ROBUST FAKE IRIS DETECTION BASED ON VARIATION OF THE REFLECTANCE RATIO BETWEEN THE IRIS AND THE SCLERA

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ABSTRACT

In this paper, we propose a new fake iris detection method based on the changes in the reflectance ratio between the iris and the sclera. The proposed method has four advantages over previous works. First, it is possible to detect fake iris images with high accuracy. Second, our method does not cause inconvenience to users since it can detect fake iris images at a very fast speed. Third, it is possible to show the theoretical background of using the variation of the reflectance ratio between the iris and the sclera. To compare fake iris images with live ones, three types of fake iris images were produced: a printed iris, an artificial eye, and a fake contact lens. In the experiments, we prove that the proposed fake iris detection method achieves high performance when distinguishing between live and fake iris.

1. INTRODUCTION

Biometrics refers to the automatic recognition of individuals based on their physiological and/or behavioral characteristics[1]. Generally the physiological characteristics include fingerprints, hand geometrical features, retinas, irises, palm prints, hand veins, and face and so on. Compared to traditional authentication systems that are based on "what he remembers" (e.g., a password) or "what he possesses" (e.g., an ID card), biometrics authentication systems have many advantages. First, they can inextricably link the authenticator to its owner. This means that they are less easily lent or stolen than other authenticators such as passwords and ID cards [13]. Second, biometric systems are more convenient, since it is not necessary for users to memorize passwords or carry ID cards. However, in spite of those advantages, biometrics authentication systems are faced with problem that arises from fake biometrics. For example, "Gummy" fingers (fingers artificially made with gelatin) have already been falsely accepted as real fingers by 11 commercial fingerprint systems [2]. In other words, biometric data can also be copied although it is more difficult to do this than with passwords and ID cards.

In this paper, we focused on the fake iris detection method for iris recognition systems. It has been reported that iris recognition systems have also been deceived by fake biometrics which is called fake iris. For instance, L. Thalheim and J. Krissler captured user's eye images with a camera used in a commercial iris recognition system and printed the images on matte paper. They then cut off a hole in the pupil and succeeded in deceiving the commercial iris recognition system with this printed fake iris [3]. In addition, Matsumoto also succeeded in deceiving three commercial iris recognition systems using the same kind of fake iris. They captured iris images not only with the camera used in the commercial iris recognition system but also with a commercial infra-red camera. They found that the commercially available infra-red camera was also good enough to get iris images for fake irises [4]. In other words, current iris recognition algorithms cannot always distinguish fake irises from live ones. Therefore, we need a more robust algorithm in order to detect fake irises with more reliability.

To detect fake irises, it is necessary to find a feature that distinguishes between live irises and fake ones. Lee et al. suggested such a feature. This was a variation of the reflectance ratio between the iris and the sclera when the wavelength of illumination changes [16][17][18]. In live irises, the reflectance ratio between the iris and the sclera significantly increases as the wavelength of near-infrared illumination increases from 750nm to 850nm. In fake irises, however, both the iris and the sclera are made from different materials than those used in live ones. Therefore, the reflectance ratio variation is not the same as that of live iris and live sclera. In this paper, we have improved on that research by considering the reflectance model and finding the iris and the sclera regions reasonably, by analyzing the gradient variation nearby the outer boundary of the iris. As a result, there was no error when detecting printed fake irises compared to previous work [16]. In addition, we perfectly

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distinguished artificial eyes and some of fake contact lenses from live irises.

The remainder of this paper is organized as follows. Section 2 explains the feature that was used for fake iris detection and how we measured them. Section 3 shows experimental results. Finally, Section 4 presents conclusions and suggestions for future work.

2. PROPOSED METHOD

In order to detect fake irises, we used the changing reflectance properties between the iris and the sclera with variations of wavelengths of incident light. Although this method was first suggested by Daugman [20, 21], he did not show how these kinds of features can be measured by image processing. In addition, he did not consider the theoretical reflectance model. Lee et al. also used this feature to detect fake irises. However, the iris and sclera regions were set arbitrarily. This meant that they could not always distinguish printed fake irises from live irises [16]. To overcome this problem, we propose a method of detecting live and fake irises based on reflectance properties considering the theoretical reflectance model. In addition, we set the iris region and the sclera region reasonably by analyzing the gradient variation nearby the outer boundary of the iris.

2.1. Reflectance Properties of the Iris and the Sclera

The iris is a diaphragm that lies in front of the lens and ciliary body and separates the anterior chamber from the posterior chamber. The color of the iris depends on the amount of melanin in the anterior border layer. For example, blue irises contain minimal pigment and few melanosomes. Green-hazel irises are the product of moderate pigment levels, melanin intensity and melanosome numbers. Brown irises are the result of high melanin levels and melanosome numbers [14]. The reflectance of the iris is also affected by the amount of melanin in the anterior border layer. The reflectance of melanin slightly increases as the wavelength of illumination increases from 750nm to 850nm [15]. Therefore, the reflectance of the iris also increases when the wavelength of illumination increases from 750nm to 850nm. The sclera is a dense, fibrous, collagenous structure that comprises the posterior five-sixths of the eye. According to previous work [5], the reflectance of the sclera slightly decreases as the wavelength of illumination increases from 750nm to 850nm.

As a result, the reflectance ratio of the iris to the sclera is greater at longer wavelengths than at shorter wavelengths. However, for fake irises produced by printers and found in photographs, the iris and the sclera are made from the same material. This means that they show similar changes in reflectance as the wavelengths vary. Therefore, the reflectance ratio of the iris to the sclera does not change when wavelength of incident light varies. Although, with fake irises from artificial eyes, where the iris and the sclera are made from different materials they are not exactly the same as the iris and the sclera of live eyes. Therefore, the change of the reflectance ratio of the iris to the sclera is not the same as that of live irises. In short, if we measure the change of the reflectance ratio between the iris and the sclera with variations of wavelengths of incident light, it is possible to detect fake irises.

2.2. How to Measure Reflectance Variation

The reflectance ratio is a kind of feature that represents the properties of a given material. Those properties can be computed as a ratio of the reflectance coefficients of two neighboring regions [6][7].

In order to estimate the reflectance ratio, we first mention some factors that influence the reflectance of a surface. These factors include the angle of incidence, the angle of reflection, surface normal, the wavelength of the incident light, and reflectance coefficient of object as shown in fig. 1. [9][10].

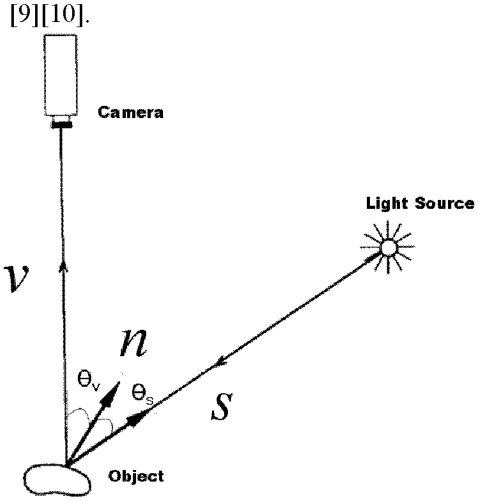

Fig. 1. Geometry of illumination, camera, and object

If we have two neighboring points located on a smoothly curved surface and they lie on the different materials, they have almost the same surface normal, n , illumination direction, s , and sensor direction, v but their reflectance coefficient differs. From that, we can see that the ratio of the reflectance coefficient can be measured by that of the image intensity (I_1 / I_2).

To detect fake irises based on the reflectance ratio, the reflectance ratio between the iris and the sclera region at 750nm was calculated as follows:

$$p_{750} = I_{I\_750} / I_{S\_750} = \rho_I(750) / \rho_S(750) \qquad (1)$$

, where, I_{S_750} and I_{I_750} are the image intensity of the sclera and the iris at 750nm illumination, respectively. They are located close to the outer boundary of the iris[19]. In addition, $\rho_S(750)$ and $\rho_I(750)$ are the reflectance coefficients of the sclera and the iris at 750nm illumination, respectively.

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Likewise, the reflectance ratio between the iris and the sclera region at 850nm illumination can be expressed as follows:

$$p_{850} = I_{I\_850} / I_{S\_850} = \rho_I(850) / \rho_S(850) \qquad (2)$$

, where, I_{S_850} and I_{I_850} are the image intensity of the sclera and the iris at 850nm illumination, respectively. They are also located close to the outer boundary of the iris. $\rho_S(850)$ and $\rho_I(850)$ are the reflectance coefficients of the sclera and the iris at 850nm illumination, respectively. Based on Eq. (1) and (2), we can see that the value p_{750} and p_{850} are only affected by the material properties such as $\rho_S(750)$, $\rho_I(750)$, $\rho_S(850)$ and $\rho_I(850)$. From these, the reflectance ratio between the iris and the sclera can be computed by averaging the reflectance ratios between the target iris region (A) and the sclera region (B) as shown in fig. 2.

The following procedure was used to acquire the iris and sclera region points in an image as shown in Fig. 2. First, we found the outer boundary of the iris by using a circular edge detector [8]. Second, we chose a region free from occlusions caused by eyelids or eyelashes.

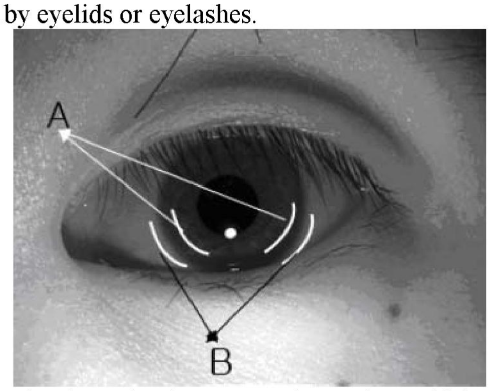
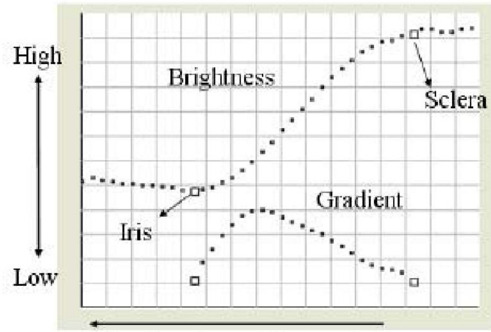


Fig. 2. Iris (A) and sclera (B) region points which are used for computing the reflectance ratios

Third, the iris and sclera region points were determined. It is important that the distance between the sclera and the iris points is small enough to have almost the same direction vector of incident light, view and surface normal. In Lee *et al.*'s work, the iris region and the sclera region were obtained with a margin of few pixels from the outer boundary of the iris [16]. With this approach, however, it is not always possible to find the correct iris and sclera regions because the outer boundary of the iris differs from person to person. Therefore, we examined the intensity profile at the outer boundary of the iris and found the gradient of image intensity, as shown in Fig 3.



Direction toward iris center

Fig. 3. Intensity and gradient profile at outer boundary of the iris

When the gradient of image intensity in the direction of the iris center decreased below a certain threshold, we determined this region as the iris. When the gradient in the direction of the sclera decreased below a certain threshold, we determined this region as the sclera.

In the live iris, the reflectance of the iris increase as the wavelengths increase from 750nm to 850nm. But the reflectance of sclera decrease as the wavelength increase from 750nm to 850nm as explained in Section 2.1. Therefore, the reflectance ratio computed at 850nm, p_{850}, is higher than that at 750nm, p_{750}. In the fake iris, however, the reflectance ratios at 750nm, p_{750}, and at 850nm, p_{850}, did not change as much as those in the live iris when the wavelengths increase.

Therefore, we set the criterion for detecting a fake iris as the ratio value between p_{850} and p_{750}, as shown in Eq. (3).

$$p_{850} / p_{750} = \frac{I_{I\_850}}{I_{S\_850}} / \frac{I_{I\_750}}{I_{S\_750}} = \frac{I_{I\_850}}{I_{I\_750}} / \frac{I_{S\_850}}{I_{S\_750}} = \frac{\rho_I(850)}{\rho_I(750)} / \frac{\rho_S(850)}{\rho_S(750)} \qquad (3)$$

In Eq. (3), the numerator refers to the increasing rate of the reflectance of the iris. The denominator refers to the decreasing rate of the reflectance of the sclera when the wavelength increases from 750nm to 850nm. From that, we can discriminate between live irises and fake ones, since the ratio value of live irises is larger than that of fake irises.

3. EXPERIMENTAL RESULTS

In order to perform a test on the proposed algorithm, the database of live and fake iris image were constructed. The performance of the proposed algorithm was evaluated by using False Accept Ratio (FAR) and False Reject Ratio (FRR). FAR refers to the probability of accepting a fake iris as a live iris and FRR refers to the probability of rejecting a live iris as a fake iris.

3.1. Database

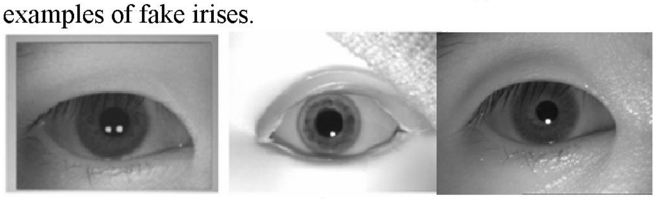
Many iris databases already exist (such as the CASIA iris database, etc.) but these databases were constructed under constant illumination conditions. In other words, when the iris images were captured, the wavelength of illumination did not change. Therefore, we constructed a new iris database by using two illuminations in sequence. First, we captured an eye image at 750nm IR (Infra-red) illumination. Next, we captured the same eye image at 850nm IR illumination. All images were captured using a near IR camera [11]. In addition, we attached an IR pass filter, which can cut off visible band illumination, in front of the camera lens so that only near infra-red illumination affected the iris images. The captured iris images were 8-bit gray images with a resolution of 640×480 pixels.

The new database includes 2800 images from both eyes of 70 subjects. Each eye was captured ten times at 750nm illumination, and ten times at 850nm illumination. The iris colors of the captured eyes varied from dark brown to light blue. The number of persons with blue irises was nine. Eight people had green irises, three had hazel irises, and fifty had brown irises. In addition, iris images were taken from Asians, Africans and Caucasians. During image acquisition, short-sighted subjects were requested to take off their glasses. However, subjects with transparent contact lenses were an exception.

In order to test the performance of our algorithm, we classified possible attacks into three cases. For the first attack, printed fake iris were produced with a high resolution ink jet printer, HP photosmart7960, which have 1200 DPI resolution [12] and a laser printer, HP laser jet 4300n, with matte paper as shown in Fig. 4.(a). We made the printed fake irises from 40 person's eye images. In addition, we made 10 fake iris samples from each person so that the numbers of fake samples that are made by the ink jet printer was 400 and that made by the laser printer was 400.

For the second attack, the artificial eyes were made from Poly Methyl Meta Acrylate (PMMA) as shown in Fig. 4.(b). The artificial eyes we used were made using three different colors: blue, gray and dark brown. We captured 10 images for each color so that the numbers of artificial eyes was 30.

For the third attack, the fake contact lenses were made with three different colors: blue, gray, and yellow as shown in Fig. 4.(c). We captured 10 images for each color so that he numbers of fake contact lenses are 30. Fig. 4 shows some examples of fake irises.



(a) (b) (c)

Fig. 4. Fake irises made with high resolution printer (a), artificial eyes (b), and fake contact lens(c).

3.2. Performance test against fake irises

With the live iris database and the entire fake iris database, we found the distribution of the p_{850}/p_{750} values as shown in Fig. 5

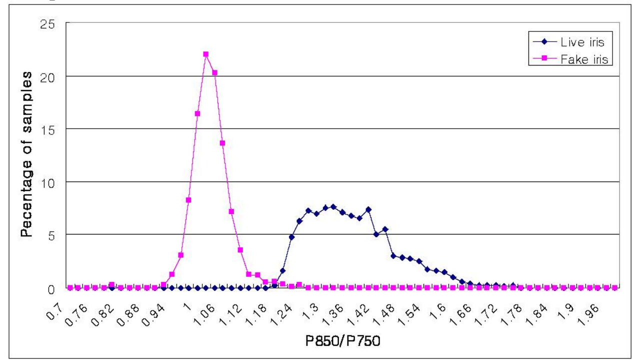


Fig. 5. Distribution of the p_{850}/p_{750} values of the live and the entire fake irises

By using the Bayesian rule based on Fig. 5, we determined the threshold as 1.204. With that threshold, we obtained the accuracy of the FAR as 0.46 % and the FRR as 0.28 %. In order to analyze the results, we also found the distribution of the p_{850}/p_{750} values for each attack.

First, we compared the live iris database with the printed fake iris database and found the distribution as shown in Fig. 6.

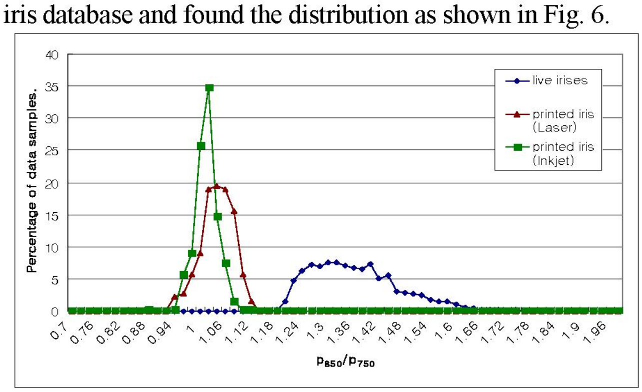


Fig. 6. Distribution of the p_{850}/p_{750} values of the live and the printed fake irises

Note that the variance of the criterion value of the printed fake iris is smaller than that of the live iris since the iris and the sclera were made from similar material in the printed fake iris.

Second, we compared the live iris database with the artificial eye database and found the distribution as shown in Fig. 7.

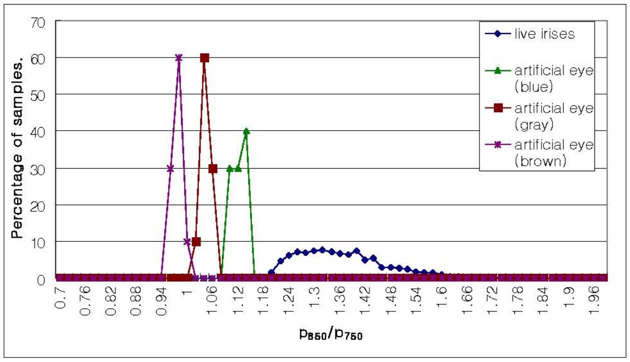


Fig. 7. Distribution of the p_{850} / p_{750} values of the live and the artificial eyes

As we can see in the results, the ratio value with the artificial eyes did not vary as much as that with the live irises. Note that the ratio values (p_{850} / p_{750}) varied according to the color of the artificial eyes, since every color has unique spectral reflectance properties. In our experiment, blue absorbed a larger amount of 750nm illumination than the other colors, so the ratio value became much closer to that of a live iris. However, the ratio value from blue artificial eyes was still small compared to that of the live irises.

Third, we compared the live iris database with the fake contact lenses database and found the distribution, as shown in Fig. 8.

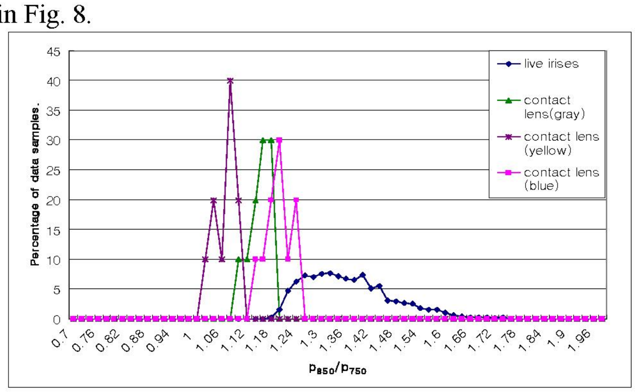


Fig. 8. Distribution of the p_{850} / p_{750} values of the live and the fake contact lenses

As shown in the results, the ratio of gray and yellow fake contact lenses did not vary as much as that of the live irises, but blue fake contact lenses showed a similar ratio value to the live irises, since blue absorbs a larger amount of 750nm illumination, and the sclera of the fake contact lenses is the same as that of the live irises. Table 1 summarizes the FAR and FRR values of each case (using the same threshold).

Table 1. FAR, and FRR obtained by comparing live irises with various fake irises

	FAR	FRR
Printed iris(inkjet)	0%	0.28%
Printed iris(laser)	0%	0.28%
Artificial eye (blue)	0%	0.28%
Artificial eye (gray)	0%	0.28%
Artificial eye (brown)	0%	0.28%
Fake contact lens (blue)	40%	0.28%
Fake contact lens (gray)	0%	0.28%
Fake contact lens (yellow)	0%	0.28%

4. CONCLUSIONS

In this paper, we have proposed a method of distinguishing between live and fake irises by measuring the ratio values of the reflectance ratio measured at 750nm and at 850nm illumination. The reflectance of live iris increases when the wavelength of illumination increases from 750nm to 850nm but that of sclera decreases. As a result, the reflectance ratio between the iris and the sclera increases as the wavelength increases from 750nm to 850nm. We used those unique reflectance properties to detect fake irises. In order to measure the reflectance ratio quantitatively, we set the iris region and the sclera region by analyzing the gradient of the outer boundary of the iris. Since the chosen iris and the sclera region were located very close to each other, they had almost the same surface normal, illumination and sensor direction. This means that we could find the reflectance ratio between the iris and the sclera by measuring the ratio between the intensity of the chosen iris and the sclera regions.

By using the proposed method, we were able to detect various kinds of fake irises. As can be seen in the experimental results, the proposed method was able to completely distinguish live irises (which included blue, green, hazel, and brown eyes) from fake iris images made by not only high resolution inkjet and laser printers, but also artificial eyes and gray and yellow fake contact lenses. However, the proposed method could not always distinguish live irises from blue contact lenses. In future work, we will research other features which can perfectly identify fake contact lenses.

ACKNOWLEDGEMENTS

This work was supported by the Korea Science and Engineering Foundation (KOSEF) through the Biometrics Engineering Research Center (BERC) at Yonsei University.

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