DETECTION OF IRIS IN IMAGE BY INTERRELATED MAXIMA OF BRIGHTNESS GRADIENT PROJECTIONS*

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ABSTRACT. A method is proposed to detect a human iris location and size in a digital image given some point lying inside the pupil. Method is based on the construction of histogram projections of local brightness gradients, and interrelating local maxima of these histograms as probable positions of pupil and iris borders. The method has a low calculation cost.

Keywords: Iris Identification, Image Processing, Brightness Gradient, Image Projection.

AMS Subject Classification: 68T45.

1. INTRODUCTION

Recognition of the human by iris is one of the most demanded biometric technologies. The algorithm of iris size and position estimation, is an essential part of iris registration systems. With that, the following characteristics of the algorithm are important:

— reliability (understood as the algorithm’s ability to detect the iris in images where it really presents and reject images without the iris)
— precision (difference between real and detected iris coordinates is small)
— performance (processing of standard video stream 640 * 480 * 30 fps)
— robustness against noises (including parasite reflections and occlusions by eyelids and eyelashes)
— ability to process images obtained by various sensors, and in various environment conditions (one of such requirements here is an ability to detect irises differing in size by several times).

Since outer borders for both pupil and iris can be approximated by circles with good precision, circle detection is a central element of any system of iris detection in image. There are plenty of methods of circle (or circumference) detection implemented and tested for this task: detecting of the mass center of an object selected by the thresholding function [9], detection of a point most remote from borders of such a selected object [8], maximizing of integro-differential circular symmetric operator [5], generalized [16], [6] and split [2] Hough transform, Hough transform using brightness gradient [7], [4], brightness gradient projection method [10], paired gradient vectors [14], circular shortest path construction [15], restoring centers of circles passing through randomly selected points [3], and separating objects by piecewise linear functions [1]. But none of these methods conform to all of the above conditions. A number of methods based on graph theory are also applicable, like using strongly connected components [11], and optimizing flow in the graph [12]. Graph methods give high quality results, but are very slow for image processing.

However, so far the fact was not employed that iris border contains two circles (pupil-iris and iris-sclera borders) with interrelated parameters. Synchronous detection of two circles with parameters subject to certain mutual restrictions, implied by the nature of iris, allows substantially enhanced algorithm characteristics in comparison with the search of a single circle. A proposed algorithm of iris location is based on the construction of histograms (local brightness gradient circular projections), and comparisons of their maxima as possible positions of iris borders.

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2. CONSTRUCTION OF CIRCULAR PROJECTIONS OF BRIGHTNESS GRADIENT

As in the majority of recognition tasks, the problem of iris location can be treated as a problem of selection of the best positions of the two circles from a set of alternatives. These alternatives are given by the positions of maxima of circular projections of the brightness gradient. These projections are constructed relative to an approximate iris center, as detected in [10].

Input data for the algorithm are a monochrome eye image and an approximate position of the eye center. Irises with diameter not exceeding image size (i.e. minimum of image width and image height) can be detected.

Denote: \( c = (c_x, c_y)^T \) be a point of approximate center position. Method [10] guarantees that the distance to the real pupil center is not greater than half of the pupil’s radius. For simplicity, consider this point as a coordinate origin.

\( x = (x, y)^T \) is a point vector, \( b(x) \) is a brightness (intensity) in this point, and \( g(x) = \nabla b(x) \) is a brightness gradient. Gradient for discrete digital image is calculated using the Sobel mask.

Only points with a certain gradient value and direction can belong to the iris border. This set is described by the indicator function:

\[
v_U(x) = \begin{cases} 
1, & \text{if } \|g\| > T_1 \text{ and } T_2 < \frac{x \cdot g}{\|x\| \|g\|} \text{ and } U, \\
0, & \text{otherwise,}
\end{cases}
\]

where \( T_1 \) and \( T_2 \) are thresholds, and \( U \) is an additional condition selecting a sector (quadrant) of the coordinate plane. \( T_1 \) is set to reject image noise (including quantization noise), and is calculated as \( 8\sqrt{2}\max\{\sigma, 2\} \), where \( \sigma \) is a dispersion caused by the noise. \( T_2 \) is set to include only points where the brightness gradient has approximately the same direction as the point vector: \( T_2 = \arccos(\pi/6) \). The following conditions are used for selecting the left, right, upper, and lower quadrants respectively:

\[
U = \begin{cases} 
L : |x| > |y|, x < 0, \\
R : |x| > |y|, x > 0, \\
B : |x| < |y|, x < 0, \\
T : |x| > |y|, x > 0.
\end{cases}
\]

Taking one of the above conditions, for instance, \( U \equiv R \) for \( v_U(x) \), one can obtain a histogram of the number of points satisfying the conditions as a function of the radius. For example, the following is a histogram of the right quadrant normalized to radius:

\[
\Pi_R(r) = \frac{1}{2\pi r} \sum_{r-0.5 < \|x\| < r+0.5} v_R(x).
\]

Here \( r \) is an integer value, and the summing procedure involves points \( x \) enclosed in a ring of unit thickness and radius \( r \), and lying in the appropriate quadrant. The histogram may have several local maxima. Denote the \( n \)-th local maxima value as \( \text{loc} \max_{n,r} \Pi_R(r) \), and its position as \( \arg \text{loc} \max_{n,r} \Pi_R(r) \).
Fig. 1 represents an eye image, and its right quadrant histogram \( \Pi_R(r) \). Eight local maxima positions \( \arg \max_{n,r} \Pi_R(r) \), \( n = 1 \ldots 8 \) are outlined in the histogram. After detecting local maxima positions for all four quadrants, one can obtain distances to hypothetic circle borders from central point in the appropriate direction.

Combining these values, one can obtain coordinates of centers \( q = (q_x \quad q_y)^T \) and radii \( \rho \) of these circles:

\[
q_{x}^{n,m} = \frac{1}{2} \left( \arg \max_{n,r} \Pi_R(r) - \arg \max_{m,r} \Pi_L(r) \right),
\]

\[
q_{y}^{u,v} = \frac{1}{2} \left( \arg \max_{u,r} \Pi_T(r) - \arg \max_{v,r} \Pi_B(r) \right),
\]

\[
\rho_{n,m,u,v} = \frac{1}{4} \left( \arg \max_{n,r} \Pi_R(r) + \arg \max_{m,r} \Pi_L(r) + \arg \max_{u,r} \Pi_T(r) + \arg \max_{v,r} \Pi_B(r) \right).
\]

The quality of the circle obtained for four given positions of local maxima \((n, m, u, v)\) (in right, left, top, and bottom projections respectively) may be estimated as the sum of projection function values in these positions:

\[
Q_{n,m,u,v} = \max_{n,r} \Pi_R(r) + \max_{m,r} \Pi_L(r) + \max_{u,r} \Pi_T(r) + \max_{v,r} \Pi_B(r).
\]

3. Selection of interrelated histogram maxima

So, various hypothetic circles are constructed by a method of circular projections. The circles can be hypothetic pupils (index \( P \) is used further), or irises (index \( I \)). Circles can be defined by their parameters, center position, and radius: \((q_P, r_P)\) \((q_I, r_I)\). If two circles are the borders of an iris the following limitations due to human iris then nature [13] are true:

1) \( r_P > \frac{1}{6} r_I \) (iris radius cannot exceed pupil radius more than six times);
2) \( r_P < \frac{3}{4} r_I \) (pupil radius cannot be bigger than 75\% of iris radius);
3) \( d < r_P, d = ||q_P - q_I|| \) iris center lies inside pupil circle;
4) \( 2(r_I - r_P - d) > r_I - r_P + d \), or after reduction \( d < \frac{r_I - r_P}{3} \) (lengths of segments between pupil and iris borders, cut by a line passing through pupil and iris centers, do not differ by more than two times).
From all pairs of circles satisfying (1–4), the one selected has the maximum sum of quality values.

Thus, the algorithm in whole consists of three steps:
1. Calculation of local gradients in the image. Each of the two gradient components require six memory reads, five additions, one subtraction, three bit shifts, and one memory write. That is 24 integer operations total, per one image point.
2. Building circular projections (histograms) for four quadrants selecting local maxima in histograms. This requires evaluating the indicator function (1) for each point. Checking condition $\|g\| > T_1$ requires two memory reads for obtaining $g_x$ and $g_y$, two multiplications, one addition, and one, comparison operations. This is a total of six integer operations. Most of the image points do not have enough of a brightness gradient to pass this check, and are not involved in the following calculations. Checking condition $T_2 < \frac{xg}{\|x\|\|g\|}$ is split to checking $x \cdot g > 0$ and $(x \cdot g)^2 > T_2^2 x^2 g^2$ to avoid the square root calculation. First of these conditions takes six integer operations and rejects half of points. The second takes an additional four multiplications, and one comparison. Summing of the projection histogram is a single memory write operation. The total processing of each image point in this step takes from 6 to 18 integer operations, and the major share of points is processed in 6 operations. Algorithmic complexity of this step is linear, relative to the number of points in image: $O(N)$
3. The enumeration of circle combinations searches the most likely (the one with the greatest quality) pair. The computational cost of this step depends on the number of local maxima selected, rather than on source image size. Up to eight maxima may be combined (four for the upper, lower, left, and right sides of the pupil, and four analogous ones of the iris). Thus, the upper limit of algorithmic complexity is $O(M^8)$, where $M$ is an average number of local maxima in histograms. A typical number of local maxima is five, hence there would be dozens of thousands of combinations from four maxima positions. However most of them do not pass the limitations (a)-(d) already after analyzing only a combinations of three or four positions rather than full combination of eight positions. That is why less than a hundred hypotheses are sensible, and require quality calculation and comparisons. The amount of calculations in this step is negligible compared to the previous two ones.

A total, from 30 to 42 integer operations per one image pixel are required, and a majority of pixels are treated with 30 operations. An image with a typical size of 640*480 pixels is processed in 10 million operations.

4. Experiments

The following databases from public domain were used for the performing this experimental study:
— UBIRIS (http://www.di.ubi.pt/ hugomcp/doc/ubiris.pdf), 1207 images
— CASIA Iris Image Database (http://www.sinobiometrics.com), 16213 images
— Iris Challenge Evaluation (http://iris.nist.gov/ice/), 2954 images

The size of these images is 640 * 480 pixels, the iris radii vary from 50 to 200 pixels.

Testing method. Eye images were reviewed by human expert who indicated pupil and iris borders in each of them. This data was then considered as true and was used for method verification. Then the images were processed automatically. The approximate eye center was detected by method [10] (this point rarely matches the true pupil center, or true iris center, but it is always close to them). With the help of the method proposed here, the pupil and iris were detected. Their parameters were compared with those indicated by the human operator. Table 1 below gives the numbers of rude errors (differences in any one of the center coordinates, or radii exceeds 10 percent of iris radius) and moderate (difference in any one of center coordinates or radii exceeds 5 percents of iris radius) errors. If all the parameter values differ from the true one by no more than five pixels, then the detection is considered correct.
Table 1. Results of the algorithm for test databases.

<table>
<thead>
<tr>
<th>Data base</th>
<th>Image count</th>
<th>Number of moderate errors in pupil detection</th>
<th>Number of rude errors in pupil detection</th>
<th>Number of moderate errors in iris detection</th>
<th>Number of rude errors in iris detection</th>
</tr>
</thead>
<tbody>
<tr>
<td>UBIRIS</td>
<td>1201</td>
<td>296</td>
<td>3</td>
<td>31</td>
<td>1</td>
</tr>
<tr>
<td>CASIA</td>
<td>16213</td>
<td>2070</td>
<td>48</td>
<td>274</td>
<td>43</td>
</tr>
<tr>
<td>ICE</td>
<td>2954</td>
<td>116</td>
<td>17</td>
<td>18</td>
<td>5</td>
</tr>
</tbody>
</table>

Execution of the algorithm takes not more than 0.01 seconds in PC with P-IV 3GHz CPU, for an image of 640 * 480 pixels. Main share of calculation time is taken by Sobel gradient estimation.

Weak points of the method are similar to those of other methods applied to the task. The method becomes unstable in images with strong occlusion of iris (and especially pupil) by eyelids and eyelashes. Very low contrast of iris-sclera, and/or iris-pupil border can also cause incorrect results. These two reasons are responsible for almost all failures in the test databases. A minor reason of errors is the presence of expressed circular patterns in iris or contact lens. The specific weakness of the method is that it works poorly if the eye center point is placed close to the pupil border (less than five pixels).

The proposed method of the iris location may be applied for preliminary determination of the pupil (with precision up to 5 pixels), and the iris (with precision up to 10 pixels) positions, if a point lying inside the pupil is known. The method is useful for real-time applications.

REFERENCES

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Ivan Matveev - received his MSc degree from the Moscow Institute of Physics and Technology in 1997, and his PhD in Applied Math from the Computer Center of the Russian Academy of Sciences in 1999. Since 2004, he is leading the Intellectual Systems sector of the Complex Systems department in CC RAS. His main research interests are biometric identification, face and iris recognition, and real time image processing.