Automated Clarity and Quality Assessment for Latent Fingerprints

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# Fingerprints

<table>
<thead>
<tr>
<th>Ink card</th>
<th>Live-scan</th>
<th>Latent</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Fingerprint Image 1" /></td>
<td><img src="image2.png" alt="Fingerprint Image 2" /></td>
<td><img src="image3.png" alt="Fingerprint Image 3" /></td>
</tr>
</tbody>
</table>

- **Ink card**
  - Traditional method
  - Unique identification
  - Criminal records
  - Employment

- **Live-scan**
  - Popular method
  - Multiple variety sensors
  - Civil and commercial applications

- **Latent**
  - Natural deposition
  - Not visible to eyes
  - Multiple lifting method
  - Forensic applications
The bigger problem

Latent print

Exemplar prints

(a)  
(b)  
(c)  
(d)  
(e)
Challenges

No end-to-end automated system exist for latent fingerprint matching!

(i) Availability of partial prints
Challenges

No end-to-end automated system exist for latent fingerprint matching!

(ii) Poor quality of ridges, smudges and dusting noise
Challenges

No end-to-end automated system exist for latent fingerprint matching!

(iii) Non-linear distortion in ridge patterns
Latent fingerprint matching system

Latent fingerprint matching system

Level 1:
- Fingerprint capture
- Fingerprint enhancement
- Fingerprint segmentation
- Feature extraction

Level 2:
- Arch
- Tentured Arch
- Left Loop
- Right Loop
- Twin Loop
- Whorl

Level 3:
- Pores, Dots, incipients, ridge flow map
Latent fingerprint matching system

- Human hand
- Fingerprint capture
- Quality assessment
- Fingerprint enhancement
- Fingerprint segmentation
- Feature extraction

\[
\langle x_1, y_1, \theta_1 \rangle \\
\langle x_2, y_2, \theta_2 \rangle \\
\vdots \\
\langle x_n, y_n, \theta_n \rangle
\]
Latent fingerprint matching system

Human hand → Fingerprint capture → Quality assessment → Fingerprint enhancement → Fingerprint segmentation → Feature extraction → Feature matching → Match Scores → Individualization Decision

Enrolled database

Subject ID

\(<x_1, y_1, \theta_1>\)
\(<x_2, y_2, \theta_2>\)
\(\ldots\)
\(<x_n, y_n, \theta_n>\)

98
45
78
12
5
37
Why quality assessment?

• Good predictor of match score and system performance

• Rejects low quality images – Failed to Enrol / Failed to Capture

• Reduces the number of queries in latent fingerprints
It started out as ...

• Latent Fingerprint Quality: A Survey of Examiners
  Hicklin et al., Journal of Forensic Identification, Aug 2011

• 86 examiners, 1090 latent prints

• Development of guidelines, metrics, and software tools for assessing fingerprint quality

• Result: Consistency, repeatability and reproducibility of human decisions is low.
Automation, here I come ...

# Automation results

**Two class problem:** \{Good quality, not-good quality\}

<table>
<thead>
<tr>
<th>Classification</th>
<th>Manual features</th>
<th>Automated features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good quality</td>
<td>93% ± 4%</td>
<td>51% ± 12%</td>
</tr>
<tr>
<td>Not-Good quality</td>
<td>46% ± 13%</td>
<td>67% ± 11%</td>
</tr>
<tr>
<td><strong>Total classification</strong></td>
<td><strong>79% ± 6%</strong></td>
<td><strong>60% ± 4%</strong></td>
</tr>
</tbody>
</table>

Clarity vs. Quality #Eye-opener

- **Clarity:** Ability to discriminate (presence /absence) of features
- **Quality:** Ability to make a good match using features – quantity of features

Go local ... local ... local ...

- Propose a local metric, instead of global
Manual solution for clarity
Problem statement

1. Local Clarity Assessment
   (Unbiased estimator of quality)

2. Local Quality Assessment
   (Unbiased estimator of MS)

3. Clarity based quality Assessment
   (Relation between clarity and quality)

Work accepted and to be presented in BTAS, October 2013.
Clarity assessment

• 2D structure tensor
  – Robust than gradient

\[
J = \begin{bmatrix}
  f_x^2 & f_x f_y \\
  f_x f_y & f_y^2 \\
\end{bmatrix}
\]

• Eigen decomposition of structure tensor
  \((\mu_1, \mu_2)\) – Eigen Values; \((v_1, v_2)\) – Eigen vectors

The larger Eigenvalue shows the strength of the local image edges, the corresponding Eigenvector points across the edge (in gradient direction.)
Clarity assessment

• Three clarity bins: Good, Bad, and Ugly.

Ugly clarity  Bad clarity  Good clarity
Quality assessment #Points-to-remember

Point1: Use clarity as a weight for assessing quality

Point2: Literature uses L2 features (number of minutiae) to assess quality – cannot be used as we are proposing a local quality metric

• Go for L1 features (ridge flow) to assess quality
Quality assessment algorithm

Latent print

Local patches

Histograms

Local clarity

Weighted average histogram
**Database**

**NIST SD-27 database**

<table>
<thead>
<tr>
<th>Global quality</th>
<th>Images</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>88</td>
</tr>
<tr>
<td>Bad</td>
<td>85</td>
</tr>
<tr>
<td>Ugly</td>
<td>85</td>
</tr>
<tr>
<td>Total</td>
<td>258</td>
</tr>
</tbody>
</table>

- Manual annotation of clarity performed for every local block
Clarity vs. ground truth analysis

<table>
<thead>
<tr>
<th>Estimated clarity</th>
<th>Ground truth clarity</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Good</td>
<td>Bad</td>
<td>Ugly</td>
<td></td>
</tr>
<tr>
<td>Good</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2453</td>
<td>2330</td>
<td>7412</td>
<td></td>
</tr>
<tr>
<td>Bad</td>
<td>1546</td>
<td>1593</td>
<td>4868</td>
<td></td>
</tr>
<tr>
<td>Ugly</td>
<td>596</td>
<td>792</td>
<td>5718</td>
<td></td>
</tr>
</tbody>
</table>

- **Manual annotation** – 16.8 % (good clarity blocks)
- **Prediction algorithm** – 44.65 % (good clarity blocks)
Clarity vs. minutiae analysis

• **Minutiae confidence**: \( \{ \text{Good, bad, ugly} \} :: \{3429, 1304, 490\} \)

• Good clarity regions, where both level-2 and level-1 are markable, should correspond to the good quality minutiae annotated.

• Manually annotated clarity maps: 800 (34.8%) minutiae positioned in the good clarity regions.

• Manually annotated clarity maps: 2301 (67%) minutiae positioned in the good clarity regions.
Quality vs. match score performance

• “All minutiae” – highest possible matching performance.
• **Aim:** If proposed quality score is a good predictor of the matching performance.
Visual analysis
Concluding remarks

• Automatic local clarity and local quality assessment algorithms are proposed for latent fingerprints.

• Influence of clarity on quality is studied.

• Further, we plan to combine L1 and L2 features for quality assessment.
Publications


Thank you

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Backup slides
Quality Assessment in LFP

• Latent value determination – analysis phase

• Three quality assessment values –
  – value for individualization (VID)
  – value for exclusion only (VEO)
  – no value (NV).

• NIST SD-27: Good, Bad and Ugly
Human Performance

PNAS, 2011

Accuracy and reliability of forensic latent fingerprint decisions
Bradford T. Ulery¹, R. Austin Hicklin⁰, JoAnn Buscaglia⁰¹, and Maria Antonia Roberts³

PloS One, 2012

Repeatability and Reproducibility of Decisions by Latent Fingerprint Examiners
Bradford T. Ulery¹, R. Austin Hicklin¹, JoAnn Buscaglia²*, Maria Antonia Roberts³

Manual assessment is neither “reproduceable” nor “consistent”
Human performance

90% of the examiners have good quality consensus on only 40% of the latent impressions

Examiner consensus on VID decisions, showing the percentage of examiners reaching consensus (y axis) on each latent (x axis).

Human performance

Repeatability and reproducibility of individualization and exclusion decisions, by examiner assessment of difficulty.


<table>
<thead>
<tr>
<th></th>
<th>Individualization</th>
<th>Exclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Repeated</td>
<td>Reproduced</td>
</tr>
<tr>
<td>Obvious/Easy/Medium</td>
<td>92%</td>
<td>85%</td>
</tr>
<tr>
<td>Difficult/Very Difficult</td>
<td>69%</td>
<td>55%</td>
</tr>
</tbody>
</table>
Observation

Very easy

Very difficult

No value

07-11-2013
Clarity Assessment (2)

• Compute the energy image.
  \[ E = \sqrt{v_1^2, v_2^2} \]

• Apply threshold on the energy image to put them in 3 bins
Quality assessment algorithm

1. Smoothened gradient orientation
2. 16x16 blocks and 3x3 neighborhood
3. Histogram of each orientation in each block
4. Create normalized histogram (from the 9 hist.)
5. Compute the kurtosis of normalized hist

x. Use weighted normalization with weights as clarity of the local window.