The Removal of Specular Reflection in Noisy Iris Image

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***Abstract*—Iris recognition is a biometric system that uses human iris features to determine and verify the identity of human. Other biometric systems are fingerprint, face, ear, voice, gait, blood vessels and many more. A complete iris recognition system includes: iris acquisition, iris segmentation, feature extraction and matching. The main factor to obtain high segmentation and recognition accuracy is the quality of iris pattern. The quality of iris pattern can be affected because of specular reflection. Specular reflection happens during iris acquisition and it can reduce the features of iris pattern. This work is significant since the improved iris pattern can enhance the performance of iris localization, iris segmentation and feature extraction in the iris recognition system. In this paper, the iris image enhancement methods are proposed to remove the specular reflection. UBIRIS v1 and CASIA v4 databases are used for testing. Based on the results, the proposed methods managed to remove the specular reflection without affecting the iris image quality. The proposed methods also obtained fast execution time and low memory.**

***Index Terms*—Iris Recognition; Iris Pattern; Specular Reflection; Iris Image Enhancement.**

I. INTRODUCTION

Security is the main concern for everyone and a lot of money has been allocated for it. Biometric technology can help authorities to identify criminals, terrorists and missing people. The biometric system is a suitable and efficient method since a lot of biometrics data are stored in the databases either by the government or the private agencies. It can be collected everyday via cameras, criminal records, work employments, administrator agency records and medical health care.

Iris recognition is a biometric system for human identification by using the irises in human eyes as in Figure 1. Iris recognition can be divided into iris acquisition, iris segmentation, feature extraction and matching. The probability to find two same irises is estimated at 1 in 10^{72} [1]. Iris is a pigmented tissue and located behind the cornea [2]. It is well-protected behind eyelids [3]. Iris is formed in the third month of pregnancy (first trimester) and completed in the eighth month of pregnancy (third trimester). Iris is physiological response to light which provides natural tests against artifice [4]. The pupillary motion controls the amount of light that enters the eye [5]. The iris is not similar between individuals and even twins have different irises. Our right and left irises also have different patterns [6]. The iris has complex features such as arching ligaments, furrows, ridges, crypts, rings, corona, freckles and zig-zag collarette [7]. Each individual has their own iris features with high degrees of freedom [8]. The texture of iris is formed by radial and longitudinal muscles that constrict or dilate due to light changes [9]. The peculiar pattern of iris shows rich features of stripes, rings, undulation and pustules. This pattern also makes iris identification unique for every person. The advantages of iris recognition are high security, high recognition accuracy, one unique ID and high speed. The characteristics of an iris are unique and tightly related to only one identity compared to token and password that can be easily forgotten and lost. The iris can be used for logical or physical access control to secret and protected buildings and information. Unfortunately, iris pattern can be easily affected by noise especially specular reflection. Specular reflection can reduce recognition accuracy and produce false result of identification.

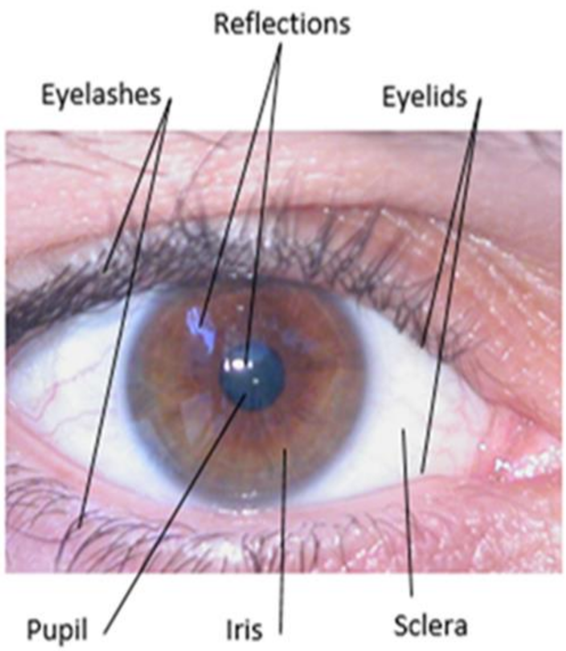

Figure 1: Iris anatomy

The contributions of this work can be divided into 2 topics, namely pupil reflection removal and iris reflection removal. For pupil reflection removal, two methods are proposed, which are pupil reflection removal based on pupil area and threshold, as well as pupil reflection removal based on bottom-hat filter. The proposed methods can eliminate reflections without affecting iris quality and can reduce execution time and memory. For iris reflection removal, the new classification of iris reflection is introduced. The iris pattern can be corrected with reduced execution time and memory.

II. Previous Works

Specular reflection is a common situation which happens during iris image acquisition due to lighting sources around the subject. It can occur on iris, pupil and sclera parts of the eyes. Lighting sources can come from camera flash, window reflection, sunlight, ambient light and others. Due to ambient light, reflection in visible wavelength image is more severe than in near infra-red image [10]. Reflection can contribute to poor iris localization and false iris segmentation that will affect the recognition accuracy of the system. It can also degrade the quality of iris image [11].

The simplest method to remove specular reflection is by installing a conventional circular aperture right in front of camera lens to reduce reflection and improve focus. Triangle aperture can also be used to improve autofocus by deducing glint's amount and direction [12]. Other than that, inpainting method based on Navier-Stokes is introduced to remove the reflection by filling the reflection spots [13]. Meanwhile, interpolation technique is proposed to remove the specular reflection [14]. Next, texture mapping and alpha-blended are used to create and remove reflection and refraction [15]. Top-hat filter is proposed by [16] to determine and reduce pupil reflection. The combination of morphological operation and anisotropic diffusion can be used to eliminate reflection [17]. Morphological operator of flood-fill is proposed to remove holes in specular reflection, which is suitable when noise lie in pupil boundary [18]. Bilinear interpolation technique along with adaptive threshold is introduced to fill the reflection region in constrained environment [19]. Meanwhile, [20] proposed a linear interpolation extension which is better than bilinear interpolation. Then, a simple method of image complement, filling holes and complement again is used to remove specular reflection [21]. Finally, morphological closing is proposed by [22] as a reflection removal method.

III. Methodology

The proposed iris image enhancement methods are divided into pupil reflection removal and iris reflection removal. Specular reflection is classified into two, which are pupil reflection (specular reflection on pupil region) and iris reflection (specular reflection on iris region). In pupil reflection removal, a new method is proposed to eliminate reflection. Then in iris reflection removal, a new classification of reflection is introduced.

A. Pupil Reflection Removal

Pupil reflection is a specular or corneal reflection that occurs inside or at the boundary of pupil. Reflection in pupil can cause false localization (to locate pupil center and radius which are important parameters for an accurate iris segmentation). The state-of-the-art methods of specular reflection removal are not fast enough to be implemented in real-time system. The real-time iris recognition system must be fast to process millions of irises without compromising accuracy, security and durability of the system. In this section, a new pupil reflection removal based on the pupil area and threshold is introduced. Basically, this method needs to locate the pupil area, determine its pixels and threshold values, and finally eliminate reflections. Firstly, the contrast of iris image is enhanced to create a sharp texture by using unsharp masking. Unsharp masking is an unsharp filter used to sharpen the texture of image. The original iris image is subtracted from an unsharp version of the original image. The sharp iris image is obtained due to a quick transition from black to white. Secondly, pixel properties are analyzed from the iris image to determine the exact location of pupil based on its area and threshold. The pupil area is the largest dark area in the iris image and the average threshold values are below 40. Thirdly, morphological closing operation is applied on the iris image to enlarge the foreground boundaries, shrink background boundaries and eliminate holes. Finally, the remaining holes are filled with the flood-fill operation. Flood-fill operation is a part of morphological reconstruction in morphological image processing which is based on morphological dilation. The dark area in the iris image that is surrounded by the light area will be filled with the same intensity of surrounding pixels. The regional minima that is not connected with image boundaries will be removed along with artefacts. For structuring elements, 4-connected elements are used instead of 6 or 8-connected elements as iris images contain two separate backgrounds. The radius value of structuring elements is set to 15 pixels where any holes with 15 pixels radius will be filled. The flowchart of the proposed method is shown in Figure 2.

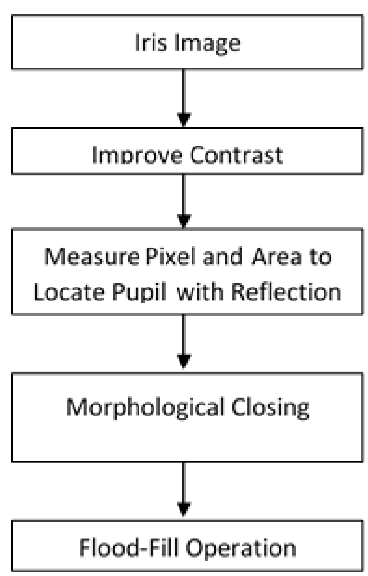

Figure 2: Flowchart of pupil reflection removal

Another pupil reflection removal method based on bottom-hat filter is proposed to compare its performance with other methods in terms of execution time, memory usage and similarity values. Bottom-hat filter is a morphological operator that is based on morphological closing operation. The input iris image is subtracted with the result of morphological closing on the input iris image. Firstly, the iris image is complemented. After that, morphological closing is applied on the complemented iris image with structuring elements of 5 pixels radius and 4-connected elements. Finally, bottom-hat filter is applied on the iris image with structuring elements of 300 pixels radius and 4-connected elements.

B. Iris Reflection Removal

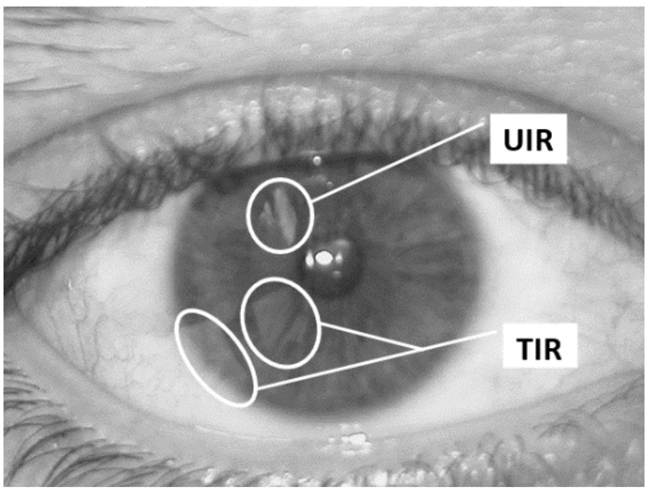

Figure 3: Tolerated and untolerated iris reflection

Iris reflection is a specular reflection that occurs on the iris region instead of other eyes region. The state-of-the-art methods of specular reflection removal will discard or ignore all types of reflections in iris region. Based on our observation, some reflections in the iris region can be corrected. The corrected reflections can enhance the iris pattern quality and add more iris features, thus improving recognition accuracy. In this section, a new classification of iris reflection is introduced: the TIR (tolerated iris reflection) and UIR (untolerated iris reflection) as in Figure 3. The iris reflection that can be corrected is called TIR. A simple image intensity adjustment is applied on the reflection region to correct the TIR. The values of intensity adjustment are set between 0.21 to 0.8 to produce a good quality of corrected reflection. Meanwhile, iris reflection that cannot be corrected is called UIR. The UIR cannot be corrected because the reflection region has lost almost all of its pixel properties. For UIR, inward interpolation is applied on the reflection region to substitute it with the average neighbour pixels. Inward interpolation is used to eliminate pixels or substitute invalid pixels with its neighbour. It will solve discrete Laplacian equation over the image without modifying boundary pixels. The flowchart of the proposed method is shown in Figure 4.

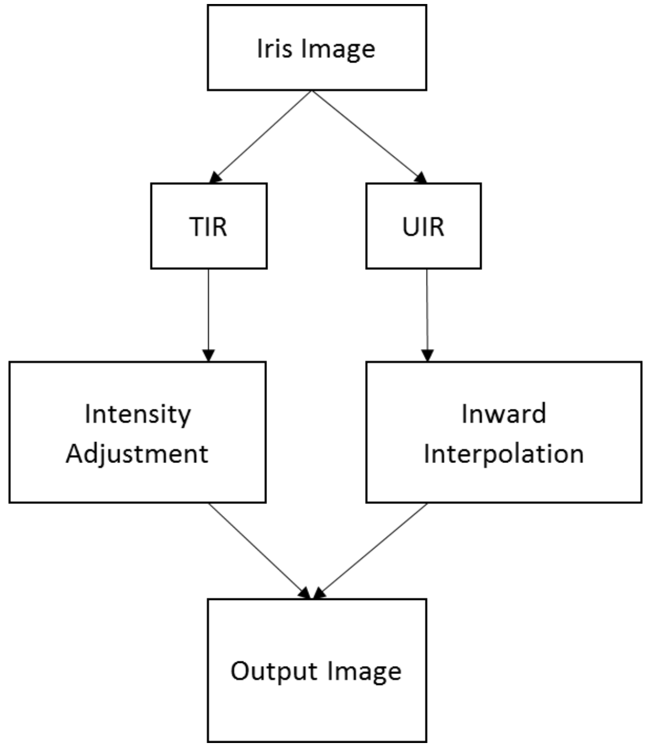

Figure 4: Flowchart of iris reflection removal

IV. RESULTS AND DISCUSSION

The experiments are conducted with an Intel Core i5 (2.3 GHz) and 4 GB RAM memory under MATLAB environment. The UBIRIS v1 [23] and CASIA v4 [24] databases are used for these experiments. UBIRIS v1 is collected by SOCIA Lab (Soft Computing and Image Analysis Group). Meanwhile, CASIA v4 is collected by the Chinese Academy of Sciences' Institute of Automation (CASIA).

A. Pupil Reflection Removal

In this section, the proposed pupil reflection removal results are presented. The methods which are based on pupil area and threshold, and bottom-hat filter are introduced in this paper. The proposed methods are compared with other methods in terms of execution time, memory usage and similarity values. Based on Figure 5, the proposed pupil area and threshold method managed to eliminate reflections inside and on the boundary of the pupil. This method is able to eliminate any numbers of reflections as long as the reflections are located within the pupil boundary.

Based on Table 1, the proposed method based on pupil area and threshold, obtained faster execution time and less average memory than other methods. Meanwhile, the proposed bottom-hat filter obtained slower execution time and more memory even though it managed to eliminate reflections. The bottom-hat filter recorded slow execution time since it used lengthy radius values (300 pixels).

Table 1
Average execution time, average memory and average SSIM

Methods	Average Execution Time (s)	Average Memory (Kb)	Average SSIM
[19]	2.59	641	0.9660
[21]	0.41	408	0.9515
[20]	0.19	634	0.9768
[18]	0.40	408	0.9505
[16]	0.95	4288	0.8170
[22]	0.15	60	0.9300
Proposed Bottom-Hat Filter	1.43	7244	0.9298
Proposed Pupil Area and Threshold	0.11	30	0.9910

For image quality evaluation before and after the proposed methods, the SSIM is calculated. Structural similarity index (SSIM) is a function to calculate the similarity of two given images. SSIM is more consistent than other methods such as peak signal-to-noise ratio (PSNR) and mean squared error (MSE) that estimate perceived error while SSIM estimates perceived changes of image degradation. In this paper, SSIM is used to calculate the similarity of the iris images before and after pupil and iris reflection removal. The quality of iris images are analyzed to determine whether the iris patterns are affected or not due to the proposed removal methods. SSIM value of zero means two images are not similar and value of 1 means that two images are similar.

$$SSIM = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu^2{}_x + \mu^2{}_y + c_1)(\sigma^2{}_x + \sigma^2{}_y + c_2)} \quad (1)$$

The proposed method of pupil area and threshold managed to obtain higher SSIM than other methods as in Table 1. This proves that the iris images similarity and quality, before and after the proposed pupil area and threshold method are almost the same. The SSIM of other methods showed that the iris patterns were affected after the respective reflection removal. Meanwhile, the proposed bottom-hat filter obtained a good similarity result but less than the proposed pupil area and threshold method.

To conclude, the proposed pupil area and threshold method obtained faster execution time and lower memory without compromising the quality of iris images compared to other methods. The execution time of the proposed method proved that it can be implemented in the real-time iris recognition system. Based on the SSIM, the quality of iris patterns were not affected and can be used for further processes in iris recognition system such as in iris segmentation and iris localization.

(a) Before reflection removal

(b) After reflection removal

Figure 5: Pupil reflection removal results

(a) Before reflection removal

(b) After reflection removal

Figure 6: Iris reflection removal results

B. *Iris Reflection Removal*

In this section, the proposed iris reflection removal results are presented. A new classification of iris reflection is introduced: the TIR and UIR. The UBIRIS v1 database is used in this experiment since it contains reflections that are suitable with our theoretical TIR and UIR reflections. Based on Figure 6, the proposed method managed to correct the TIR and remove the UIR. The TIR is corrected with intensity adjustment and UIR is removed and substituted with inward interpolation. This method also obtained fast execution time with low memory as in Table 2, which might be suitable for the real-time implementation. Based on the SSIM, the proposed method managed to obtain higher similarity value (near 1). The corrected reflections will add more iris features along with the existing iris features to improve the recognition accuracy in the next processes (iris segmentation and feature extraction). To conclude, the proposed iris reflection removal method achieved fast execution time and low memory without compromising the quality of iris patterns and iris images.

Table 2
Average execution time, average memory and average SSIM

Average Execution Time (s)	Average Memory (Kb)	Average SSIM
0.24	3853	0.9967

V. Conclusion

The proposed iris image enhancement methods of pupil reflection removal and iris reflection removal have been presented to improve and enhance the iris image quality. For pupil reflection removal, the proposed method based on pupil area and threshold managed to eliminate any reflections in pupil area. It also achieved faster execution time and lower memory compared to other methods. For iris reflection removal, the reflections in iris region are classified into untolerated iris reflection (UIR) and tolerated iris reflection (TIR). The proposed method managed to correct the TIR and remove the UIR. Furthermore, this method also obtained fast execution time and low memory. In terms of similarity, both methods managed to remove reflections without compromising the quality of iris patterns.

For future work in pupil reflection removal, more accurate location of pupil region can be created to reduce the searching time and to simplify the calculation complexity. Other image sharpening techniques such as deconvolution and edge enhancement can be considered to create better and sharper iris image. Meanwhile for iris reflection removal, histogram equalization and adaptive histogram equalization can be used to enhance the image contrast rather than a simple image intensity adjustment. In order to reduce the execution time of this method, a specific region-of-interest processing can be applied by enhancing the selected iris region only. With this processing, some parts of the eye such as eyelids, eyelashes and sclera are excluded and can reduce the removal time. Other than that, the segmentation and recognition accuracy can be calculated to investigate the effects of our iris image enhancement methods.

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