 0% allowing for the second trial of fake checking. In this case, FRR does not happen in case of live iris with normal contact lens. In detail, about 2D printed iris image on planar or on / with convex surface, the FAR is 0% (0/200). About 3D artificial eye, the FAR is also 0% (0/40). However, the FAR is increased to 1.67% (1/60) about 3D patterned contact lens. In case of fake contact lens, the attacker uses his live pupil and 1 cases of FAR (that the 1st, 2nd and 4th Purkinje images happen like live iris) happen.

At second test, we measure the error rate according to Z distance between eye and camera. As shown in Table 1, the FAR and FRR are almost same irrespective of Z distance.

Table 1. Z Distance vs. the FAR and the FRR

Distance(mm)	80	100	120	140	160	180	200	220	240	250
FAR(%)	0.11	0.10	0.09	0.11	0.11	0.09	0.12	0.11	0.09	0.11
FRR(%)	0.34	0.31	0.33	0.30	0.32	0.33	0.33	0.34	0.30	0.34

At third test, we measure the accuracy according to the size of searching boxes for the 2nd and 4th Purkinje images. Experimental results show that when the size of searching box is increased, the FAR is increased and FRR is decreased, vice versa. From that, we can know that if we use the size of searching box for the 2nd and 4th Purkinje images as 20*20 and 37*37 pixels respectively, we can obtain the performance of minimum EER (FAR = FRR = 0.33%).

Fig. 2. The test examples of live and fake iris.(a) Live eye. (b) Live eye with a normal contact lens. (c) Live eye with glasses. (d) 2D printed eye. (e) 3D print eye with a contact lens. (f) Eye with 3D fake patterned lens. (g) 3D artificial eye. (The left of each part image is normal image and the right of each part is the Purkinje image).

The processing time of detecting Purkinje images is so small as 11ms in PC of Pentium-4 2GHz CPU. Fig. 2 is the test examples of live and fake eyes. As shown in Fig.2 (a), (b), (c), we can know that the 1st and 2nd Purkinje images exist in an iris area and 4th Purkinje image does in pupil area. In case of (c), though the specular reflection on glasses surface happen, such 3 Purkinje images still happen. As shown

in Fig.2 (d), (e), (f), we can know that the fake eye shows the different characteristics from the live eye about Purkinje image. Especially, in case of (d) and (e), we can find that a big bright spot happens in the pupil region different from live iris. That is because the pupil area of such fake iris is not a hole and a big bright spot reflected on surface happens. In case of (f), we can't find the 2nd Purkinje image because the refraction factor of patterned lens is different from that of live iris. In case of (g), the 3D artificial eye shows also big bright spot. And though it shows the 1st, 2nd and 3rd Purkinje images, the distances between them are different from those of live iris.

4 Conclusions

For higher security level of iris recognition, the importance for detecting iris is much highlighted recently. In this paper, we propose the new method of detecting fake iris attack based on the Purkinje image. Experimental results show that the FRR and FAR are 0.33%, respectively. To enhance the performance of our algorithm, we should have more field tests and consider more countermeasures against various situations and counterfeit samples in future.

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