Study of an Algorithm for Iris Image Enhancement

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Abstract: An iris image enhancement algorithm is proposed. By analyzing the grayscale distribution of serial iris images, the collected iris images are detected whether they are over-bright, too dark or uneven in brightness. For over-bright or too dark iris images, the stability of iris recognition is improved through interactive operations. For iris images with uneven brightness distribution, the histogram distribution fitting equalization method is used to modify the brightness. Therefore, the influence of iris distortion and uneven grayscale on the accuracy and real-time of iris recognition under complex illumination conditions can be solved. Consequently, the adaptability to complex illumination environment of iris recognition can be improved, which is beneficial to improve the robustness of iris recognition system.

1. Introduction

Iris recognition is the most accurate and fast biometrics technology at present. With its high accuracy, stability, security, non-contact and other advantages, iris recognition has become the key direction and development trend of biometrics research and application. In practical applications, in order to improve the user experience and enhance the degree of freedom and acceptance of iris recognition, iris recognition scenes under complex lighting conditions are often involved, and complex lighting environment has always been the difficulty of iris recognition applications [1]. If the ambient light is over-bright or too dark, the pupil will be extremely constricted or dilated, resulting in a large degree of nonlinear distortion in the iris region, which will affect the accuracy of recognition. While, uneven ambient light will cause random distribution of grayscale of iris image, which will increase the difficulty of iris image preprocessing and affect the real-time recognition [2]. Therefore, it is necessary to provide an efficient iris image enhancement method to improve the accuracy and real-time performance of iris recognition in complex lighting conditions, to improve the user experience.

2. Algorithm Implementation

An iris image enhancement algorithm is proposed to solve the problem of the effects of iris distortion and uneven grayscale on the accuracy and real-time of iris recognition, when captured iris images are over-bright, under-dark, or uneven in brightness, with complex lighting conditions, so as to improve the adaptability of iris recognition to complex lighting environment. The specific implementation steps of the algorithm are as follows.

2.1 Illumination Distribution Detection

First, n frames of iris sequence images are captured, and single frame correction and sequence registration are conducted based on the pupil center of the binocular eye and its horizontal connection to obtain the sequence iris images $\boldsymbol{P}\{i\}_{i=1,\ldots,n}$ after registration, and then, the iris sequence images are fused in grayscale to obtain the iris image $\boldsymbol{I}$ to be detected.

$$\boldsymbol{I} = \mathrm{imfus}(\boldsymbol{P}\{i\}) = \mathrm{median}\big(\boldsymbol{P}_i(j,k)\big), i = 1, \ldots, n \tag{1}$$

Where, imfus( ) is the image fusion function, median( ) is the grayscale median function, and j and k are the number of rows and columns of image pixels, respectively. Typically, n is equal to the frame frequency of iris image acquisition.

Then, the distribution of grayscale histogram of iris image and the gray level difference of pixel block are integrated to determine whether the overall brightness of iris image is over-bright or under-dark [3].

The grayscale histogram distribution of iris image $\boldsymbol{I}$ is calculated to obtain the grayscale values corresponding to the m maxima.

$$\boldsymbol{gs}\{i\} = \text{rank}(\text{imhist}(\boldsymbol{I}), m, '\text{descend}'), i = 1, \ldots, m \tag{2}$$

Where, imhist( ) is the statistical function of grayscale histogram, rank( ) is the sorting function by value, and $\boldsymbol{gs}\{i\}$ is the grayscale value sequence corresponding to the largest m maxima in the grayscale histogram of iris image $\boldsymbol{I}$. Typically, the value of m is from 5 to 7.

The gray level difference of the pixel blocks of iris image $\boldsymbol{I}$ are calculated to obtain the maximum l gray level difference values.

$$\boldsymbol{gd}\{j\} = \text{rank}(\text{gsdiffer}(\text{imgblk}(\boldsymbol{I}, q), '\text{med}'), l, '\text{descend}'), j = 1, \ldots, l \tag{3}$$

Where, imgblk( ) is the image partitioning function, and the sub-block size is $q \times q$, gsdiffer( ) is the statistical function of sub-block gray level difference, and the difference is made with the median of the grayscale of the pixels in the two sub-blocks, rank( ) is the sorting function by value, $\boldsymbol{gd}\{j\}$ is the sequence composed of l values with the largest gray level differences of the pixel blocks of iris image $\boldsymbol{I}$. Typically, q is equal to 4, and the value of l is from 2 to 4.

On the basis of the above $\boldsymbol{gs}\{i\}$and $\boldsymbol{gd}\{j\}$, the overall brightness of the detected iris image is determined whether over-bright or under-dark.

$$\begin{cases} \text{if } \min(\boldsymbol{gs}\{i\}) \geq \alpha_1 \cap \max(\boldsymbol{gd}\{j\}) < \alpha_2, \text{over} - \text{bright} \\ \text{elseif } \max(\boldsymbol{gs}\{i\}) < \beta_1 \cap \max(\boldsymbol{gd}\{j\}) < \beta_2, \text{under} - \text{dark} \\ \text{else}, \quad \text{others} \end{cases} \tag{4}$$

Where, min ( ) is the minimum function, max( ) is the maximum function, and α_1, α_2, β_1, β_2 are the discriminant thresholds of the overall image brightness distribution. Typically, α_1 is equal to 120, α_2 is equal to 100, β_1 is equal to 80, and β_2 is equal to 100.

Finally, the iris images that are not too bright or too dark are determined whether uneven in brightness distribution.

Given the grayscale histogram distribution of the captured iris image under the condition of uniform illumination is f, and the grayscale histogram distribution of the iris image to be detected is $g(\boldsymbol{I})$, the brightness distribution of the image is determined whether or not even by the correlation of the grayscale histogram distribution [4].

$$\begin{cases} \text{if } \text{imhcorr}(g(\boldsymbol{I}), f) \geq \tau, \text{even brightness} \\ \text{else}, \quad \text{uneven brightness} \end{cases} \tag{5}$$

Where, imhcorr( ) is the function for calculating the correlation coefficient of image grayscale histogram distribution, and τ is the discriminant threshold of image brightness distribution uniformity. Typically, the value of τ is from 0.55 to 0.75.

2.2 Over-Bright Image Correction

An over-bright iris image, on the one hand, the iris texture is noisy polluted due to a large number of miscellaneous lights into the imaging system, on the other hand, a larger nonlinear distortion is produced by the pupil constriction and iris dilation. As a result, aforementioned two factors make the iris region a serious loss of clarity and resolution, so that the substantial decrease in iris recognition accuracy [5].

Once the iris image is detected to be over-bright in the first step, the imaging system will automatically turn on the auxiliary optical filter device, take the iris imaging wavelength as the center, realize multiple filter imaging by controlling the bandwidth of the filter band, and obtain the multi-spectral iris sequence images $\boldsymbol{I}\{i\}_{i=1,\dots,N}$, and then, $\boldsymbol{I}\{i\}$ is processed with multi-spectral imaging differential filtering to remove the interference of the hetero-optical imaging, and the iris image $\boldsymbol{GI}$ with brightness correction is obtained.

$$\boldsymbol{GI} = \text{imdiffit}(\boldsymbol{I}\{i\}), i = 1, \dots, N \tag{6}$$

Where, imdiffit( ) is the multi-spectral imaging differential filter function, and $\boldsymbol{GI}$ is the image after brightness correction of an over-bright iris image. Typically, the value of N is from 3 to 7.

At the same time of brightness correction, the iris imaging system prompts the user to blink, then increases the imaging frame frequency, and captures and screens the image sequence of moderate iris size when the pupil changes from large to small during the blink process. For the iris image sequence $\boldsymbol{F}\{j\}_{j=1,\dots,M}$ with brightness correction, feature enhancement is achieved through feature fusion process [6].

$$\boldsymbol{fr} = \text{ffus}\big(\text{fext}(\boldsymbol{F}\{j\})\big), j = 1, \dots, M \tag{7}$$

Where, fext( ) is the iris feature extraction function, ffus( ) is the iris feature fusion function, and $\boldsymbol{fr}$ is the enhanced iris feature vector. Typically, the value of $\boldsymbol{M}$ is from 3 to 5.

2.3 Under-Dark Image Correction

An Under-Dark iris image, on the one hand, the texture resolution of the iris region is seriously reduced by the compression of the gray level of the iris image, on the other hand, the iris constriction due to the dilation of the pupil results in a larger nonlinear distortion, which greatly reduces the accuracy of iris recognition [7].

When the iris image is detected to be under-dark in the first step, the imaging system automatically turns on auxiliary light filling devices, the cameras up, down, left, and right four bearing alternately turn on the auxiliary light filling source array, and then, comprehensive auxiliary light supplement is implemented to capture iris sequence images $\boldsymbol{G}\{k\}_{k=1,\dots,L}$ with light filling imaging, then the iris image $\boldsymbol{PG}$ with brightness correction is obtained by grayscale fusion of $\boldsymbol{G}\{k\}$.

$$\boldsymbol{PG} = \text{gsfus}(\boldsymbol{G}\{k\}), k = 1, \dots, L \tag{8}$$

Where, gsfus( ) is the grayscale fusion function. Typically, the value of L is from 5 to 10.

Due to the normal dilation of the pupil in the process of light supplementing, the iris size of the captured iris image sequence is moderate. Therefore, the nonlinear distortion and texture resolution of the iris region of the iris image $\boldsymbol{PG}$ are corrected at the same time with the aforementioned brightness correction process [8].

2.4 Uneven Illumination Correction

For iris images with uneven brightness distribution, the histogram distribution fitting equalization method is used to modify the brightness.

Under different lighting conditions, iris images are captured by the iris imaging system with uniform imaging conditions, and their grayscale histogram distribution curves are calculated to obtain the histogram curves sequence $\boldsymbol{gl}\{s\}_{s=1,\dots,t}$ of uniform grayscale distribution of iris images. Given the iris image $\boldsymbol{R}$ with uneven brightness, $\boldsymbol{R}$ is histogram-fitting equalized according to $\boldsymbol{gl}\{s\}$ [9].

$$\boldsymbol{RE}\{s\} = \text{imheq}(\boldsymbol{R}, \boldsymbol{gl}\{s\}), s = 1, \dots, t \tag{9}$$

Where, imheq( ) is the histogram fitting equalization function, and $\boldsymbol{RE}\{\text{s}\}$ is the grayscale fitting sequence of iris image. Then $\boldsymbol{RE}\{\text{s}\}$ is weighted grayscale fusion to obtain the iris image $\boldsymbol{RI}$ with brightness correction.

$$\begin{cases} \boldsymbol{RI} = \text{gsfuswd}(\boldsymbol{RE}\{s\}, \boldsymbol{w}\{s\}), s = 1, \dots, t \\ \forall\, \boldsymbol{w}(s) = \text{abs}\big(\boldsymbol{fd}(s)\big) / \sum_{s=1}^{t} \text{abs}\big(\boldsymbol{fd}(s)\big) \end{cases} \tag{10}$$

Where, gsfuswd( ) is the weighted grayscale fusion function, $\boldsymbol{w}\{s\}$ is the weighted coefficient sequence, abs( ) is the absolute value function, ***fd*** is the histogram equalization fitting error sequence, and ***RI*** is the iris image after brightness correction for the iris image with uneven brightness distribution. Typically, the value of t is from 5 to 9.

After the above steps, the situation of over-bright, under-dark or uneven brightness distribution of iris imaging can be detected under complex lighting conditions, and the iris image with the defect of brightness distribution can be modified to realize the enhancement of iris image, so as to meet the performance requirements of iris recognition system [10].

3. Summary

Through detecting iris images which are over-bright, too dark, or of uneven brightness distribution by overall brightness distribution and local grayscale difference, auxiliary optical filtering and light filling devices with adaptive design, as well as effective methods of grayscale fusion, feature fusion and nonlinear fitting, are used to correct the brightness of iris images with luminance defects under complex lighting conditions. Based on the above studies, an iris image enhancement algorithm is proposed, which can effectively solve the problem of poor accuracy and real-time of iris recognition under complex lighting conditions, so as to improve the adaptability of iris recognition application.

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