Minutiae Interoperability Exchange Test (MINEX)

An Evaluation of the INCITS 378 Fingerprint Minutiae Templates

Patrick Grother
NIST

IAI :: AFIS Committee Meeting
NIST, February 28, 2007
Overview of Talk

§ MINEX primer
§ MINEX major results
§ Recent results
§ Toward an explanation
§ Recent minutia standardization activities
§ Conclusions
MINEX Overview

- **4 datasets**
  - POEBVA, DHS2, POE, and DOS
  - Left and right index fingers

- **Test size**
  - 493418 match “genuine” comparisons
  - 975890 non-match “impostor” comparisons

- **Multiple vendors**
  - 14 vendors in proprietary testing
  - 14 vendors in MIN:A testing
  - 6 participants in MIN:B testing

- **Largest test ever conducted**
  - Cubic complexity
  - 4.4 billion comparisons

- **INCITS 378 standard templates**
  - MIN:A templates
    - encodes coordinates (x, y), angle (θ), type, (no quality)
  - MIN:B templates
    - MIN:A data plus ridge count, core, and delta information

- **Proprietary templates**
  - Individual vendor’s representation of images

- **Performance test**
  - Interoperable performance is stated in terms of verification accuracy (FNMR vs. FMR)
MINEX Purpose

$\textbf{MINEX is intended}$

$\textgreater$ To assess performance of the new INCITS 378 standard

$\textgreater$ INTEROPERABILITY - to assess core capability of algorithms matching standard templates against those generated by other suppliers’ implementations

$\textgreater$ Template “competence”

$\textgreater$ SUFFICIENCY - to compare performance of algorithms based on standardized vs. proprietary (i.e. image-based) templates

$\textbf{MINEX is not intended}$

$\textgreater$ To predict performance of PIV, TWIC, RT …

$\textgreater$ Why not? Actual performance is dependent on environment, habituation, multiple attempts …
Three way interoperability

Enrolment Template Produced by Vendor A

Vendor B Matcher

Authentication Template Produced by Vendor C

similarity score

Repeat this for all $14^3$ supplier triplets, and all genuine and impostor comparisons

Measure Performance
## Native vs. Proprietary

<table>
<thead>
<tr>
<th>Supplier of Enrollment Template</th>
<th>False Non-Match Rate at False Match Rate of 0.01</th>
<th>Supplier of Template Matcher</th>
</tr>
</thead>
<tbody>
<tr>
<td>MINEX Vendors</td>
<td>Proprietary</td>
<td>Native Standard</td>
</tr>
<tr>
<td>Vendor A</td>
<td>0.0047</td>
<td>0.0129</td>
</tr>
<tr>
<td>Vendor B</td>
<td>0.0089</td>
<td>0.0136</td>
</tr>
<tr>
<td>Vendor C</td>
<td>0.0089</td>
<td>0.0140</td>
</tr>
</tbody>
</table>

**Native**

- Representation of the template is constrained by the INCITS 378 standard
- One supplier generates and matches the template.

**Proprietary**

- Representation of the template is completely unconstrained.
- Construe it to be the supplier’s “best effort maximum accuracy” template.
# Performance Interoperability

<table>
<thead>
<tr>
<th>False Non-Match Rate at False Match Rate of 0.01</th>
<th>Supplier of Verification Template + Template Matcher</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier of Enrollment Template</td>
<td>Vendor A</td>
</tr>
</tbody>
</table>

Red values refer to NATIVE performance: One vendor generates and matches all templates.
**Performance Interoperability**

<table>
<thead>
<tr>
<th>Supplier of Enrollment Template</th>
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<th>Supplier of Verification Template + Template Matcher</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vendor A</td>
<td>0.0129</td>
<td>Vendor B</td>
</tr>
<tr>
<td>Vendor B</td>
<td>0.0316</td>
<td>0.0205</td>
</tr>
</tbody>
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<td>Vendor B</td>
</tr>
<tr>
<td>Vendor A</td>
<td>0.0129</td>
<td>0.0205</td>
</tr>
<tr>
<td>Vendor B</td>
<td>0.0316</td>
<td>0.0140</td>
</tr>
<tr>
<td>Vendor C</td>
<td>0.0417</td>
<td>0.0225</td>
</tr>
</tbody>
</table>

Red values refer to NATIVE performance: One vendor generates both templates and matches them.
## Interoperability :: Scenario 1

Vendor makes enrollment template and executes the comparison

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>L</th>
<th>M</th>
<th>N</th>
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</tr>
</tbody>
</table>

Diagonal elements are usually smallest. Within-vendor operation is superior to interoperable.

Single finger, *POEBVA* dataset, FNMR at FMR = 0.01.
PIV

MINEX is being used by GSA as one criterion for PIV

MINEX Report 2006 formed initial interoperable group
Ongoing MINEX testing allows others in.
Minutiae encoders qualify if their output templates can be matched by all matchers with FNMR < 0.01 at FMR = 0.01 using two fused fingers
In all cases, matchers qualify if they compare all suppliers’ templates with FNMR < 0.01 at FMR = 0.01 using two fused fingers
MINEX Eligible for GSA

- Template Generators
  - Cogent Systems
  - Dermalog Identification Systems
  - Bioscrypt
  - Sagem Morpho
  - Neurotechnologija
  - Innovatrics
  - NEC
  - Cross Match Technologies
  - L1 / Identix
  - Precise Biometrics
  - X Tec
  - SecuGen
  - BIO-key International
  - Motorola
  - Aware
  - Sonda Technologies

16 suppliers

- Matchers
  - Cogent Systems
  - Dermalog Identification Systems
  - Bioscrypt
  - Sagem Morpho
  - Innovatrics
  - NEC
  - L1 / Identix
  - X Tec
  - SecuGen
  - BIO-key International
  - Motorola
  - Startek Engineering
  - Sagem Morpho (MOC)

12 suppliers
2 Conformance

A system conforms to this standard if it satisfies the mandatory requirements herein for extraction of minutiae from a fingerprint image as described in Section 5 and the generation of a minutiae data record as described in Section 6.
2004 :: 5.3.2 Minutia Placement on a Ridge Ending
The minutia for a ridge ending shall be defined as the point of forking of the medial skeleton of the valley area immediately in front of the ridge ending. If the valley area were thinned down to a single-pixel-wide skeleton, the point where the three legs intersect is the location of the minutia. In simpler terms, the point where the valley “Y”’s, or (equivalently) where the three legs of the thinned valley area intersect.

2007 :: 5.3.2 Minutia Placement on a Ridge Ending
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The standards contain analogous text for bifurcations also.
Minutiae from two products

- Insertion / Deletion
- Angle Difference
- Angle, position and type Differences
2D Minutiae Density

Intensity, \( I(x, y) \), is proportional to the estimated likelihood that a minutiae will be found by a template generator at \((x,y)\).

No registration applied. No consideration of angle, type, class, or quality value.

Each 2D density function is estimated from \(~ 72000\) templates derived from 368x368 images collected using a single model of sensor.

These effects are observed for other optical sensors.

Order of appearance is not the alphabetic order of vendors in the MINEX reports.
Performance depends on source of enrollment and verification templates

“Excess” FNMR = FNMR_{XYZ} − FNMR_{ZZZ}

= 0.023 − 0.014

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
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</tr>
</thead>
<tbody>
<tr>
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<td>0.038</td>
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<td>0.037</td>
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<td>0.035</td>
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<td>0.019</td>
<td>0.047</td>
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<tr>
<td>G</td>
<td>0.037</td>
<td>0.024</td>
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<td>0.021</td>
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<td>0.066</td>
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<td>0.085</td>
<td>0.078</td>
<td>0.100</td>
<td>0.097</td>
<td>0.053</td>
</tr>
</tbody>
</table>

Top left portion of Table 11a in NIST IR 7296. Scenario 2. Matcher D.
# Interoperability Models

<table>
<thead>
<tr>
<th>Regression Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>When matcher Z compares templates from generators A and B it produces an “excess” error over its native performance.</td>
</tr>
</tbody>
</table>

| Model 1          | FNMR\textsubscript{ABZ} – FNMR\textsubscript{ZZZ} \sim RegionalOverlap(T\textsubscript{A}, T\textsubscript{B}) + NonUniformity(T\textsubscript{A}) \cdot NonUniformity(T\textsubscript{B}) |
| Model 2          | FNMR\textsubscript{ABZ} – FNMR\textsubscript{ZZZ} \sim RegionalOverlap(T\textsubscript{A}, T\textsubscript{B}) + Matcher + NonUniformity(T\textsubscript{A}) \cdot NonUniformity(T\textsubscript{B}) |

where

\[
\text{RegionalOverlap}(T\textsubscript{A}, T\textsubscript{B}) = P\textsubscript{A}(x, y) \cdot P\textsubscript{B}(x, y) \quad \text{(i.e. dot product)}
\]

\[
P\textsubscript{B} = \text{Estimated 2D PDF for template generator B}
\]

A measure of similarity between where A and B are finding minutiae

and

\[
\text{NonUniformity}(T\textsubscript{A}) = \text{Energy( HighPassFilter}(P\textsubscript{A}(x, y)) )
\]

A scalar measure of local non-uniformity in minutiae occurrence. Used here as a proxy for minutiae location quantization.
Non-uniformity as Proxy for Minutiae Misplacement

Establish a scalar proxy of the degree to which unexpected regular patterns exist in the PDF.

Local non-uniformity is 0.011

Local non-uniformity is 0.029
Interoperability Models :: Results

- Model 1: Adjusted $R^2 = 0.49$
- Model 2: Adjusted $R^2 = 0.60$
- Non-uniformity (high frequency content) positively contributes to “excess” FNMR
- Non-uniformity in both the enrollment and verification templates negatively contributes to FNMR
- Regional overlap negatively contributes to “excess” FNMR
- The matcher significantly contributes to “excess” FNMR, positively and negatively
- All effects above are strongly significant
- The regression is imperfect
  - There are missing explanatory variables (minutiae angle encoding differences and other).
A revision of INCITS 378 is progressing through M1

Posted as M1/06-0680, September 13 2006

It includes refined guidance on minutia placement
Standards Activity 19794-2

Text from New Work Item Proposal: SC37N1656
Approved per National Body vote Sep 14: SC37N1787

Scope
The scope of the proposed new work item is to standardise methods for the binarisation of gray-scale finger images, for the thinning of ridges (skeletonisation), and for the extraction of location, direction, and type of minutiae from ridge skeletons.

Purpose and Justification
Interoperability tests have shown that the location, the direction, and the type of minutiae extracted by different minutiae extraction subsystems from the same finger image tend to be different. This is due to supplier-specific image-processing algorithms. However, in order to achieve interoperability between subsystems from different suppliers, it is important that the individual minutiae extraction algorithms yield matchable minutiae. This can be achieved by standardising a minutiae extraction method. The results obtained from different minutiae extraction algorithms can then be compared to a well-defined ground truth, which is obtained by applying the standard minutiae extraction method. This would allow the suppliers to compensate for any biases that their minutiae extraction algorithms may produce.
Conclusions

- FNMR is lowest when both templates and the matcher come from the same supplier (“native”)
- FNMR is lower when both templates come from one supplier
- Template generation is idiosyncratic
- Syntactic conformance is not enough for interoperability
- Some template generators are semantically non-conformant
  - Non-conformance is evident in the 2D minutiae occurrence density.
- Such non-conformance degrades interoperability
- Single image-template analysis is necessary to explain empirical MINEX results further
- Extraction algorithm standardization should embed testing
- Offline technology testing is suited to measurement of core algorithmic interoperability
Thank you

The MINEX report is online
http://fingerprint.nist.gov/minex04/

Ongoing MINEX program
http://fingerprint.nist.gov/minex

Feedback will be welcomed.
For further information contact
patrick.grother@nist.gov