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IRIS FINDER – PROGRAM FOR RELIABLE IRIS LOCALIZATION IN IMAGES TAKEN UNDER VISIBLE LIGHT

In this paper the *Iris Finder* program is presented for the first time. It is a software for reliable iris localization in images taken under visible light. The program is intended for researches on a system for automatic persons identification based on iris pattern. The paper structure is as follows. First other researchers concepts are introduced. Next the proposed algorithm applied in the *Iris Finder* program is described in detail. Finally the algorithm implementation details are listed and obtained results are discussed.

1. INTRODUCTION

Nowadays the importance of biometric identification technologies is increasing due to their innate features such as reliability, speed and difficulty of forgery. Systems for people recognition based on biometric features have broad applications in both commercial and security areas. One of the most reliable and being actively developed biometric technology is persons identification based on iris pattern. The first successful implementation of the iris recognition system was described by J. Daugman in 1993 [3]. This work, though published more than 10 years ago, still remains very valuable because it presents well thought solutions for each part of the system. The publication is known as fundamental in the area of iris identification and further researchers refer to it. It is worth mentioning that most publicly operational iris recognition systems worldwide today are based on the algorithms described by J. Daugman [4].

Each algorithm of iris identification begins with localization of the iris. If this stage fails the person will not be properly recognized. This paper focuses on the iris localization method for images taken under visible light. It presents proposed solution and stresses the impact of localization effectiveness on the overall performance of the system.

2. RELATED WORK

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2.1. DAUGMAN'S INTEGRODIFFERENTIAL OPERATOR

The integrodifferential operator [2, 3] uses the fact that both outer and inner iris boundaries may be modelled as non concentric circles. Let $I(x, y)$ denote grayscale intensity at (x, y) coordinates of an image point. Next let $I_{ave}(r, x_0, y_0)$ denote average intensity of points which belong to circle $\Gamma(x_0, y_0, r)$ of radius r and centre coordinates (x_0, y_0) as in equation (1):

$$I_{ave}(r, x_0, y_0) = \oint_{\Gamma(x_0, y_0, r)} \frac{I(x, y)}{2\pi r} ds \tag{1}$$

Iris localization may be performed by computing for each image pixel partial derivative of function $I_{ave}(r, x_0, y_0)$ with respect to increasing radius r. After smoothing the function with Gaussian kernel $G_\sigma(r)$ of space-scale σ, its maximum will denote parameters (r, x_0, y_0) of circle arc for which there is observed the biggest difference between mean intensity of pixels from its inner and outer neighbourhood. This may be expressed as finding global maximum of the formula (2):

$$\max_{(r, x_0, y_0)} \left| G_\sigma(r) * \frac{\partial I_{ave}(r, x_0, y_0)}{\partial r} \right| \tag{2}$$

The presented technique may be applied for both inner and outer iris boundary. However as the outer one is usually occluded by eyelids, the algorithm differs a bit. There is computed average intensity of pixels not from the whole circular arc, but only from its left and right parts forming 90° arcs.

2.2. CAMUS AND WILDES METHOD

Another approach has been proposed by Camus and Wildes in [1]. The researchers model the outer iris boundary as a circle, while the inner one is modelled as an ellipse. The first step of the approach is reducing the input grayscale image size to 80 pixels x 60 pixels. Next the reflections are segmented by a threshold operation. The threshold value is constant and is set to 250 out of range 0..255. Then the reflections are filled in by bilinear interpolation from the surrounding intensities. The next step is selecting seed points for the iris centre fits. They are chosen as points that correspond to local minima of image intensity. A local minimum is defined as an image intensity value below a certain global threshold and also one that is the smallest within a 5 x 5 pixel region. Based on experiments the researchers set the global threshold value to 128.

For each seed point there is computed a goodness of fit value based on mapping of radial rays into a polar representation, in which pupil and iris boundaries become vertical edges. The goodness of fit value is generally based on gradient of intensities near the vertical edges. However as this part of the approach was not used by the authors, its detail description is not given here.

3. PROPOSED ALGORITHM APPLIED IN THE *IRIS FINDER* PROGRAM

3.1. GENERAL DESCRIPTION

The general idea of the proposed algorithm and its main processing steps are depicted in Fig. 1. In the figure results of some of the processing steps have been illustrated as well.

The procedure of iris localization in the colour image starts from loading the photo from a file. Next the image size is reduced, so that its height equals 250 pixels. Then the image is converted to grayscale based on YIQ (luminance in-phase quadrature) model. On such preprocessed image a threshold operation is applied to localize reflections. Obtained reflections image is then enhanced by performing morphological operations.

The authors noticed that when searching the inner boundary of the iris, red components of the RGB (Red Green Blue) pixel values are particularly useful. Hence the next step is extracting only the red component intensities from the colour image with reduced size. Obtained red component image is then preprocessed by filling in the segmented reflections based on interpolation of values of neighbour pixels from outside of reflections.

Having the red component iris image with filled in reflections, the search for iris boundaries begins based on Daugman's integrodifferential operator. First the outer boundary is localized, next the inner one. Detailed explanation of such order may be found in [5]. The result of finding the outer boundary indicates a search area for the inner one. That is because centres of both boundaries are located close to each other. Moreover a search range of the inner boundary radius is determined by the radius of the outer boundary.

In the following sections key processing steps of the algorithm are documented in more detail.

3.2. FINDING REFLECTIONS

The reflections are localized by applying a threshold operation to the preprocessed iris image. The value of an intensity threshold is computed individually for each image based on its histogram.

Example histograms of two preprocessed iris images are shown in Fig. 2 (both images come from the *DMCS* database which is described later). Because of the complexity of the iris pictures there is often no significant local maximum in histogram which denotes reflections intensities. Hence computing the threshold value can not be based on searching for such maximum. Instead the average image intensity I_{ave} is calculated first. Next the maximum intensity of image pixels I_{max} is found. Finally the threshold t is set in a fixed proportion p between these two values as in equation (3):

$$t = I_{ave} + p(I_{\max} - I_{ave}) \,, \qquad where \quad p \in (0,1) \,. \tag{3}$$

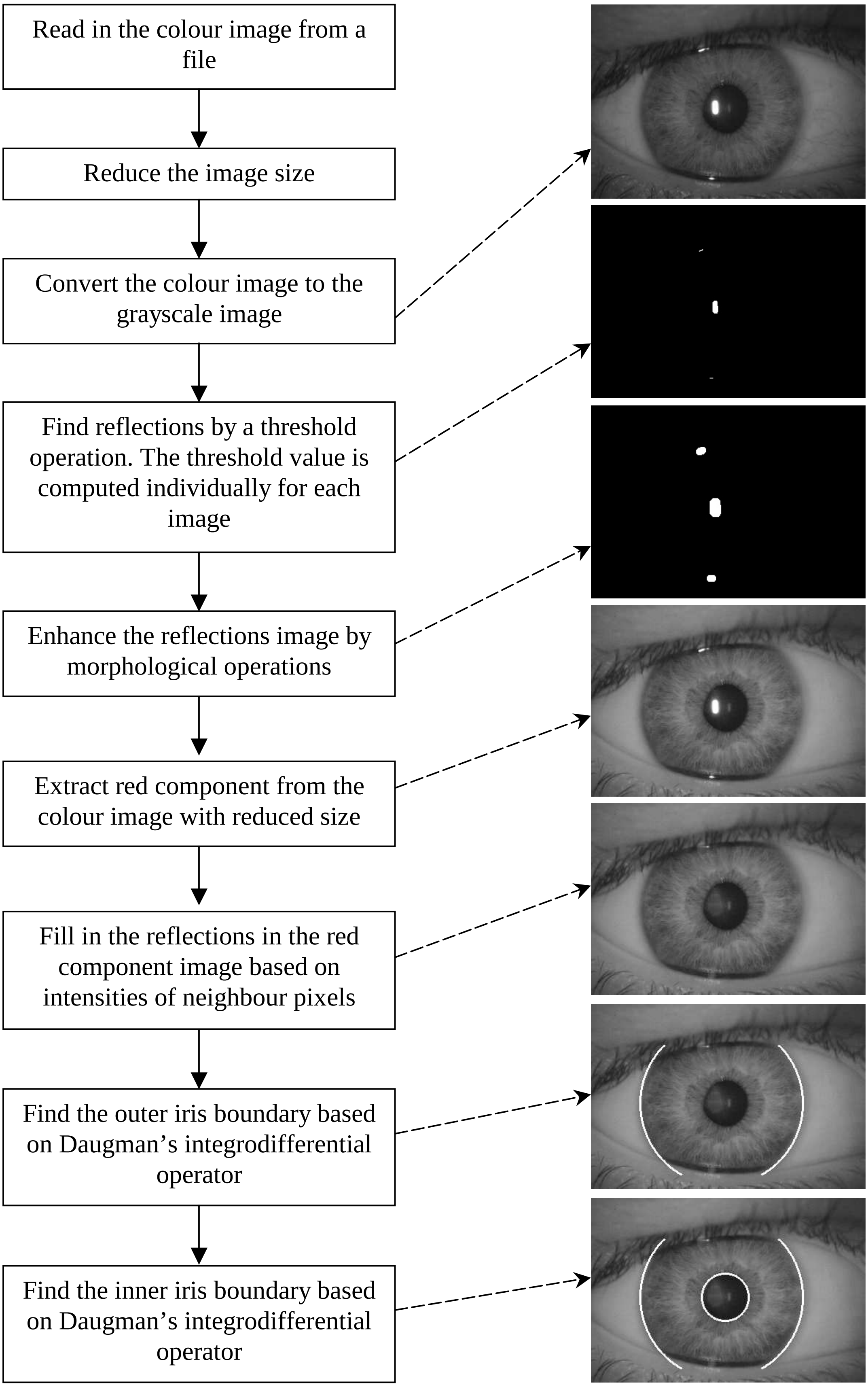

Fig. 1. Main image processing steps performed by the *Iris Finder* program. Dashed arrows depict results of corresponding processing steps.

The proposed method has one drawback - it is vulnerable to noise, because it relies on intensity of a single brightest pixel in the entire image. To eliminate this inconvenience the maximum value of intensity is taken as an average intensity of fixed amount of brightest pixels. This amount, based on experiments, was set to 0.04% of the total number of pixels. Results of computing I_{ave}, I_{max} and t are depicted by arrows in Fig. 2.

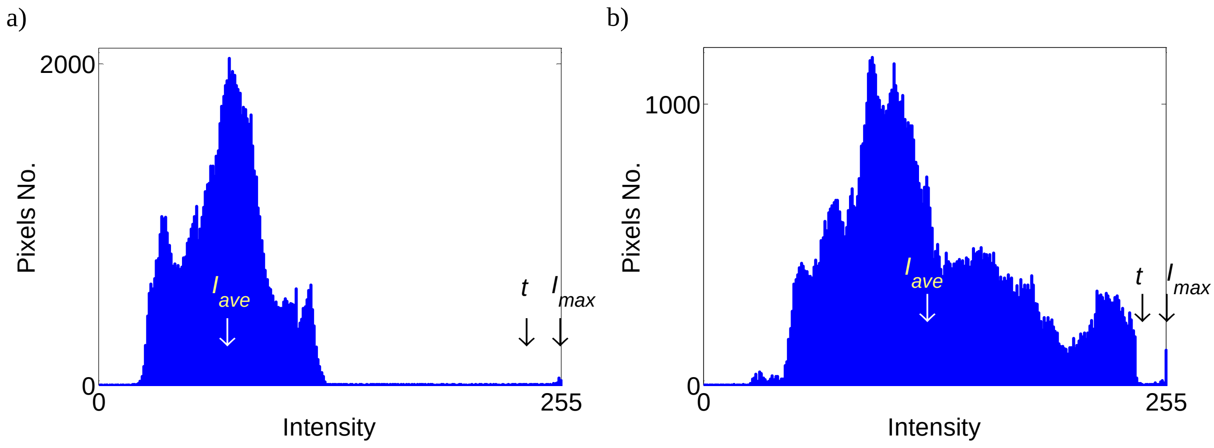

Fig. 2. Examples of preprocessed iris image histogram: a) histogram computed for the image presented in Fig. 1, b) histogram of a different photo (both images come from the *DMCS* database). Arrows depict the average intensity of all pixels, the average intensity of the brightest pixels and the computed threshold value.

3.3. REFLECTIONS IMAGE ENHANCEMENT

The threshold segmentation localizes only the brightest area of reflections. However this is not sufficient for further filling in reflections, hence the obtained reflections image needs enhancement.

Firstly localized areas of reflections should be slightly increased because of a glow around them. The glow consists of pixels with intensities that are intermediate between high reflection intensity and intensity of surrounding pixels not affected by the reflection. This is performed by dilation on the reflections image. As a structuring element there is chosen a wheel because none particular direction is singled out. Next the closure operation is performed, which results in connecting reflection areas which are close to each other. As before, as a structuring element a wheel is taken. In both applied morphological operations the size of the structuring element is determined by experiments.

3.4. FILLING IN REFLECTIONS

Based on the enhanced reflections image, the reflections in the iris red component image are filled-in. The general idea is to replace an intensity of each pixel from reflections areas by the intensity interpolated from neighbour pixels positioned outside reflections.

This is performed as follows: firstly for each pixel in each reflection area four nearest neighbours lying outside the reflection are found – the left, right, upper and bottom one. For each neighbour *i* its weight w_i is computed. The weight simply equals the inversed distance d_i between this neighbour and the pixel being filled-in. Next the intensity I_f of the pixel being filled-in is interpolated based on intensities I_i of found neighbour pixels, as in equation (4):

$$I_f = \frac{\sum_{i=1}^{4} w_i I_i}{\sum_{i=1}^{4} w_i}, \qquad \text{where} \quad w_i = \frac{1}{d_i} \quad \text{for} \quad i = 1, 2 \,..\, 4. \tag{4}$$

4. RESULTS

4.1. ALGORITHM IMPLEMENTATION

The authors implemented the proposed algorithm in the *Iris Finder* program. As a programming language the C++ was chosen mainly due to its object-oriented approach and efficiency. The prepared software relies on three libraries: the *ITK* library [9] for image I/O, the *FLTK* library [8] for GUI (Graphics User Interface) and the *CxxTest* library [7] for unit testing. *ITK* stands for Insight Segmentation and Registration Toolkit and *FLTK* stands for Fast Light Tool Kit.

4.2. DMCS DATABASE

The *Iris Finder* program was initially designed for the *DMCS* database (*DMCS* - Department of Microelectronics and Computer Science). This database has been established by the authors. At the moment it contains 141 images of left and right eyes of 4 persons. It is worth mentioning that photos were taken not at once, but in three consecutive sessions during 6 months. The images are colour with 8 bits per pixel for each red, blue and green components. The photos dimension equals 3072 pixels x 2048 pixels. The acquisition was performed using Canon EOS 10D camera (6.3 Megapixel CMOS sensor). Instead of using standard lens the camera was connected to Kontron Fundus Camera - a medical device intended for diagnosis in ophthalmology. The images are stored in the *raw* format. However the compression doesn’t affect the localization algorithm due to its innate averaging properties. Hence the photos could be converted to the *JPEG* format (*JPEG* - Joint Photographic Experts Group) before experiments. The *Iris Finder* program correctly localizes iris for all images from the prepared database, that is its effectiveness equals 100% as presented in Table 1. Example results of iris localization are depicted in Fig. 3.

4.3. UBIRIS DATABASE

As the *DMCS* database is not publicly available yet, the effectiveness of the proposed algorithm can not be compared with results obtained by other researchers. This is the reason why the authors used the *UBIRIS* database, which is publicly available [6], to verify the proposed method. The authors performed experiments on a subset of the database - images from session I. This subset contains 1214 images of eyes of 241 persons. It is worth mentioning that on some images eyes are closed, hence iris is not visible. Another ones accidentally contain larger area of face. Both such types of photos were removed from the database before experiments (the number of removed images equals 9). Photos from the *UBIRIS* database are available in few formats. The authors chose colour image format with the highest resolution available (800 pixels x 600 pixels). The *Iris Finder* program incorrectly localizes iris only for 4 images from this database, that is its effectiveness equals 99.67 % as presented in Table 1. Example results of iris localization are depicted in Fig. 3.

Database	**Iris localization effectiveness**	
	Grayscale image method	**Red component image method**
DMCS	100.00 %	100.00 %
UBIRIS (session I)	92.20 %	99.67 %

Table 1. Iris localization effectiveness of the *Iris Finder* program for the *DMCS* and *UBIRIS* databases. The “grayscale image method” column is given only for comparison here – it contains results obtained when searching the iris boundaries within the grayscale image, which was the first approach of the authors. The “red component image method” column summarises results obtained when utilizing the red component image for iris boundaries search as explained in the proposed algorithm description.

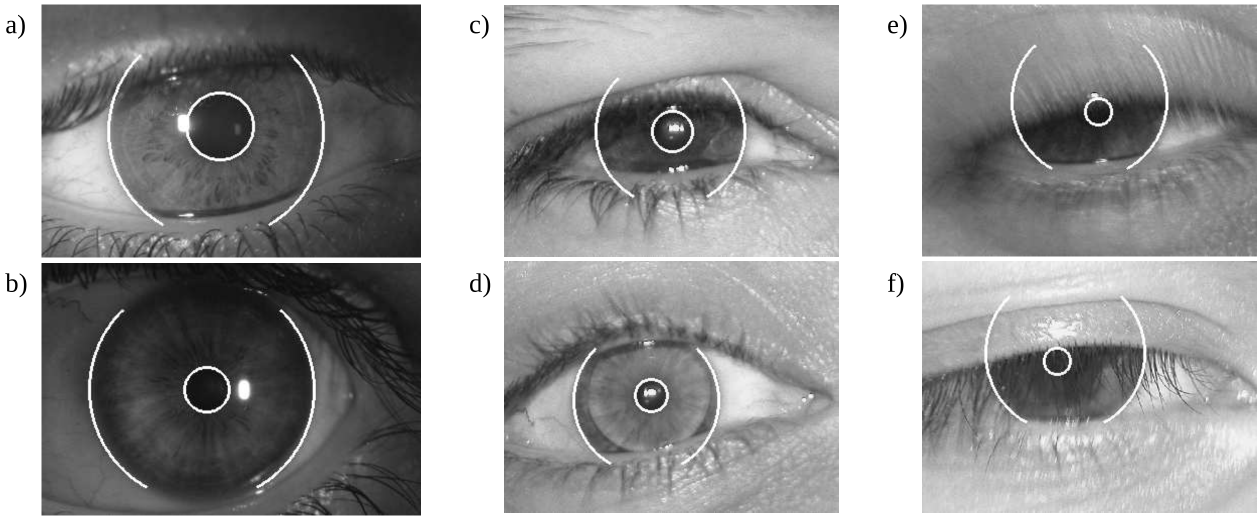

Fig. 3. Localization results illustrated on input images: a, b) correct localization for photos from the *DMCS* database, c, d) correct localization for photos from the *UBIRIS* database - on image d) a contact lens is visible, e, f) incorrect pupil localization for photos from the *UBIRIS* database due to iris being obscured by eyelids.

5. CONCLUSION

The proposed iris localization algorithm has been designed based on two ideas - Daugman’s solution and Camus and Wildes concept. Hence it applies Daugman’s integrodifferential operator, however it preprocesses image by filling in reflections as in the work of Camus and Wildes.

Although based on known ideas, the *Iris Finder* program introduces a few innovations as well. The first one is the method of computing the threshold value based on the image histogram instead of setting this value to some fixed number. The second concept is the enhancement of reflections image by morphological operations. Also details of the method of filling in the reflections were designed by the authors, as Camus and Wildes give only general guidelines. Moreover the authors noticed that effectiveness of searching the inner boundary significantly increases when only the red component of the colour image is used.

The authors wish to underline the importance of iris localization for the overall performance of the iris recognition system. This segmentation step is often treated as simple, well known and error free. Obtained results indicate that low error rate can be achieved, however this requires applying advanced techniques.

During experiments and algorithm development some results were different than expected. For example it appeared that most unsuccessful cases of iris localization were caused by wrong localization of the inner boundary, while the outer one was found properly. This may seem surprising as the outer boundary is being localized first and then, based on its parameters the inner boundary is being found. Therefore intuitively once it is known where in the entire image the outer boundary is, it should be fairly easy to find the inner one.

It should be mentioned that this paper is the first public presentation of the *Iris Finder* program.

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