System of methods for iris segmentation in image

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Tom Goldstein and Stanley Osher, SIAM J. Imaging Sciences, Vol. 2, No. 2

www.ccas.ru

www.iritech.com
Related work

Iris recognition is a relatively new field, with first systems appearing in 1994. Pioneer works of Daugman and Wildes.

It is most precise among all other biometry modalities (face, fingerprint, etc).

Most close for real large-scale biometric applications (passports, border control, etc).

Iris segmentation is a crucial part, attracting much attention, with many methods developed.

However, the general approach to segmentation is not changed.

A: Sequence of detection: Pupil — Iris — occlusions

B: Once detected, never refined

Only few attempts have been made to broaden this scheme:

- Pupil refinement: Z. He, T. Tan, Z. Sun, and X. Qiu, 2009.

Still, only one method is used for each eye feature.
Proposed scheme of methods

1. Center detection (Hough transform)
   - Pupil, Iris both detected
   - Pupil only detected
   - Iris only detected
   - Iris not detected

2. Base radius detection (gradient projection)
   - Neither Pupil nor Iris detected
   - Iris only detected
   - Pupil is not detected

3. Iris-from-Pupil detection (gradient projection)
   - Iris is not detected

4. Pupil-from-Iris detection (triangulation)
   - Pupil is not detected

5. Pupil refinement (circular shortest path)

6. Occlusion detection (gradient orientation)

Finish, Eye is detected

Center detection uses both border information

Base radii detection located both borders synergetically

Center and Base radii do not attempt precise detection

Three possible paths:
1 - 2 - 5 - 6,
1 - 2 - 3 - 5 - 6,
1 - 2 - 4 - 5 - 6

Blocks 1 - 4 may terminate eye location process

Blocks 5 and 6 do not terminate. If the quality is low, the unrefined properties are used.
Center detection

Hough approach, drawing segments from edges in direction of brightness anti-gradient

Hough accumulator is 2-dimensional

Using both boundaries (pupil-iris and iris-sclera) for detection

I. Matveev, System of methods for iris segmentation in image  SIAM-IS14
Center detection results

Center is detected outside in 1 of 2000 images

Center is detected outside half of pupil in 0.15% of images

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Image count</th>
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<td>$1.0 \leq E$</td>
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</table>

Average absolute error, pixels 2.78
Median of absolute error, pixels 2
0.001-quantile of absolute error, pixels 20
Base radii detection

Oriented gradients

Knowing basic center point one can select image pixels according to brightness gradient direction: anti-gradient in the pixel should be directed towards the center.

Red: basic center and directions to center from other pixels.

Green element: anti-gradient almost matches direction to center.

Blue element: directions match not so good.

Yellow element: anti-gradient does not match direction to center.
Base radii detection
Sample of orientation thresholding of gradient

Common gradient map

\[ V(\bar{x}) = \begin{cases} 
1, & \text{if } \|\tilde{g}\| > T_1 \\
0, & \text{otherwise} 
\end{cases} \]

Oriented gradient map

\[ V(\bar{x}) = \begin{cases} 
1, & \text{if } \|\tilde{g}\| > T_1 \text{ and } T_2 < \frac{\bar{x} \times \tilde{g}}{\|\bar{x}\| \|\tilde{g}\|} \\
0, & \text{otherwise} 
\end{cases} \]

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Base radii detection

Gradient projection in quadrant

Image is split into four quadrants relative to basic center point

\[
\text{Quadrant} = \begin{cases} 
\text{Left} : & |x| > |y|, \ x < 0 \\
\text{Right} : & |x| > |y|, \ x > 0 \\
\text{Bottom} : & |x| < |y|, \ y < 0 \\
\text{Top} : & |x| < |y|, \ y > 0 
\end{cases}
\]

Oriented gradient map in each image quadrant is projected circularly to form a histogram of density of pixels with high gradient value

\[
P_Q(r) = \frac{1}{2\pi} \sum_{0.5 < r \leq 1} V_Q(\vec{x})
\]

Local maxima are selected in the projection
Base radii detection

Sample of projections

$P_T(r)$

$P_L(r)$

$P_B(r)$

$P_R(r)$

UBIRIS image

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Combining local maxima to form circle

Combining maxima in four projections one can obtain different circles as:

\[
p_{x}^{n,m} = \frac{1}{2} \left( \arg \max_{n,r} P_{R}(r) - \arg \max_{m,r} P_{L}(r) \right) \quad \left( p_{x}, p_{y} \right) - \text{circle center}
\]

\[
p_{y}^{u,v} = \frac{1}{2} \left( \arg \max_{u,r} P_{T}(r) - \arg \max_{v,r} P_{B}(r) \right)
\]

\[
\rho^{n,m,u,v} = \frac{1}{4} \left( \arg \max_{n,r} P_{R}(r) + \arg \max_{m,r} P_{L}(r) + \arg \max_{u,r} P_{T}(r) + \arg \max_{v,r} P_{B}(r) \right)
\]

\[
1 - \varepsilon < \frac{\arg \max_{n,r} P_{R}(r) + \arg \max_{m,r} P_{L}(r)}{\arg \max_{u,r} P_{T}(r) + \arg \max_{v,r} P_{B}(r)} < 1 + \varepsilon \quad \text{(consistency condition)}
\]

\[
Q_{n,m,u,v} = \max_{n,r} P_{R}(r) + \max_{m,r} P_{L}(r) + \max_{u,r} P_{T}(r) + \max_{n,v} P_{B}(r)
\]
Base radii detection

Combining pair of circles

Limitations imposed by human iris nature:

(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) \[ \frac{r_I}{10} > \sqrt{(x_I - x_p)^2 + (y_I - y_p)^2} \] displacement of centers do not exceed 10% of iris radius
Pupil-from-iris detection by triangulation

Known approximate iris circle (a)

Map of oriented gradients (b)

Selecting triplets of points by condition

\[ \frac{2\pi}{3} - \epsilon < |\vec{g}_i \cdot \vec{g}_j| < \frac{2\pi}{3} + \epsilon \]

Center coordinates:

\[
\begin{align*}
c_x &= \frac{\sum_{i=0}^{2} p_{i,y} (\vec{p}_{i+2}^2 - \vec{p}_{i+1}^2)}{2 \sum_{i=0}^{2} p_{i,y} (p_{i+2,x} - p_{i+1,x})} \\
\end{align*}
\]

Two accumulators: 2D position and 1D radius (c)
Pupil border refinement
Circular shortest path method

- Locate shortest continuous path from left side to right side of polar image,
- under condition that ordinate of starting and ending points are equal

Path \( S = [\rho(\varphi)]_{\varphi=0}^{2\pi} \approx [\rho_n]_{n=1}^W \)

Cost of path \( C \) depends on path shape (inner) and on image pixel values (outer)

Optimal path \( S^* = \arg\min_S C(S) \)

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Pupil border refinement

Samples of pupil shape deviation

Source images
- (BATH DB)

Magnified pupil region
- with circular approximation of pupil

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Pupil border refinement

Refined circle

- Originally located pupil circles

- Pupil circles obtained from precise border as inertial equivalent to the enclosed region
Occlusion detection

Violation of gradient condition along iris border means occlusion

Violation of gradient condition (a)

Represent violations as cyclic sequence (b)

Morphology operations of opening and closing to remove noises (c)

Mapping filtered violation sequence back to iris image (d)

Mask formed by subtenses (e)
Performance evaluation

3 ways to evaluate performance

1) compare automatic border detection with expert marking
2) comparison with other methods
3) using ultimate system characteristics (recognition performance)

Databases from public domain used in tests

1) BATH — University of Bath DB, 32000 images
2) CASIA — Chinese Academy of sciences DB, 54000 images
3) MMU — 1400 images
4) NDIRIS — Notre Dame university DB, 64000 images
## Results

### Comparison with expert marking

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<thead>
<tr>
<th>Database</th>
<th>$\varepsilon_{\bar{c}_P, abs}$</th>
<th>$\varepsilon_{r_P, abs}$</th>
<th>$\varepsilon_{\bar{c}_I, abs}$</th>
<th>$\varepsilon_{r_I, abs}$</th>
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<tbody>
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<td>BATH</td>
<td>0.52</td>
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<tr>
<td>CASIA</td>
<td>1.05</td>
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<td>MMU</td>
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<td>NDIRIS</td>
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### Comparison with other methods

<table>
<thead>
<tr>
<th>Database</th>
<th>Errors</th>
<th>Methods</th>
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<td>$\varepsilon_{r_P, abs}$</td>
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Results (NIST IREX test)

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SIAM-IS14
Conclusions

Using several steps and different algorithms for each feature

Primary approximate detection, successive refinements

Simple methods, joined to the framework give competitive results