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GPU Implementation of Sub-Iris Technique in Iris Recognition System

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ABSTRACT

Iris recognition has become a widely popular biometric system. The stable textures and features of the human iris have made such biometric systems efficient and accurate for purposes of verification and identification. The term non-ideal iris refers to a situation in which the iris is occluded by noise, including reflections, eyelashes, eyelids and so on. Most current iris recognition algorithms assume that the iris is not occluded, which is less accurate. A method using only some parts of the iris may be suitable to deal with a non-ideal iris. The current application of iris recognition systems are plagued by weaknesses such as slow processing times, especially when dealing with many irises. In this study, a sub-iris recognition technique is proposed to deal with the non-ideal iris, while reducing execution time via an embedded system using a graphical processing unit (GPU). The experiment revealed that the proposed method was accurate and fast.

Keywords: Execution time, graphical processing unit, iris recognition system, non-ideal iris, sub-iris technique

INTRODUCTION

Many studies have examined the performance of iris recognition systems which have significant advantages such as high identification rate and high feasibility. Each iris is unique, with the possibility of locating two identical irises being only 1 in 10^{72} (Flom & Safir, 1987). Its pattern might be stable for a lifetime (Daugman & Downing, 2001). The iris also has rich features such as arching ligaments, rings, freckles, coronas, collarettes and crypts (Muron & Pospisil, 2000). Unfortunately, existing iris recognition

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systems are disappointing in terms of execution time and/or processing speed (Tozer, 2012). Additionally, shape of the iris is not always circular and may be occluded by eyelids, eyelashes, reflections and noises, becoming a non-ideal iris. Thus, a new method must be introduced in order to improve accuracy and speed of an iris recognition system.

Conventional iris recognition systems are based on three algorithms: the integro-differential operator, the Hough transform, and the active contour. The integro-differential operator (IDO) was introduced by Daugman (1993), and it is used in order to detect two circles that represent the pupil and iris regions respectively. Meanwhile, a method to locate two circles of pupil and iris regions based on Hough transform (HT) was introduced by Wildes (1997). This method also uses the edge detection method to detect the edges that represent the pupil and iris boundaries. The active contour method was introduced by Daugman (2007) in order to detect the irregular boundary of the iris.

Most current methods are partly based on these pioneer works and implemented in a CPU. Unfortunately, existing algorithms suffer from slow operations time (Yu & Zhou, 2012). Because of that, an iris recognition system must be developed on another platform with better performance than the CPU. Not all regions of the iris are rich with features. According to Krichen (2007), the region near the pupil boundary is rich with patterns and is also less occluded by eyelids, eyelashes, and noise. Hence, a method that uses only the important parts in of the iris must be developed in order to reduce the complexity of the system and to make it more efficient by excluding the unimportant parts. This method may reduce resources, thus reducing the processing time of the iris recognition system.

Therefore, in this paper, a method using only the important part of the iris region (sub-iris technique) is proposed to reduce the complexity of the iris recognition system. The proposed method will be implemented on the graphical processing unit (GPU) to reduce execution time.

Previous Works

Recently, the conventional iris recognition methods have been modified to improve their performance. Radman et al. (2013) modified the existing IDO method which made it more adaptable to locate the irregular boundary of iris. Meanwhile, Hilal et al. (2012) modified the active contour method to be more accurate in locating the irregular boundary of pupil. This method also used HT to detect the iris boundary. Additionally, Abdullah et al. (2014) used a morphological operator to estimate the location of pupil and iris boundaries. After that, the active contour was used to detect the exact pupil and iris boundaries. The HT was improved by Qin et al. (2013), where the edge gradient direction information was used along with HT to locate the exact boundary.

All of the methods described above use the entire or full-iris region for iris recognition systems. The full-iris region contains more iris textures and features which are more accurate to allow recognition of identity. Unfortunately, acquisition of full-iris region is not always possible. Some people may have small eyes that are occluded by eyelids. The iris region can also be occluded by eyelashes, reflections, and other objects. There are few methods that use only some parts of iris region in the iris recognition system. The lower part of iris is used in the phase-based algorithm (Miyazawa et al., 2006; Ito & Aoki, 2013) for iris recognition system instead of the full-iris region. Unfortunately, some iris images may consist of the lower eyelid, leading to less accurate performance. Thus, the eyelid masking has been used to eliminate the eyelid region. Unfortunately, eyelid detection requires a longer execution time. Du et al. (2005) introduced the partial iris for iris recognition system. This method generated four options for partial iris. The partial iris was defined as the combination of upper and lower parts of iris region with a reduced radius. Unfortunately, the heavy occlusion of eyelid on the upper iris may reduce accuracy. Zhao and Kumar (2015) have used some parts of the iris region based on the total variation model to suppress noises and to obtain an accurate localisation. In the present study, the above methods are analysed, and the disadvantages addressed in order to create a better sub-iris or partial iris technique. Generally, the full-iris technique has higher recognition accuracy compared with the sub-iris technique if the iris features themselves are not occluded. Unfortunately, this is impossible due to the nature of human eyes, especially in non-cooperative environments (Zhao & Kumar, 2015). Hence, the sub-iris technique is proposed to obtain almost similar recognition accuracy with the full-iris technique, but with reduced execution time.

Most iris recognition systems are implemented on the CPU but the latter is not fast enough to handle many processes (Sakr et al., 2012). The processes of iris localisation and feature extraction have the most extensive computation in the system (Sakr et al., 2012). Thus, GPU is proposed to reduce the execution time of the iris recognition system. It was used by Sakr et al. (2012) to implement the Daugman (1993) algorithm to compute localisation and feature extraction processes, achieving 9.6 and 14.8 times speedup compared with CPU. Meanwhile, Nazneen et al. (2016) used the GPU for iris template matching and achieved good performance. Based on these findings, the proposed sub-iris technique will be implemented on the GPU in order to further improve the time performance of the iris recognition system.

METHOD

The iris recognition system consists of iris acquisition, iris segmentation, normalisation, feature extraction, and matching as shown in Figure 1. In iris acquisition, the iris image is captured by using a camera under the near infrared or visible wavelength environment. The near infrared image consists of grey level values. Meanwhile, the visible wavelength image consists of colour values (red, green and blue). The near infrared image is suitable for security and verification systems, while the visible wavelength image is suitable for surveillance and forensic systems. In this work, the near infrared iris image is used for iris acquisition because the rich iris features can be captured under the near infrared environment. The near infrared iris images are taken from the CASIA v4 database (Chinese Academy of Sciences' Institute of Automation (CASIA), 2002).

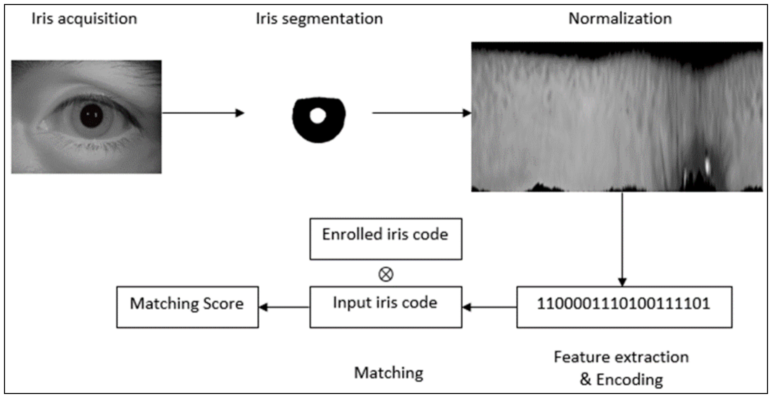


Figure 1. The iris recognition system

In iris segmentation, the iris region is segmented from the rest of iris image. The iris image may consist of eyelids, eyelashes, eyebrows, reflections, noise, and so on. The iris region can be occluded because of those elements, thus, reducing the iris features in the iris region. A non-ideal iris is common in real-time compared with the ideal iris that has circular shape without any occlusion. In this work, iris segmentation is developed based on the active contour of Chan and Vese (2001). This active contour is less dependent on the gradient information, which is suitable to segment the irregular boundary of iris region.

First, pupil boundary is located by investigating pixel property in the iris image based on calculated threshold; the latter is obtained from the average value of pupil region in the iris image. The threshold value is calculated from the 100 iris images of CASIA v4 database. Based on these calculations, the threshold value is set at 35. After that, the iris image is analysed according to the threshold. Based on the threshold, all black connected components in the pupil region can be located. The pupil region is presumed to be the largest connected component in the iris image based on the threshold value. Finally, the pupil boundary can be located from the detected pupil region.

The iris boundary is later located using the active contour method. The active contour method introduced by Chan and Vese (2001) is the segmentation method without edges. It uses an energy function instead of gradient information to segment the desired object boundary. The active contour is defined as in (1) where $\mu 0$ (x, y) is input image, c_1 is average input image when $\phi \geq 0$ and c_2 when $\phi < 0$, λ_1 is fit weight inside curve C, and λ_2 is outside of curve C. This function is minimised by adding the functions of length in curve, C and area inside of curve, C.

$$
\begin{aligned}
F(c_1, c_2, C) &= \mu \cdot Length(C) + v \cdot Area(inside(C)) \\
&+ \lambda_1 \int_{inside(C)} |\mu_0(x, y) - c_1|^2 dxdy \\
&+ \lambda_2 \int_{outside(C)} |\mu_0(x, y) - c_2|^2 dxdy
\end{aligned} \qquad [1]
$$

The initial contour is an evolution contour used in the active contour as the starting place for the latter to start converging towards the desired object boundary. The accurate initialisation of initial contour is important in order to avoid segmenting the separate boundary (Getreuer, 2012). The initial contour in this work is based on a circular shape, so a circle function (Hilal et al., 2012) as in (2) is used, where r is circle radius, and (x, y) is circle centre point.

$$circle = r - \sqrt{(x-a)^2 + (y-b)^2} \quad [2]$$

In order to create the initial contour, the parameters of centre point and radius as in (2) need to be defined. Since the position of initial contour on the desired object boundary is crucial, few conditions need to be met. First, the initial contour must be located within the desired object boundary. Due to this, the proposed initial contour must be located at the top of the iris boundary. Second, the initial contour must not regularly intercept the desired object boundary in order to avoid segmenting the wrong boundary. Because of this, the boundary of the proposed initial contour must not regularly intercept the iris boundary. Finally, the oversize initial contour may include the unwanted boundary. Thus, the proposed initial contour must not be too big in order to avoid the unwanted elements such as eyelids, eyelashes, and reflections to be included into the correct iris boundary.

Based on above considerations, the proposed initial contour is designed with the following properties: its centre point must be at the centre of the iris region; the radius must not be too long in order to avoid oversize initial contour; and the initial contour must not regularly intercept the iris boundary. Since the iris centre is not necessary similar to the pupil centre, an initial contour centre is proposed which is not always at the centre of pupil. Hilal et al. (2012) used a HT to detect the pupil centre. Unfortunately, this method is less accurate if the pupil region is occluded. Because of that, the pixel property in the occluded pupil is analysed to calculate the centroid which represents the initial contour centre. After that, the initial contour is shifted towards the negative y-axis to reduce error of detecting complex upper eyelid boundary. Meanwhile, for initial contour radius, a radius value must be assigned for which the initial contour must not be oversized. The iris and pupil radius of 100 iris images are observed to obtain the initial contour radius value. An iris radius is then assigned which does not exceed three times of the pupil radius. The example of the proposed initial contour can be observed in Figure 2.

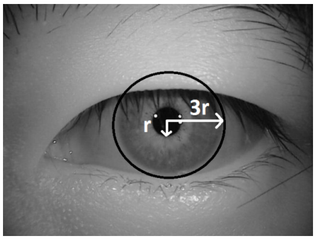
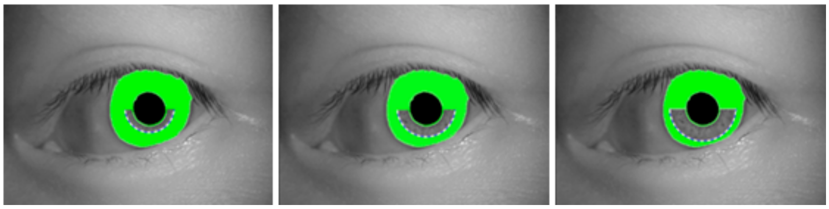


Figure 2. The example of the proposed initial contour

After creating the initial contour, the parameters of iteration number, contraction bias (v), and smooth factor (μ) must be assigned. The pre-test of the proposed Chan-Vese active contour is conducted on 100 iris images. From the pre-test, the average values of parameters are obtained as follows: iteration number = 35, contraction bias (v) = 0.7 and smooth factor (μ) = 1.5. Finally, the active contour can be deployed on the iris image to segment the irregular iris boundary.

In order to reduce complexity and improve the performance of the iris recognition system, the sub-iris technique is proposed, in which only the important parts of iris region are used in the system. Based on our observation of the previous methods (Miyazawa et al., 2006; Ito & Aoki, 2013; Du et al., 2005; Zhao & Kumar, 2015) and work by Krichen (2007), three sub-iris regions are proposed for the sub-iris technique. The iris region is divided into two regions: the upper iris (θ=0° – 180°) and the lower iris (θ=180° – 360°). The upper iris can be occluded by the upper eyelid and eyelashes. Meanwhile, the lower iris can be occluded by the lower eyelid only. The occlusion of the lower eyelid on the lower iris can simply be eliminated by reducing the radius value, r of the iris boundary. Because of that, the lower iris is selected for the proposed sub-iris region. The three proposed sub-iris regions can be observed in Figure 3. Each sub-iris region has similar value of θ but with a different value of r. The value of r represents the following: when r=0.4 means that 40% of iris radius, r=0.6 means that 60% of iris radius and r=0.9 means that 90% of iris radius. Each sub-iris region will be analysed in order to determine which region has the best performance.



(a) (b) (c)

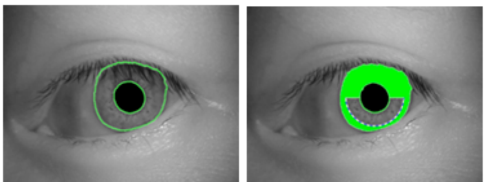
Figure 3. The proposed sub-iris regions of: (a) θ=180° – 360°, r=0.4; (b) θ=180° – 360°, r=0.6; and (c) θ=180° – 360°, r=0.9

After implementation of sub-iris technique, the roundness of sub-iris region is converted into a fixed rectangular polar coordinate in a process known as normalisation. In this work, the normalisation method of Daugman (1993) is used, which is known as the rubber sheet model. The codes of rubber sheet model from Masek (2003) and Aydi et al. (2014) are modified in order to reduce their complexity and execution time. After normalisation, the iris features in the iris image are extracted by using the 1D log-Gabor filter (Daugman, 2003). Next, the extracted features are encoded into a binary code to create the iris template (Daugman, 2003). Finally, the iris template is matched with the database template in order to calculate the matching score using the Hamming distance method (Daugman, 2003).

The CPU implementation of iris recognition system is not fast enough in terms of execution time and operation (Yu & Zhou, 2012). The CPU used the sequential computation while the embedded system such as graphical processing unit (GPU) and field-programmable gate array (FPGA) used the parallel computation. According to Pauwels et al. (2012), a GPU has major advantages over a FPGA in terms of absolute performance, external and random memory access, and development time. Because of these advantages, GPU is selected as a platform for the proposed method. First, the code of the proposed iris recognition system is modified in order to accommodate the parallel processing of the GPU. The iris segmentation code is modified to locate the pupil region in parallel. After that, the normalisation and feature extraction codes of Masek (2003) and Aydi et al. (2014) are modified so that these processes can be calculated in parallel. Finally, the matching score of the iris template and the database template is calculated in parallel. In this work, NVIDIA GTX 960 GPU with 4 GB RAM and 1127 MHz base clock was used. The CPU specifications are Intel Core i5 (2.3 GHz) and 4 GB RAM. The iris recognition algorithm is implemented on MATLAB with parallel computing toolbox.

RESULTS AND DISCUSSION

Figure 4 shows the comparison between full-iris and the sub-iris technique. Figure 4(a) shows the proposed iris segmentation method based on the pixel property in the iris image and the active contour method. The results show the proposed method is able to segment the irregular boundary of iris and pupil regions. This method can locate an iris boundary which is occluded by the upper and lower eyelids. Meanwhile, the eyelashes region can be eliminated by using a simple thresholding technique. Figure 4(b) shows the sub-iris region of r=0.9. Based on this observation, the sub-iris region does not need to locate the upper iris (occluded by eyelash) and the lower eyelid (no eyelid detection) but at the same time it can capture the rich iris features near the pupil region. The sub-iris region excludes the iris features at the upper iris (50% of iris features near the pupil region), but the captured iris features in the lower iris can be used to match the full-iris features in the database. The sub-iris technique may reduce the possibility of capturing the unwanted eyelashes and eyelids into the iris template. This technique can also save time and resources needed to locate eyelids and eyelashes in the iris image.



(a) (b)

Figure 4. The segmentation example of: (a) full-iris; and (b) sub-iris (r=0.9)

Figure 5 shows the location of the proposed sub-iris region in the full-iris template in the database. The red box is the iris features captured by the proposed sub-iris technique. Meanwhile, the blue box is the iris region occluded by the upper and lower eyelids. The green box is the possible location of the eyelashes. Based on this figure, the proposed sub-iris technique has managed to avoid capturing the iris region that is occluded by the eyelids and eyelashes. The presence of both eyelids and eyelashes are quite common in the non-ideal iris. The occluded regions have no iris features which leads to waste of time and resource if added into the system.

Figure 5. The sub-iris region (r=0.9) in the database template

Table 1 shows a comparison of all three sub-iris regions in terms of equal error rate (EER) and area under curve (AUC). The sub-iris region of r=0.9 achieved the lowest EER and the highest AUC compared with other sub-iris regions. This is because the sub-iris region of r=0.9 managed to capture the most iris features without the inclusion of noise and occlusion. The captured iris featuresare similar with the database template. The low value of EER means that this method has high recognition accuracy. The EER is obtained on the receiver operating characteristic (ROC) curve when the proportion of acceptance and rejection error is equal. The ROC curve is plotted from the matching score to show the genuine acceptance rate (GAR) against the false acceptance rate (FAR). Meanwhile, AUC is another indicator for the accuracy of the proposed method. The AUC refers to the probability of the algorithm classifier to indicate the acceptance rate is higher than the rejection rate. The AUC is obtained from the ROC curve by calculating the area under the respective graph. Based on the result, the sub-iris region of r=0.9 achieves the highest value of AUC which indicates that this method has the highest recognition accuracy.

Table 1
Analysis of three sub-iris regions

Method	Equal Error Rate (%)	Area Under Curve
r=0.4	6.21	0.9710
r=0.6	4.55	0.9755
r=0.9	3.77	0.9821

Table 2 shows the performance comparison between the CPU implementation and the GPU implementation of the proposed iris recognition system. The full-iris technique used the entire iris features and implemented on the CPU. Meanwhile, the sub-iris region of r=0.9 is used because it has the optimal performance compared with r=0.4 and r=0.6. The sub-iris technique was implemented on both CPU and GPU. In terms of recognition accuracy, the full-iris technique achieved the lowest EER and the highest AUC compared with the sub-iris technique. This is understandable because the full-iris technique has more iris features to be matched with the database template compared with the sub-iris technique, resulting in less error. But the differences between full-iris and sub-iris in terms of EER and AUC were quite small (differences of EER=3% and AUC=0.1%). This shows that even though the sub-iris technique used fewer than 50% of full-iris features, it still managed to achieve a relatively small difference of EER and AUC compared with the full-iris technique. Meanwhile, the EER and AUC values of the sub-iris CPU and the sub-iris GPU were similar because only the programming and platform were changed, which did not affect the accuracy. The IDO-based method of Radman et al. (2013) achieved the lowest recognition accuracy because it was not able to capture the iris features that were occluded by the reflections.

Table 2
Performance comparison between CPU and GPU

Method/Technique	Equal Error Rate (%)	Area Under Curve	Execution Time (s)
Radman et al. (2013) (full-iris with CPU)	7.23	0.9576	2.420
Proposed full-iris with CPU	3.66	0.9831	1.017
Proposed sub-iris (r=0.9) with CPU	3.77	0.9821	0.954
Proposed sub-iris (r=0.9) with GPU	3.77	0.9821	0.573

In terms of execution time, the sub-iris GPU was the fastest compared with the sub-iris CPU and the full-iris CPU. The sub-iris GPU achieved speedups of 43.66% and 39.94% over the full-iris CPU and the sub-iris CPU respectively. This shows that the parallel processing of GPU is faster than the sequential processing of CPU. The GPU implementation is also more efficient than the CPU implementation for the iris recognition system. Meanwhile, Radman et al. (2013) achieved the slowest execution time because their method used two IDOs to locate the pupil and iris boundaries. The IDO is a complex algorithm with extensive computation. This method also uses a separate eyelid detection based on the live-wire method to locate the eyelid boundary, which results in longer execution time for the iris recognition system. This method is also implemented on the CPU, in which all processes are executed sequentially.

Based on the discussions, the GPU implementation of the sub-iris technique was the fastest compared with the CPU implementation of the sub-iris technique. On the other hand, the recognition accuracy of the sub-iris and the full-iris techniques was not too different. This shows that the proposed GPU implementation of sub-iris technique can be used in the iris recognition system. The proposed method is suitable for real-time implementation because of its speed and high recognition accuracy.

CONCLUSION

This study had looked at the GPU implementation of the sub-iris technique in the iris recognition system. The iris segmentation algorithm is based on the pixel property and active contour methods. The proposed segmentation was combined with the sub-iris technique and implemented on a GPU platform. Based on the results, the proposed method managed to achieve a fast execution time and acceptable recognition accuracy compared with the iris recognition system using the full-iris technique. The proposed method is suitable for screening identification, which is the first line of identification in the airport and immigration. It is also suitable for the non-ideal iris, in which the iris region is occluded by unwanted elements. Future research should look at how GPU performance may be increased by overclocking it to the higher clock speed by increasing the core voltage, core clock and memory clock. Other than that, the scalable link interface (SLI) can be used by linking two or more GPUs to carry out parallel processing in order to increase processing speed. The GPU is the future since most computers nowadays have a dedicated GPU, reducing upfront costs. The GPU offers great potential due to its advanced technology in terms of speed and memory.

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