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

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Abstract This paper presents improvements in *Iris Finder* – authors' program for reliable iris localization in images taken under visible light. Moreover it focuses on how key parameters of the program have been adjusted. Additionally iris localization reliability of proposed method is briefly summarized.

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 the 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 implemented by authors in the *Iris Finder* program and gives guidelines on how to adjust key program parameters. Moreover the paper summarizes iris localization reliability of proposed method. Additionally improvements on an earlier version of *Iris Finder* program are emphasized and commented, as the paper is a continuation of previous authors' publication [6], in which the earlier version of the program has been presented.

2. RELATED WORK

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. Then let $I_{ave}(r;\ x_0,\ y_0)$ denote average intensity of points that belong to circle $\Gamma(x_0,\ y_0,\ r)$ of radius r and centre coordinates (x_0, y_0) as in equation (1):

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

Next let $G_\sigma(r)$ denote Gaussian kernel of scale σ, as in formula (2):

$$G_\sigma(r) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{r^2}{2\sigma^2}\right) \qquad (2)$$

The 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 the Gaussian kernel, 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 (3):

$$\max_{(r,x_0,y_0)}\left|G_\sigma(r)*\frac{\partial I_{ave}(r,x_0,y_0)}{\partial r}\right| \quad (3)$$

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. 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 the 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. Camus and Wildes 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 presented here.

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

3.1. General idea

The general idea of proposed algorithm and its main processing steps are depicted in Fig. 1. In the figure the 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 and finding reflections. Next the input colour image is preprocessed by filling in the segmented reflections based on interpolation of RGB values of neighbour pixels from outside of reflections. Then the image is converted to grayscale based on YIQ (luminance in-phase quadrature) model. Next size of the grayscale image is reduced and the outer iris boundary is roughly found based on Daugman's integrodifferential operator. The height of the reduced size image equals 250 pixels.
The authors noticed that when searching the inner boundary of the iris, red components of the RGB (Red Green Blue) values of colour pixels are particularly useful [6]. Hence the next step is extracting only the red component values from the colour image with filled in reflections. Then size of the red component image is reduced and the inner iris boundary is roughly found based on Daugman's integrodifferential operator. The height of the resized red component image equals 250 pixels as in case of the resized grayscale image.
After the iris boundaries are roughly found in reduced size images, their position is precisely estimated utilizing original size images. The outer boundary is precisely located in the original size grayscale image, while the inner one is found in the original size red component image. The precise search is based on Daugman's integrodifferential operator, as in case of the rough search.
In the following sections key processing steps of the algorithm are documented in more detail.

3.2. Reflections localization

Image processing steps applied to localize reflections are listed below:

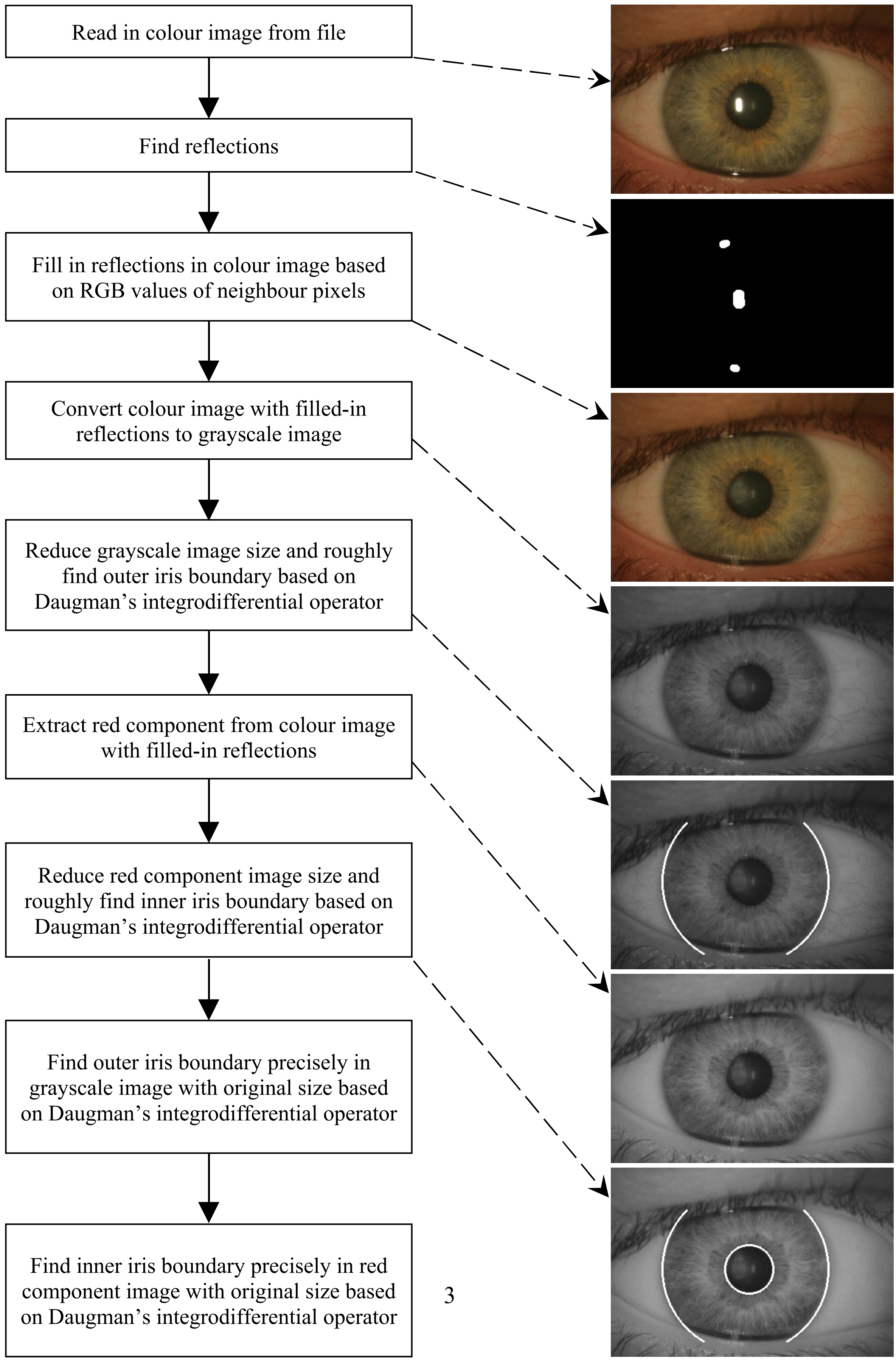
- Reduce the colour image size so that the image height equals 250 pixels;
- Convert the image to grayscale based on YIQ model;
- Apply a threshold operation to the grayscale image. The value of an intensity threshold is computed individually for each image based on its histogram, as described in [6].
- Enhance the reflections image by morphological operations, as explained in [6].
- Resize the enhanced reflections image back to the original size.

3.3. Filling-in reflections

Based on the reflections image, the reflections in the colour image are filled-in. The general idea is to replace RGB values of each pixel from reflections areas by the RGB values 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 RGB values R_f, G_f, B_f of the pixel being filled-in are interpolated based on RGB values R_i, G_i, B_i of found neighbour pixels. R_f is interpolated as in equation (4), G_f and B_f - analogously.

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



$$R_f = \frac{\sum_{i=1}^{4} w_i R_i}{\sum_{i=1}^{4} w_i}, \quad (4)$$

where $w_i = \frac{1}{d_i}$ for $i = 1, 2, ..., 4$.

3.4. Outer iris boundary search

Outer iris boundaries are usually occluded by eyelids. That is why Daugman proposes to compute in equation (1) average intensity of pixels from left and right parts of circular arc, which form 90° arcs. The authors increased this range slightly, as they noticed that in analysed databases occlusion of upper part of the iris is usually bigger than occlusion of the bottom part. That is why as the search pattern of outer iris boundary the authors applied the pattern presented in Fig. 2:

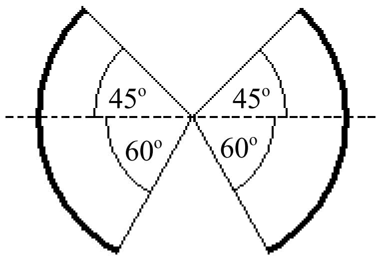


Fig. 2. Search pattern of outer iris boundary (marked with thick line).

4. ADJUSTING GAUSSIAN KERNEL SCALE

One of the key parameters of the *Iris Finder* program is the scale σ of the Gaussian kernel from equation (2). This parameter has been adjusted experimentally, separately for the outer iris boundary and the inner one. For a few iris photos the authors plotted average intensity $I_{ave}(r, x_0, y_0)$ from equation (1) for coordinates (x_0, y_0) fitting the centre of the searched boundary. Example of such analysis performed for the outer iris boundary is depicted in Fig. 3. The figure has been plotted for resized grayscale image obtained from one of the colour images from the *DMCS* (Department of Microelectronics and Computer Science) database [6]. Horizontal axes represents radius search range – the axes is labelled by Δr, which equals $r - r_{min}$, where r_{min} is a minimal value of searched radius. In Fig. 3. for intermediate values of Δr value of $I_{ave}(r, x_0, y_0)$ increases, which represents transition from (colour) iris to (white) sclera. Apart from the average intensity, in Fig. 3 its partial derivative with respect to increasing radius r is depicted (the vertical axes scale is linear, however exact values are not preserved, so that both functions may be shown).
Scale of the Gaussian kernel has been adjusted by the authors so that the kernel approximates shape of the partial derivative in the neighbourhood of the transition from iris to sclera. Based on observations of the partial derivative shape for a few photos the authors have estimated the scale parameter as depicted in Tab. 1. In the table there are given scale values relative to an average radius of the outer iris boundary, which is a parameter specific to the applied image acquisition hardware.

Tab. 1.
Experimentally adjusted Gaussian filter scale.

Iris boundary	Gaussian filter scale divided by average radius of outer iris boundary
outer	0.033
inner	0.016

The Gaussian kernel of scale adjusted to represent the outer iris boundary is depicted in Fig. 3. The kernel has been shifted to Δr for which the transition from iris to sclera is observed. This allows verification of how well the kernel approximates the partial derivative.
In Fig. 4 the partial derivative smoothed with the Gaussian kernel is depicted. For comparison the partial derivative from Fig. 3 is presented again. Maximum of the smoothed partial derivative indicates searched outer iris boundary. It is worth mentioning that this maximum is observed for slightly different radius than maximum of the partial derivative before smoothing.
The scale of the Gaussian kernel for the inner iris boundary was determined analogously. Adjusted value is depicted in Tab. 1.

5. IRIS LOCALIZATION RELIABILITY

The authors verified proposed method by measuring iris localization effectiveness, which is defined as number of photos with correct localized iris divided by total number of photos in the analysed database.
The measurements were analogous to the ones presented in [6], which were performed for the previous version of the algorithm. As before, the experiments were performed on *DMCS* [6] and *UBIRIS* [5] databases. Description of analysed photos and details of performed measurements may be found in [6], while obtained results are summarized in Tab. 2.

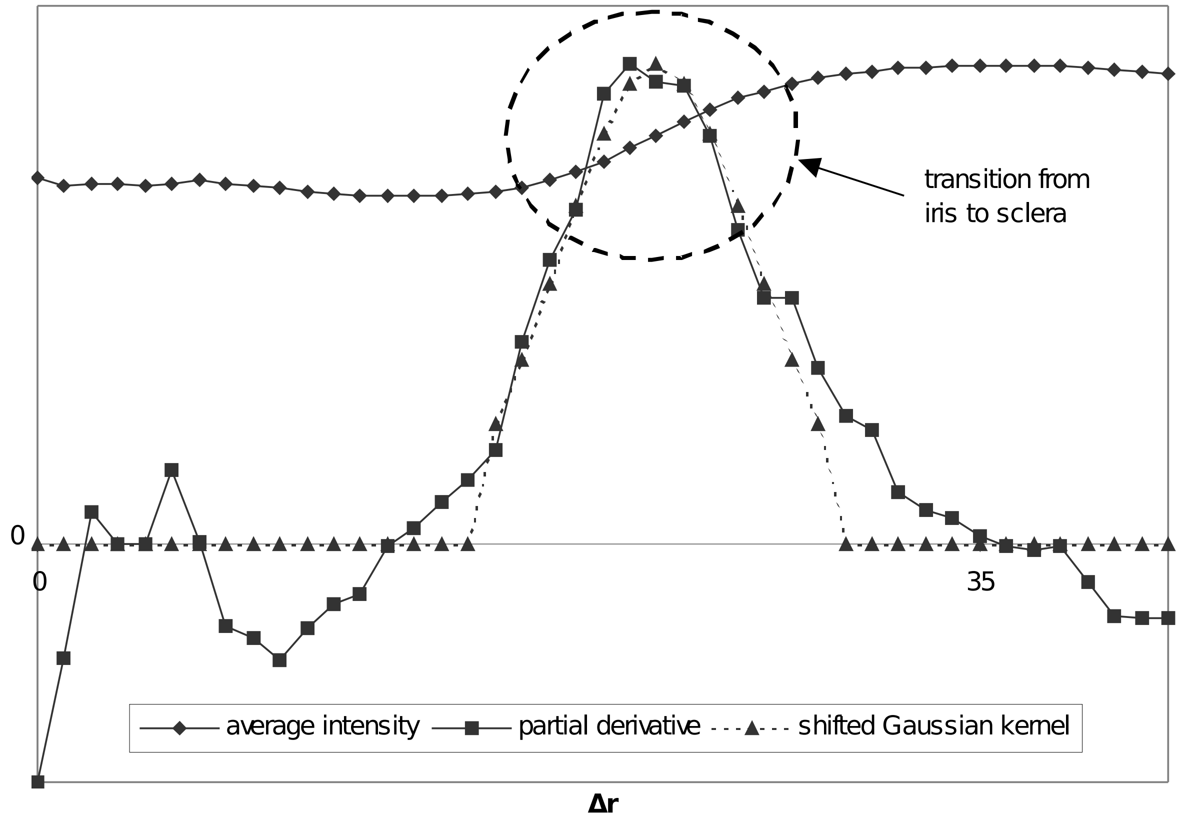


Fig. 3. Illustration of computing outer iris boundary position.

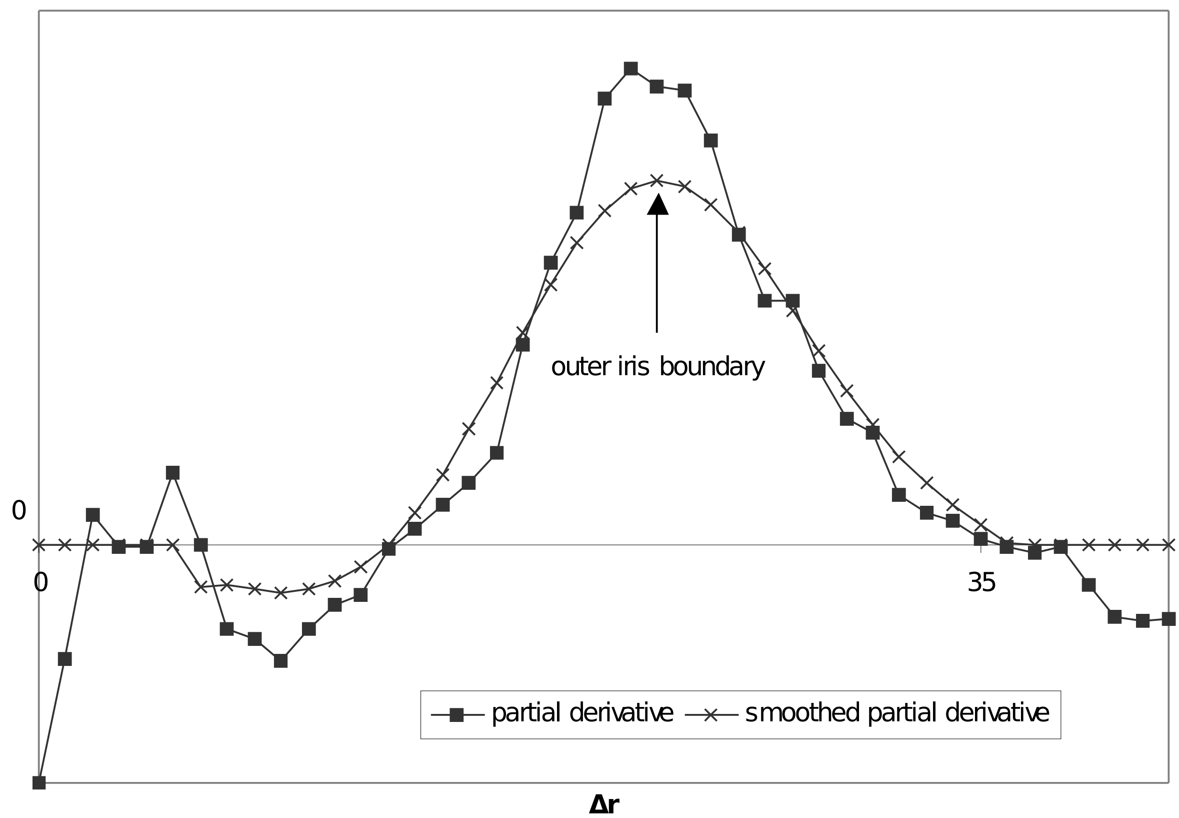


Fig. 4. Illustration of computing outer iris boundary position (continued).

Tab. 2.
Obtained iris localization effectiveness.

Database	Number of photos in the database	Iris localization effectiveness
DMCS	141	100.00 %
UBIRIS (session I)	1205	99.67 %

6. CONCLUSION

This paper presents improved version of the *Iris Finder* program published in [6]. Compared to the earlier version of the algorithm the biggest improvement is performing precise iris search in the original size images. Moreover the outer iris boundary is searched in the grayscale image, not the red component one. Although it makes the algorithm more complex, such solution have proved to give more accurate results when searching the outer boundary with greater precision. Another modification is filling-in reflections in colour image, which is a consequence of applying two different images for iris search – the grayscale and the red component one.
One of key parameters of the *Iris Finder* program is the scale of the Gaussian kernel applied for convolution in equation (3). In the paper adjustment of this parameter for both the outer iris boundary and the inner one has been presented.
Obtained iris localization effectiveness of proposed algorithm is the same as for the earlier version. The reason is that introduced precise search relies on the result of the rough one – when the rough search fails, the precise one has no chance to properly localize the iris. On the other hand once the iris has been correctly roughly found, the precise search have never given wrong results in performed experiments.

ACKNOWLEDGEMENTS

The authors deeply thank Dorota Korzycka MD PhD and Adam Rojek MD PhD from the *Hospital of Ministry of Interior and Administration of Poland* in Łódź for cooperation in the *DMCS* iris database acquisition. The authors wish to thank Adam Olszewski MSc from the *DMCS* for help with the image acquisition.
The authors would like to thank *Departamento de Informática da Universidade da Beira Interior* for sharing the *UBIRIS* database.
The work reported in this paper has been supported by the Polish State Committee for Scientific Research Grant 3 T11 B00 827 and Internal University Grant K-25/1/2006-Dz.S.

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