Conformance to Standardized Minutia Detection Requirements

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Conformance to Standardized Minutia Detection Requirements

MOTIVATION

March 8, 2012
Motivation

Minutiae Templates

1. Fingerprint image (biometric sample) after acquisition as generated by capture device.

2. Features (minutiae) as identified during feature extraction process.

3. Biometric template encoding.
   According to ISO/IEC 19794-2:
   1. Minutia $x$-coordinate
   2. Minutia $y$-coordinate
   3. Minutia angle $\theta$
   4. Minutia type $t$
   5. Minutia quality $q$

   $$m = \langle x, y, \theta, t, q \rangle \in \mathcal{M}$$
Motivation

Minutiae Detection Deficiency

Vendor A
Vendor B
Vendor C
Motivation

Minutiae Misplacement

- MINEX results presented at BIOSIG 2009
  - 2D histogram of minutiae locations
  - Angle and type information ignored

(Source: Tabassi et al., BIOSIG2009)
ISO/IEC 29109-x: Conformance testing methodology for biometric data interchange formats defined in ISO/IEC 19794-x:

– Level 1: Data format conformance
– Level 2: Internal consistency checking
– Level 3: Content checking
Motivation

Conformance Testing

- ISO/IEC 29109 - Part2: Finger minutiae data
- ISO/IEC 29109-2 AMD1: Semantic conformance testing - Part2: Finger minutiae data
  - Scope: tests of semantic assertions
  - Type A Level 3 as defined in ISO/IEC 29109-1:2009
ISO/IEC 29109-2 AMD1:

„The reason these tests are necessary is because in practice minutia detectors sometimes
- fail to properly place a minutia
- detect a false minutia within the ridge structure of a parent fingerprint;
- detect a false minutia outside or at the periphery of an image of the parent fingerprint
- fail to detect a minutia within the fingerprint data
- fail to determine type correctly
- fail to measure angle correctly „
Motivation

Conformance Testing

- ISO/IEC 29109-2 AMD1 (SC37N4834):
  - Clause 7.4 Minutiae conformance measure
    \[
    \text{MINUTIA\_CONFORMITY}(r, t) = (1 - p)H(W/4 - d)
    \]
  - Clause 7.5 Out-of-area test
    \[
    \text{OUTSIDE}(T) = \frac{1}{N} \sum_{i=1}^{N} \text{MPS}(t_i)
    \]
  - Clause 7.6 False minutia test
    \[
    \text{TRUE\_MINUTIA\_FRACTION}(R, T) = 1 - \frac{N_{IT}}{N_T}
    \]
Conformance to Standardized Minutia Detection Requirements

REVISED PERSPECTIVE ON

SEMANTIC CONFORMANCE TESTING
• Level 3: Content checking
  – „to test that the BDIRs produced by an IUT are faithful representations of the original biometric data and that they satisfy those requirements of the base standard that are not simply a matter of syntax and format [...]“ (ISO/IEC 29109-1)

• Strict (loose) definition of ‚faithfulness‘
  – „A biometric template resulting from a noise-free and linear transformation applied to the input biometric characteristic’s (sample’s) traits.“
  – Faithfulness in strict sense desired
  – Faithfulness in loose sense measured, due to non-linear physical effects during data acquisition
Faithfulness
  – Modeled as continuous function
  – With reference set $R_i$ and test set $T_{k,i}$
  – Measured at minutiae-level
    • Per attribute equality
    • No addition of spurious minutiae

$\mathcal{F} : \mathcal{M} \times \mathcal{M} \rightarrow \mathbb{R}, \mathcal{F}(R_i, T_{k,i})$

$m \in R_i, m' \in T_{k,i}$
$\forall \psi \in \{x, y, \theta, t\} : \psi =_{\mathcal{R}} \psi'$
$|R_i| = |T_{k,i}|$

Computation Model
  – For a set of feature extractors
  – compute conformance rates
  – based on a reference data set
  – and on definition of faithfulness

$SCM = (\mathcal{A}, \mathcal{GTM}, \mathcal{F}, CR_{\text{max}})$

$\forall A_k \in \mathcal{A} :$
$\frac{1}{N_{\mathcal{GTM}}} \sum_{i=1}^{N_{\mathcal{GTM}}} (\omega_i \cdot \mathcal{F}(R_i, T_{k,i}))$
Ground-Truth Minutiae

Consists of triplets
  – Biometric sample
  – Reference template
  – Weight

Based on biometric samples of NIST special databases SD14 and SD29

Samples manually analyzed by dactyloscopic experts of BKA

Results in a scattered set of ground truth minutiae per biometric sample

Sample fusion?
• **Explicit** Fusion Methodology
  – Requires explicit data fusion process
  – Computes *harmonized* reference from scattered expert data - see

• **Implicit** Fusion Methodology
  – Implicit fusion during conformance rate computation
  – Requires adjusted weights
  – Uses scattered references as-is

• **Known-Truth** Methodology
  – Utilizes synthetically generated data
• Minutiae quality scores
  – Valued $0 \leq q \leq 100$ according to ISO/IEC 19794-2
  – Can be interpreted as confidence value
  – Usage of minutiae quality is controversially discussed in SC37
    as no standardized method for determination exists
  – However, standardization of minutiae quality not required

• Quality-score honoring instance
  
  \[ \text{SCM}_{QBL} = (A, GTM, F_{QBL}, 1) \]

  \[ F_{QBL}(R_i, T_{k,i}) = \lambda_1 \gamma_1(R_i, T_{k,i}) + \lambda_2 \gamma_2(R_i, T_{k,i}) \]

  – Function to measure faithfulness
    – Addresses minutiae misplacement and
    – spurious minutiae placement problems
    – Honores minutiae quality values
Semantic Conformance Testing

Minutiae Misplacement Problem

- Quantifies degree to which automatically generated minutiae deviate from ground-truth minutiae
- Equally penalizes location, angle and type differences
- Penalty weighted according to minutiae reliability

\[ \gamma_1(R_i, T_k, i) = \frac{1}{|R_i|} \sum_{j=1}^{|R_i|} (1 - f_{\text{faith}}(m_j, m_j')) e^{-\left(1 - \frac{q_j'}{100}\right)^2} \]

\[ f_{\text{faith}}(m_j, m_j') = \begin{cases} 
0, & \text{if } d_2(m_j, m_j') > tol_d \\
\hat{f}_j, & \text{otherwise}
\end{cases} \]

\[ \hat{f}_j = \frac{s_j^{\Delta d} + s_j^{\Delta \theta} + s_j^{\Delta t}}{3} \]

\[ s_j^{\Delta d} = \frac{tol_d - d_2(m_j, m_j')}{tol_d} \]

\[ s_j^{\Delta \theta} = \frac{\pi - \min\{2\pi - |\theta_j - \theta_j'|, |\theta_j - \theta_j'|\}}{\pi} \]

\[ s_j^{\Delta t} = \begin{cases} 
1, & \text{if } t_j = t_j' \\
0, & \text{if } t_j \neq t_j' \text{ and } t_j \text{ is unknown} \\
0, & \text{otherwise}
\end{cases} \]
Semantic Conformance Testing

Spurious Minutiae Problem

- Compute ratio of spurious minutiae
  - no distinction between „out of fingerprint area“ and „inside“
- Weighted according to minutiae reliabilities

\[
\gamma_2(R_i, T_{k,i}) = 1 - \frac{1}{|T_{k,i}|} \sum_{j=1}^{q'_j} \frac{|S_{k,i}|}{100}
\]

\[
S_{k,i} = \{m' \in T_{k,i} \mid \#m \in R_i : d_2(m, m') \leq tol_d\}
\]
Assessing Semantic Conformance of Minutiae-based Feature Extractors

EVALUATION AND RESULTS
• Development of feature extractors and comparators using 3 SDKs
• Computation of 162 DET curves
• Analysis of 3294 biometric samples
• Creation of 12661 biometric templates
• Computation of 34,6M comparison scores
Evaluation and Results

Real World Correlation

- Comparison of CRs and avg. non-native equal error rates (nnEER)
- nnEER estimate of real-world inter-vendor performance:
  - Average of equal error rates in non-native case,
  - i.e. using probe templates from $V_x$ and reference templates from $V_y$

$$nnEER_\phi = \frac{1}{2(|\mathcal{V}| - 1)} \sum_{\psi \in \mathcal{V} \setminus \{\phi\}} (EER_{\phi,\psi} + EER_{\psi,\phi})$$

$$\mathcal{V} = \{A_{V_A}, A_{V_B}, A_{V_C}\}$$

- Benchmarked using non quality honoring approach ($SCM_{BL}$) described in

<table>
<thead>
<tr>
<th>avg. EER</th>
<th>$A_{V_A}$</th>
<th>$A_{V_B}$</th>
<th>$A_{V_C}$</th>
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<tr>
<td>$A_{V_A}$</td>
<td>0.0415</td>
<td>0.0459</td>
<td>0.0493</td>
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<tr>
<td>$A_{V_B}$</td>
<td>0.0455</td>
<td>0.0428</td>
<td>0.0519</td>
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<td>$A_{V_C}$</td>
<td>0.0495</td>
<td>0.0516</td>
<td>0.0376</td>
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<table>
<thead>
<tr>
<th>IUT</th>
<th>nnEER</th>
<th>$CR_{QBL}$(·)</th>
<th>$CR_{BL}$(·)</th>
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<td>$A_{V_A}$</td>
<td>0.0476</td>
<td>0.6214</td>
<td>0.6285</td>
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<tr>
<td>$A_{V_B}$</td>
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<tr>
<td>$A_{V_C}$</td>
<td>0.0506</td>
<td>0.4039</td>
<td>0.6192</td>
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</table>
Evaluation and Results

- Evaluation of implicit vs. explicit fusion methodologies
- Evaluation shows that both methodologies lead to comparable results
  ➤ Explicit clustering not necessary!

<table>
<thead>
<tr>
<th></th>
<th>Implicit fusion</th>
<th></th>
<th>Explicit fusion</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>$\gamma_1(R_i, T_{k,i})$</td>
<td>$\gamma_2(R_i, T_{k,i})$</td>
<td>$CR(\cdot)$</td>
<td>$\gamma_1(R_i, T_{k,i})$</td>
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<tr>
<td>$A_{VA}$</td>
<td>0.483</td>
<td>0.795</td>
<td>0.639</td>
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<tr>
<td>$A_{VB}$</td>
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<td>0.614</td>
<td>0.514</td>
<td>0.352</td>
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<tr>
<td>$A_{VC}$</td>
<td>0.345</td>
<td>0.444</td>
<td>0.394</td>
<td>0.289</td>
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</table>
Assessing Semantic Conformance of Minutiae-based Feature Extractors

CONCLUSION AND FUTURE WORK
Conclusion and Future Work

Conclusion and Contribution

- Semantic conformance computation based on formal definition of faithfulness
- Plausibility testing yields reasonable results
- Conformance rates of quality honoring approach correlate with real-world inter-vendor performance estimates
- Explicit clustering not necessary

Contribution
  - Integration of ideas into ISO/IEC 29109-2 AMD1
  A copy is available at:
  http://www.christoph-busch.de/standards-gtd.html
ISO/IEC 29109-2 AMD1 requires further contributions

What is a common definition of a markup?
   a) an automated SDK generated minutia?
   b) a minutia generated by an individual
      (i.e. a dactyloscopic expert)
   c) any minutiae either a) or b)

Need for Semantic Conformance Computation Challenge (SC3)
   - Stronger evaluation (more templates and algorithms)
   - in cooperation with NIST
Thanks to...

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