Ongoing MINEX Report Card

Matcher 2J

NIST

**National Institute of
Standards and Technology**

U.S. Department of Commerce

Last Updated: October 9, 2015

Participant Details

Company: Bioscrypt Enterprise Access, L-1 Identity Solutions
Date Submitted: 3/17/2009
Date Validated: 3/25/2009
Date Completed: 4/3/2009

Library	Size (bytes)	MD5 Checksum
piv_minex.dll	225280	39065773f0d68a84ed389393827df16c

NOTE: NIST plans to decertify Windows-based libraries in MINEX III.

Compliance Test Results

The following presents **PIV compliance** results per the criteria detailed in NIST Special Publication 800-76-2: Biometric Specifications for Personal Identity Verification.

PIV Level One: PASS
- Must match templates from all certified template generators with an $\text{FNMR}_{\text{FMR}}(0.01) \leq 0.01$ using two fingers (4.5.2.1-4). ✓

PIV Level Two: FAIL
- Must pass PIV level one compliance. ✓
- Native template generator must pass level one compliance. ✗
- Must match templates from native template generator with an $\text{FNMR}_{\text{FMR}}(0.0001) \leq 0.02$ using one finger (4.5.3-2) ✗

Notes

- This report will be updated as new matching algorithms and template generators pass the compliance test. These updates will not change the PASS/FAIL decision above.

- NIST reserves the right to decertify a matcher if it later discovers the matcher violates PIV specifications in some previously undetected way.

Contents

List of Figures

List of Tables

1   Introduction

This report card presents measurements of performance and interoperability for a single fingerprint matching algorithm submitted to NIST as part of the ongoing MINEX Evaluation. It reports whether the matcher passes the technical requirements for PIV-compliance described in the NIST Special Publication 800-76-2: Biometric Specifications for Personal Identity Verification.

2   Methodology

Testing is performed at a NIST facility. Each participant's submission is validated by NIST (http://www.nist.gov/itl/iad/ig/ominex.cfm) before undergoing full testing to ensure it operates correctly. If the matcher passes the validation procedure, it is then used to compare standard fingerprint templates. Performance is assessed against templates created by a template generation algorithm submitted by the participant as well as templates created by other compliant template generators.

2.1   Dataset

Testing is performed over a single dataset of sequestered fingerprint images. The images were collected by U.S. Visit at ports of entry into the United States. They consist of Live-scan plain impressions of left and right index fingers. WSQ [1] compression was applied to all images at a ratio of 15:1. The most recent capture of each subject was treated as the authentication sample, and the next most recent as the enrolled sample.

The dataset was divided into 123 962 mated and 124 994 non-mated subject pairings. Since both left and right index fingerprints are available for each subject, this provides 247 924 mated and 249 988 nonmated single-finger comparisons (after database consolidation). This also means that when left and right index fingers are fused at the score level [2, 6], the sets condense to 123 962 mated and 124 994 nonmated comparison scores.

2.2   Accuracy Metrics

Core matching accuracy is presented in the form of Detection Error Tradeoff (DET) plots [5], which show the trade-off between the False Match Rate (FMR) and the False Non-Match Rate (FNMR) as a decision threshold is adjusted. Formally, let m_i ($i = 1 \ldots M$) be the ith mated comparison score, and n_j ($j = 1 \ldots N$) the jth non-mated comparison score. Then the statistics are

$$\text{FNMR}(\tau) = \quad \frac{1}{M} \sum_{i=1}^{M} \mathbb{1}\{m_i < \tau\}, \tag{1}$$

$$\text{FMR}(\tau) = \quad \frac{1}{N} \sum_{j=1}^{N} \mathbb{1}\{n_j \geq \tau\}. \tag{2}$$

where $\mathbb{1}\{A\}$ is the indicator [3] of event A. Equations 1 and 2 define the curve parametrically with the decision threshold, τ, as the free parameter. In some figures and tables, FNMR is presented as a function of FMR. This relationship is determined by

$$\text{FNMR}_{\text{FMR}}(\alpha) = \min_{\tau} \{ \text{FNMR}(\tau) \mid \text{FMR}(\tau) \leq \alpha \}, \tag{3}$$

which reads as the smallest FNMR that can be achieved while maintaining an FMR less than or equal to α, the targeted FMR. This method of relating the two error statistics ensures FNMR is well-defined for all $0 \leq \alpha \leq 1$. When the matching algorithm produces only a few unique comparison scores, the maximum threshold, τ_0, that elicits an $\text{FMR}(\tau_0) \leq \alpha$ may, in fact, be quite a bit lower than α. Thus, Equation 3 imposes a natural penalty on matching algorithms that produce overly discretized scores.

Some figures show *pooled* DET accuracy, which is a measure of the accuracy of the matcher against all compliant template generators. Accuracy is measured by concatenating all comparison scores involving the matcher together and computing FMR and FNMR using Equations 2 and 1. This roughly simulates performance for a biometric system that employs one matcher and templates created by several template generators.

Figure 1: MINEX Interoperability Test Setup

2.3   Interoperability

Interoperability is tested in a manner similar to *Scenario 1* from the MINEX Evaluation Report [4] (see Figure 1). An enrolment template is prepared using submission X. Submission Y is used to prepare the authentication template and perform the match. The authentication template is always prepared by the same submission used to compare the templates. However, enrolment templates need not originate from the same submission. When they do, we refer to it as "native" mode.

3   Results

This section details the performance of matcher 2J when it compares verification templates created by its own template generator to enrolment templates created by all MINEX compliant template generators. Sections 3.1 and 3.2 present accuracy results for single finger and two finger matching respectively. Sections 3.3 and 3.4 present potentially useful statistics not directly related to the performance of the matcher.

3.1   Single Finger

Singe finger comparison results show the combined results for left and right index comparisons. For reference, *NIST Special Publication 800-76-2* requires that the matcher and template generator achieve a native accuracy of $\text{FNMR}_{\text{FMR}}(0.0001) \leq 0.02$.

Figure 2: *Single finger DET statistics for matcher 2J. Each box shows the distribution of FNMRs at a fixed FMR across all MINEX compliant template generators. The ends of the whiskers show the minimum and maximum FNMRs. The orange DET curve shows pooled performance against all template generators.*
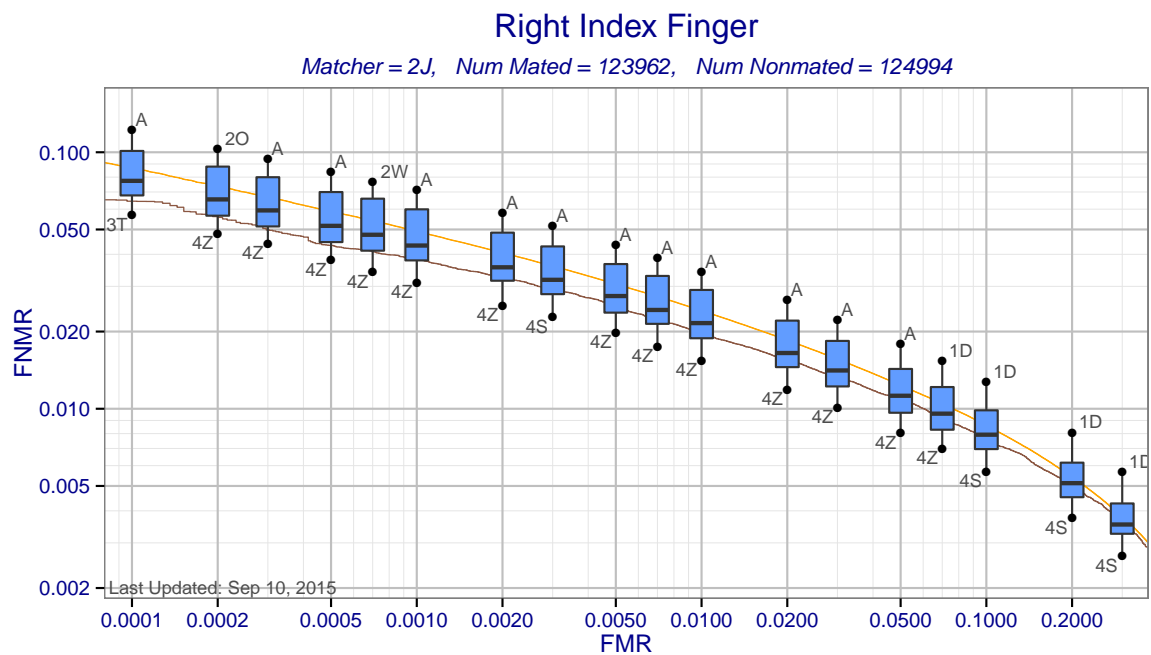
Figure 3: *Right index finger DET statistics for matcher 2J. Each box shows the distribution of FNMR at a fixed FMR across all MINEX compliant template generators. The ends of the whiskers show the minimum and maximum FNMRs. The orange DET curve shows pooled performance against all template generators.*
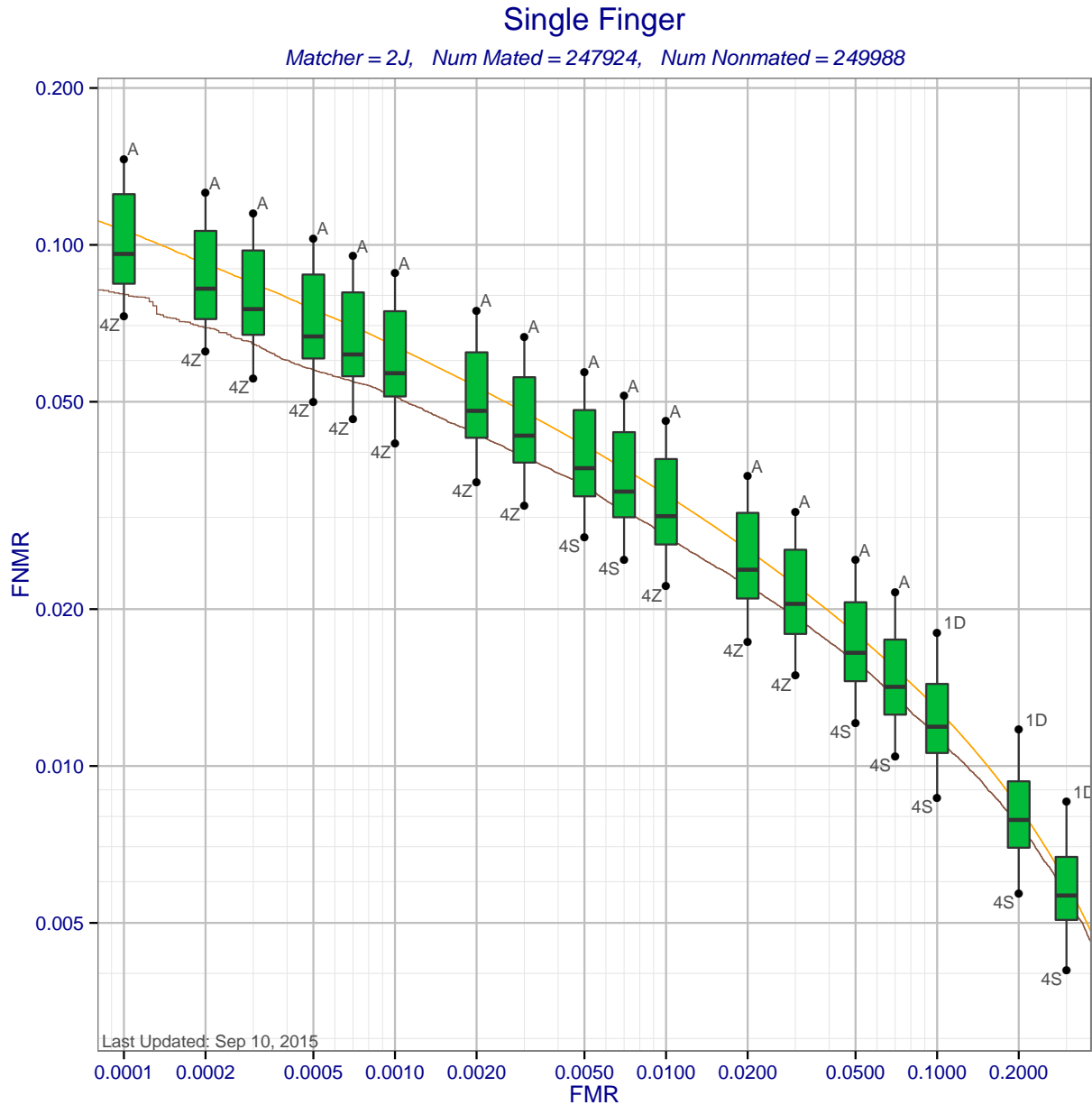

Figure 4: *Left index finger DET statistics for matcher 2J. Each box shows the distribution of FNMRs at a fixed FMR across all MINEX compliant template generators. The ends of whiskers show the minimum and maximum FNMRs. The orange DET curve shows pooled performance against all template generators.*
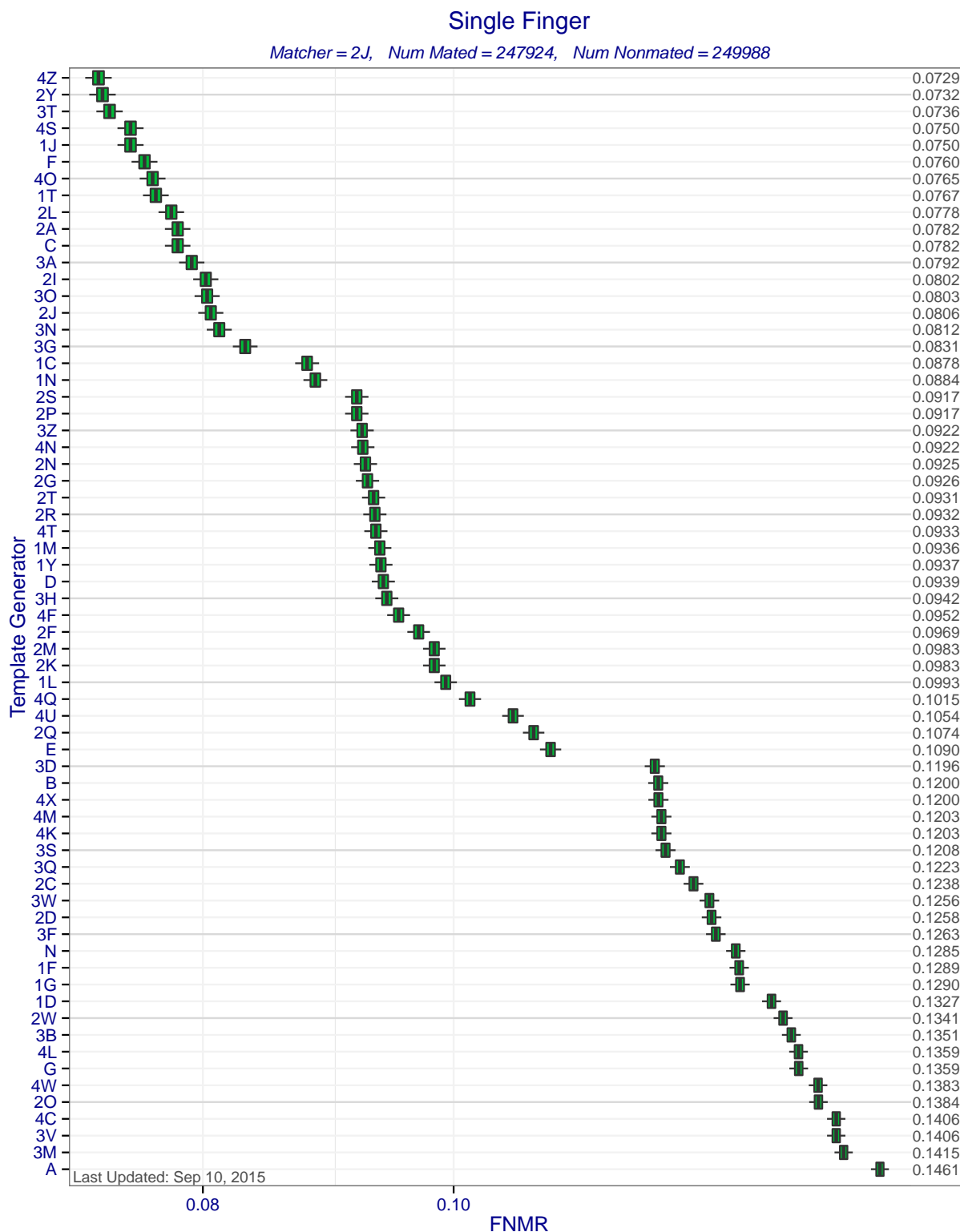
Figure 5: *Single finger FNMRs at FMR = 0.0001 when matcher 2J compares templates created by different template generators. The ends of the whiskers show the minimum and maximum FNMRs. Each box represents uncertainty about the true FNMR. The box edges mark the 50% confidence intervals while the whiskers mark the 90% confidence intervals. The numbers on the right show the actual computed FNMRs.*
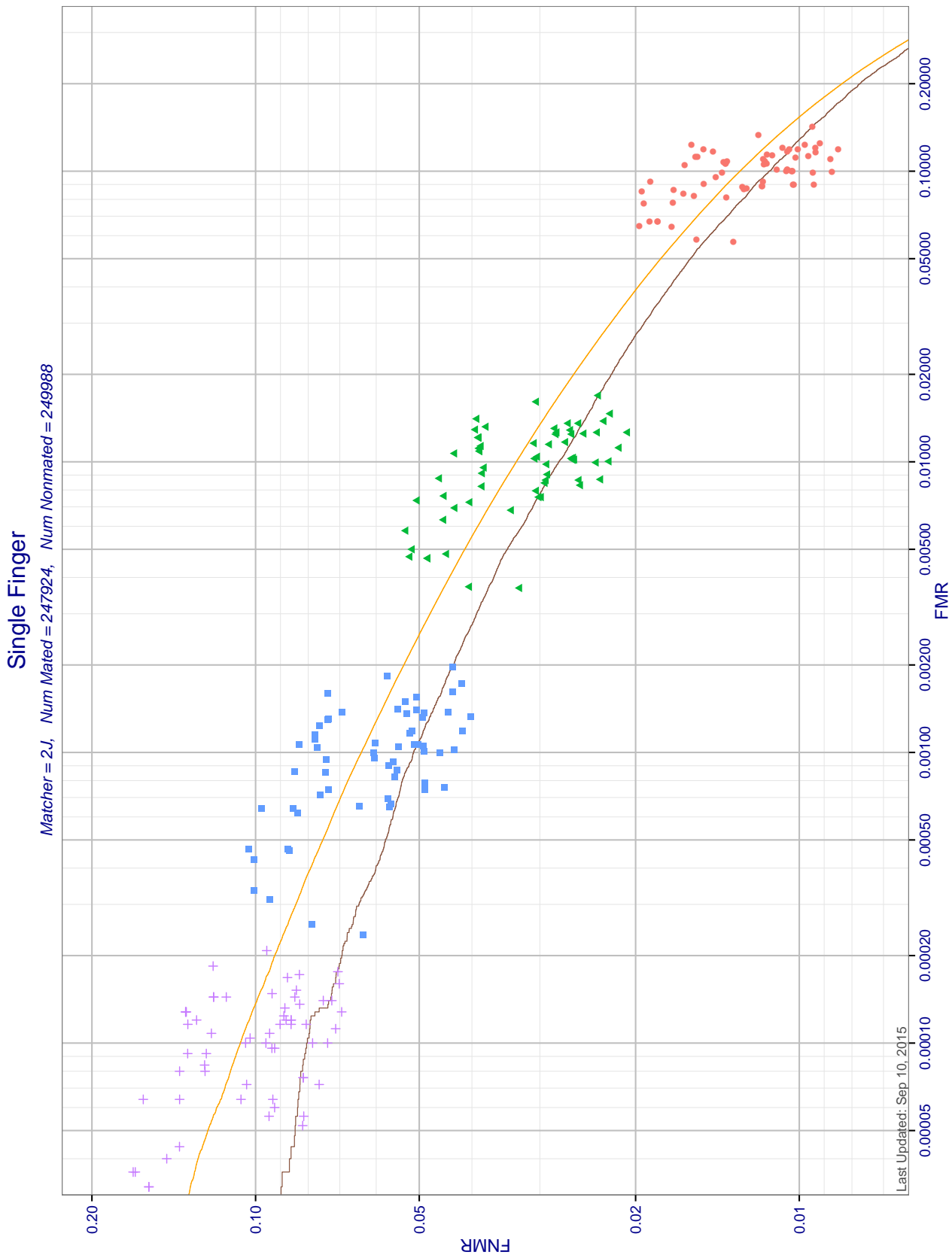
Figure 6: *Single finger DET accuracy for matcher 2J. Each cluster of points represents the variation in FMR and FNMR across MINEX compliant template generators at a fixed decision threshold. Each point corresponds to an (FMR, FNMR) pair for a specific template generator at a particular decision threshold. Four clusters are produced corresponding to four decision thresholds which produce pooled FMRs of 10^{-1}, 10^{-2}, 10^{-3}, and 10^{-4}. The orange DET curve shows pooled performance against all template generators.*

3.2 Two Finger

This section presents accuracy when matcher 2J compares templates created by all MINEX compliant template generators. Two-finger fusion is achieved by averaging the scores for left and right index fingers for each person. *NIST Special Publication 800-76-2* requires the matcher to achieve an accuracy of $\text{FNMR}_{\text{FMR}}(0.01) \leq 0.01$ for all MINEX compliant template generators.
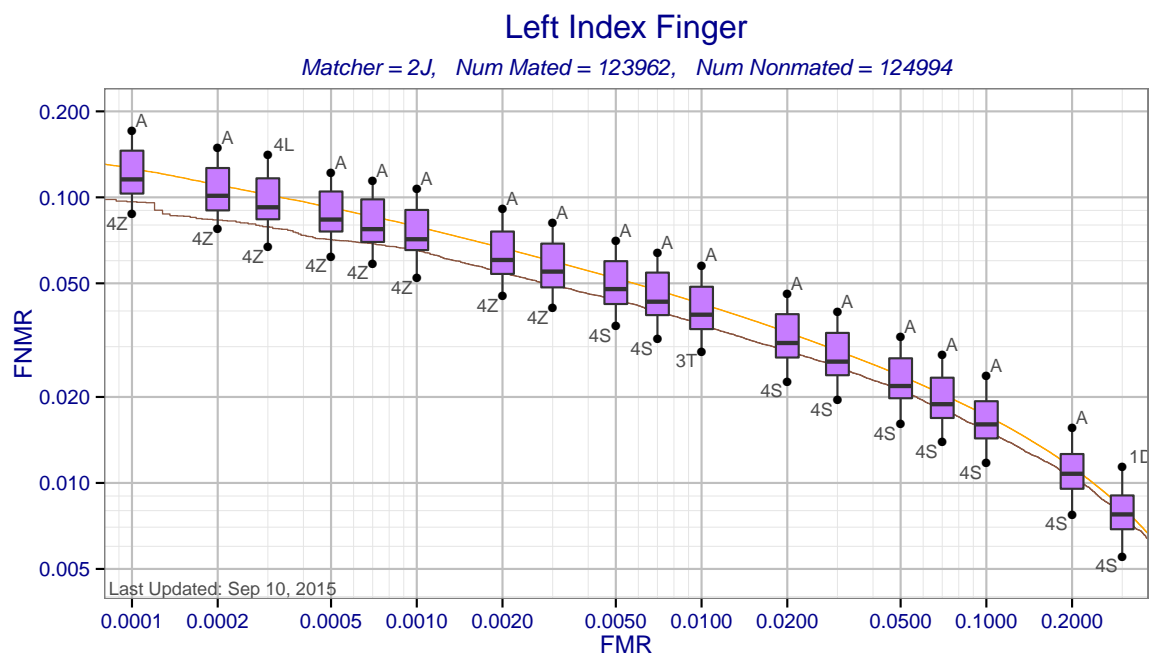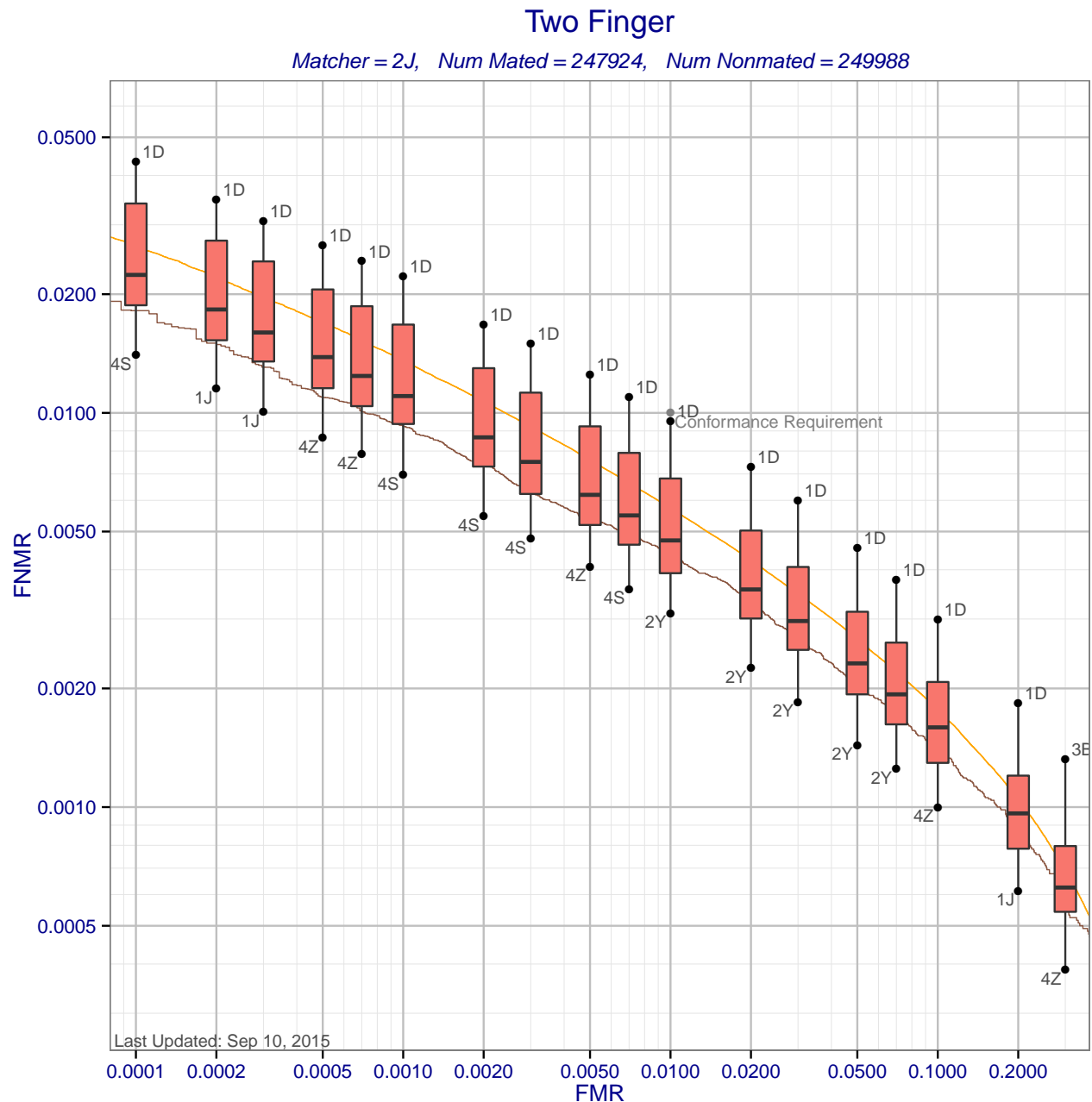

Figure 7: *Two finger DET statistics for matcher 2J. Each box shows the distribution of FNMRs at a fixed FMR across all MINEX compliant template generators. The whisker ends show the minimum and maximum FNMRs. The orange DET curve shows pooled performance against all template generators. Score-level fusion is achieved by averaging the scores for left and right index fingers.*
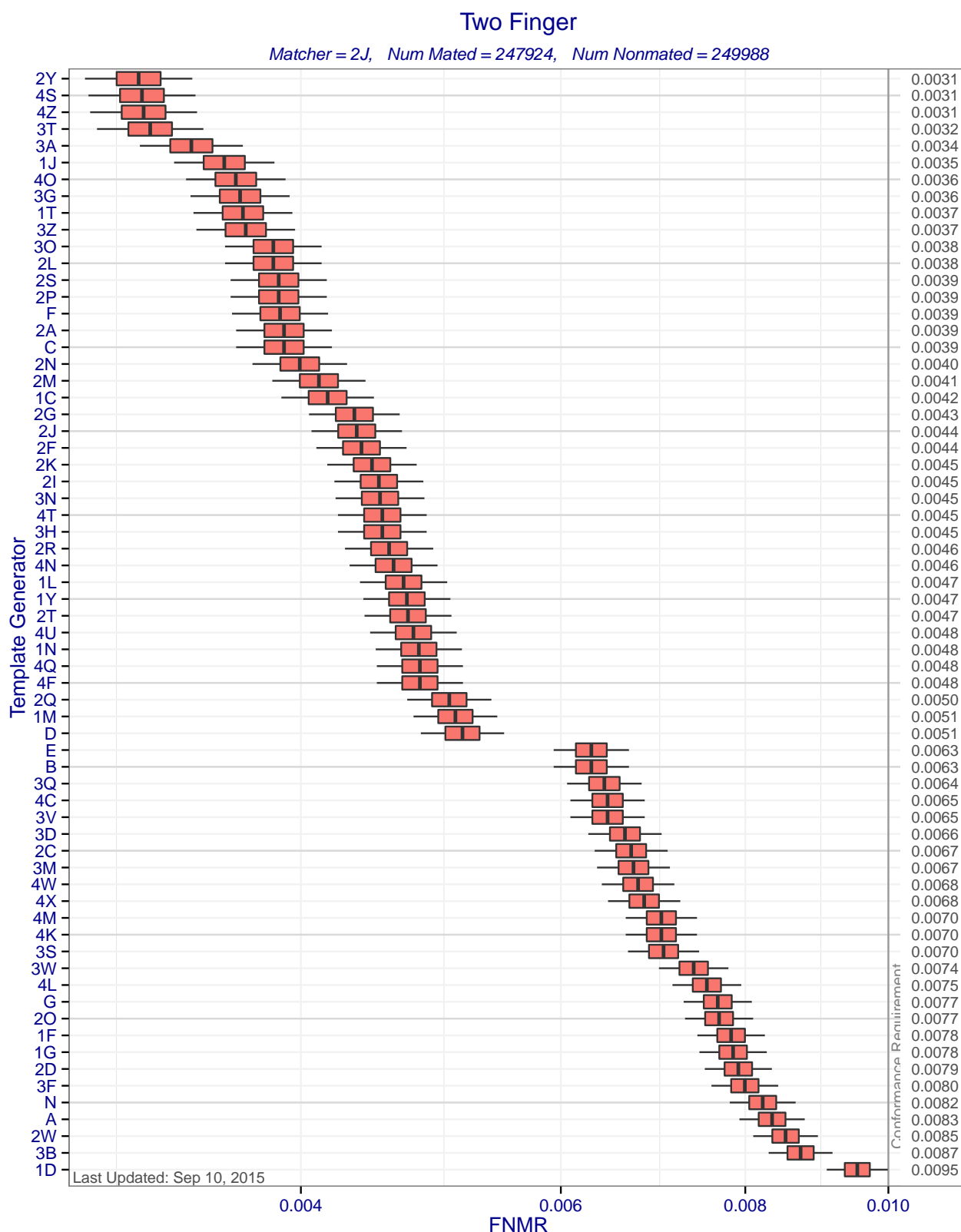
Figure 8: *Two finger FNMR at FMR=0.01 when matcher 2J compares templates created by different template generators. Each box represents uncertainty about the true FNMR. The box edges mark the 50% confidence intervals while the whiskers mark the 90% confidence intervals. The numbers on the right show the actual computed FNMRs. Score-level fusion is achieved by averaging the scores for left and right index fingers.*
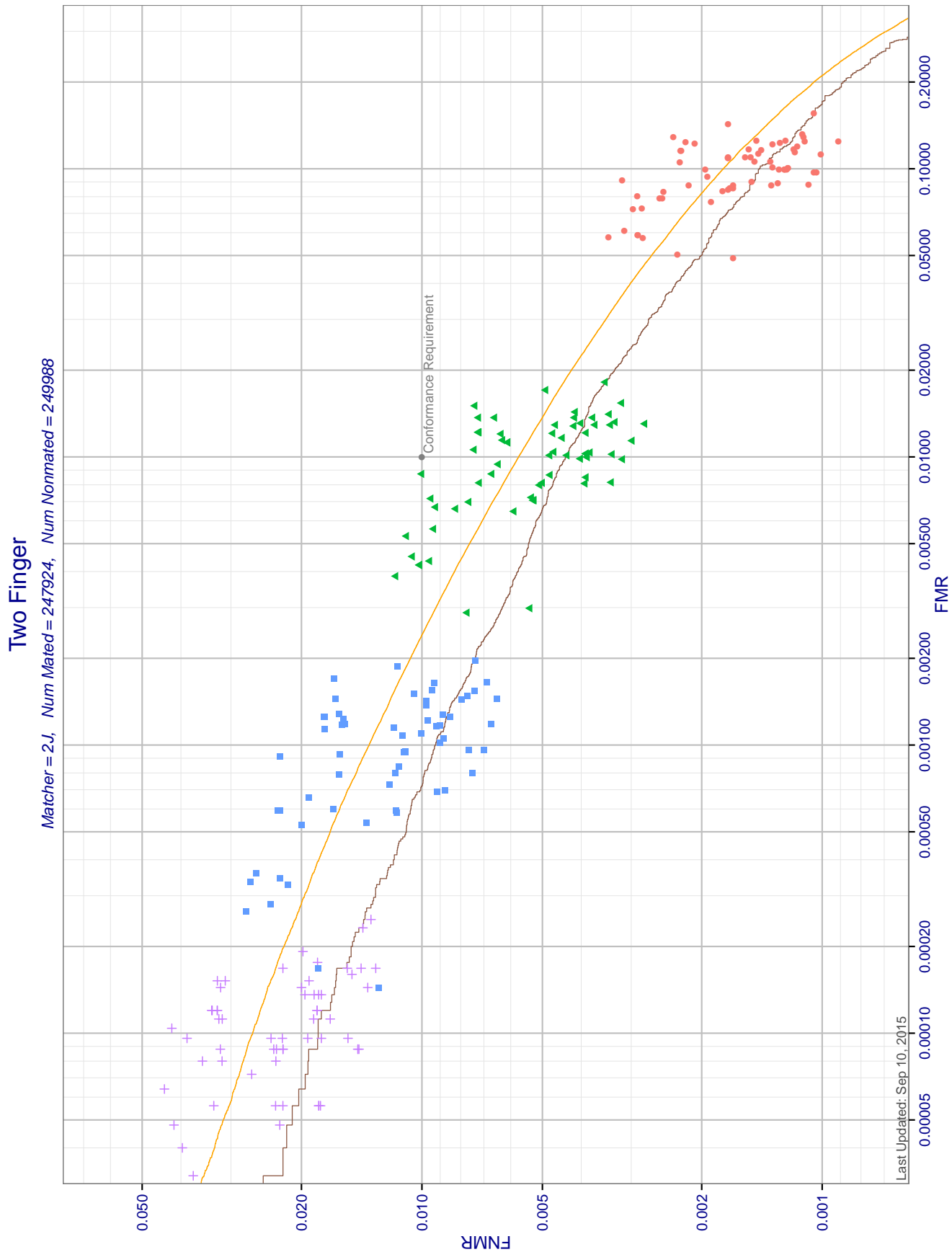
Figure 9: *Two finger DET accuracy for matcher 2J. Each cluster of points represents the variation in FMR and FNMR across MINEX compliant template generators at a fixed decision threshold. Each point corresponds to an (FMR, FNMR) pair for a specific template generator at a particular decision threshold. Four clusters are produced corresponding to four decision thresholds which produce pooled FMRs of 10^{-1}, 10^{-2}, 10^{-3}, and 10^{-4}. The orange DET curve shows pooled performance against all template generators. Score-level fusion is achieved by averaging the scores for left and right index fingers.*

3.3 Threshold Statistics

Results in this section are computed by concatenating comparison scores for matcher 2J across all MINEX compliant template generators.
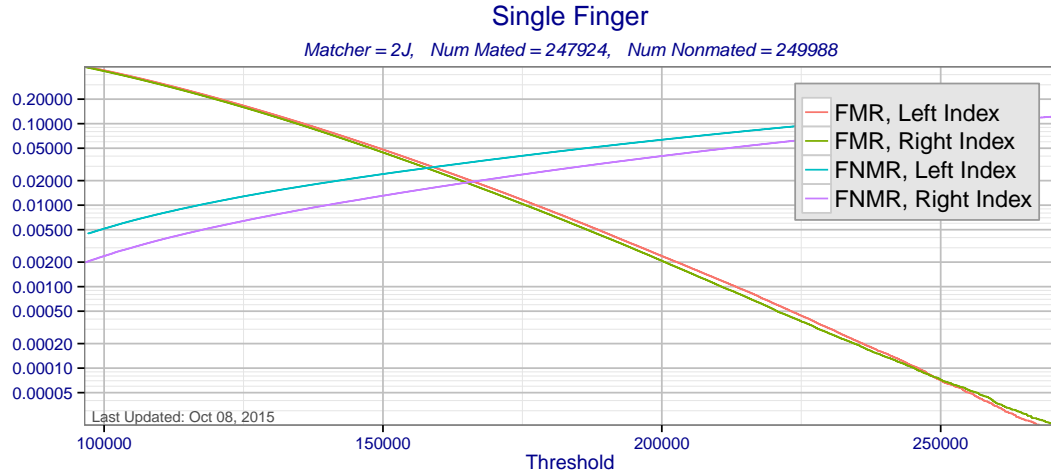
Figure 10: *Single finger FMR and FNMR as a function of score threshold for matcher 2J using templates created by all MINEX compliant template generators. Separate curves are presented for left and right index fingers.*
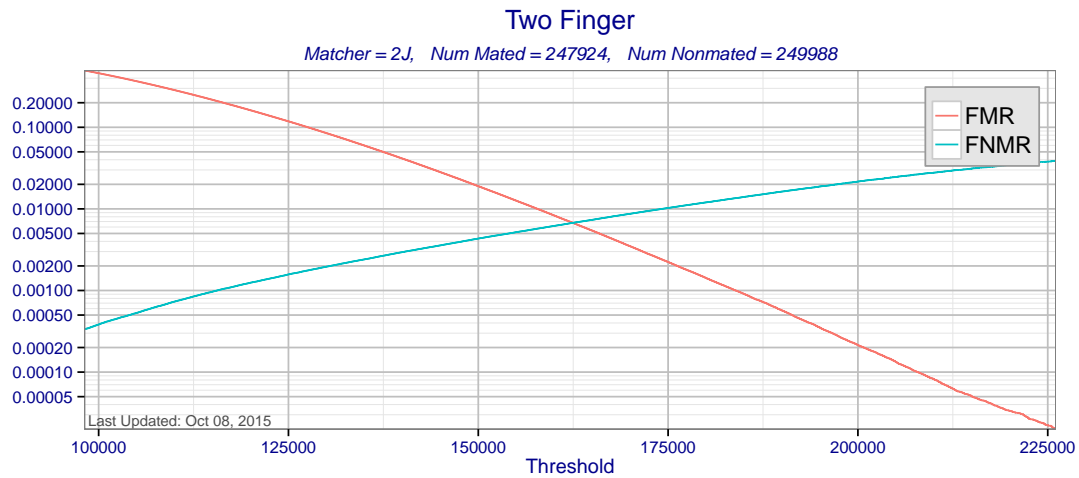
Figure 11: *Two finger FMR and FNMR as a function of score threshold for matcher 2J using templates created by all MINEX compliant template generators. Score-level fusion is achieved by averaging scores for the left and right index fingers.*

	FMR=0.1	FMR=0.01	FMR=0.001	FMR=0.0001
Right index finger	134770	175680	210770	245290
Left index finger	135980	177570	213360	246000
Single finger	135380	176670	212100	245280
Two finger	127710	157890	183990	207920

Table 1: *Threshold calibration table. The cells show the thresholds corresponding to the FMR indicated by the column header.*

3.4 Q-Q Plot

The Q-Q plot compares two probability distributions. It plots the quantile of one distribution as a function of the other. If the curve follows the $y = x$ line, then the distributions are identical. If the FMR curve is above the $y = x$ line, then the left index finger tends to produce lower non-mated scores than the left index finger. If the FNMR curve is above the $y = x$ line, then the left index finger tends to produce lower mated scores than the left index finger. A jagged and/or truncated cur ve is indicative of discretized scores.
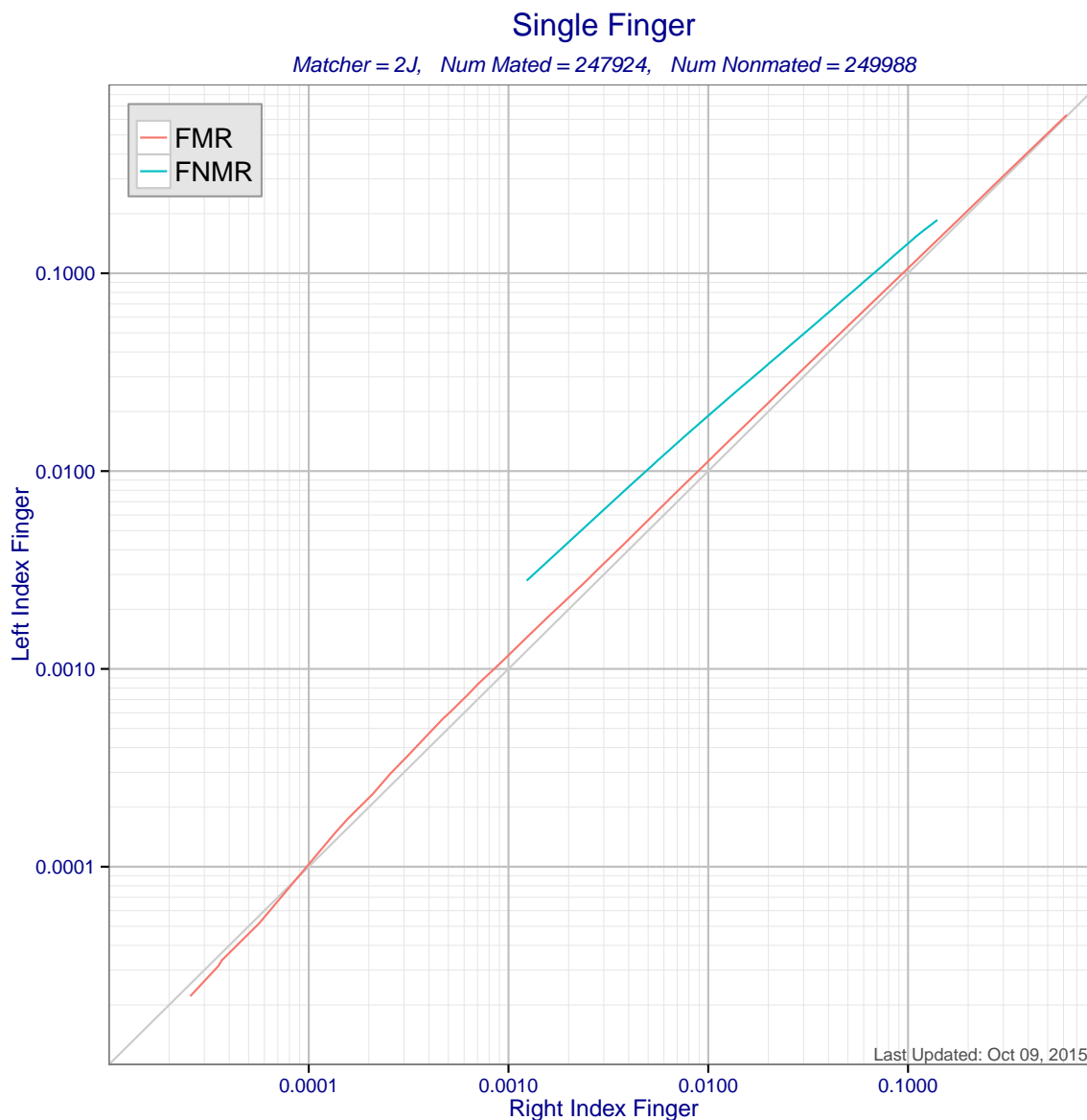
Figure 12: *Q-Q plot comparing score distributions for left and right index fingers.*

3.5   Minutiae Count Statistics

This section shows how the number of minutia found in the samples affects recognition accuracy. To be robust to spoofing and other active attacks, the algorithm should not allow FMR to rise sharply as the number of available minutia decreases. Nor should it allow FMR to rise sharply as the number of detected minutia increases.
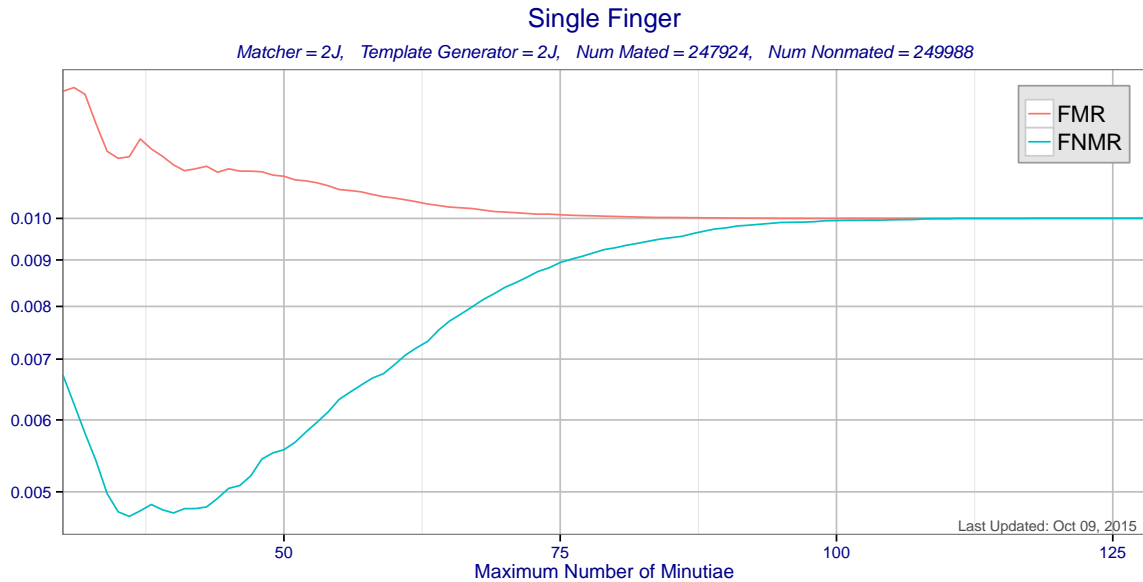
Figure 13: *FNMR and FMR as a function of the number of minutia found by the template generator. The vertical axis defines a filter criterion such that FNMR and FMR are computed over only those comparisons where at least one of the compared templates has* no more *than the specified number of minutia. The threshold is fixed separately for FNMR and FMR to elicit an error rate of approximately 0.01 over unfiltered comparisons.*
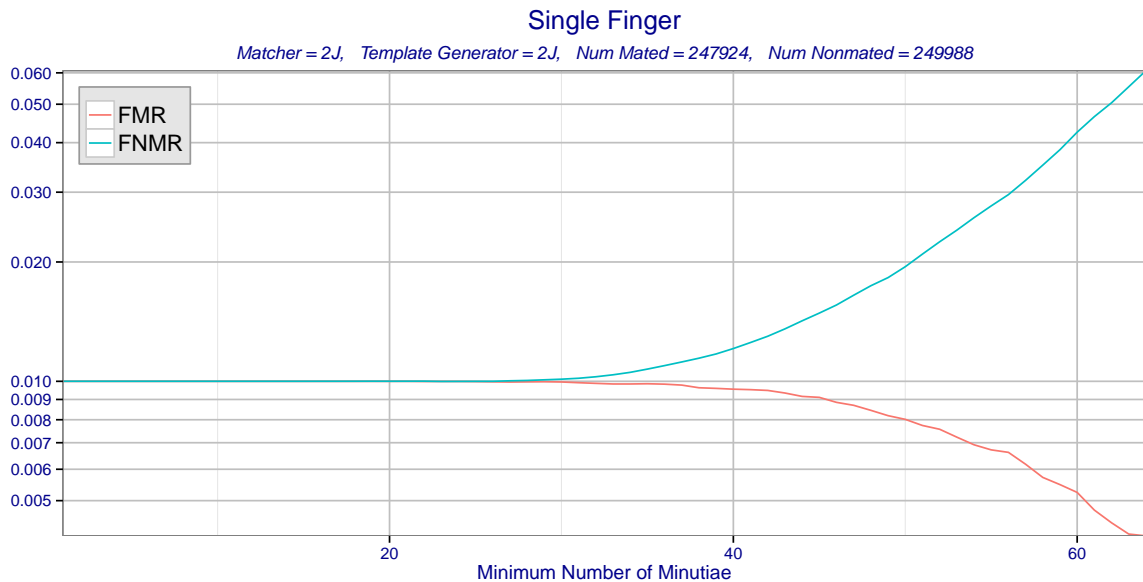
Figure 14: *FNMR and FMR as a function of the number of minutia found by the template generator. The vertical axis defines a filter criterion such that FNMR and FMR are computed over only those comparisons where at least one of the compared templates has* at least *the indicated number of minutia. The threshold is fixed separately for FNMR and FMR to elicit an error rate of approximately 0.01 over unfiltered comparisons.*

4 Performance Tables

The following tables present accuracy number, including estimates of uncertainty in the form of 90% confidence bounds. These tables are provided because most of the figures in the main body of this report do not present numerical results.

Table 2: *Single finger FNMRs at various FMRs when matcher 2J compares templates created by its template generator and PIV-compliant template generators.*

| Enroller	FNMR @ FMR=0.01	FNMR @ FMR=0.001	FNMR @ FMR=0.0001
A	0.0459 ± 0.0007	0.0883 ± 0.0009	0.146 ± 0.001
B	0.0374 ± 0.0006	0.0730 ± 0.0009	0.120 ± 0.001
C	0.0262 ± 0.0005	0.0500 ± 0.0007	0.0782 ± 0.0009
D	0.0301 ± 0.0006	0.0585 ± 0.0008	0.0939 ± 0.0010
E	0.0354 ± 0.0006	0.0662 ± 0.0008	0.109 ± 0.001
F	0.0260 ± 0.0005	0.0492 ± 0.0007	0.0760 ± 0.0009
G	0.0429 ± 0.0007	0.0802 ± 0.0009	0.136 ± 0.001
N	0.0411 ± 0.0007	0.0748 ± 0.0009	0.129 ± 0.001
1C	0.0282 ± 0.0005	0.0532 ± 0.0007	0.0878 ± 0.0009
1D	0.0441 ± 0.0007	0.0815 ± 0.0009	0.133 ± 0.001
1F	0.0414 ± 0.0007	0.0783 ± 0.0009	0.129 ± 0.001
1G	0.0415 ± 0.0007	0.0784 ± 0.0009	0.129 ± 0.001
1J	0.0247 ± 0.0005	0.0467 ± 0.0007	0.0750 ± 0.0009
1L	0.0308 ± 0.0006	0.0599 ± 0.0008	0.0993 ± 0.0010
1M	0.0303 ± 0.0006	0.0585 ± 0.0008	0.0936 ± 0.0010
1N	0.0283 ± 0.0005	0.0527 ± 0.0007	0.0884 ± 0.0009
1T	0.0253 ± 0.0005	0.0472 ± 0.0007	0.0767 ± 0.0009
1Y	0.0297 ± 0.0006	0.0561 ± 0.0008	0.0937 ± 0.0010
2A	0.0262 ± 0.0005	0.0500 ± 0.0007	0.0782 ± 0.0009
2C	0.0360 ± 0.0006	0.0694 ± 0.0008	0.124 ± 0.001
2D	0.0415 ± 0.0007	0.0760 ± 0.0009	0.126 ± 0.001
2F	0.0290 ± 0.0006	0.0554 ± 0.0008	0.0969 ± 0.0010
2G	0.0282 ± 0.0005	0.0544 ± 0.0007	0.0926 ± 0.0010
2I	0.0276 ± 0.0005	0.0511 ± 0.0007	0.0802 ± 0.0009
2J	0.0276 ± 0.0005	0.0512 ± 0.0007	0.0806 ± 0.0009
2K	0.0280 ± 0.0005	0.0549 ± 0.0008	0.0983 ± 0.0010
2L	0.0253 ± 0.0005	0.0483 ± 0.0007	0.0778 ± 0.0009
2M	0.0283 ± 0.0005	0.0543 ± 0.0007	0.0983 ± 0.0010
2N	0.0265 ± 0.0005	0.0518 ± 0.0007	0.0925 ± 0.0010
2O	0.0403 ± 0.0006	0.0797 ± 0.0009	0.138 ± 0.001
2P	0.0263 ± 0.0005	0.0512 ± 0.0007	0.0917 ± 0.0010
2Q	0.0325 ± 0.0006	0.0620 ± 0.0008	0.107 ± 0.001
2R	0.0288 ± 0.0006	0.0547 ± 0.0008	0.0932 ± 0.0010
2S	0.0263 ± 0.0005	0.0512 ± 0.0007	0.0917 ± 0.0010
2T	0.0302 ± 0.0006	0.0550 ± 0.0008	0.0931 ± 0.0010
2W	0.0445 ± 0.0007	0.0856 ± 0.0009	0.134 ± 0.001
2Y	0.0223 ± 0.0005	0.0437 ± 0.0007	0.0732 ± 0.0009
3A	0.0236 ± 0.0005	0.0459 ± 0.0007	0.0792 ± 0.0009
3B	0.0437 ± 0.0007	0.0833 ± 0.0009	0.135 ± 0.001
3D	0.0363 ± 0.0006	0.0691 ± 0.0008	0.120 ± 0.001

Table 2: *(continued)*

Enroller	FNMR @ FMR=0.01	FNMR @ FMR=0.001	FNMR @ FMR=0.0001
3F	0.0410 ± 0.0007	0.0781 ± 0.0009	0.126 ± 0.001
3G	0.0242 ± 0.0005	0.0467 ± 0.0007	0.0831 ± 0.0009
3H	0.0302 ± 0.0006	0.0567 ± 0.0008	0.0942 ± 0.0010
3M	0.0403 ± 0.0006	0.0806 ± 0.0009	0.141 ± 0.001
3N	0.0278 ± 0.0005	0.0512 ± 0.0007	0.0812 ± 0.0009
3O	0.0254 ± 0.0005	0.0481 ± 0.0007	0.0803 ± 0.0009
3Q	0.0370 ± 0.0006	0.0720 ± 0.0009	0.122 ± 0.001
3S	0.0385 ± 0.0006	0.0743 ± 0.0009	0.121 ± 0.001
3T	0.0222 ± 0.0005	0.0438 ± 0.0007	0.0736 ± 0.0009
3V	0.0400 ± 0.0006	0.0811 ± 0.0009	0.141 ± 0.001
3W	0.0389 ± 0.0006	0.0726 ± 0.0009	0.126 ± 0.001
3Z	0.0270 ± 0.0005	0.0533 ± 0.0007	0.0922 ± 0.0010
4C	0.0400 ± 0.0006	0.0811 ± 0.0009	0.141 ± 0.001
4F	0.0299 ± 0.0006	0.0567 ± 0.0008	0.0952 ± 0.0010
4K	0.0384 ± 0.0006	0.0746 ± 0.0009	0.120 ± 0.001
4L	0.0440 ± 0.0007	0.0854 ± 0.0009	0.136 ± 0.001
4M	0.0384 ± 0.0006	0.0746 ± 0.0009	0.120 ± 0.001
4N	0.0279 ± 0.0005	0.0523 ± 0.0007	0.0922 ± 0.0010
4O	0.0238 ± 0.0005	0.0454 ± 0.0007	0.0765 ± 0.0009
4Q	0.0309 ± 0.0006	0.0602 ± 0.0008	0.1015 ± 0.0010
4S	0.0224 ± 0.0005	0.0436 ± 0.0007	0.0750 ± 0.0009
4T	0.0279 ± 0.0005	0.0526 ± 0.0007	0.0933 ± 0.0010
4U	0.0306 ± 0.0006	0.0606 ± 0.0008	0.105 ± 0.001
4W	0.0401 ± 0.0006	0.0777 ± 0.0009	0.138 ± 0.001
4X	0.0353 ± 0.0006	0.0715 ± 0.0009	0.120 ± 0.001
4Z	0.0221 ± 0.0005	0.0416 ± 0.0007	0.0729 ± 0.0009

Table 3: *Right index finger FNMRs at various FMRs when matcher 2J compares templates created by its template generator and PIV-compliant template generators.*

Enroller	FNMR @ FMR=0.01	FNMR @ FMR=0.001	FNMR @ FMR=0.0001
A	0.0342 ± 0.0008	0.071 ± 0.001	0.122 ± 0.002
B	0.0270 ± 0.0008	0.055 ± 0.001	0.101 ± 0.001
C	0.0183 ± 0.0006	0.0363 ± 0.0009	0.061 ± 0.001
D	0.0215 ± 0.0007	0.0427 ± 0.0009	0.078 ± 0.001
E	0.0272 ± 0.0008	0.052 ± 0.001	0.088 ± 0.001
F	0.0181 ± 0.0006	0.0354 ± 0.0009	0.061 ± 0.001
G	0.0308 ± 0.0008	0.062 ± 0.001	0.114 ± 0.001
N	0.0302 ± 0.0008	0.059 ± 0.001	0.102 ± 0.001
1C	0.0212 ± 0.0007	0.0432 ± 0.0009	0.070 ± 0.001
1D	0.0331 ± 0.0008	0.063 ± 0.001	0.110 ± 0.001
1F	0.0306 ± 0.0008	0.061 ± 0.001	0.111 ± 0.001
1G	0.0307 ± 0.0008	0.061 ± 0.001	0.111 ± 0.001
1J	0.0169 ± 0.0006	0.0345 ± 0.0009	0.059 ± 0.001
1L	0.0217 ± 0.0007	0.0455 ± 0.0010	0.082 ± 0.001
1M	0.0220 ± 0.0007	0.0448 ± 0.0010	0.074 ± 0.001
1N	0.0202 ± 0.0007	0.0378 ± 0.0009	0.065 ± 0.001
1T	0.0183 ± 0.0006	0.0365 ± 0.0009	0.063 ± 0.001
1Y	0.0211 ± 0.0007	0.0419 ± 0.0009	0.073 ± 0.001
2A	0.0183 ± 0.0006	0.0363 ± 0.0009	0.061 ± 0.001
2C	0.0257 ± 0.0007	0.053 ± 0.001	0.094 ± 0.001
2D	0.0300 ± 0.0008	0.060 ± 0.001	0.114 ± 0.001
2F	0.0204 ± 0.0007	0.0416 ± 0.0009	0.080 ± 0.001
2G	0.0204 ± 0.0007	0.0400 ± 0.0009	0.076 ± 0.001
2I	0.0195 ± 0.0006	0.0361 ± 0.0009	0.063 ± 0.001
2J	0.0196 ± 0.0006	0.0381 ± 0.0009	0.064 ± 0.001
2K	0.0200 ± 0.0007	0.0411 ± 0.0009	0.082 ± 0.001
2L	0.0182 ± 0.0006	0.0363 ± 0.0009	0.065 ± 0.001
2M	0.0213 ± 0.0007	0.0440 ± 0.0010	0.076 ± 0.001
2N	0.0187 ± 0.0006	0.0389 ± 0.0009	0.074 ± 0.001
2O	0.0305 ± 0.0008	0.064 ± 0.001	0.118 ± 0.002
2P	0.0185 ± 0.0006	0.0382 ± 0.0009	0.074 ± 0.001
2Q	0.0236 ± 0.0007	0.0475 ± 0.0010	0.086 ± 0.001
2R	0.0205 ± 0.0007	0.0407 ± 0.0009	0.069 ± 0.001
2S	0.0185 ± 0.0006	0.0382 ± 0.0009	0.074 ± 0.001
2T	0.0215 ± 0.0007	0.0403 ± 0.0009	0.069 ± 0.001
2W	0.0341 ± 0.0008	0.067 ± 0.001	0.110 ± 0.001
2Y	0.0157 ± 0.0006	0.0316 ± 0.0008	0.059 ± 0.001
3A	0.0169 ± 0.0006	0.0350 ± 0.0009	0.065 ± 0.001
3B	0.0323 ± 0.0008	0.064 ± 0.001	0.110 ± 0.001
3D	0.0270 ± 0.0008	0.054 ± 0.001	0.098 ± 0.001

Table 3: *(continued)*

Enroller	FNMR @ FMR=0.01	FNMR @ FMR=0.001	FNMR @ FMR=0.0001
3F	0.0314 ± 0.0008	0.063 ± 0.001	0.106 ± 0.001
3G	0.0169 ± 0.0006	0.0352 ± 0.0009	0.067 ± 0.001
3H	0.0217 ± 0.0007	0.0433 ± 0.0010	0.077 ± 0.001
3M	0.0294 ± 0.0008	0.064 ± 0.001	0.118 ± 0.002
3N	0.0196 ± 0.0006	0.0366 ± 0.0009	0.064 ± 0.001
3O	0.0180 ± 0.0006	0.0368 ± 0.0009	0.071 ± 0.001
3Q	0.0274 ± 0.0008	0.057 ± 0.001	0.101 ± 0.001
3S	0.0283 ± 0.0008	0.060 ± 0.001	0.098 ± 0.001
3T	0.0158 ± 0.0006	0.0326 ± 0.0008	0.057 ± 0.001
3V	0.0295 ± 0.0008	0.064 ± 0.001	0.118 ± 0.002
3W	0.0292 ± 0.0008	0.057 ± 0.001	0.099 ± 0.001
3Z	0.0192 ± 0.0006	0.0405 ± 0.0009	0.069 ± 0.001
4C	0.0295 ± 0.0008	0.064 ± 0.001	0.118 ± 0.002
4F	0.0217 ± 0.0007	0.0432 ± 0.0010	0.074 ± 0.001
4K	0.0286 ± 0.0008	0.060 ± 0.001	0.093 ± 0.001
4L	0.0319 ± 0.0008	0.066 ± 0.001	0.107 ± 0.001
4M	0.0286 ± 0.0008	0.060 ± 0.001	0.093 ± 0.001
4N	0.0197 ± 0.0007	0.0386 ± 0.0009	0.076 ± 0.001
4O	0.0165 ± 0.0006	0.0348 ± 0.0009	0.061 ± 0.001
4Q	0.0230 ± 0.0007	0.0468 ± 0.0010	0.085 ± 0.001
4S	0.0160 ± 0.0006	0.0324 ± 0.0008	0.058 ± 0.001
4T	0.0198 ± 0.0007	0.0390 ± 0.0009	0.076 ± 0.001
4U	0.0226 ± 0.0007	0.048 ± 0.001	0.086 ± 0.001
4W	0.0295 ± 0.0008	0.062 ± 0.001	0.117 ± 0.002
4X	0.0264 ± 0.0007	0.056 ± 0.001	0.100 ± 0.001
4Z	0.0154 ± 0.0006	0.0310 ± 0.0008	0.059 ± 0.001

Table 4: *Left index finger FNMRs at various FMRs when matcher 2J compares templates created by its template generator and PIV-compliant template generators.*

Enroller	FNMR @ FMR=0.01	FNMR @ FMR=0.001	FNMR @ FMR=0.0001
A	0.058 ± 0.001	0.107 ± 0.001	0.171 ± 0.002
B	0.0481 ± 0.0010	0.091 ± 0.001	0.138 ± 0.002
C	0.0342 ± 0.0008	0.064 ± 0.001	0.094 ± 0.001
D	0.0392 ± 0.0009	0.074 ± 0.001	0.110 ± 0.001
E	0.0440 ± 0.0010	0.081 ± 0.001	0.128 ± 0.002
F	0.0341 ± 0.0008	0.063 ± 0.001	0.091 ± 0.001
G	0.055 ± 0.001	0.099 ± 0.001	0.157 ± 0.002
N	0.052 ± 0.001	0.091 ± 0.001	0.153 ± 0.002
1C	0.0352 ± 0.0009	0.064 ± 0.001	0.106 ± 0.001
1D	0.055 ± 0.001	0.101 ± 0.001	0.157 ± 0.002
1F	0.052 ± 0.001	0.096 ± 0.001	0.148 ± 0.002
1G	0.052 ± 0.001	0.096 ± 0.001	0.148 ± 0.002
1J	0.0328 ± 0.0008	0.059 ± 0.001	0.092 ± 0.001
1L	0.0400 ± 0.0009	0.075 ± 0.001	0.118 ± 0.002
1M	0.0388 ± 0.0009	0.072 ± 0.001	0.110 ± 0.001
1N	0.0366 ± 0.0009	0.067 ± 0.001	0.106 ± 0.001
1T	0.0328 ± 0.0008	0.059 ± 0.001	0.090 ± 0.001
1Y	0.0385 ± 0.0009	0.071 ± 0.001	0.113 ± 0.001
2A	0.0342 ± 0.0008	0.064 ± 0.001	0.094 ± 0.001
2C	0.0464 ± 0.0010	0.087 ± 0.001	0.151 ± 0.002
2D	0.053 ± 0.001	0.092 ± 0.001	0.137 ± 0.002
2F	0.0378 ± 0.0009	0.070 ± 0.001	0.112 ± 0.001
2G	0.0364 ± 0.0009	0.069 ± 0.001	0.109 ± 0.001
2I	0.0357 ± 0.0009	0.066 ± 0.001	0.097 ± 0.001
2J	0.0358 ± 0.0009	0.065 ± 0.001	0.096 ± 0.001
2K	0.0361 ± 0.0009	0.069 ± 0.001	0.117 ± 0.002
2L	0.0329 ± 0.0008	0.061 ± 0.001	0.092 ± 0.001
2M	0.0355 ± 0.0009	0.065 ± 0.001	0.114 ± 0.001
2N	0.0344 ± 0.0009	0.066 ± 0.001	0.109 ± 0.001
2O	0.050 ± 0.001	0.095 ± 0.001	0.157 ± 0.002
2P	0.0341 ± 0.0008	0.066 ± 0.001	0.106 ± 0.001
2Q	0.0415 ± 0.0009	0.077 ± 0.001	0.133 ± 0.002
2R	0.0371 ± 0.0009	0.069 ± 0.001	0.114 ± 0.001
2S	0.0341 ± 0.0008	0.066 ± 0.001	0.106 ± 0.001
2T	0.0389 ± 0.0009	0.071 ± 0.001	0.118 ± 0.002
2W	0.055 ± 0.001	0.103 ± 0.001	0.161 ± 0.002
2Y	0.0291 ± 0.0008	0.056 ± 0.001	0.088 ± 0.001
3A	0.0304 ± 0.0008	0.058 ± 0.001	0.092 ± 0.001
3B	0.055 ± 0.001	0.104 ± 0.001	0.159 ± 0.002
3D	0.0458 ± 0.0010	0.085 ± 0.001	0.141 ± 0.002

Table 4: *(continued)*

Enroller	FNMR @ FMR=0.01	FNMR @ FMR=0.001	FNMR @ FMR=0.0001
3F	0.050 ± 0.001	0.094 ± 0.001	0.146 ± 0.002
3G	0.0317 ± 0.0008	0.058 ± 0.001	0.098 ± 0.001
3H	0.0392 ± 0.0009	0.070 ± 0.001	0.110 ± 0.001
3M	0.051 ± 0.001	0.100 ± 0.001	0.165 ± 0.002
3N	0.0360 ± 0.0009	0.066 ± 0.001	0.102 ± 0.001
3O	0.0333 ± 0.0008	0.060 ± 0.001	0.094 ± 0.001
3Q	0.0467 ± 0.0010	0.087 ± 0.001	0.146 ± 0.002
3S	0.049 ± 0.001	0.089 ± 0.001	0.145 ± 0.002
3T	0.0289 ± 0.0008	0.055 ± 0.001	0.090 ± 0.001
3V	0.051 ± 0.001	0.100 ± 0.001	0.162 ± 0.002
3W	0.049 ± 0.001	0.088 ± 0.001	0.150 ± 0.002
3Z	0.0352 ± 0.0009	0.066 ± 0.001	0.110 ± 0.001
4C	0.051 ± 0.001	0.100 ± 0.001	0.162 ± 0.002
4F	0.0381 ± 0.0009	0.071 ± 0.001	0.118 ± 0.002
4K	0.048 ± 0.001	0.089 ± 0.001	0.143 ± 0.002
4L	0.056 ± 0.001	0.105 ± 0.001	0.165 ± 0.002
4M	0.048 ± 0.001	0.089 ± 0.001	0.143 ± 0.002
4N	0.0360 ± 0.0009	0.067 ± 0.001	0.109 ± 0.001
4O	0.0311 ± 0.0008	0.056 ± 0.001	0.092 ± 0.001
4Q	0.0391 ± 0.0009	0.073 ± 0.001	0.117 ± 0.002
4S	0.0290 ± 0.0008	0.055 ± 0.001	0.093 ± 0.001
4T	0.0362 ± 0.0009	0.067 ± 0.001	0.110 ± 0.001
4U	0.0391 ± 0.0009	0.073 ± 0.001	0.125 ± 0.002
4W	0.051 ± 0.001	0.094 ± 0.001	0.161 ± 0.002
4X	0.0444 ± 0.0010	0.089 ± 0.001	0.140 ± 0.002
4Z	0.0291 ± 0.0008	0.052 ± 0.001	0.087 ± 0.001

Table 5: *Two finger FNMRs at various FMRs when matcher 2J compares templates created by its template generator and PIV-compliant template generators.*

Enroller	FNMR @ FMR=0.01	FNMR @ FMR=0.001	FNMR @ FMR=0.0001
A	0.0083 ± 0.0003	0.0189 ± 0.0004	0.0395 ± 0.0006
B	0.0063 ± 0.0003	0.0159 ± 0.0004	0.0310 ± 0.0006
C	0.0039 ± 0.0002	0.0091 ± 0.0003	0.0170 ± 0.0004
D	0.0051 ± 0.0002	0.0110 ± 0.0003	0.0258 ± 0.0005
E	0.0063 ± 0.0003	0.0139 ± 0.0004	0.0281 ± 0.0005
F	0.0039 ± 0.0002	0.0090 ± 0.0003	0.0169 ± 0.0004
G	0.0077 ± 0.0003	0.0179 ± 0.0004	0.0374 ± 0.0006
N	0.0082 ± 0.0003	0.0188 ± 0.0004	0.0343 ± 0.0006
1C	0.0042 ± 0.0002	0.0092 ± 0.0003	0.0182 ± 0.0004
1D	0.0095 ± 0.0003	0.0222 ± 0.0005	0.0435 ± 0.0007
1F	0.0078 ± 0.0003	0.0191 ± 0.0005	0.0359 ± 0.0006
1G	0.0078 ± 0.0003	0.0192 ± 0.0005	0.0360 ± 0.0006
1J	0.0035 ± 0.0002	0.0074 ± 0.0003	0.0143 ± 0.0004
1L	0.0047 ± 0.0002	0.0110 ± 0.0003	0.0227 ± 0.0005
1M	0.0051 ± 0.0002	0.0118 ± 0.0004	0.0216 ± 0.0005
1N	0.0048 ± 0.0002	0.0107 ± 0.0003	0.0225 ± 0.0005
1T	0.0037 ± 0.0002	0.0082 ± 0.0003	0.0170 ± 0.0004
1Y	0.0047 ± 0.0002	0.0114 ± 0.0003	0.0194 ± 0.0005
2A	0.0039 ± 0.0002	0.0091 ± 0.0003	0.0170 ± 0.0004
2C	0.0067 ± 0.0003	0.0151 ± 0.0004	0.0280 ± 0.0005
2D	0.0079 ± 0.0003	0.0189 ± 0.0004	0.0363 ± 0.0006
2F	0.0044 ± 0.0002	0.0108 ± 0.0003	0.0208 ± 0.0005
2G	0.0043 ± 0.0002	0.0104 ± 0.0003	0.0193 ± 0.0005
2I	0.0045 ± 0.0002	0.0100 ± 0.0003	0.0208 ± 0.0005
2J	0.0044 ± 0.0002	0.0093 ± 0.0003	0.0182 ± 0.0004
2K	0.0045 ± 0.0002	0.0110 ± 0.0003	0.0222 ± 0.0005
2L	0.0038 ± 0.0002	0.0088 ± 0.0003	0.0178 ± 0.0004
2M	0.0041 ± 0.0002	0.0100 ± 0.0003	0.0221 ± 0.0005
2N	0.0040 ± 0.0002	0.0099 ± 0.0003	0.0191 ± 0.0005
2O	0.0077 ± 0.0003	0.0181 ± 0.0004	0.0383 ± 0.0006
2P	0.0039 ± 0.0002	0.0097 ± 0.0003	0.0187 ± 0.0004
2Q	0.0050 ± 0.0002	0.0125 ± 0.0004	0.0238 ± 0.0005
2R	0.0046 ± 0.0002	0.0107 ± 0.0003	0.0204 ± 0.0005
2S	0.0039 ± 0.0002	0.0097 ± 0.0003	0.0187 ± 0.0004
2T	0.0047 ± 0.0002	0.0106 ± 0.0003	0.0251 ± 0.0005
2W	0.0085 ± 0.0003	0.0193 ± 0.0005	0.0425 ± 0.0007
2Y	0.0031 ± 0.0002	0.0073 ± 0.0003	0.0150 ± 0.0004
3A	0.0034 ± 0.0002	0.0076 ± 0.0003	0.0144 ± 0.0004
3B	0.0087 ± 0.0003	0.0199 ± 0.0005	0.0349 ± 0.0006
3D	0.0066 ± 0.0003	0.0166 ± 0.0004	0.0304 ± 0.0006

Table 5: *(continued)*

Enroller	FNMR @ FMR=0.01	FNMR @ FMR=0.001	FNMR @ FMR=0.0001
3F	0.0080 ± 0.0003	0.0182 ± 0.0004	0.0353 ± 0.0006
3G	0.0036 ± 0.0002	0.0082 ± 0.0003	0.0211 ± 0.0005
3H	0.0045 ± 0.0002	0.0107 ± 0.0003	0.0215 ± 0.0005
3M	0.0067 ± 0.0003	0.0170 ± 0.0004	0.0346 ± 0.0006
3N	0.0045 ± 0.0002	0.0100 ± 0.0003	0.0211 ± 0.0005
3O	0.0038 ± 0.0002	0.0086 ± 0.0003	0.0177 ± 0.0004
3Q	0.0064 ± 0.0003	0.0152 ± 0.0004	0.0305 ± 0.0006
3S	0.0070 ± 0.0003	0.0169 ± 0.0004	0.0386 ± 0.0006
3T	0.0032 ± 0.0002	0.0071 ± 0.0003	0.0153 ± 0.0004
3V	0.0065 ± 0.0003	0.0168 ± 0.0004	0.0340 ± 0.0006
3W	0.0074 ± 0.0003	0.0163 ± 0.0004	0.0307 ± 0.0006
3Z	0.0037 ± 0.0002	0.0091 ± 0.0003	0.0186 ± 0.0004
4C	0.0065 ± 0.0003	0.0168 ± 0.0004	0.0340 ± 0.0006
4F	0.0048 ± 0.0002	0.0108 ± 0.0003	0.0228 ± 0.0005
4K	0.0070 ± 0.0003	0.0163 ± 0.0004	0.0365 ± 0.0006
4L	0.0075 ± 0.0003	0.0184 ± 0.0004	0.0334 ± 0.0006
4M	0.0070 ± 0.0003	0.0163 ± 0.0004	0.0365 ± 0.0006
4N	0.0046 ± 0.0002	0.0109 ± 0.0003	0.0222 ± 0.0005
4O	0.0036 ± 0.0002	0.0080 ± 0.0003	0.0178 ± 0.0004
4Q	0.0048 ± 0.0002	0.0114 ± 0.0003	0.0229 ± 0.0005
4S	0.0031 ± 0.0002	0.0070 ± 0.0003	0.0140 ± 0.0004
4T	0.0045 ± 0.0002	0.0111 ± 0.0003	0.0216 ± 0.0005
4U	0.0048 ± 0.0002	0.0109 ± 0.0003	0.0222 ± 0.0005
4W	0.0068 ± 0.0003	0.0169 ± 0.0004	0.0344 ± 0.0006
4X	0.0068 ± 0.0003	0.0166 ± 0.0004	0.0316 ± 0.0006
4Z	0.0031 ± 0.0002	0.0071 ± 0.0003	0.0153 ± 0.0004

5 References

[1] Jonathan N. Bradley, Christopher M. Brislawn, and Thomas Hopper. FBI wavelet/scalar quantization standard for gray-scale fingerprint image compression. In *SPIE, Visual Information Processing II*, 1961. 3

[2] Patrick Grother Elham Tabassi, George W. Quinn. When to fuse two biometrics. In *IEEE Computer Society on Computer Vision and Pattern Recognition, Workshop on Multi-Biometrics*, 2006. 3

[3] Robert Fontana, Giovanni Pistone, and Maria Rogantin. Cliassification of two-level factorial fractions. *Journal of Statistical Planning and Inference*, 87:149–172, 2000. 3

[4] P. Grother, M. McCabe, C. Watson, M. Indovina, W. Salamon, P. Flanagan, E. Tabassi, E. Newton, and C. Wilson. Performance and Interoperability of the INCITS 378 Fingerprint Template. Technical report, NIST, 2006. 4

[5] A. Martin, G. Doddington, T. Kamm, M. Ordowski, and M. Przybocki. The DET curve in assessment of detection task performance. In *Proc. Eurospeech*, pages 1895–1898, 1997. 3

[6] George W. Quinn. Evaluation of latent fingerprint technologies: Fusion. In *NIST Latent Fingerprint Testing Workshop Recognition, Workshop*, 2009. 3