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Contact Lenses Detection Based on the Gaussian Curvature

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Abstract. Iris recognition is a kind of biometrics recognition with good stability, which is reliable, effective and safe. However, some attack means such as paper printed iris, iris images, simulated eyes, color contact lenses and the others are quite deceptive for iris recognition system. The recognition result of iris recognition system is meaningful only when the authenticity of the feature is guaranteed. At present, the iris anti-spoofing with contact lenses is seldom studied, and the recognition rate is not ideal. Based on the above background, aiming at the characteristics of gaussian curvature change of corneal outer surface caused by wearing contact lenses, this essay proposes a detection method of contact lenses based on depth feature. The effective depth information of cornea is obtained by depth camera, gaussian curvature of cornea is calculated, and features are extracted by sum of squared deviations. Experimental results show that this method can effectively identify whether to wear contact lenses, low error rate, high efficiency, which can meet the requirements of practical application.

Keywords: contact lenses detection, gauss curvature, iris recognition, live iris detection, sum of squared deviations

1 Introduction

In recent years, iris recognition technology has attracted more and more attention in the field of biometric recognition [1]. An important problem of iris recognition is that in the face of a forged physical composite sample (photos, fake eyes, contact lenses) [2-4], new effective protection measures need to be developed to ensure the authenticity and legitimacy of the features. Over the past decade, biometric researchers, developers, institutions, and vendors have engaged in the challenging task of developing effective protection against spoofing threats.

Living iris detection technology can be divided into two types:hardware-based methods and software-based methods.

The hardware-based approach detects specific features of a living body (such as the dynamic reflexes of the eyes or pupils) by adding special devices. In general, the hardware-based method detects one of the following three features: (1) Inherent characteristics of the living body; (2) An involuntary living signal; (3) The response to external stimuli is also known as the “challenge-response” method. Hardware based methods mainly include: Daugman performed in vivo iris detection by analyzing pupil contraction and contraction changes and corneal reflex under light of different bands [5]. A method of Purkinje reflection imaging was proposed to determine iris activity [6]. The pupil contraction under light stimulation was used for in vivo iris detection [7].

Software-based approach: in this case, the false feature is detected once the sample is acquired, that is, using the feature extracted from the biological feature to distinguish the true or false feature, rather than through the human body itself. Representative methods include: [10] proposed a method of iris texture spectrum analysis based on FFT. Weighted LBP iris texture analysis was used to detect forged iris [11].

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A method of iris texture analysis based on deep learning was proposed [12-13] proposed an iris texture analysis method using CNN convolutional neural network.

The methods mentioned above have higher recognition rate for photos, paper printed irises and artificial eyes, and are less effective in detecting contact lenses and contact lenses attacks. In view of the gaussian curvature change of the external corneal surface caused by wearing contact lenses, this essay proposes a contact lens detection method based on depth feature. he effective depth information of cornea is obtained by depth camera, gaussian curvature of cornea is calculated, and features are extracted by sum of squared deviations. Compared with other methods, this algorithm has better recognition effect in detecting contact lenses.

2 Principle and Algorithm

2.1 Principles

The structure of the human eye is shown in the following picture: the iris of the front of the eyeball is the object of our iris recognition, and the outer layer is the cornea, which is the membrane of the front of the eyeball. The normal cornea appears as a sphere, the gaussian curvature of each point is basically unchanged, and the shape of the cornea of human eyes tends to be stable after the age of 3. Myopia has no influence on the curvature of the cornea [14], which is also the main part covered by contact lenses. The above conditions indicate that the gaussian curvature of the outer corneal surface is a stable and detectable intrinsic characteristic.

Contact lenses are shown in Fig. 2: the standard type of contact lenses is about 14mm in diameter, and the thickness decreases from the center to the edge, with the center thickness being 0.04-0.09mm and the edge thickness being 0.01-0.02mm. After wearing contact lenses, the gaussian curvature of the outer surface of the cornea will change obviously from the original sphere to an ellipsoid with large central curvature and small marginal curvature.

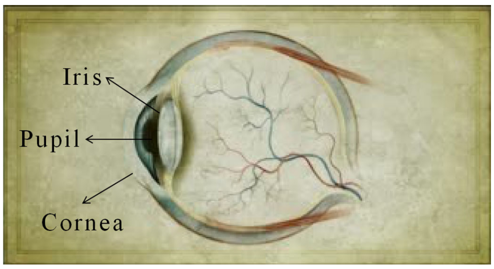
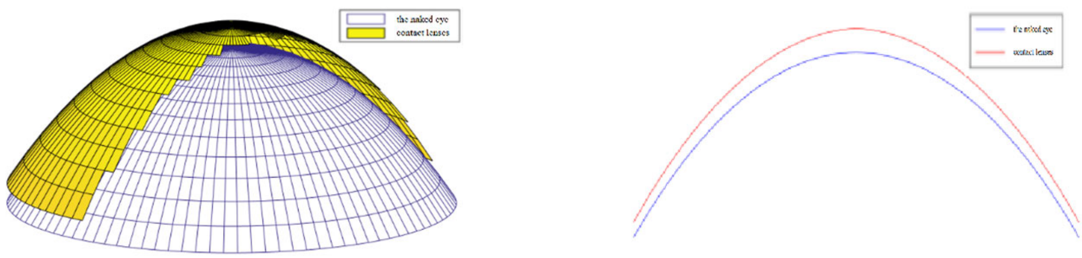


Fig. 1. The structure of the eye

Fig. 2. Contact lenses

Fig. 3 shows the three-dimensional curved surface and vertical profile curve of wearing contact lens. In Fig. 3(a), the blue transparent grid part is the 3d scanning surface of the naked eye, the yellow part is the 3d surface after wearing contact lenses. In Fig. 3(b). The blue curve is the vertical profile of the naked eye, while the red curve is the vertical profile after wearing contact lenses. As can be seen from Fig. 3, there is a significant difference in gaussian curvature between the two surfaces, which can be used to contact lens detection.



(a) The 3d surface

(b) The vertical profile

Fig. 3. Three-dimensional scanning and vertical profile of wearing contact lens

2.2 Algorithm

The contact lens detection algorithm proposed in this essay can be summarized as follows:

Image acquisition: the optical structure depth camera was used to obtain the naked eyes of N samples and the depth images after wearing contact lenses, as well as the corresponding gray images.

Normalization: depth image and gray image are normalized to make one correspond with the other.

Get depth information: the pupil and iris of the grayscale image were located to obtain the effective range free from the interference of eyelids and eyelashes and projected into the depth image. The effective depth information matrix M was extracted and the size of M will be normalized.

Computed gaussian curvature: Gaussian curvature of each point in M is calculated by using the gaussian curvature modeling method in section 3.2, and the gaussian curvature matrix M_1 is obtained.

Feature extraction: the sum of squared deviations algorithm is used to deal with the difference square of M_1, and the matrix M_2 is obtained.

Sample classification: A classifier was used to classify the sample data M_2 after the above processing.

3 Feature Extraction and Processing

3.1 Get Depth Information

Depth images were collected using a depth camera based on the principle of optical structure method, Grayscale images are collected using the corresponding normal camera. Depth image acquisition is a static process and requires high accuracy. The projection coding of depth camera adopts time-division multiplexing (TDM) coding, which can acquire human eye depth images with micron accuracy.

In order to eliminate the interference caused by the depth information of the eyelids and eyelashes, an effective interval should be delimited on the depth image, and the depth information matrix should be obtained within the interval. Therefore, the depth image and the grayscale image are normalized to locate the position of the pupil and iris on the grayscale image, define the effective range, and project it into the depth image. The specific process is as follows:

In the grayscale image, the Hough circle transform algorithm is used to detect the inner and outer boundaries of the iris to obtain the central position of the pupil, pupil diameter d and iris diameter D (as shown in Fig. 4). Find the effective area (A) of a rectangle with H as the center. To ensure complete elimination of eyelids and eyelashes, use coefficients a,b to adjust the range of the effective area: $A = ad * bD$ ($a < 1$, $b > 1$). In the formula, ad is the width of A and bD is the length of A, the effective area obtained is shown in Fig. 5. The effective area is projected onto the depth image to obtain the depth information matrix within the range.

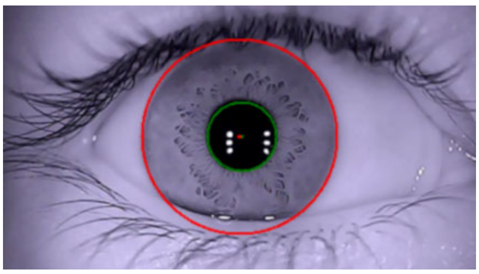


Fig. 4. Iris edge detection

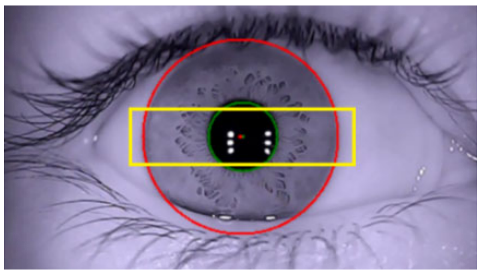


Fig. 5. Location of the effective area (within the yellow area)

3.2 Gaussian Curvature Calculation Based on Triangular Mesh

Gaussian curvature reflects the general curvature of a surface. Let the two principal curvature of point P on the surface be k_1 and k_2, then $k=k_1*k_2$ is called the total curvature or gaussian curvature of point P [15]. The depth information matrix extracted in the above section needs to calculate the gaussian curvature of each point through the triangular mesh method. The specific steps are as follows:

(1) The depth information matrix M is put into the three-dimensional cartesian coordinate system to obtain the coordinates of each point.

(2) KNN (K Nearest Neighbor) is used to replace geometric connection information with spatial information to determine the Nearest Neighbor of a certain point and collect the Nearest Neighbor set:

$$\tilde{N}_i(x_i) = \{ j : \| x_i - x_j \| < r_i \} \quad \textbf{(1)}$$

(3) Project the point in $\tilde{N}_i$ into the tangent plane of x_i and get $P(x_J)$. Delaunay Triangle is used to process $P(x_J)$. and get T_i. To redefine the Nearest Neighbor set.

(4) By solving the eigenvectors of the covariance matrix to approximate the normal vector, the covariance matrix of the neighborhood of x_i can be defined as:

$$C = \begin{bmatrix} x_{i1} & - & \bar{x} \\ \vdots & \cdots & \vdots \\ x_{ik} & - & \bar{x} \end{bmatrix}^T \begin{bmatrix} x_{i1} & - & \bar{x} \\ \vdots & \cdots & \vdots \\ x_{ik} & - & \bar{x} \end{bmatrix} \quad \textbf{(2)}$$
$$i_j \in N_l, Cv = \lambda v$$

$\bar{x}$ is the center of all adjacent points of x_i. The eigenvector v_{min} corresponding to the minimum eigenvalue K_{min} of matrix C can be used as an effective estimation of normal vector n. This kind of estimation algorithm used in the above algorithm for finding adjacent points can work well.

(5) Gaussian curvature is estimated, and the calculation formula of gaussian curvature at 1 point on the triangular grid is:

$$K_G(x_i) = \frac{2\pi - \Sigma_{j=1}^{\#f} \theta_j}{A} \quad \textbf{(3)}$$

$\#f$ is the number of triangles of x_i, A is the sum of the areas of voronoi region [16] where x_i is located (as shown in Fig. 6(a)), and the angle is as shown in Fig. 6(b). Through the above calculation, the estimated value of the surface gaussian curvature of triangular mesh data can be obtained [17].

(a) Voronoi area (b) Gaussian curvature

Fig. 6. Differential operators on triangular grids

3.3 Feature Extraction Based on the Sum of Squared Deviations

After the above calculation, the gaussian curvature matrix M_1 is obtained, from which can be obtained that the gaussian curvature value caused by wearing contact lenses has a small change. If it is directly used as the input of the classifier, the classification effect is poor.

Select the difference square sum operator X of n×n:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nn} \end{bmatrix} \quad \textbf{(4)}$$

The elements in X were taken to calculated as:

$$\bar{X} = \sum_{n^2}^{i=1} \left(x_i - \bar{x} \right)^2 \quad \textbf{(5)}$$

Taking 5×5 operator as an example, gaussian curvature variation characteristics caused by wearing contact lenses can be extracted effectively after difference square and processing. The classification effects are described in the next section.

4 Experimental Protocol

The radius of curvature of cornea in normal people is normally distributed within 7.10-8.30. Therefore, 200 human eye sample sets (left and right eyes of 100 people) with normal distribution between 7.10 and 8.30 were selected. This sample set can represent the distribution of human eye curvature. The depth image and the corresponding grayscale image (10 for each sample) of 200 samples of naked eyes and wearing contact lenses were collected to complete the above data acquisition, gaussian curvature calculation and feature extraction.

In this essay, the AdaBoost classifier was selected for experiment, and the processed data were randomly divided into training set and test set according to the proportion of 5:1. The following Fig. 7 and Fig. 8 respectively show the classification results and running time of the AdaBoost classifier. The input data in Fig. 7 is the gaussian curvature matrix without feature extraction. The input data in Fig. 8 is processed by the difference square sum.

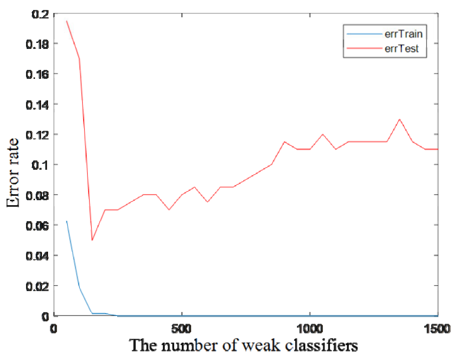


Fig. 7. The classification results of the original data T = 1205S

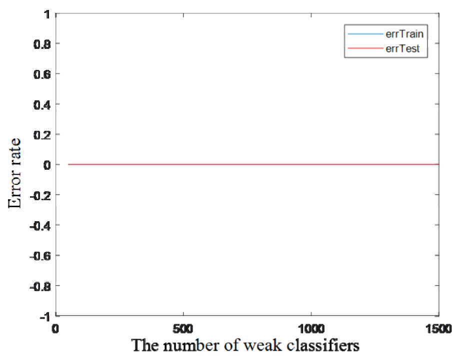


Fig. 8. The classification results of feature extraction T = 1.75S

Table 1 shows the comparison between the algorithm used in this paper and the other two contact lens detection algorithms. [19] adopted a hardwares based method, using multi-spectral imaging technology to detect conjunctival vessels, with an error rate of 0.2%. [20] adopted a software-based method to detect contact lenses through iris texture analysis, with an error rate of 0.5%. The gaussian curvature of the cornea in this essay is a hardware-based method with an error rate of 0%. In this essay, the algorithm uses the depth information feature, puts forward the demarcation method of effective interval to eliminate the interference of eyelids and eyelashes, and adopts the local difference square and operator suitable for gaussian curvature feature extraction, so as to obtain a higher recognition rate.

Table 1. Comparison of gaussian curvature method with other algorithms

Comparison of gaussian curvature method with other algorithms					
Reference	Subtype	Features and methodology	Attack	Database	Error
2012, Chen et al. [19]	Intrinsic property	Conjunctival vessels detection using multispectral imaging	Photo, contact-lens, artificial	Proprietary, 100 identities, 2000 samples	0.2%
2015, Menotti et al. [20]	Static	Iris texture analysis using deep learning	Photo	Public, ATVS-FIr-DB +LivDet-Iris-DB +MobBIOfake-DB	0.9%
This essay	Intrinsic property	gaussian curvature of the cornea	Contact-lens	Proprietary, 100 identities, 2000 samples	0%

5 Conclusions

In this essay, a contact lens detection algorithm based on depth feature is proposed, which can effectively detect contact lenses. Different from traditional detection methods, the gaussian curvature of the cornea is used as a stable physical feature, puts forward the demarcation method of effective interval to eliminate the interference of eyelids and eyelashes, and adopts the local difference square and operator suitable for gaussian curvature feature extraction. The recognition rate is 100%. However, this method requires more accurate depth data acquisition equipment, which will generate higher equipment costs in practical applications. How to combine the detection system as a front-end device with the iris recognition system, and other problems that may be encountered in the practical application will be direction of the author's further research.

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