IRIS IMAGE SEGMENTATION BY PAIRED GRADIENT METHOD WITH PUPIL BOUNDARY REFINEMENT

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October 11, 2016

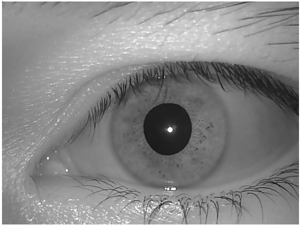
Problem statement

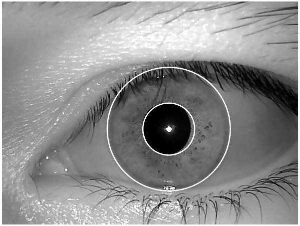
Input:

I — grayscale bitmap sized $W \times H$. Every pixel is encoded in one byte.

Output:

An approximation of iris boundaries in an eye image **I** by two circles, i.e. to determine center coordinates and the corresponding radii $(x, y, r)_{\mathrm{P}}$ and $(x, y, r)_{\mathrm{I}}$.





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Iris detection: related work

1. **Daugman's approach**
   Circular approximation parameters are determined by integro-differential operator:

$$\max_{(r,x_0,y_0)} \left| G_\sigma(r) \frac{\partial}{\partial r} \oint_{(x_0,y_0,r_0)} \frac{I(x,y)}{2\pi r} ds \right|$$

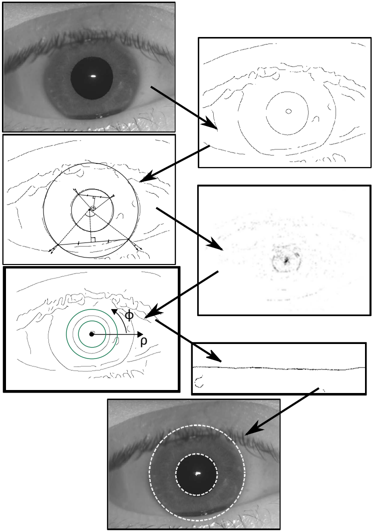
2. **Wildes' approach and its modifications**
   Searching for local maxima in the parameter space. There are modifications, allowing to reduce the computational complexity: gradient-based approaches, randomized algorithms for circle detection, separation of the accumulator parameter space.
3. **Active contours**

Pupil detection: related work

1. **Projection methods**
   Intensity projection method, gradient projection method, blob detection.
2. **Morphological methods**
   A method of recursive erosion.
3. **Hough methodology**
4. **Contour-based methods**
   Pupil boundary is considered to be a curve, determined directly by a sequence of pixels and not belonging to any existing class of figures.

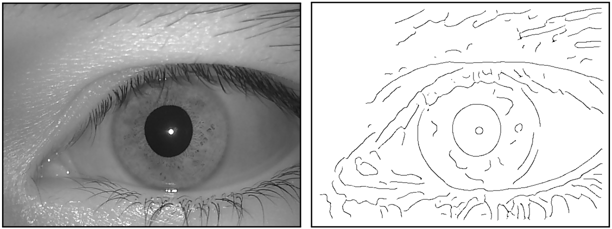
Proposed solution

Input bitmap
↓
A set of edge points
↓
Pairs for a voting prosess
↓
Accumulator analysis
↓
Polar transformation
↓
Optimal path search
↓
Result



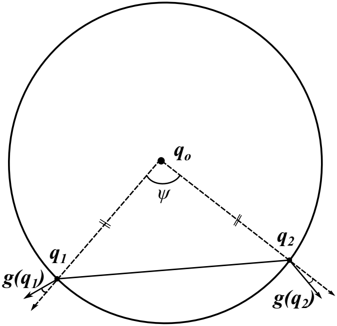
Edge points selection

To detect possible edges in an image Canny operator is applied. In the neighborhood of the selected points gradient components $\mathbf{g_x}(x, y)$ and $\mathbf{g_y}(x, y)$ are calculated using Sobel masks and then gradient magnitude $g(x, y)$ and angle $\phi(x, y)$ are defined. A set of edge points $G = \{x, y, g(x, y), \phi(x, y)\} = \{\mathbf{L}, \mathbf{W}\}$ is formed.



Paired Gradient method

Main concept:



Let $\mathbf{q} = (x, y)$ be an edge point. Then the selection criteria for a pair $\{\mathbf{q}_1, \mathbf{q}_2\}$, corresponding to a hypothetical circle:

$$||\mathbf{g}(\mathbf{q}_1)|| > T_g,$$

$$||\mathbf{g}(\mathbf{q}_2)|| > T_g,$$

$$\angle(\mathbf{g}(\mathbf{q}_1), \mathbf{g}(\mathbf{q}_2)) = \psi,$$

$$||\mathbf{q}_1 - \mathbf{q}_o|| = ||\mathbf{q}_2 - \mathbf{q}_o||$$

Paired Gradient method

If the pair $\{\mathbf{q}_1, \mathbf{q}_2\}$ is selected, then the parameters $\mathbf{p}(\mathbf{q}_1, \mathbf{q}_2) = \{x_c, y_c, r\}$ of the correspondong hypothetical circle are calculated as follows:
the coordinates of an interception point $\mathbf{q}^*$ for the following lines

$$l_1 = \mathbf{q}_1 - t_1 \cdot \mathbf{g}(\mathbf{q}_1),$$

$$l_2 = \mathbf{q}_2 - t_2 \cdot \mathbf{g}(\mathbf{q}_2)$$

specify its center (x_c, y_c) and the radius can be found as

$$r = \sqrt{(x_1 - x_c)^2 + (y_1 - y_c)^2}.$$

A set of hypothetical circle parameters $P = \{x_c^i, y_c^i, r^i\}_{i=1}^M$ is formed, where M is the number of selected pairs.

Circular approximation

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Center search:
The mentioned set $P = \{x_c^i, y_c^i, r^i\}_{i=1}^M$ is used during the Hough voting process in the accumulator array Q. The zero-initialized array is filled with the center votes $\{x_c^i, y_c^i\}$:

$$Q(x, y) = \sum_{i=1}^{M} \begin{cases} 1, & \text{if } (x, y) = (x_c^i, y_c^i), \\ 0 & \text{otherwise.} \end{cases}$$

An accumulator element, which received the most votes, i.e. the argument maxima $\mathbf{q}_1^* = (x_c^*, y_c^*) = \underset{(x,y)}{\operatorname{argmax}} Q(x, y)$ is the most probable center position of the circle, approximating the most expressed iris boundary.

Circular approximation

Center search:

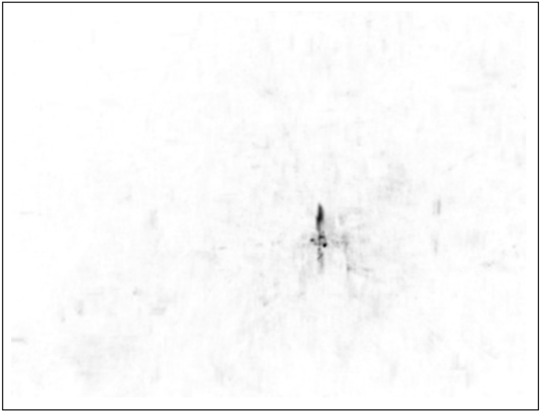
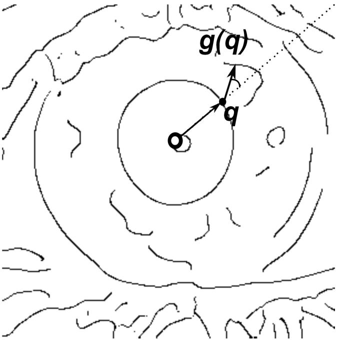


Figure: An accumulator array for $\psi = \frac{2\pi}{3}$

Circular approximation

Noise suppression:



Considering the found eye center position and using the gradient information, a constraint may be introduced for edge points in **G**:

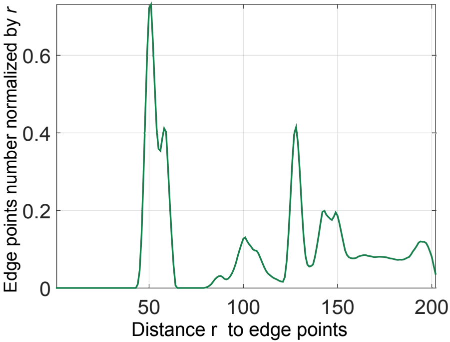
$$arccos\left(\frac{\mathbf{q}\cdot\mathbf{g}(\mathbf{q})}{|\mathbf{q}|\cdot|\mathbf{g}(\mathbf{q})|}\right) < T_a$$

Circular approximation

Radius detection: To determine the radius a distance histogram $H(r)$ is built:

$$H(r) = |\{\mathbf{q} : \mathbf{q} = (x, y) \in \mathbf{G}, ||\mathbf{q} - \mathbf{q}_1^*|| \in (r - 0.5, r + 0.5)\}|.$$

Its argument maxima corresponds to the sought-for radius r_1^*.



Circular approximation

Approximating the second boundary To detect the second iris boundary limiting constraints are imposed on its inner and outer radii:

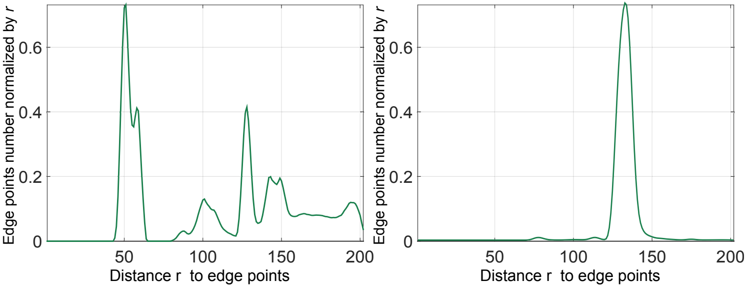
$$r_{\mathrm{P}} > \frac{1}{7} r_{\mathrm{I}},$$

$$r_{\mathrm{P}} < \frac{3}{4} r_{\mathrm{I}}.$$

$$r_{\mathrm{P}} > \sqrt{(x_{\mathrm{I}} - x_{\mathrm{P}})^2 + (y_{\mathrm{I}} - y_{\mathrm{P}})^2}.$$

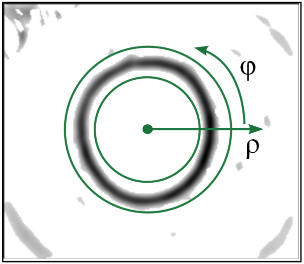
Circular approximation

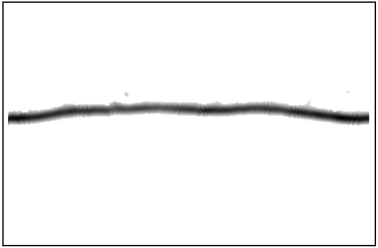
Approximating the second boundary: Values of the original histogram in region $r \in [0; \frac{1}{7}r_1^*] \cup [\frac{3}{4}r_1^*; \frac{4}{3}r_1^*]$, are set to zero not to detect the already found iris boundary. New argument maxima corresponds to the second sought-for radius r_2^*.



Pupil boundary refinement

Polar representation: A polar transformation is applied to the edge map with the pole in (x_c^*, y_c^*). A narrow zone of the polar representation $\mathbf{G}_p$ is considered, where $y \in [r_P - 20; r_P + 20]$.





Pupil boundary refinement

Circular shortesh path method: Let there be a contour in the polar representation, defined by a sequence of pixels: $S = \{\rho(\phi_k)\}_{k=1}^{M}$. A cost for the path from (n, ρ_n) to (m, ρ_m) consists of two components:

$$C(\rho_n, \rho_m) = C_0(n, \rho_n) + C_1(\rho_n, \rho_m).$$

$$C_0(n, \rho_n) = g(n, \rho_n).$$

$$C_1(\rho_n, \rho_m) = \begin{cases} 0, \text{ if } \rho_n = \rho_m, \\ T_1, \text{ if } |\rho_n - \rho_m| = 1, \\ \infty, \text{ otherwise.} \end{cases}$$

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Pupil boundary refinement

Circular shortest path method:

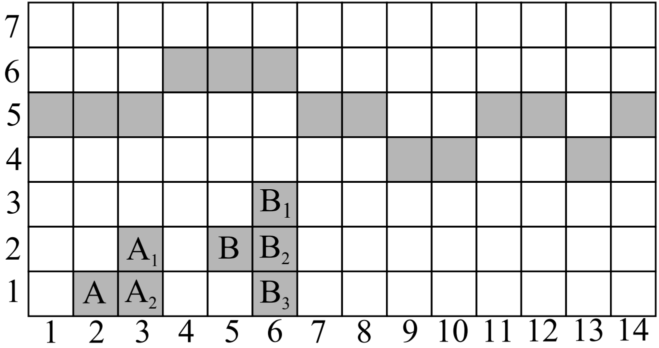

Figure: Neighbour points for a circular path.

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Pupil boundary refinement

Circular shortest path method: For the given path $S = \{\rho_k\}_{k=1}^{W_p}$ the total cost is calculated:

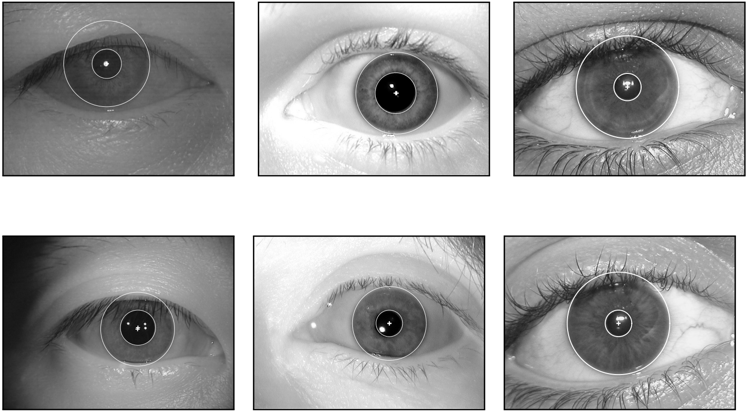
$$C(S) = \sum_{k=1}^{W_p} C(\rho_k, \rho_{k+1}).$$

An optimal contour has the minimal total cost:

$$S^* = \operatorname*{argmin}_S C(S).$$

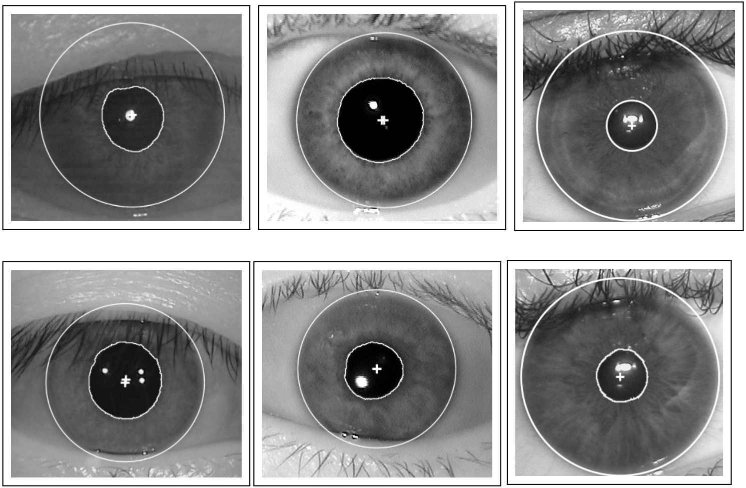
Results

Circular approximation:



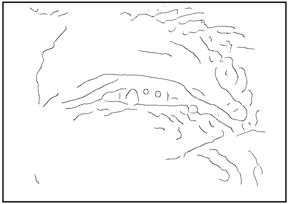
Results

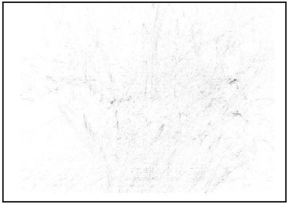
Pupil boundary refinement:

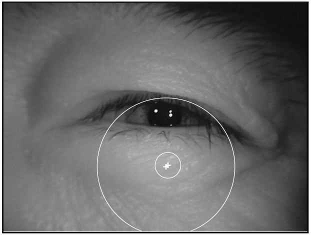


Incorrect segmentation

Narrowed eyelids







Experiments

Goals:

- Testing the iris segmentation system on real data.
- Building an error plot for further analysis

Input data format:

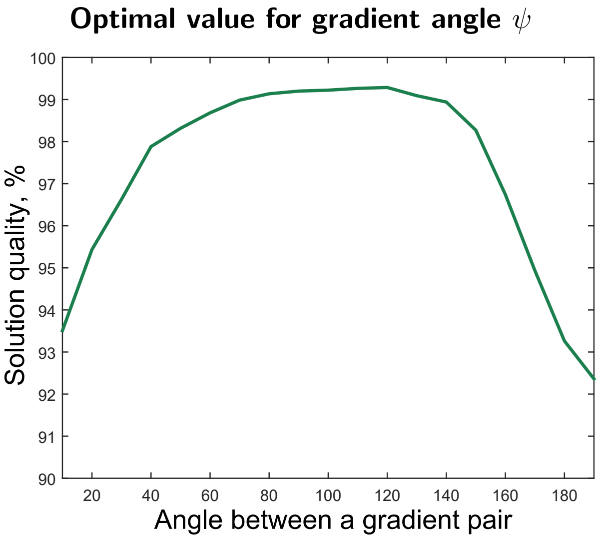
Grayscale eye images sized 640×480 pixels (CASIA(20000), ND-IRIS(20000), UBI(1207)).

Experiments

Quality estimation:

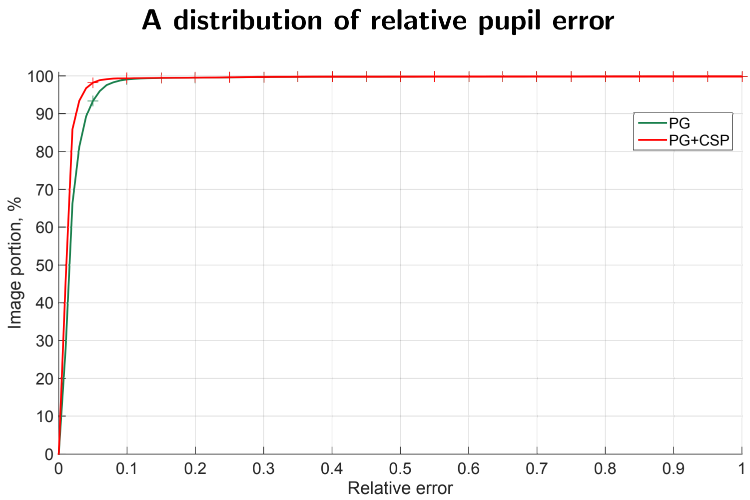
- Segmentation result: $\omega = \{x_P, y_P, r_P, x_I, y_I, r_I\}$.
- Expert markup: $\tilde{\omega} = \{\tilde{x}_P, \tilde{y}_P, \tilde{r}_P, \tilde{x}_I, \tilde{y}_I, \tilde{r}_I\}$.
- Center detection error: $S_c(\omega) = \sqrt{(x_P - \tilde{x}_P)^2 + (y_P - \tilde{y}_P)^2} + \sqrt{(x_I - \tilde{x}_I)^2 + (y_I - \tilde{y}_I)^2}$.
- Radii estimation error: $S_r(\omega) = |r_P - \tilde{r}_P| + |r_I - \tilde{r}_I|$.
- Total error is the sum: $S(\omega) = S_c(\omega) + S_r(\omega)$.
- Relative errors: $\varepsilon(\omega) = \frac{S(\omega)}{\tilde{r}_I}, \varepsilon_c(\omega) = \frac{S_c(\omega)}{\tilde{r}_I}$.
- Average relative error: $E = \frac{1}{N}\sum_{i=1}^{N} \varepsilon(\omega_i)$.
- Error distribution histogram: $e(p) = |\{I : \varepsilon(w) \leq p\}|, p \in [0; 1]$.

Analysis



Optimal value for gradient angle ψ
Solution quality, %
100
99
98
97
96
95
94
93
92
91
90
20
40
60
80
100
120
140
160
180
Angle between a gradient pair

Analysis


A distribution of relative pupil error
100
90
80
70
60
50
40
30
20
10
0
Image portion, %
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Relative error
PG
PG+CSP

Analysis

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Summed relative error $\varepsilon(\omega)$ distribution, %

$e < 5\%$	$e < 10\%$	$e < 15\%$	$e < 20\%$	$e < 25\%$
32.2	85.33	95.09	98.21	99.02

Center detection relative error $\varepsilon_c(\omega)$ distribution, %

$e_c < 5\%$	$e_c < 10\%$	$e_c < 15\%$	$e_c < 20\%$	$e_c < 25\%$
73.01	97.03	99.44	99.65	99.78

Average relative error E, %

	Daugman	Ma et al.	Wildes	Masek	PG+CSP
CASIA	1.19	4.79	5.37	5.15	2.51
NDIRIS	1.10	5.92	6.33	5.59	2.24

Average time, ms

$\bar{t}$,ms	52.31	363.64	379.61	97.52	203.9

Conclusion

- A system of methods for detecting iris region in eye image is presented.
- The system is implemented in C and Matlab.
- To estimate the overall efficiency, a computational experiment was performed on images from public domain databases.

Thank you for your attention!