IRIS recognition

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Outline

Foreword

- Overview of biometric identification

Iris recognition process

- Acquiring
- Iris Segmentation
- Projection
- Feature extraction
- Encoding
- Comparison / matching
Biometrics basics

- Identification based on individual characteristics
- Useful when ID not present or can not be trusted
- **Ancient history**: wall paintings (30t years BC), fingerprint in Babylonia and China, hand shape for identification in ancient Egypt
- 1890’s: *Francoise Bertillon*, **antropometry**, soon superseded by fingerprint (ca 1903)
Biometric characteristics

- **Biological traces**
  - DNA, blood, saliva, etc.

- **Biological (physiological) characteristics**
  - fingerprints, eye irises and retinas, hand and palm geometry, facial geometry

- **Behavioral characteristics**
  - dynamic signature, gait, keystroke dynamics, lip motion

- **Combined**
  - Voice
Basic techniques: Fingerprint

- Ink and paper vs digital
- Acquisition: optical, CMOS capacitance, thermal, ultrasound
- Cheap sensors
- Uses the ridge endings and bifurcations on a person's finger to plot points known as minutiae
- Computing score between two minutia graphs
Basic techniques: overview

Dynamic signature
  • Trajectory over time, pressure, tilt...

Face
  • Facial geometry or nonparam.

Retina
  • Retinal vein patterns

Vein recognition
  • Vein patterns on hand

Hand geometry
  • Hand measurements at given characteristic points

Gait, voice, keystroke dynamics, lip motion...
Everyday biometrics

• **ePassport**
  • Obligatory in CZ since 2009
  • RFID with: **2 fingerprints + face image**, name etc, digitally signed

• **Smartphones**
  • **Face**: Android since v. 4.0
  • **Fingerprint**: iPhone since 5s, Samsung since S5
  • **Iris**: Windows 10 Hello (also **3D face** - intel RealSense)
Basic biometric statistics

Example:

United Arab Emirates eBorder iris-based system (in operation since 2003)

- Assume 1 000 000 subjects enrolled in a database of expellees
- Assume 10 000 travelers checked daily
- Assume False match error rate 1 in 10 million

Results

- 10k X 1M = 10 billion comparisons daily
- 1 in 10 travelers incorrectly matched!
Basic biometric statistics

False match rate (FMR): proportion of falsely admitted impostors
-> also „false accept“, security

False non-match rate (FNMR): falsely rejecting legitimate user
-> also „false reject“, convenience
IRIS vs Other biometric techniques

- IRIS
- Signature
- Face
- Hand
- Fingerprint
- Voice / Speech

Price vs Accuracy graph: iris has higher accuracy but lower price than other biometric techniques.
IRIS for biometry

- Well protected (internal organ of the eye, cornea)
- Externally visible from a distance
- Unique, highly complex pattern
- Stable over the lifetime (except pigmentation)
- Most of the structure formed in 3rd - 8th month of gestation (prenatal period)
- Pigmentation can continue after birth
- Iris color: mostly melanin pigment (blue iris = absence of pigment)
The IRIS (Basics)

- **duhovka** (iris)
- **zornice** (pupil)
- **oční mok** (aqueous humor)
- **sklivec** (vitreous humor)
- **cornea**
- **rohovka**
- **čočka**
- **sclera**
- **bělma**
- **lens**
Iris recognition process

iris image

iris region segmentation

unwrapping

feature extraction & encoding

iris code comparison (database)

Result
Iris scan: devices
Visible or Infrared light IRIS

Visible light

- Layers visible
- Less texture information
- Melanin pigment (dark eyes) absorbs visible light
- Ambient reflections

(Near) Infrared light (NIR)

- Similar results for dark and light eyes
- More texture visible
- Does not interfere with ambient light
- Preferred for iris recognition systems
Iris image acquisition: requirements

- At least 70 pixels per iris radius (typically 100-140px)
- Monochrome CCD camera 640x480 px with NIR filter usually sufficient
- Getting the detailed view of the iris:
  1. Another wider-angle “face” camera used to steer the Iris camera to the direct spot
  2. User asked to move to desired position
Segmentation

Aim: find the region of clean iris image

- Annular area between pupil and sclera
- Occlusions by eyelids and eyelashes + reflections need to be eliminated
- Easiest modelled by 2 circles
Intra-class variations

The segmenting algorithm has to address following problems:

- pupil dilation (lighting changes)
- inconsistent iris size (distance from the camera)
- eye rotation (head tilt)
Anomalous eye shape

- The polar transform assumes circular iris boundary
- This may not be true especially for off-axis gaze
- Individual deviations can also play role
Detected Curvilinear boundaries

limbic boundary

pupillary boundary
Curvilinear detector

Assumption: both the pupilary and limbic boundary can be approximated by (non-concentric) circles
(problem: off-axis gaze and specific cases)

Daugman's approach

\[
\max_{(r, x_0, y_0)} \left| G_\sigma(r) \ast \frac{\partial}{\partial r} \int_{r, x_0, y_0} \frac{I(x, y)}{2\pi r} \, ds \right|
\]

- searching circle parameters \((x_0, y_0, r)\) that maximize blurred integro-differential function of the iris image. This maximum is gained when the circle parameters meet either the pupil or limbic properties.

Other possibilities

- Hough transform
- RANSAC
- Active contours ...
Daugman’s circular detector

\[
\max_{(r, x_0, y_0)} \left| G_\sigma(r) \cdot \frac{\partial}{\partial r} \int_{r, x_0, y_0} \frac{I(x, y)}{2\pi r} \, ds \right|
\]

I(x,y) – image, \( G(r) \) – 1D Gaussian smoothing,

\( x_0, y_0, r \) – circle center coordinates + radius

Idea: for given center \( x_0, y_0 \) and defined range of radius values \( <r_{\text{min}}, r_{\text{max}}> \)

1. \( c_1 = \text{mean of image values over a circular path} \ (x_0, y_0, r_{\text{min}}) \)
2. change radius by 1px (until \( r_{\text{max}} \)), compute and store \( c_i \) using 1.
3. Compute difference \( \tilde{d} = \text{diff} \ (\tilde{c}) \)
4. smooth D by 1D-gaussian (low-pass) filter
5. Maximum in the sequence of smoothed \( c \)'s corresponds to best \( r \)

The sequence is repeated for different combinations of \( x_0, y_0 \)
Separate search for limbic (outer) and pupillary (inner) iris boundary
Daugman’s circular detector

\[ \max_{(r, x_0, y_0)} \left[ G_\sigma(r) \right] \ast \frac{\partial}{\partial r} \int_{r, x_0, y_0} \frac{I(x, y)}{2\pi r} \, ds \]

Gaussian smoothing
#2 Hough transform

We search for most likely values of the circle parameters: \((x_0, y_0, r)\)

The Hough procedure:

1. Edges are found in the image using edge detector
   - Threshold on local gradient in smoothed image
2. Projection to parametric space
3. Repeated for different circle sizes
4. Search the parameter space for maxima (the circle center and radius)

tutorial: [http://www.aishack.in/tutorials/circle-hough-transform/](http://www.aishack.in/tutorials/circle-hough-transform/)
#2 Hough transform: given radius

- A circle of given radius is drawn around each edge point in the parameter space.
- Intersecting circles sum up.
- The most probable center for given radius is where most circles in the parameter space intersect = maximum value

Source: http://www.aishack.in/tutorials/circle-hough-transform/
Segmentation: Other options

**RANSAC** for circles (RANdom SAmple Consensus)

Operates on edge points (i.e. Canny detector)

1. Randomly pick subset of all original edge points,
2. Fit candidate circle to the subset (e.g. least squares: Gauss-Newton)
3. Throw away points “far” from current candidate circle
4. Re-fit circle to the filtered set, compare to current best solution
5. Compare 1-4 N times (or until sufficient fit achieved), keep the best solution

**Active contours** (“snakes”)

Can be used to improve non-circular iris segmentation from initial circular solution

**CAREFUL PARAMETER SETTING CRITICAL FOR ALL ALGORITHMS!**
Eyelid boundaries

Similar procedures to annular iris region detection can be used. Many methods exist, e.g.:

- **Typical**: Daugman's integro-differential operator with splines in place of circles

- **Simplest**: Hough transform with lines
Detected eyelid boundaries

- Similar algorithm is used to detect eyelid boundaries
Projection

- The model has to be invariant to iris size (distance from camera), pupil size (amount of light)
- Invariance to rotation (head tilt) is addressed later in the recognition process

Solution: transformation to (pseudo)radial coordinates
(pseudo-) Radial coordinates

- Each point remapped to a pair of polar coordinates (ρ, θ), where ρ∈(0,1), θ∈(0, 2π)
- The model compensates pupil dilation and size inconsistencies in size and translation invariant coordinate system
- Rotational inconsistencies not compensated
Feature extraction

- Processing the unwrapped image to extract information
- 2D Gabor wavelet filtering
- Phase quantization
- 2048-bit iris code
The unwrapped iris image is filtered using two 2D Gabor wavelet filters using multiple parameter settings.

The demodulating wavelets are parameterized with four degrees-of-freedom: size, orientation, and two positional coordinates. They span several octaves in size, in order to extract iris structure at many different scales of analysis.
Encoding: Phase quantization

- The phase of resulting complex numbers is observed and coded into 2 bits according to the figure.

- Phase quantization - continuous phase to 2 bits.

- 2048 such phase bits (256 bytes) are computed for each iris.
Masking

- Areas with noise (eyelids, eyelashes...) need to be excluded
- A binary mask of the same size as the iris code is calculated. 1 in the areas of useful signal, 0 elsewhere
Iris code

Projection: doubly-dimensionless polar coordinate system

- invariant to the size of the iris (imaging distance and the optical magnification factor) and pupil dilation (lighting)

Filtering: only phase information used

- invariant to contrast, absolute image function value (camera gain), and illumination level (unlike correlation methods)

Very compact

- Typically just 256 bytes + 256 bytes mask (depends on settings of the Gabor wavelet filtering) - small for storage
- Thanks to phase quantization.
Example iris codes
Iris code comparison

- Different eyes’ Iris Codes are compared by vector Exclusive-OR’ing in order to detect the fraction of their bits that disagree.
Iris code comparisons

Iris code bits are all of equal importance

**Hamming distance:**

- Distance between 2 binary vectors (strings)
- Number of differing bits (characters)
- “Number of substitutions required to change one string to the other”
- Sequence of XOR and \textit{norm} operators (number of ones in XOR'ed sequences)

**Examples:**

- hockey and soccer, $H=3$
- 1001011 and 1100011, $H=2$
Code comparison

\[ H = \frac{\| (\text{code}A \otimes \text{code}B) \cap \text{mask}A \cap \text{mask}B \|}{\| \text{mask}A \cap \text{mask}B \|} \]

- \( \otimes \) - XOR operator - one for each bit that disagrees
- codeA codeB - iris codes,
- \( \cap \) - AND - keep only bits unmasked by both masks
- maskA maskB - noise masking templates for respective iris codes
- \( \| \) - norm operator - calculate number of „1“ bits
- Normalized by the number of bits that are available in both codes (denominator)
irisCode comparisons: rotation

- To account for iris rotation, the codes are shifted one against another in selected range
- Minimum HD is calculated

```
Template 1  10 00 11 00 10 01
Template 2  00 11 00 10 01 10
              ▶
              HD = 0.83

Template 1  00 11 00 10 01 10
Template 2  00 11 00 10 01 10
              ◀  Shift 2 bits left
              HD = 0.00

Template 1  01 10 00 11 00 10
Template 2  00 11 00 10 01 10
              ▶  Shift 2 bits right
              HD = 0.33
```
Iris comparisons
Comparison properties

Left distribution: different images of the same eye are compared; typically about 10% of the bits may differ.

Right distribution: IrisCodes from different eyes compared, with rotations (best match - min HD). Tightly packed around 45%

Very narrow right-hand distribution (different irises), it is possible to make identification decisions with astronomic levels of confidence.

Probability of two different irises agreeing just by chance in more than 75% of their IrisCode bits (HD<0.25) is only 1 in $10^{14}$

Extremely low probabilities of False Match enable the iris recognition algorithms to search through extremely large databases ($10^{10}$) scale despite many opportunities to make a false match
Comparisons: system quality

Comparing distributions for the same and different irises says a lot about the identification system.

Factors: imaging, segmentation, reflections, eyelashes, simplifying assumptions (pupil/iris shape, ),
### Observed False Match Rates in 200 billion comparisons

<table>
<thead>
<tr>
<th>HD Criterion Policy</th>
<th>Observed False Match Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.220</td>
<td>0 (theor: 1 in 5 × 10^{15})</td>
</tr>
<tr>
<td>0.225</td>
<td>0 (theor: 1 in 1 × 10^{15})</td>
</tr>
<tr>
<td>0.230</td>
<td>0 (theor: 1 in 3 × 10^{14})</td>
</tr>
<tr>
<td>0.235</td>
<td>0 (theor: 1 in 9 × 10^{13})</td>
</tr>
<tr>
<td>0.240</td>
<td>0 (theor: 1 in 3 × 10^{13})</td>
</tr>
<tr>
<td>0.245</td>
<td>0 (theor: 1 in 8 × 10^{12})</td>
</tr>
<tr>
<td>0.250</td>
<td>0 (theor: 1 in 2 × 10^{12})</td>
</tr>
<tr>
<td>0.255</td>
<td>0 (theor: 1 in 7 × 10^{11})</td>
</tr>
<tr>
<td>0.262</td>
<td>1 in 200 billion</td>
</tr>
<tr>
<td>0.267</td>
<td>1 in 50 billion</td>
</tr>
<tr>
<td>0.272</td>
<td>1 in 13 billion</td>
</tr>
<tr>
<td>0.277</td>
<td>1 in 2.7 billion</td>
</tr>
<tr>
<td>0.282</td>
<td>1 in 284 million</td>
</tr>
<tr>
<td>0.287</td>
<td>1 in 96 million</td>
</tr>
<tr>
<td>0.292</td>
<td>1 in 40 million</td>
</tr>
<tr>
<td>0.297</td>
<td>1 in 18 million</td>
</tr>
<tr>
<td>0.302</td>
<td>1 in 8 million</td>
</tr>
<tr>
<td>0.307</td>
<td>1 in 4 million</td>
</tr>
<tr>
<td>0.312</td>
<td>1 in 2 million</td>
</tr>
<tr>
<td>0.317</td>
<td>1 in 1 million</td>
</tr>
</tbody>
</table>
On a 300MHz PC (Daugman 2004 = long ago):

**Execution Speeds of Various Stages in the Iris Recognition Process on a 300-MHz RISC Processor**

<table>
<thead>
<tr>
<th>Operation</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assess image focus</td>
<td>15 msec</td>
</tr>
<tr>
<td>Scrub specular reflections</td>
<td>56 msec</td>
</tr>
<tr>
<td>Localize eye and iris</td>
<td>90 msec</td>
</tr>
<tr>
<td>Fit pupillary boundary</td>
<td>12 msec</td>
</tr>
<tr>
<td>Detect and fit both eyelids</td>
<td>93 msec</td>
</tr>
<tr>
<td>Remove lashes and contact lens edges</td>
<td>78 msec</td>
</tr>
<tr>
<td>Demodulation and IrisCode creation</td>
<td>102 msec</td>
</tr>
<tr>
<td>XOR comparison of two IrisCodes</td>
<td>10 μs</td>
</tr>
</tbody>
</table>
Public implementations

VASIR (by NIST)
- http://www.nist.gov/itl/iad/ig/vasir.cfm
- C++, Qt, openCV
- Video-based

Libor Masek’s toolbox in Matlab
- http://www.peterkovesi.com/studentprojects/libor/
- simplifications: (Hough transform for iris segmentation, 1D Gabor wavelets, linear eyelid boundaries, simple threshold for reflections/eyelashes)

Daugman’s iris segmentation in Matlab

Non-ideal Iris Recognition (elliptical unwrapping) in Matlab
- http://www.csee.wvu.edu/~xinl/demo/nonideal_iris.html

Iris segmentation in python
- https://github.com/pctroll/computer-vision/tree/master/iris_recognition
Key messages

1. Imaging using infrared light (dark vs light eyes, reflections)
2. Iris region found by circular detector
3. Image unwrapped in a polar coordinate system
4. Image filtered using Gabor wavelet filters
5. Only phase information is used (phase quantization)
6. Phase quantization converts filtered image to binary code
7. Binary mask showing noise, eyelids and eyelashes stored along with the code
8. Iris codes compared using hamming distance
9. Iris recognition has extremely low false accept rate
Iris recognition summary

Strengths

• Exceptionally high levels of accuracy
• Reliable identification as well as verification
• Believed to be the most reliable metric
• Stable over a lifetime
• Distant cameras – less obtrusive, high throughput

Weaknesses

• Acquisition requires moderate training and cooperation
• Proprietary acquisition device necessary - expensive
• Sunglasses, ambient light etc
• Distant cameras – can be compromised
Sources + Literature

John Daugman’s website https://www.cl.cam.ac.uk/~jgd1000/ (many papers in PDF + details)


Daugman J (2006) "Probing the uniqueness and randomness of IrisCodes: Results from 200 billion iris pair comparisons." Proceedings of the IEEE, 94(11), pp 1927-1935. (PDF)


Lectures by Andrzej Drygajlo, EPFL Switzerland (not available anymore)

NIST biometrics committee: http://www.biometrics.gov/
Thank you for your attention