Fingerprint, palmprint and iris
An introduction on several biometric modalities
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Biometrics: an Overview
Why biometrics: the cliché

- The way human beings use to recognize each other: equip machines with that capability
- Passwords can be forgotten, tokens can be lost
- Post–9/11 era: thirst for ever-increasing security control
- ...

…
Projected growth of biometrics market

Annual Biometric Industry Revenues, 2007-2012 ($m USD)

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<table>
<thead>
<tr>
<th>Year</th>
<th>Revenues ($m USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>3012.6</td>
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<tr>
<td>2008</td>
<td>3836.2</td>
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<tr>
<td>2009</td>
<td>4634.3</td>
</tr>
<tr>
<td>2010</td>
<td>5633.9</td>
</tr>
<tr>
<td>2011</td>
<td>6553.8</td>
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<tr>
<td>2012</td>
<td>7407.7</td>
</tr>
</tbody>
</table>
Market share by different modalities

Biometric Market by Technology, 2007

- AFIS / Live-Scan: 33.6%
- Fingerprint: 25.3%
- Iris Recognition: 5.1%
- Hand Geometry: 4.7%
- Face Recognition: 12.9%
- Middleware: 5.4%
- Voice Recognition: 3.2%
- Vein Recognition: 3.0%
- Other Modalities: 4.0%
- Multiple-Biometric: 2.9%
## Biometric modalities

<table>
<thead>
<tr>
<th>Modality</th>
<th>Example</th>
<th>Invasiveness</th>
<th>Accuracy</th>
<th>Typical Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fingerprint</td>
<td><img src="image" alt="Fingerprint" /></td>
<td>Moderate</td>
<td>★★★</td>
<td>Law enforcement, financial, POS</td>
</tr>
<tr>
<td>Palmprint</td>
<td><img src="image" alt="Palmprint" /></td>
<td>Moderate</td>
<td>★★★</td>
<td>Access control</td>
</tr>
<tr>
<td>Iris</td>
<td><img src="image" alt="Iris" /></td>
<td>Moderate/high</td>
<td>★★★</td>
<td>ATMs, access control</td>
</tr>
<tr>
<td>Hand Geometry</td>
<td><img src="image" alt="Hand Geometry" /></td>
<td>Moderate</td>
<td>★</td>
<td>Access control, border control</td>
</tr>
<tr>
<td>Face</td>
<td><img src="image" alt="Face" /></td>
<td>Low</td>
<td>★★</td>
<td>Surveillance, Passports</td>
</tr>
<tr>
<td>Voice</td>
<td><img src="image" alt="Voice" /></td>
<td>Low/Moderate</td>
<td>★</td>
<td>Access control, logon</td>
</tr>
<tr>
<td>Signature</td>
<td><img src="image" alt="Signature" /></td>
<td>Moderate</td>
<td>★★</td>
<td>Financial, PocketPC</td>
</tr>
</tbody>
</table>
Fingerprint recognition
Fingerprint recognition

- The earliest, most widely studied, most acceptable, most widely deployed...
- Best commercial system: capable of identifying more than 98% of matches, with a false accept rate of 0.01% (NEC)
  - As published by The Fingerprint Vendor Technology Evaluation (FpVTE) 2003 conducted by the National Institute of Standards & Technology (NIST)
Different features

Ridge ending
Enclosure
Bifurcation
Island
Minutiae
Texture

And there’s more:
Ridges
Ridge count
Orientation field
Ridge frequency
If higher resolution scanner is used, i.e.
$\geq 1000$ pixels per inch (ppi). (current AFIS system 500 ppi.)
Minutiae is the most used technique
Minutiae feature extraction overview [A. K. Jain et al]

Gray-scale image

Image skeleton

Extraction of minutiae

Minutia features
Need for Image enhancement

- High contrast
- Typical dry print
- Faint print
- Low contrast
- Typical wet print
- Creases / scars
Traditional image processing methods (Gaussian, low pass etc.) cannot work.

- Fingerprint: oriented texture
- Ridges only need enhancing in a direction parallel to their orientation, and at a specific frequency.

We need location specific filtering.
Image Enhancement – Gabor filter

- A sinusoidal plane of particular frequency and orientation, modulated by a Gaussian envelope: \( h(x, y) = s(x, y)g(x, y) \), where

\[
s(x, y) = e^{-j2\pi(u_0x + v_0y)}
\]

and

\[
g(x, y) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{1}{2}\left(\frac{x^2}{\sigma_x^2} + \frac{y^2}{\sigma_y^2}\right)}
\]

1-D

3-D

Fourier spectrum
Divide into cells, each has an orientation angle and a frequency

Apply gabor filter corresponding to a specific orientation and frequency, to each cell
Each minutiae point has:
• (x, y) location
• Θ direction
• pixels of the ridge associated with particular minutia
• Compare all possible pairs of minutiae from the template and input images, using the ridges associated with minutiae.

• Compute a correlation between two planar curves:

\[ S = \frac{\sum d_iD_i}{\sqrt{\sum d_i^2} \sqrt{\sum D_i^2}} \]
Minutiae matching – align the two point sets

For those pairs that pass the similarity threshold, estimate rotation and translation parameters using the two ridges associated, and align the two point sets.
Minutiae matching – find similarity of two point sets

- Turn each \((x, y, \Theta)\) into polar coordinates \((r, e, \Theta)\)
- Find similarity using string matching algorithm
Palmprint and iris
Palmprint recognition
[D. Zhang et al]

- Completely different approach
- Texture-based, rather than minutiae-based
- Experimental result has comparable level of accuracy as that of fingerprint or iris
Palmprint recognition

Original palmprint image

Copped Region Of Interest

Real parts of the results after filtering with the 4 Gabor filters

Gabor filter revisited:
• a Gabor filter bank consists of 4 complex gabor filter that differ only in its orientation, i.e. of orientation 0°, 45°, 90°, 135°
• each filter is applied to the ROI, strengthening texture at a specific orientation, at the same time attenuating noise
Let $M_j$ be the magnitude of the image filtered with the $j$th filter, and $P_j$ the phase, then PalmCode is generated according the following way: (hr is the real part of the code, while hi is the imaginary part)

$$k = \arg \max_j (M_j(x, y))$$

$(h_r, h_i) = (1, 1)$ if $0 \leq P_k(x, y) < \pi / 2$ ,

$(h_r, h_i) = (0, 1)$ if $\pi / 2 \leq P_k(x, y) < \pi$ ,

$(h_r, h_i) = (0, 0)$ if $\pi \leq P_k(x, y) < 3\pi / 2$ ,

$(h_r, h_i) = (1, 0)$ if $3\pi / 2 \leq P_k(x, y) < 2\pi$

Hamming distance between two PalmCode as the similarity score.
Iris recognition – IrisCode
[D. Daugman]

• Any given iris has a unique texture that is generated through a random process before birth
• Gabor filters turn out, again, to be very good at detecting patterns in this unique texture
• Matching is done again in hamming distance comparison
Texture Based fingerprint recognition: FingerCode [A. K. Jain]

- Uses texture information (lost in optical and minutiae based schemes)
- Performs well with poor quality prints
- Features are statistically independent from minutiae and can be combined with minutiae matchers for higher accuracy
- Requires accurate alignment of the two prints (unreliable in poor prints)
- Not invariant to translation, orientation and non-linear distortion.
- Less Accurate than minutiae based matchers
Matching using PalmCode, IrisCode or FingerCode

- In theory, two codes independently generated from same person would be exactly the same
- In reality, not true, due to imperfect cameras, lighting or small rotational errors
- If the distance between them is below a certain threshold: match!
- Assumption: statistical independence, only the same person can fail test
- Iris has more randomness than the other two modalities, as inferred by the high accuracy of the technology

United Arab Emirates’ border control since 2001: 7 trillion comparisons, 73,180 mismatches
A peak at a few key implementations
US-VISIT, requires travelers to provide fingerprint for verifying identity

At Disney World, fingerprints of guests are used to make sure the ticket is used by the same person from day to day

Fingerprint minutiae data is encrypted in this Biometric card for federal workers, mandated by DHS
IrisCode matching using Dr. Daugman’s algorithm helps confirms the woman found 18 years later is indeed the famous Afghan girl.
Biometric passports

- Stores image of facial recognition, fingerprint recognition, or iris scans (usually in JPEG format) in a chip

Symbol for biometric passports, usually printed on the cover of the passports
Multi-modal fusion
Even though recognition rates are increasing and many modalities are in the very high 90%, real-life applications do worse than this.

Failure to enroll is the biggest issue:
- Some people's fingerprints / palmprints are of poor quality (scars, calluses etc).
- Some people's iris is mostly hidden under eyelid, some people are not comfortable with their iris being scanned.

The most practical way to overcome this is to use more than one modality.
Biometric Fusion

- Fingerprint with palmprint, with iris, with face, or even with voice, you name it
- The simpleminded approach is to combine the final match "scores"
  - but this can be proven to be suboptimal
- More intelligent methods of fusion are being earnestly sought
- Focus of immediate research