Minutiae Interoperability Exchange Test (MINEX)

An Evaluation of the INCITS 378 Fingerprint Minutiae Templates

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Overview of Talk

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

MINEX Overview

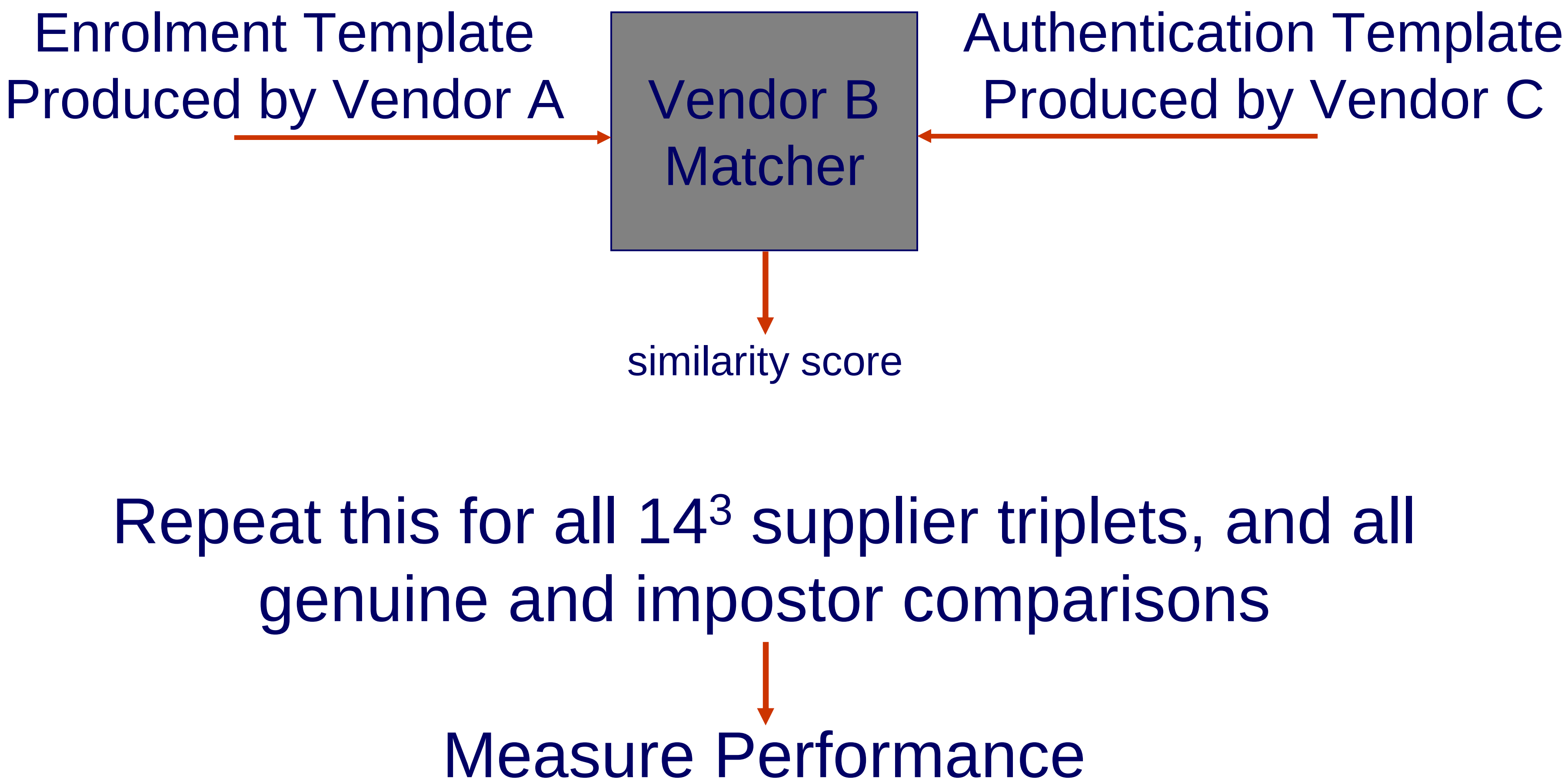
- INCITS 378 standard templates
  - MIN:A templates
    - encodes coordinates (x, y), angle (θ), type, (no quality)
  - MIN:B templates
    - MIN:A data plus ridge count, core, and delta information
- Proprietary templates
  - Individual vendor's representation of images
- Performance test
  - Interoperable performance is stated in terms of verification accuracy (FNMR vs. FMR)
- 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

MINEX Purpose

- **MINEX is intended**
  - To assess performance of the new INCITS 378 standard
    - INTEROPERABILITY - to assess core capability of algorithms matching standard templates against those generated by other suppliers' implementations
      - Template "competence"
    - SUFFICIENCY - to compare performance of algorithms based on standardized vs. proprietary (i.e. image-based) templates

- **MINEX is not intended**
  - To predict performance of PIV, TWIC, RT …
    - Why not? Actual performance is dependent on environment, habituation, multiple attempts …

Three way interoperability



Native vs. Proprietary

False Non-Match Rate at False Match Rate of 0.01	Supplier of Template Matcher		
	MINEX Vendors	Proprietary	Native Standard
Supplier of Enrollment Template	Vendor A	0.0047	0.0129
	Vendor B	0.0089	0.0136
	Vendor C	0.0089	0.0140

PROPRIETARY	Representation of the template is completely unconstrained.
	Construe it to be the supplier's "best effort maximum accuracy" template.
NATIVE	Representation of the template is constrained by the INCITS 378 standard
	One supplier generates and matches the template.

Performance Interoperability

False Non-Match Rate at False Match Rate of 0.01		Supplier of Verification Template + Template Matcher		
		Vendor A		
Supplier of Enrollment Template	Vendor A	0.0129		

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

Performance Interoperability

False Non-Match Rate at False Match Rate of 0.01		Supplier of Verification Template + Template Matcher		
		Vendor A	Vendor B	
Supplier of Enrollment Template	Vendor A	0.0129	0.0205	
	Vendor B	0.0316	0.0140	

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

Performance Interoperability

False Non-Match Rate at False Match Rate of 0.01		Supplier of Verification Template + Template Matcher		
		Vendor A	Vendor B	Vendor C
Supplier of Enrollment Template	Vendor A	0.0129	0.0205	0.0300
	Vendor B	0.0316	0.0140	0.0207
	Vendor C	0.0417	0.0225	0.0136

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

Vendor makes enrollment template

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
A	0.0136	0.0549	0.0458	0.0225	0.0641	0.0459	0.0417	0.0834	0.0334	0.1707	0.0747	0.0659	0.0792	0.0966
B	0.0218	0.0251	0.0385	0.0173	0.0402	0.0382	0.0192	0.1136	0.0336	0.1501	0.1599	0.0506	0.0442	0.0561
C	0.0357	0.0428	0.0225	0.0204	0.0519	0.0225	0.0348	0.1969	0.0484	0.3034	0.2451	0.0743	0.0493	0.0691
D	0.0207	0.0357	0.0301	0.0140	0.0485	0.0303	0.0316	0.0945	0.0392	0.2013	0.1218	0.0655	0.0551	0.0582
E	0.0236	0.0365	0.0340	0.0225	0.0301	0.0341	0.0286	0.0874	0.0476	0.1885	0.0896	0.0600	0.0557	0.0397
F	0.0359	0.0430	0.0222	0.0206	0.0522	0.0224	0.0345	0.1967	0.0485	0.3038	0.2456	0.0743	0.0493	0.0686
G	0.0300	0.0291	0.0447	0.0205	0.0390	0.0441	0.0129	0.0905	0.0441	0.1747	0.1632	0.0559	0.0419	0.0526
H	0.0437	0.1336	0.1212	0.0656	0.1860	0.1215	0.1339	0.1027	0.0796	1.0000	0.1748	0.1181	0.1818	0.2296
I	0.0397	0.0806	0.0830	0.0518	0.1062	0.0828	0.0548	0.2227	0.0348	0.2470	0.2756	0.0791	0.1030	0.1383
J	0.0403	0.0602	0.0939	0.0455	0.0987	0.0943	0.0489	0.2852	0.0542	0.1505	0.7314	0.0773	0.1026	0.1169
K	0.0188	0.0593	0.0476	0.0280	0.0661	0.0467	0.0428	0.0790	0.0400	0.1920	0.0461	0.0770	0.0885	0.1015
L	0.0467	0.0558	0.0704	0.0428	0.0822	0.0708	0.0432	0.1640	0.0485	0.1901	0.2375	0.0524	0.0866	0.0938
M	0.0496	0.0493	0.0455	0.0307	0.0545	0.0454	0.0327	0.2066	0.0616	0.3022	0.3929	0.0868	0.0359	0.0855
N	0.0368	0.0436	0.0428	0.0293	0.0458	0.0428	0.0393	0.1019	0.0497	0.1945	0.0865	0.0682	0.0621	0.0486

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
- XTec
- SecuGen
- BIO-key International
- Motorola
- Aware
- Sonda Technologies

16 suppliers

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

12 suppliers

INCITS 378 Conformance Clause

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.

INCITS 378 on Placement

2004 :: 5.3.2 Minutia Placement on a Ridge Ending

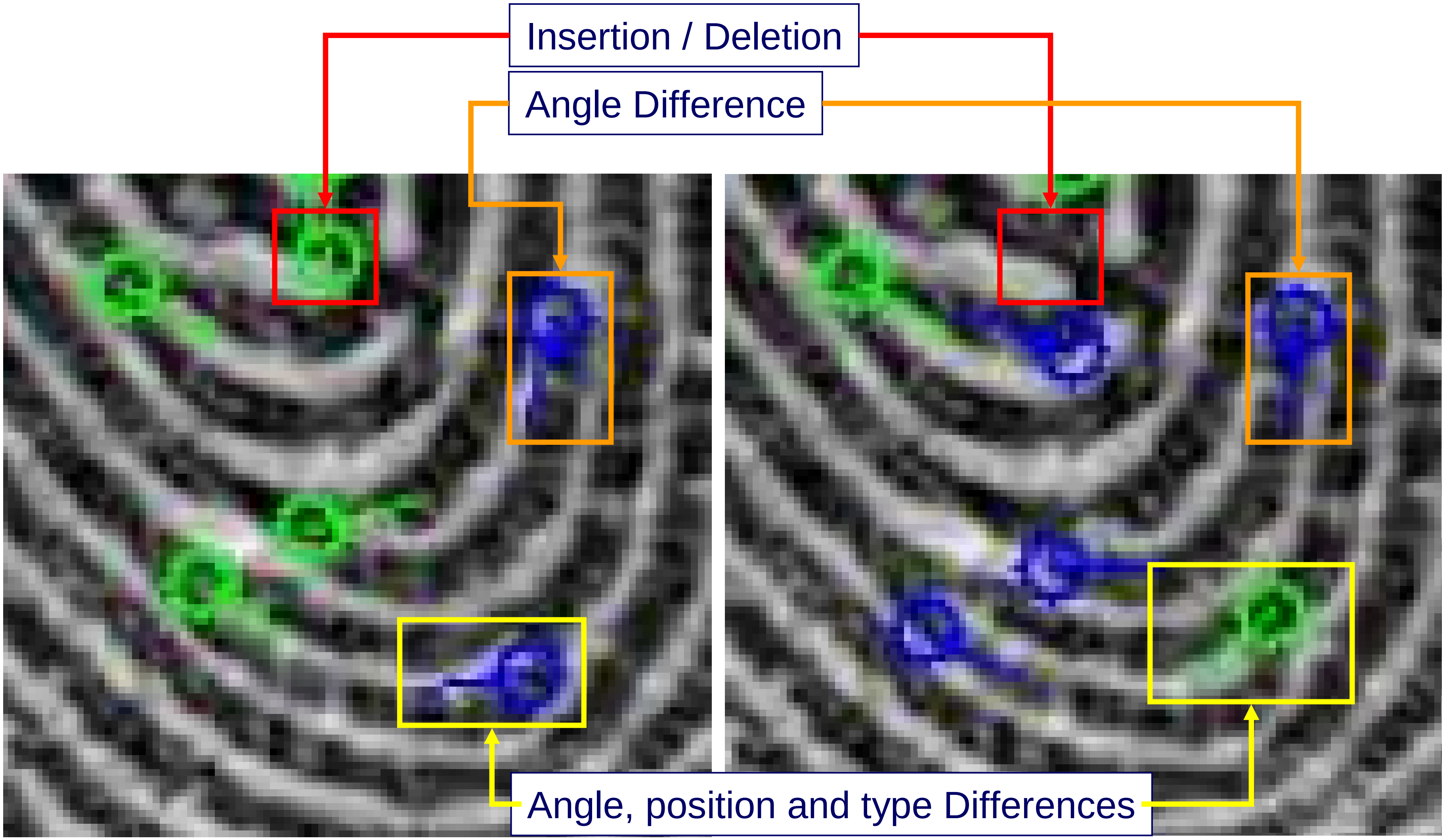
The minutia for a ridge ending shall be defined as the point of forking of the medial skeleton of the valley area immediately in front of the ridge ending. If the valley area were thinned down to a single-pixel-wide skeleton, the point where the three legs intersect is the location of the minutia. In 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

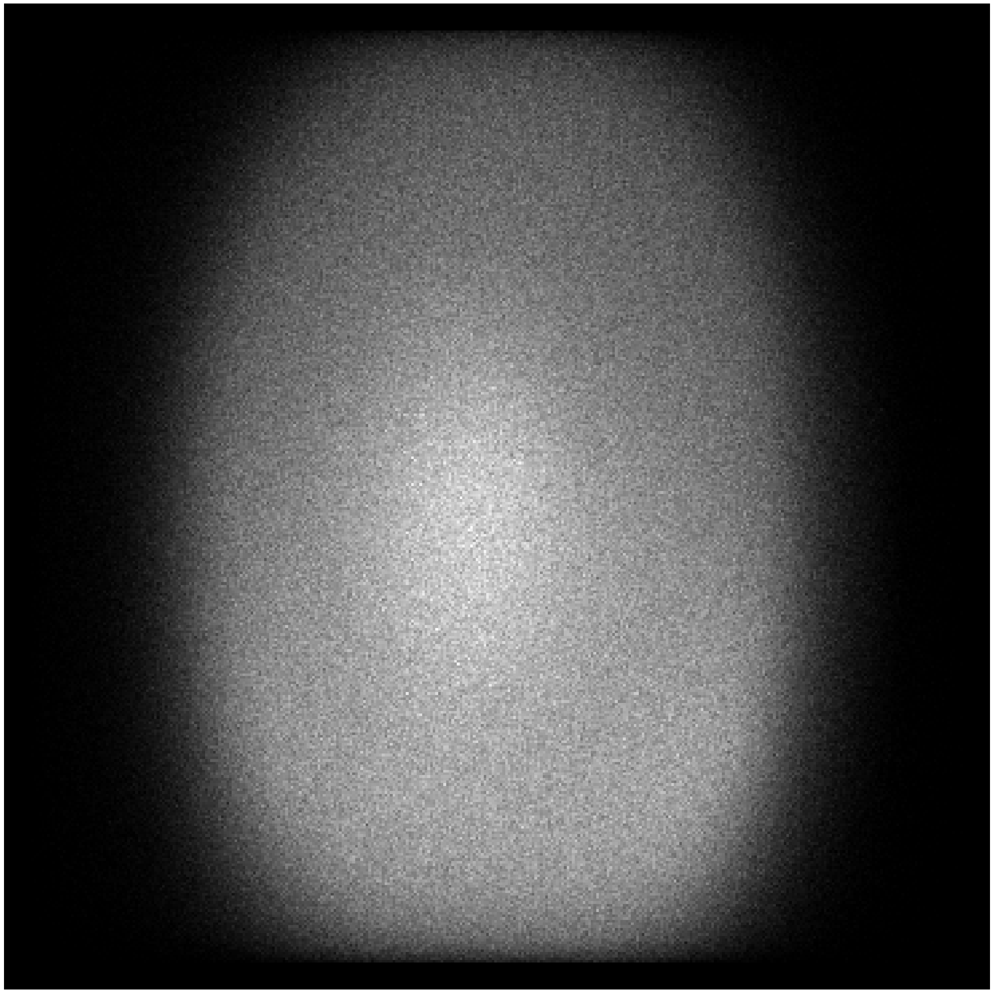
The minutia for a ridge ending shall be defined as the point of forking of the medial skeleton of the valley area immediately in front of the ridge ending. If the valley area were thinned down to a single-pixel-wide skeleton, the point where the three legs intersect is the location of the minutia. In simpler terms, the point where the valley "Y"'s, or (equivalently) where the three legs of the thinned valley area intersect. A Ridge Ending shall be encoded only if all of the legs used to calculate the minutiae angle length (as defined in 5.4.2 – Angle of a Ridge Ending) are greater than or equal to 0.02 inches in length.

The standards contain analogous text for bifurcations also.

Minutiae from two products



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

Verification Template Generator (columns); Enrollment Template Generator (rows)

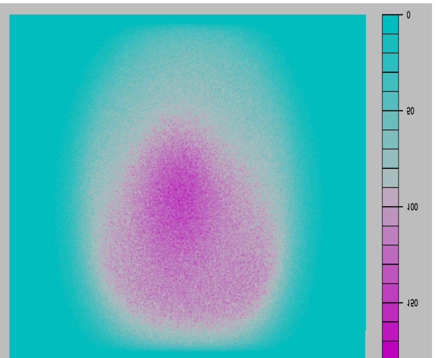
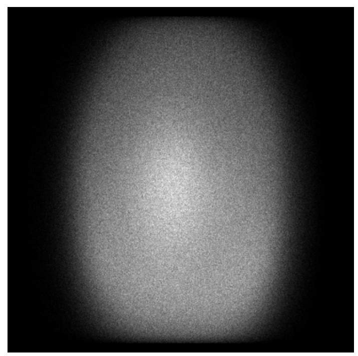
	A	B	C	D	E	F	G	H	I
A	0.019	0.034	0.038		0.047	0.038	0.054	0.059	0.041
B	0.028	0.021	0.029	0.017	0.034	0.028	0.028	0.071	0.053
C	0.039	0.034	0.019	0.020	0.040	0.019	0.047	0.106	0.072
D	0.026	0.025	0.023		0.035	0.023	0.034	0.070	0.049
E	0.034	0.030	0.029	0.023	0.030	0.030	0.037	0.083	0.058
F	0.040	0.035	0.019	0.021	0.040	0.019	0.047	0.107	0.072
G	0.037	0.024	0.033	0.021	0.034	0.033	0.024	0.087	0.068
H	0.056	0.085	0.108	0.066	0.119	0.109	0.127	0.081	0.084
I	0.046	0.070	0.078	0.052	0.085	0.078	0.100	0.097	0.053

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

Interoperability Models

Regression Models	
	When matcher Z compares templates from generators A and B it produces an "excess" error over it's native performance.
Model 1	$FNMR_{ABZ} – FNMR_{ZZZ}$ ~ RegionalOverlap(T_A, T_B) + NonUniformity(T_A) * NonUniformity(T_B)
Model 2	$FNMR_{ABZ} – FNMR_{ZZZ}$ ~ RegionalOverlap(T_A, T_B) + Matcher + NonUniformity(T_A) * NonUniformity(T_B)
where	RegionalOverlap(T_A, T_B) = $P_A(x, y) . P_B(x, y)$ (i.e. dot product) P_B = Estimated 2D PDF for template generator B A measure of similarity between where A and B are finding minutiae
and	NonUniformity(T_A) = Energy(HighPassFilter(P_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

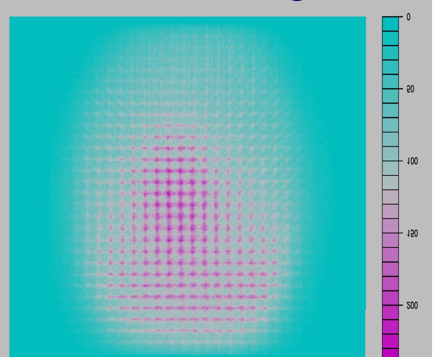
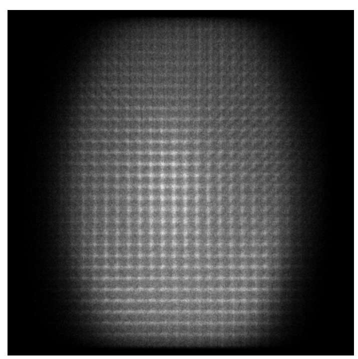
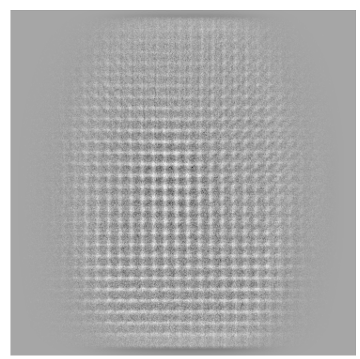




Local non-uniformity is 0.011

false color original

original

high pass filtered

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).

Standards Activity INCITS 378

- 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
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