# Detection of Iris in Image by Brightness Gradient Projections

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

## 1 Introduction

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

— reliability (understood as algorithm's ability to detect iris in images where it really presents and reject images without 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 mass center of an object selected by thresholding function [1], detection of a point most remote from borders of such selected object [2], maximizing of integro-differential circular symmetric operator [3], generalized [4], [5], [14] and split [6] Hough transform, Hough transform using brightness gradient [7], [8], brightness gradient projection method [9], paired gradient vectors [10], circular shortest path construction [11], restoring centers of circles passing through randomly selected points [12]. But none of these methods does conform to all of the above conditions. Thresholding and image morphology methods are fast but fail if specular reflection is present inside pupil. On the other hand, generalized Hough transforms and Daugman's

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operator give stable results but are calculation intensive and inadequate for real-time applications. More elaborated later methods [10,11,12] give better robustness/time compromise.

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 nature of iris allows substantially enhance algorithm characteristics in comparison with search of single circle. A proposed algorithm of iris location is based on construction of histograms (local brightness gradient circular projections) and comparisons of their maxima as possible positions of iris borders.

## 2 Construction of Circular Projections of Brightness Gradient

As in majority of recognition tasks the problem of iris location can be treated as a problem of selection of best positions of the two circles from a set of alternatives. These alternatives are given by positions of maxima of circular projections of brightness gradient. These projections are constructed relative to an approximate iris center, as detected in [9].

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

Denote: $\mathbf{c} = (c_x \quad c_y)^T$ be a point of approximate center position. Method [9] guarantees its distance to real pupil center is not greater than half of pupil's radius. For simplicity consider this point as a coordinate origin. $\mathbf{x} = (x \quad y)^T$ is a point vector, $b(\mathbf{x})$ is a brightness (intensity) in this point, $\mathbf{g}(\mathbf{x}) = \nabla b(\mathbf{x})$ is a brightness gradient. Gradient for discrete digital image is calculated using Sobel mask.

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

$$v_U(\mathbf{x}) = \begin{cases} 1, if & \|\mathbf{g}\| > T_1 \; and \; T_2 < \dfrac{\mathbf{x} \cdot \mathbf{g}}{\|\mathbf{x}\| \, \|\mathbf{g}\|} \; and \; U, \\ 0, & \text{otherwise}, \end{cases} \tag{1}$$

where $T_1$ and $T_2$ are thresholds, $U$ 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 $6\sqrt{2}\max\{\sigma, 2\}$ , where $\sigma$ is a dispersion caused by the noise. $T_2$ is set to include only points where brightness gradient has approximately same direction as the point vector: $T_2 = \arccos(\pi/6)$. Following conditions are used for selecting of left, right, upper and lower quadrants respectively:

$$U = \begin{cases} L: \; |x| > |y|, \; x < 0, \\ R: \; |x| > |y|, \; x > 0, \\ B: \; |x| < |y|, \; x < 0, \\ T: \; |x| > |y|, \; x > 0. \end{cases} \tag{2}$$

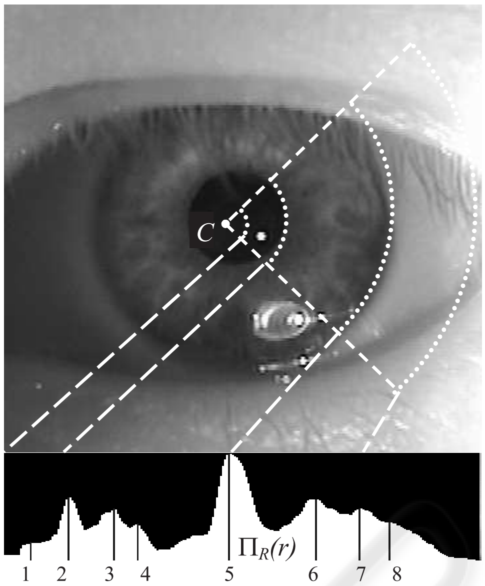


**Fig. 1.** Sample of circular projection and local maxima positions.

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

$$\Pi_R(r) = \frac{1}{2\pi r} \sum_{r-0.5<\|\mathbf{x}\|<r+0.5} v_R(\mathbf{x}). \tag{3}$$

The histogram may have several local maxima. Denote n-th local maxima value as $\underset{n,r}{loc\max}\, \Pi_R(r)$ and its position as $\arg \underset{n,r}{loc\max}\, \Pi_R(r)$.

Fig.1. represents eye image and its right quadrant histogram $\Pi_R(r)$. Eight local maxima positions $\arg \underset{n,r}{loc\max}\, \Pi_R(r)$, $n = 1 \ldots 8$ 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 appropriate direction.

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

$$q_x^{n,m} = \frac{1}{2} \left( \arg \underset{n,r}{loc\max}\, \Pi_R(r) - \arg \underset{m,r}{loc\max}\, \Pi_L(r) \right), \tag{4}$$

$$q_y^{u,v} = \frac{1}{2} \left( \arg \underset{u,r}{loc\max}\, \Pi_T(r) - \arg \underset{v,r}{loc\max}\, \Pi_B(r) \right), \tag{5}$$

$$\rho^{n,m,u,v} = \frac{1}{4} \begin{pmatrix} \arg \underset{n,r}{loc\max}\, \Pi_R(r) + \arg \underset{m,r}{loc\max}\, \Pi_L(r) + \\ \arg \underset{u,r}{loc\max}\, \Pi_T(r) + \arg \underset{v,r}{loc\max}\, \Pi_B(r) \end{pmatrix}. \tag{6}$$

Quality of 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 sum of projection function values in these positions:

$$Q_{n,m,u,v} = loc\max_{n,r} \Pi_R(r) + loc\max_{m,r} \Pi_L(r) + loc\max_{u,r} \Pi_T(r) + loc\max_{n,r} \Pi_B(r). \quad (7)$$

## 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: $(\mathbf{q}_P, r_P)$ $(\mathbf{q}_I, r_I)$. If two circles are the borders of an iris the following limitations due to human iris nature [13] are necessarily 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) $d < r_P$, $d = \|\mathbf{q}_P - \mathbf{q}_I\|$ 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 is selected with maximum sum of quality values.

Thus algorithm in whole consists of three steps:

1. Calculation of local gradients in image. Each of two gradient components require six memory reads, five additions, one subtraction, three bit shifts and one memory write, that is totally 24 integer operations per one image point.

2. Building circular projections (histograms) for four quadrants selecting local maxima in histograms. This requires evaluating indicator function (1) in each point. Checking condition $\|\mathbf{g}\| > T_1$ requires two memory reads for obtaining $g_x$ and $g_y$, two multiplications, one addition and one comparison operations, totally six integer operations. Most of image points do not have enough brightness gradient to pass this check and are not involved in the following calculations. Checking condition $T_2 < \frac{\mathbf{x} \cdot \mathbf{g}}{\|\mathbf{x}\| \|\mathbf{g}\|}$ is split to checking $\mathbf{x} \cdot \mathbf{g} > 0$ and $(\mathbf{x} \cdot \mathbf{g})^2 > T_2^2 \mathbf{x}^2 \mathbf{g}^2$ to avoid square root calculation. First of these conditions takes six integer operations and rejects half of points. Second takes additional four multiplications and one comparison. Summing to projection histogram is a single memory write operation. Totally, 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.

3. Enumeration of circle combinations searching most likely (with biggest quality) pair. The computational cost of this step depends on the number of local maxima selected rather than on source image size. Typical number of local maxima is around ten, and there could be dosens of thousands of combinations from four maxima positions,

however most of them do not pass the limitations (1)-(4). Only less than hundred hypotheses are sensible and require quality calculation and comparison. Hence the amount of calculations in this step is negligible compared to the previous ones.

Totally, from 30 to 42 integer operations per one image pixel are required, and majority of pixels are treated with 30 operations. Image of the typical size of $640 * 480$ pixels is processed in 10 million operarions.

## 4 Experiments

The following databases from public domain were used for performing 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

Size of these images is $640 * 480$ pixels, 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. These data were then considered as true and were used for method verification. Then images were processed automatically. The approximate eye center was detected by method [9] (this point rarely matches true pupil center or true iris center, but is always close to them). With the help of method proposed here pupil and iris were detected. Their parameters were compared with those indicated by human operator. Table below gives numbers of rude errors (difference in any one of center coordinates or radii exceeds 10 percents of iris radius) and moderate (difference in any one of center coordinates or radii exceeds 5 percents of iris radius) errors. If all parameter values differ from true one not more than by five pixels, detection is considered correct.

**Table 1.** Results of algorithm for test databases.

| Data base | Image count | Number of moderate errors in pupil detection | Number of rude errors in pupil detection | Number of moderate errors in iris detection | Number of rude errors in iris detection |
|---|---|---|---|---|---|
| UBIRIS | 1201 | 296 | 3 | 31 | 1 |
| CASIA | 16213 | 2070 | 48 | 274 | 43 |
| ICE | 2954 | 116 | 17 | 18 | 5 |

Execution of the algorithm takes not more than 0.01 second 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.

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

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