A comparison of iris image segmentation techniques

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Abstract. The paper compares three different methods of iris image segmentation, namely the method using the Daugman`s integro-differential operator, the method using the Hough transform for the detection of circles, and the method based on the analysis of the distribution of edge points. The accuracy and run time of the implemented methods were estimated in the experimental study conducted using the MMU Iris Image Database. The carried out research has shown that the method using the Daugman`s integro-differential operator has the greatest accuracy, and the method based on the analysis of the distribution of boundary points has the shortest operating time.

1. Introduction

In recent years, identifying a person by his/her biometric parameters becomes a more and more popular field of research. The reason for this is both the increased interest in the biometric identification by public and commercial bodies and the intensive development of technical tools of recording, storage and processing of such information. Today, a broad range of features of human body is used for the identification, including face images [1, 2], fingerprints, iris patterns, voice, manner of walking etc. The identification of a person by an iris pattern is of particular interest in this list, because this method ensures the most accurate identification [3].

In fact, the iris is a circular movable diaphragm with a diameter of about 12 mm, at the core of which there is a round hole, a pupil [4]. An example iris image is presented in figure 1.

The iris color (eye color) depends on the coloration (pigmentation) of iris anterior surface visible through the transparent cornea [5]. However, if the iris color changes during the first 10-12 years of a human life and may change in old age, the iris pattern with clear individual characteristics, which is formed during the intrauterine growth, remains almost the same throughout the human life [6, 7]. These iris characteristics cause significant interest to this identification method.

Generally, the identification systems using an iris image are built according to the classical scheme:

- selection of an informative region (iris) on the image,
- feature description of the selected region,
- comparison of the feature descriptions.

In this case, the quality assessment of both obtained images and effectiveness of individual method stages may be included into the above scheme [8].

It should be noted that the accuracy of the first of the above-mentioned stages (selection of the iris on the image) plays an important role in the achievement of high quality.

The selection of the region corresponding to the iris on the image is the segmentation-related task that can be completed using a variety of methods. Specifically, the approaches based on the edge detection [9], thresholding [10], Daugman's integro-differential operator [11], circular Hough Transform [12] etc. are popular.

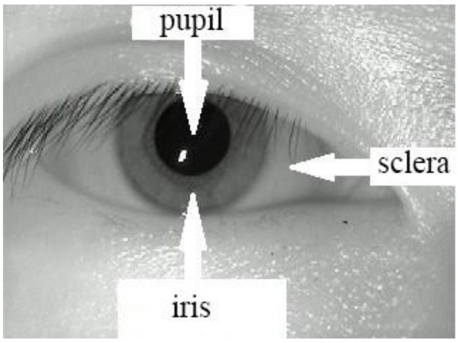


Figure 1. Example image from the data set [15].

When using these approaches, the internal and external iris boundaries (boundaries "iris-sclera" and "pupil-iris") are sought, and the further approximation of detected boundaries with circles is performed. It should be noted that such approximation is only the first stage of a segmentation, because after selecting the ring (which may be non-concentric) formed by these circles, the part of the iris may remain closed and shaded by eyelids and eyelashes.

This paper describes the experimental comparison of three approaches to the selection of the iris on the image.

This paper has the following structure. Sections 2-4 briefly describe the methods considered in this report. Specifically, Section 2 describes the method based on the Daugman's integro-differential operator, Section 3 describes the method based on the circular Hough transform, and Section 4 describes the method based on the edge detection and edge points distribution analysis. The results of experimental studies carried out with MMU Iris Image Database are presented in Section 5. In the end of this paper, there are Section 6 containing the conclusion and Section 7 containing the reference list.

2. The method based on the Daugman's integro-differential operator

According to the method based on the Daugman's integro-differential operator, the possible centers of the iris should be calculated first on an input image I_{in}. To do this, the points on I_{in} with the brightness level below the predefined threshold are selected. Then, the points, which correspond to the local minima of the brightness, are selected from the above-mentioned points.

Local minimum is the minimum of the circular neighborhood with a radius equal to the minimum iris radius. In this method, the minimum and maximum radii of the iris should be set to overlap a little bit the iris radius values from the image database.

Then, the parameters of circle approximating boundary "iris-sclera" should be calculated. This is done by using the Daugman's integro-differential operator [11] defined as the maximum of the smoothed derivative of the average image intensity along the round contour with coordinates (x_0, y_0) and radius r:

$$\max_{(r,x_0,y_0)} \left| G_\sigma(r) * \frac{\partial}{\partial r} \oint_{r,x_0,y_0} \frac{I(x,y)}{2\pi} ds \right|.$$

Here $I(x, y)$ is the image intensity function, $G_\sigma(r)$ is the Gaussian smoothing function, s is the circle contour with the coordinates (x_0, y_0) and radius r. This operator is applied for the points of I_{in} selected as possible iris centres and having r values changing from minimum to maximum iris radius.

Example of how the method described in this section works for figure 1 is presented in figure 2.

3. The method based on the circular Hough transform

According to the method based on the circular Hough Transform, the Canny edge detector [13] is applied first to the input image I_{in} to generate the image of edge points I_{ed1}. The intervals of the pupil and iris radius values used for searching should be established beforehand, depending on an existing image database, so as to overlap a little bit these values.

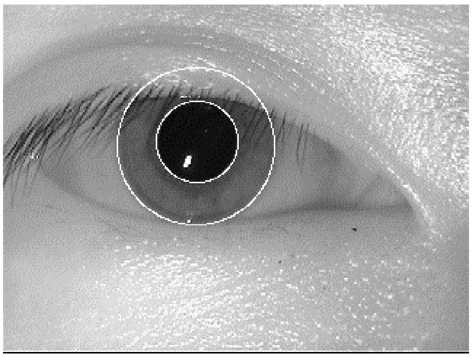


Figure 2. The result of the method based on the Daugman's integro-differential operator for the image depicted in Figure 1.

Then, the parameters of the circle, which approximates the “iris-sclera” boundary, should be determined on the image I_{ed1} of edge points using the circular Hough transform [9]. Maximum and minimum radii used for searching are taken from the pre-determined interval of iris radius values.

Thereafter, image I_{ed2} is made up of the points of the image I_{ed1} that are within the circle determined at the first stage. The parameters of the circle, which approximates the “pupil-iris” boundary, should be determined on the image I_{ed2} using the circular Hough transform [9]. Maximum and minimum radii used for searching are taken from the pre-determined interval of pupil radius values.

An example obtained using this method is shown in figure 3.

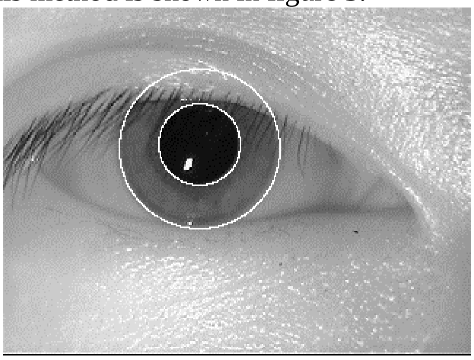


Figure 3. The result obtained using the method based on the circular Hough transform for the image depicted in figure 1.

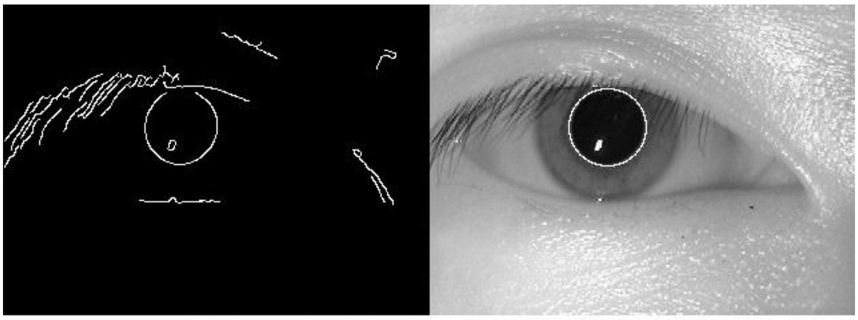
4. The method based on the analysis of the edge points distribution

As a part of this work, the method based on the circular Hough transform and the analysis of the edge point distribution was proposed. This method includes the following stages. At the first stage, the iris internal boundary (boundary “pupil-iris”) should be selected on the input image, and the parameters of the circle approximating the pupil should be determined. At the second stage, the iris external boundary (boundary “iris-sclera”) is selected, and the parameters of the circle approximating the iris external boundary are determined using the least squares method. These stages are described below in more detail.

4.1. Pupil boundary determination

To determine the internal boundary of the iris, the Canny edge detector [13] is applied to the input image I_{in} to generate the image I_{ed1} of edge points. Then, using the circular Hough transform [9], the centre and the radius R_{pupil} of a pupil are determined on I_{ed1}. The minimum and maximum circle radii used for searching with Hough transform should be taken so as to overlap a little bit the pupil radius values from the image database.

Figure 4 below provides the example of pupil boundary determination for the image depicted in figure 1.



(a) (б)

Figure 4. Example of pupil boundary determination for the image depicted in figure 1: (a) - edge points image; (b) - method results.

4.2. Determination of iris external boundary

To determine the iris external boundary, the function of the edge point distribution from the pupil centre, which is described in [14], is analyzed. The Canny edge detector [13] is applied to the input image I_{in} to generate the image I_{ed2} of edge points. The parameters of the Canny edge detector, which used to search for the pupil and iris boundaries, are different and should be selected in an experimental fashion based on the existing image set. It is known [14] that the value of the iris external radius R_{iris} is within the range ($5/4R_{pupil}$, $5R_{pupil}$), so the points, the distance from which to the pupil centre is not within the specified range, shall be removed from I_{ed2}. The function *f(R)* of the edge point distribution on the distance R to the centre of the pupil shall be calculated for the obtained image. It is expected that this function has a local maximum around the target iris radius value, because the pupil and the iris are approximately concentric. However, this maximum may hide among other maxima caused by the noise contamination of the image I_{ed2}.

An example of the graph of the function *f(r)* of the edge point distribution on the distance R to the centre of the pupil is shown in figure 5. The argument r of the function *f(r)* equals to the difference between R and R_{pupil}.

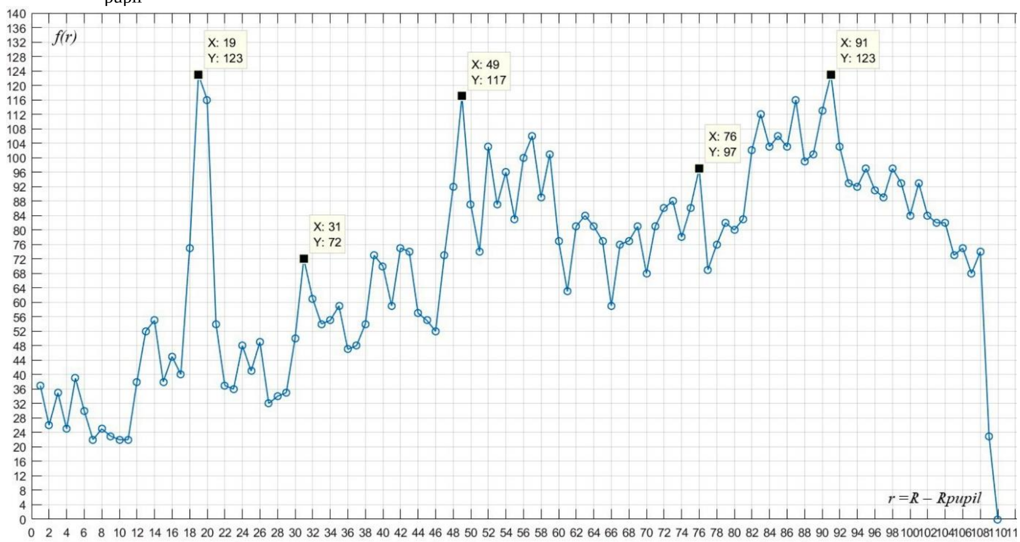


Figure 5. Example of the graph of the function *f(r)* of the edge point distribution on the distance R to the centre of the pupil.

Thereafter, the direct search for the local maxima of the *f(R)* function is performed starting with the highest maximum. For the selected local maximum R_M, the edge points, which fall into the ring defined by the radii $R_M - s$ and $R_M + s$, are approximated by the circle using the least squares method. The circle, for which the approximation error is lower than the predefined value, is selected. It is considered that this circle approximates the iris external boundary.

An example obtained using this method is shown in figure 6.

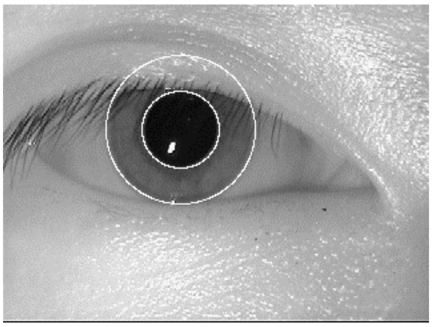


Figure 6. The results of the method based on the analysis of the edge point distribution for the image depicted in figure 1.

5. Experiment

To compare the accuracy of segmentation and operation time of the above methods, the simulation experiment was carried out. All methods were implemented in MATLAB. The experiment is carried out on a personal computer powered by Intel Core i5-4210M with a frequency 2.6 GHz and random-access memory of 6 GB.

When conducting this experiment, 30 iris images taken from MMU Iris Image Database [15] were used. For each image, the expert performed the reference (true) segmentation and defined the true values of pupil and iris boundary parameters (centre coordinates and radii). Thereafter, the similar values of parameters were assessed using each of the methods considered in this paper.

To assess the precision of each method, the Jaccard index [16] averaged over all test images was used. The Jaccard index is defined in this paper as the ratio between the intersection of rings (non necessarily concentric) with reference and evaluated parameters, and the area of interconnection of these rings. Besides, the image-averaged operation time of the assessed methods was evaluated.

The results of the experiments are presented in Table 1 and figures 7, 8. Specifically, “A” section describes the method based on the Daugman's integro-differential operator, “B” section describes the method based on the circular Hough transform, and “C” section describes the method based on the analysis of the edge point distribution.

Table 1. Experimental results.

Method	Precision		Operation time (s)	
	Average value	RMSD	Average value	RMSD
A	0.90	0.03	4.36	1.14
B	0.86	0.03	1.74	0.49
C	0.86	0.05	0.76	0.06

These results demonstrate that the Daugman's integro-differential operator is the most precise, but requires the longest operation time. The method based on the circular Hough transform is a little bit less precise, but has a significantly lower operation time (in 2.5 times).

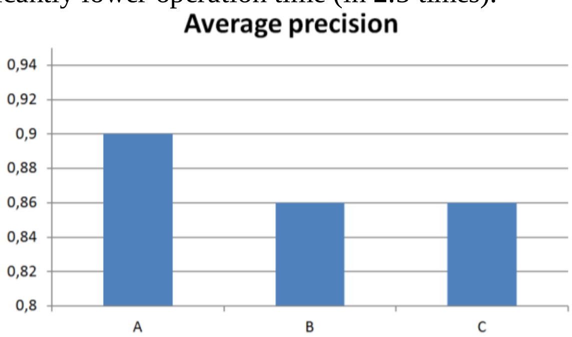


Figure 7. Average precision value for three studied methods: the method based on the Daugman's integro-differential operator (A), the method based on the circular Hough transform (B), the method based on the analysis of the edge point distribution (C).

The method based on the analysis of the edge point distribution was the fastest one (almost 6 times faster than the method of Daugman's integro-differential operator). In this case, it showed the same precision with the used data set as the method based on the Hough transform.

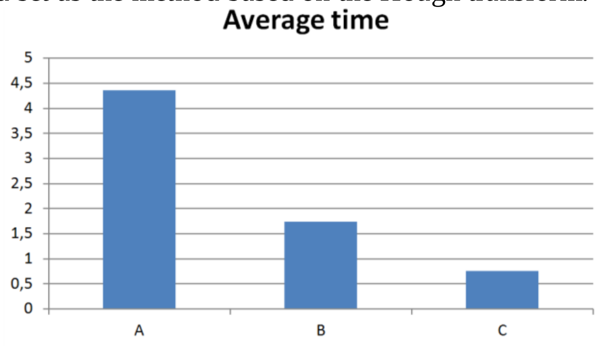


Figure 8. Average operating time (in seconds) for three methods: the method based on the Daugman's integro-differential operator (A), the method based on the circular Hough transform (B), the method based on the analysis of the edge point distribution (C).

6. Conclusion

Three methods of assessment of iris boundary parameters were evaluated in this study, namely: the method based on the Daugman's integro-differential operator, the method based on the circular Hough transform, and the method based on the analysis of the edge point distribution.

For images from MMU Iris Image Database, the reference segmentation of iris images was performed, and numerical experiments to assess the precision and operating time of implemented methods were carried out. The experiments show that the method of the Daugman's integro-differential operator is the most precise with regard to the applied data set, and the method based on the analysis of the edge point distribution proposed in this paper is marked by the lowest operation time and has the same level of precision as the Hough transformation.

In future, it is planned to use study results to develop the method of person identification by the picture of iris.

7. References

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