Ongoing MINEX Report Card

Matcher 4D

National Institute of
Standards and Technology
U.S. Department of Commerce

Last Updated: October 9, 2015

Participant Details

Company: Veridis Tecnologia Da Informacao Ltda.
Date Submitted: 5/1/2013
Date Validated: 5/15/2013
Date Completed: 5/21/2013

Library	Size (bytes)	MD5 Checksum
veridisminex.dll	223744	`86b0eb1b436410b612d6667526078fcd`

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: FAIL

- 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). ✗ *(See Table 5)*

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

Participant Details 1

Compliance Test Results 1

Notes 1

1 Introduction 3

2 Methodology 3
- 2.1 Dataset . . . 3
- 2.2 Accuracy Metrics . . . 3
- 2.3 Interoperability . . . 4

3 Results 5
- 3.1 Single Finger . . . 5
- 3.2 Two Finger . . . 9
- 3.3 Threshold Statistics . . . 12
- 3.4 Q-Q Plot . . . 13

4 Performance Tables 14

5 References 22

List of Figures

1 MINEX Interoperability Test Setup . . . 4
2 DET (Single Finger) . . . 5
3 DET (Right Index) . . . 6
4 DET (Left Index) . . . 6
5 FNMR @ FMR = 0.01 (Single Finger) . . . 7
6 DET Scatterplot (Single Finger) . . . 8
7 DET (Two Finger) . . . 9
8 FNMR @ FMR = 0.01 (Two Finger) . . . 10
9 DET Scatterplot (Two Finger) . . . 11
10 Cummulative Score Functions (Single Finger) . . . 12
11 Cummulative Score Functions (Two Finger) . . . 12
12 Q-Q Plot (Left vs. Right Index) . . . 13

List of Tables

1 Threshold calibration table . . . 12
2 Single finger . . . 14
3 Right index finger . . . 16
4 Left index finger . . . 18
5 Two finger . . . 20

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

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

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

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.

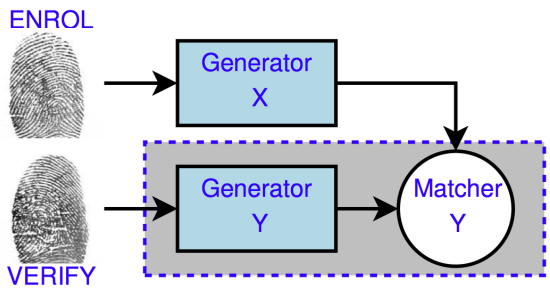

Figure 1: MINEX Interoperability Test Setup

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 4D 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 $\mathrm{FNMR}_{\mathrm{FMR}}(0.0001) \leq 0.02$.

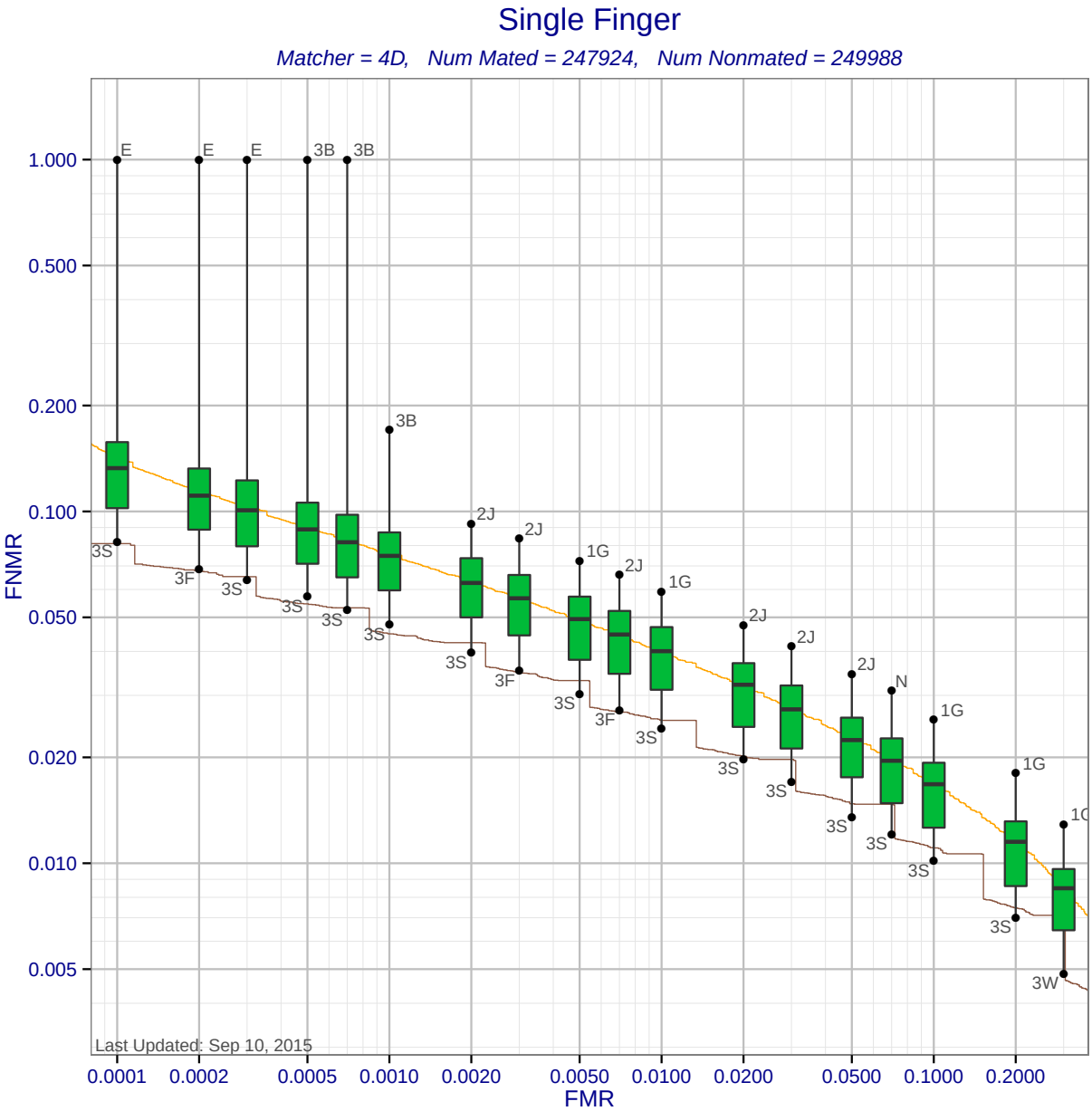

Figure 2: *Single finger DET statistics for matcher 4D. Each box shows the distribution of FNMRs at a fixed FMR across all MINEX compliant template generators. The ends of the whiskers show the minimum and maximum FNMRs. The orange DET curve shows pooled performance against all template generators.*

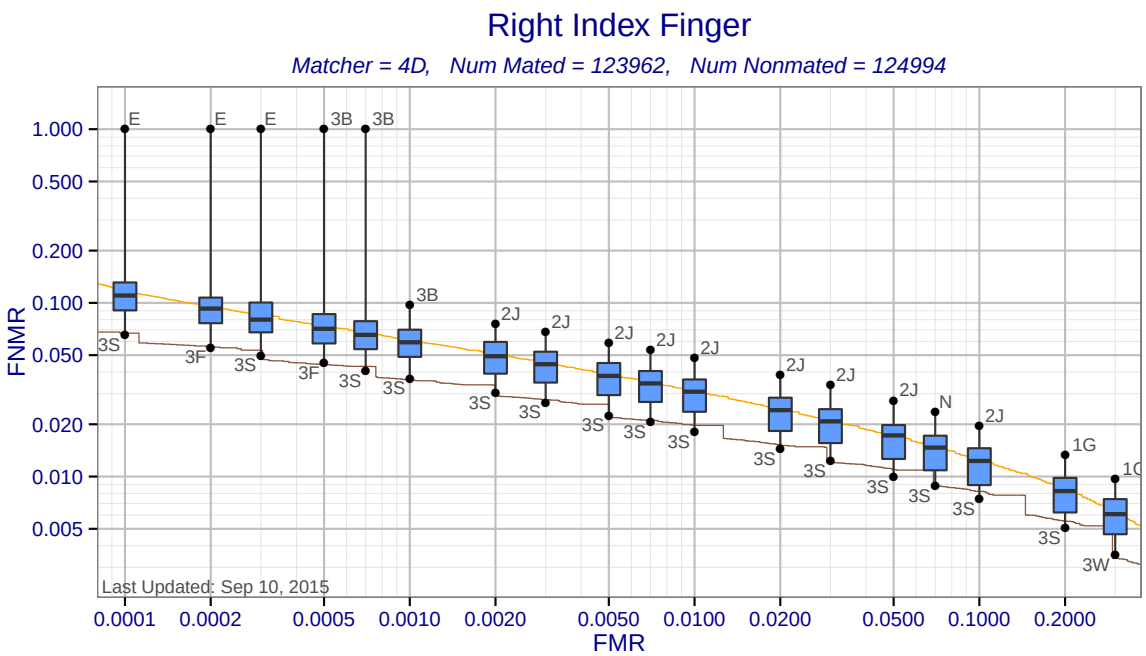

Figure 3: *Right index finger DET statistics for matcher 4D. Each box shows the distribution of FNMR at a fixed FMR across all MINEX compliant template generators. The ends of the whiskers show the minimum and maximum FNMRs. The orange DET curve shows pooled performance against all template generators.*

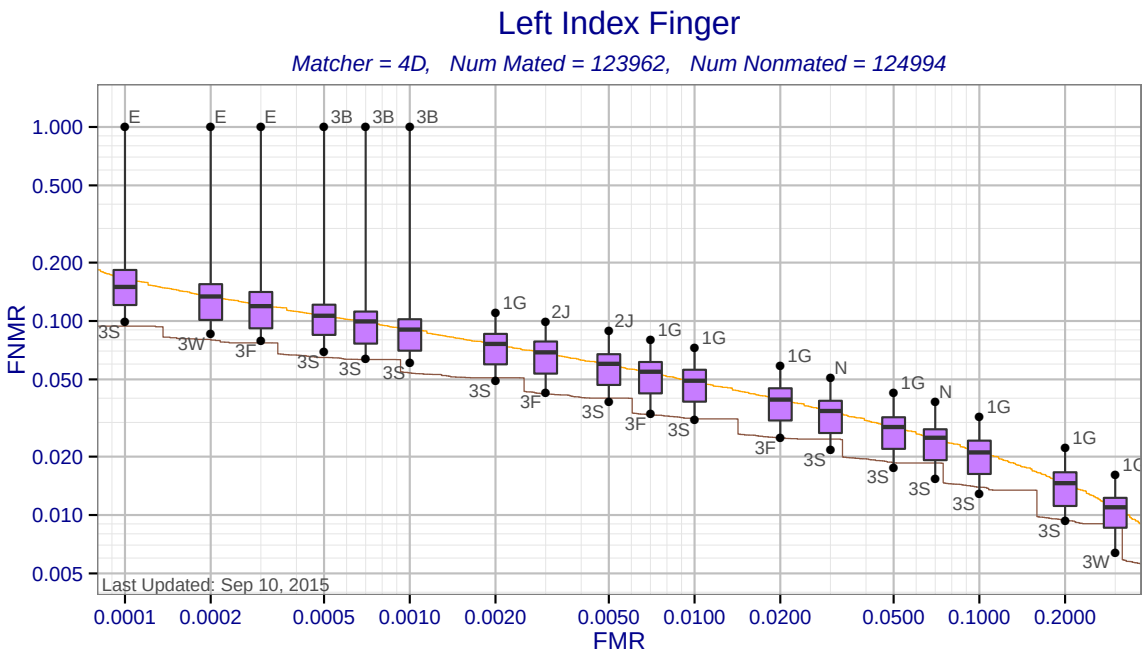

Figure 4: *Left index finger DET statistics for matcher 4D. Each box shows the distribution of FNMRs at a fixed FMR across all MINEX compliant template generators. The ends of whiskers show the minimum and maximum FNMRs. The orange DET curve shows pooled performance against all template generators.*

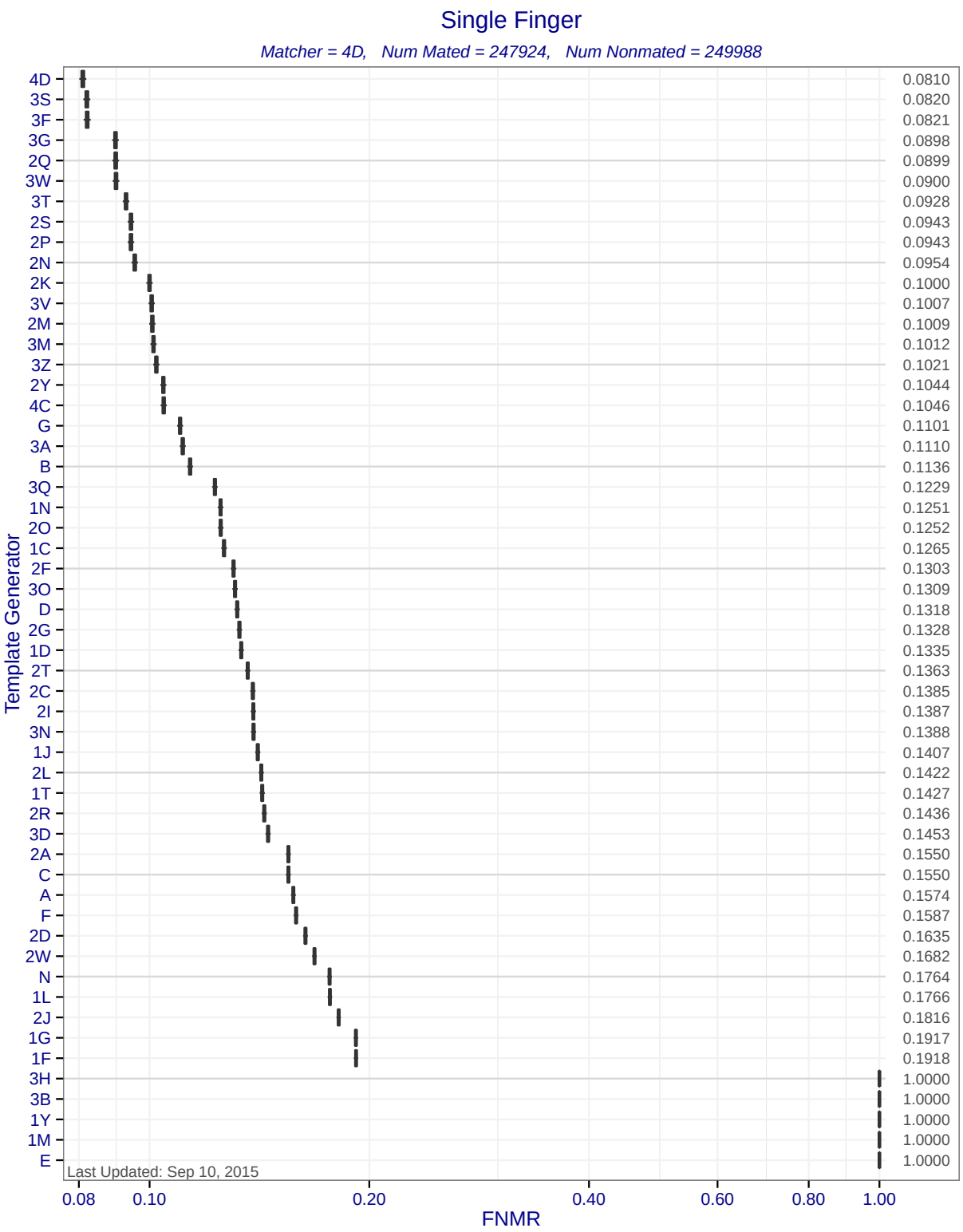

Figure 5: *Single finger FNMRs at FMR = 0.0001 when matcher 4D compares templates created by different template generators. The ends of the whiskers show the minimum and maximum FNMRs. Each box represents uncertainty about the true FNMR. The box edges mark the 50% confidence intervals while the whiskers mark the 90% confindence intervals. The numbers on the right show the actual computed FNMRs.*

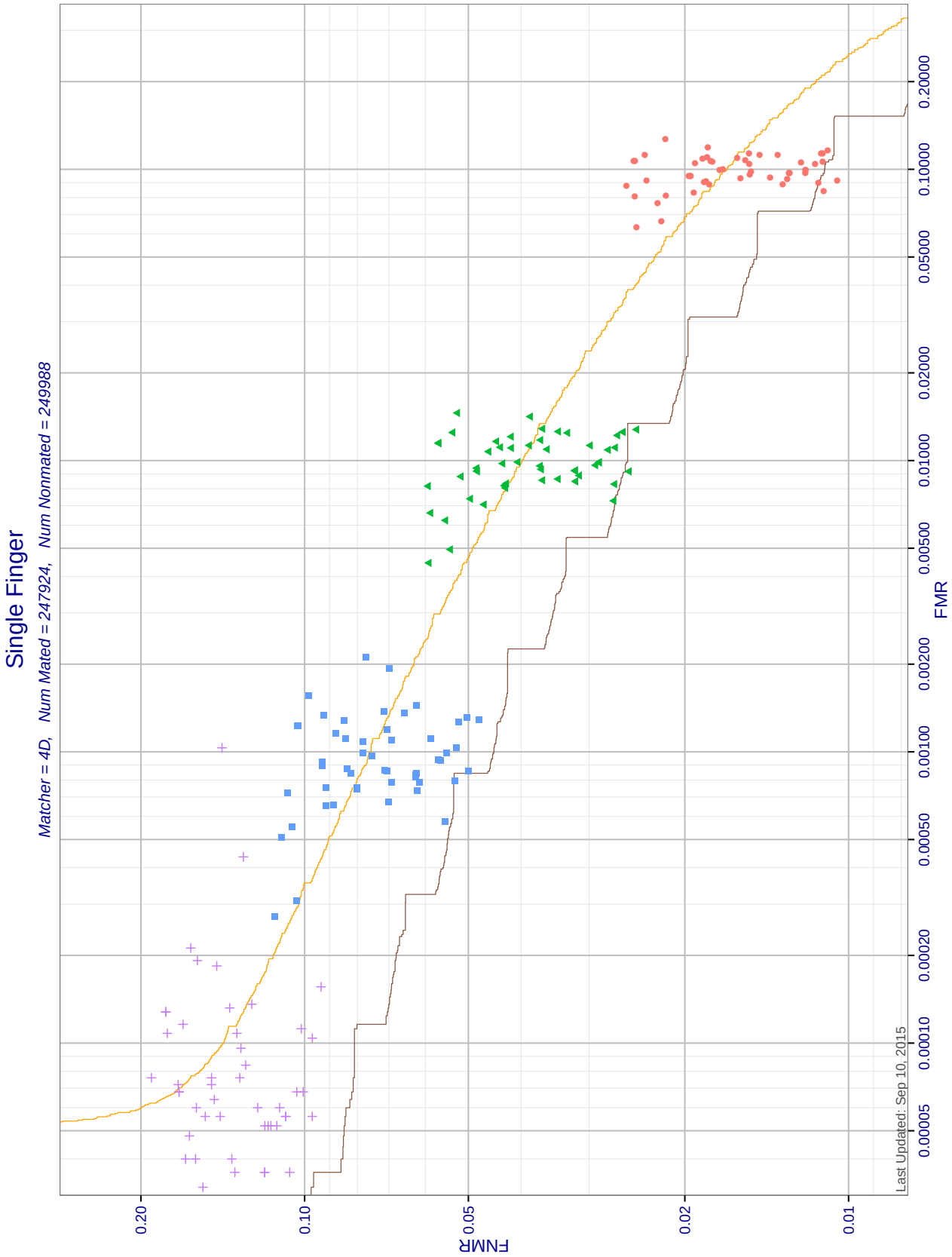

Figure 6: *Single finger DET accuracy for matcher 4D. Each cluster of points represents the variation in FMR and FNMR across MINEX compliant template generators at a fixed decision threshold. Each point corresponds to an (FMR, FNMR) pair for a specific template generator at a particular decision threshold. 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 4D 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.

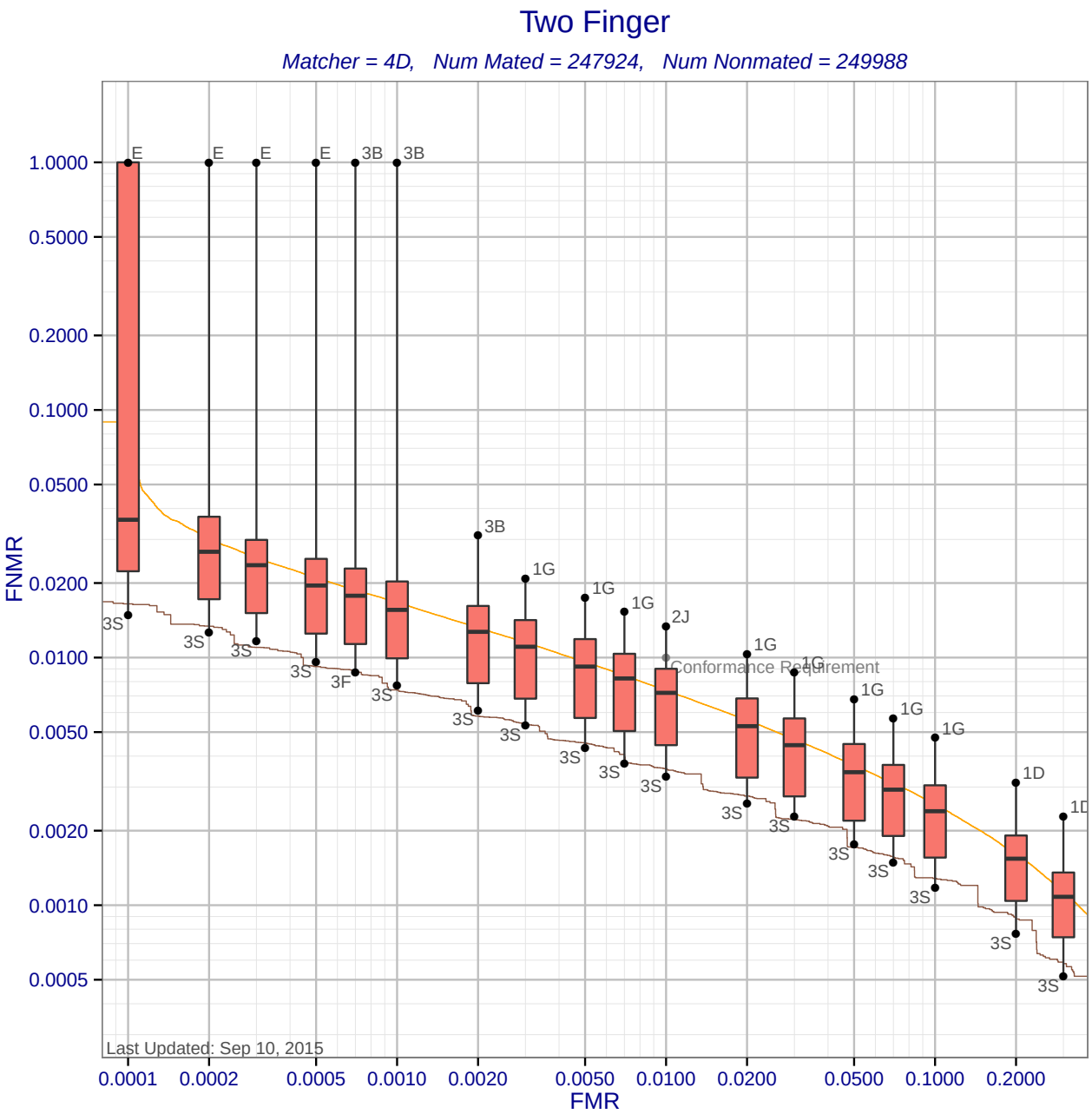

Figure 7: *Two finger DET statistics for matcher 4D. Each box shows the distribution of FNMRs at a fixed FMR across all MINEX compliant template generators. The whisker ends show the minimum and maximum FNMRs. The orange DET curve shows pooled performance against all template generators. Score-level fusion is achieved by averaging the scores for left and right index fingers.*

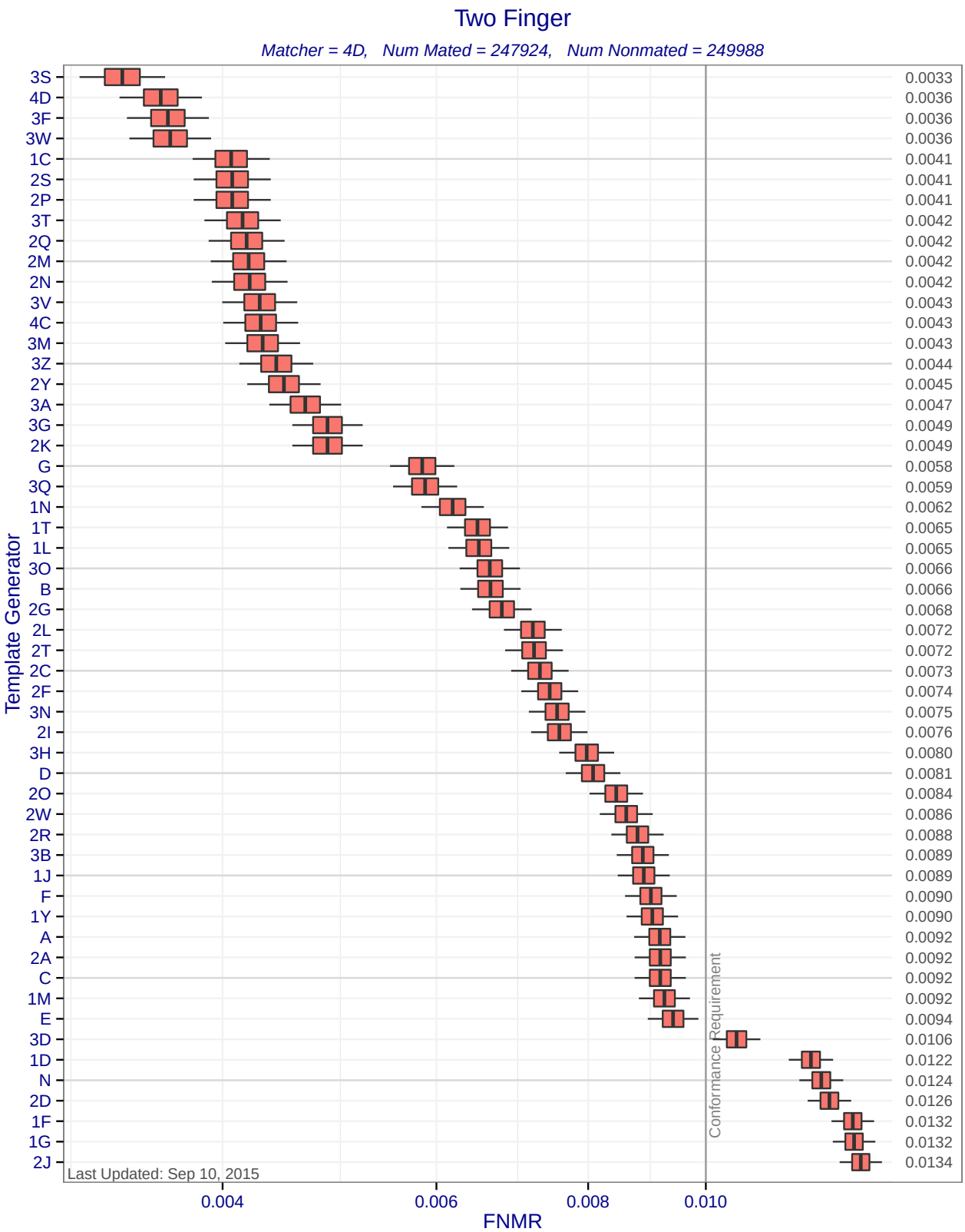

Figure 8: *Two finger FNMR at FMR=0.01 when matcher 4D compares templates created by different template generators. Each box represents uncertainty about the true FNMR. The box edges mark the 50% confidence intervals while the whiskers mark the 90% confindence intervals. The numbers on the right show the actual computed FNMRs. Score-level fusion is achieved by averaging the scores for left and right index fingers.*

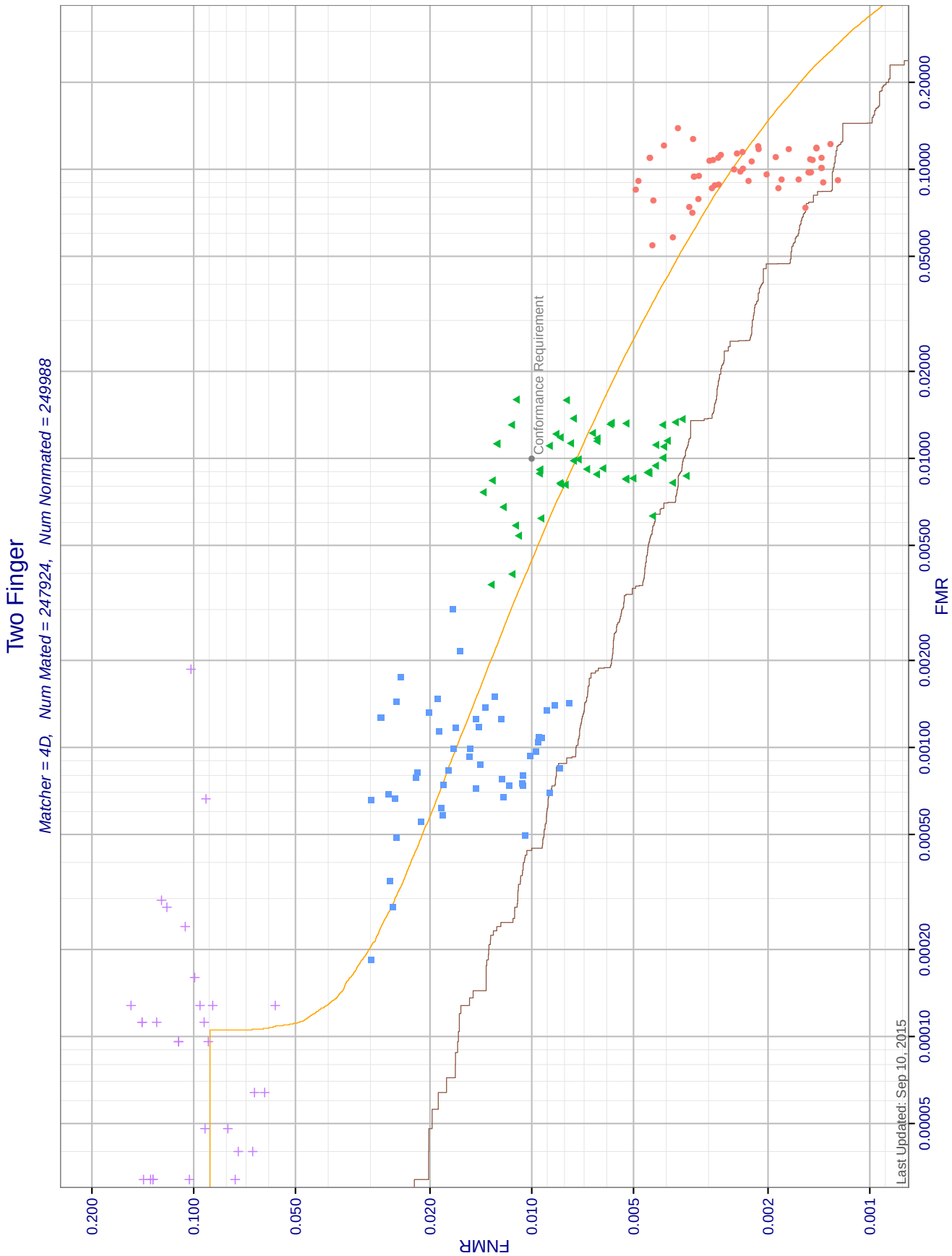

Figure 9: *Two finger DET accuracy for matcher 4D. Each cluster of points represents the variation in FMR and FNMR across MINEX compliant template generators at a fixed decision threshold. Each point corresponds to an (FMR, FNMR) pair for a specific template generator at a particular decision threshold. 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 4D across all MINEX compliant template generators.

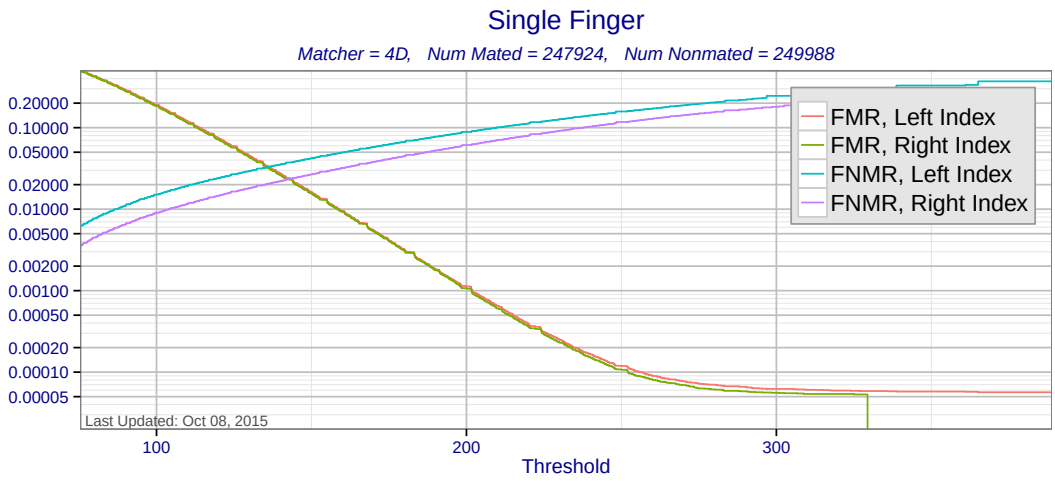

Figure 10: *Single finger FMR and FNMR as a function of score threshold for matcher 4D using templates created by all MINEX compliant template generators. Separate curves are presented for left and right index fingers.*

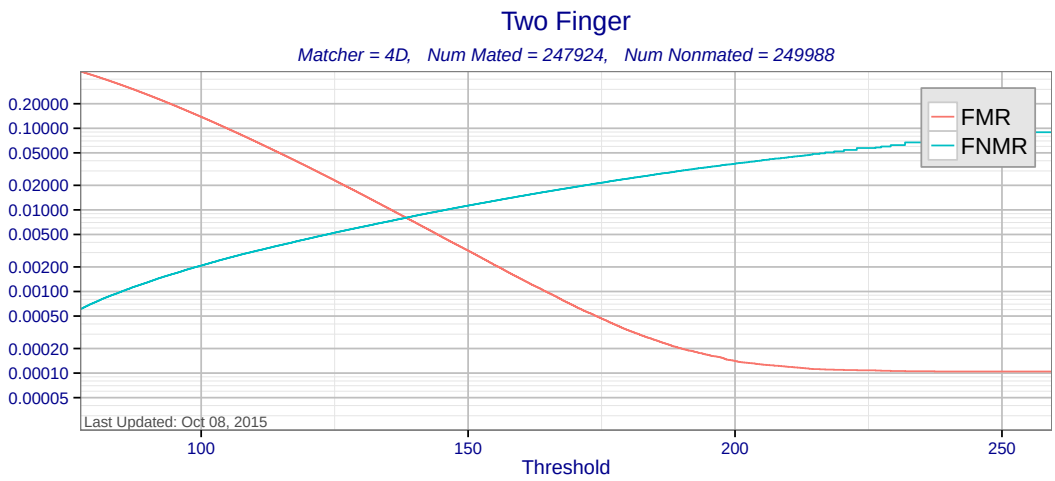

Figure 11: *Two finger FMR and FNMR as a function of score threshold for matcher 4D using templates created by all MINEX compliant template generators. Score-level fusion is achieved by averaging scores for the left and right index fingers.*

	FMR=0.1	FMR=0.01	FMR=0.001	FMR=0.0001
Right index finger	113.21	158.42	201.68	252.25
Left index finger	114.29	159.09	201.83	256.76
Single finger	113.64	158.73	201.68	253.97
Two finger	104.97	135.72	164.64	259.35

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.

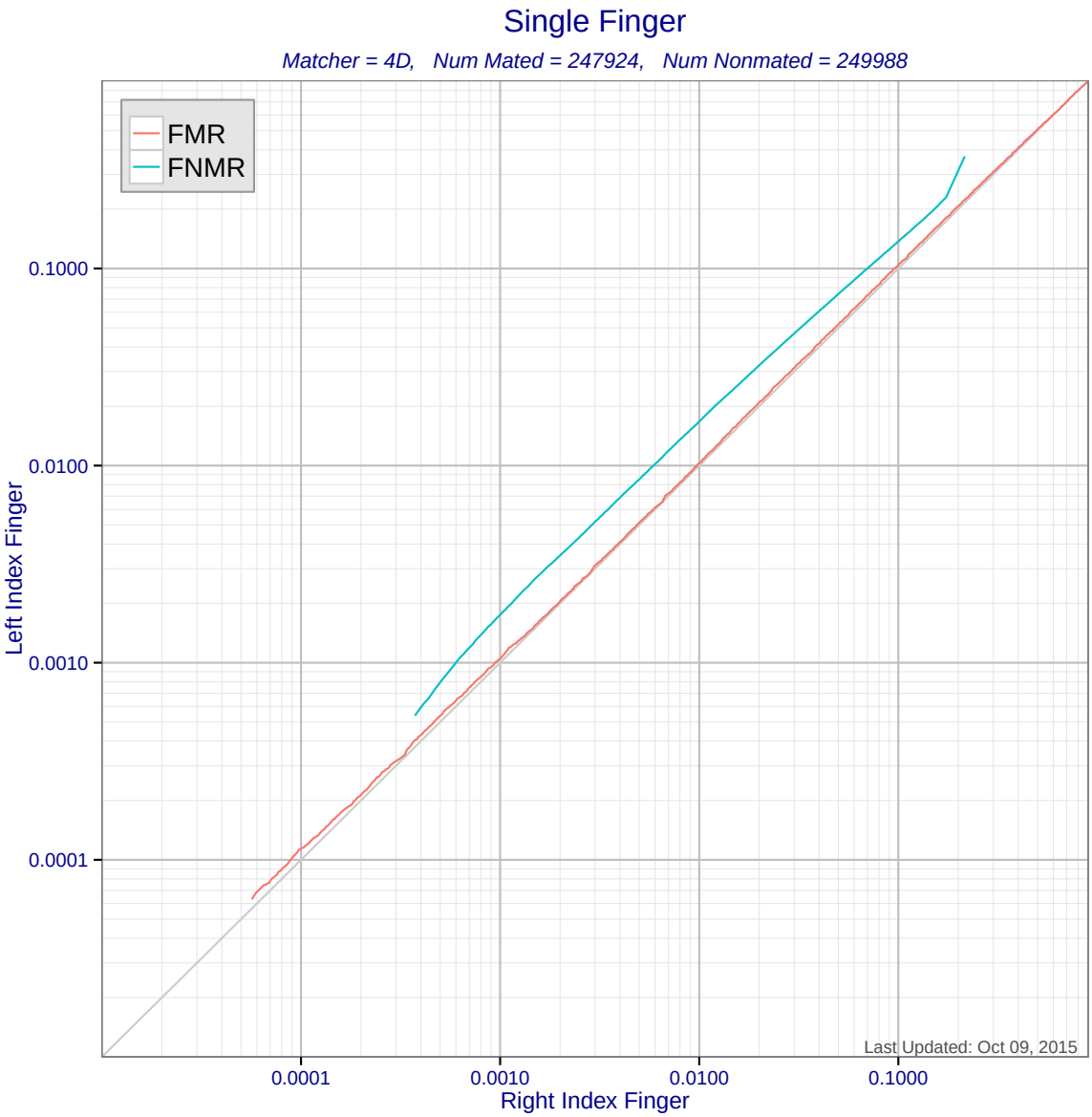

Figure 12: *Q-Q plot comparing score distributions for left and right index fingers.*

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 4D 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	0.0519 ± 0.0007	0.0962 ± 0.0010	0.157 ± 0.001
B	0.0364 ± 0.0006	0.0685 ± 0.0008	0.114 ± 0.001
C	0.0469 ± 0.0007	0.0887 ± 0.0009	0.155 ± 0.001
D	0.0423 ± 0.0007	0.0784 ± 0.0009	0.132 ± 0.001
E	0.0437 ± 0.0007	0.0858 ± 0.0009	1.000000 ± 0.000005
F	0.0476 ± 0.0007	0.0924 ± 0.0010	0.159 ± 0.001
G	0.0352 ± 0.0006	0.0688 ± 0.0008	0.110 ± 0.001
N	0.0564 ± 0.0008	0.1013 ± 0.0010	0.176 ± 0.001
1C	0.0266 ± 0.0005	0.0520 ± 0.0007	0.126 ± 0.001
1D	0.0503 ± 0.0007	0.0860 ± 0.0009	0.134 ± 0.001
1F	0.0591 ± 0.0008	0.108 ± 0.001	0.192 ± 0.001
1G	0.0592 ± 0.0008	0.108 ± 0.001	0.192 ± 0.001
1J	0.0470 ± 0.0007	0.0872 ± 0.0009	0.141 ± 0.001
1L	0.0399 ± 0.0006	0.0782 ± 0.0009	0.177 ± 0.001
1M	0.0472 ± 0.0007	0.0911 ± 0.0010	1.000000 ± 0.000005
1N	0.0348 ± 0.0006	0.0646 ± 0.0008	0.125 ± 0.001
1T	0.0366 ± 0.0006	0.0714 ± 0.0009	0.143 ± 0.001
1Y	0.0473 ± 0.0007	0.0903 ± 0.0009	1.000000 ± 0.000005
2A	0.0469 ± 0.0007	0.0887 ± 0.0009	0.155 ± 0.001
2C	0.0405 ± 0.0007	0.0779 ± 0.0009	0.139 ± 0.001
2D	0.0561 ± 0.0008	0.1014 ± 0.0010	0.164 ± 0.001
2F	0.0428 ± 0.0007	0.0796 ± 0.0009	0.130 ± 0.001
2G	0.0401 ± 0.0006	0.0748 ± 0.0009	0.133 ± 0.001
2I	0.0404 ± 0.0007	0.0742 ± 0.0009	0.139 ± 0.001
2J	0.0587 ± 0.0008	0.111 ± 0.001	0.182 ± 0.001
2K	0.0303 ± 0.0006	0.0576 ± 0.0008	0.1000 ± 0.0010
2L	0.0390 ± 0.0006	0.0751 ± 0.0009	0.142 ± 0.001
2M	0.0282 ± 0.0005	0.0544 ± 0.0007	0.1009 ± 0.0010
2N	0.0289 ± 0.0006	0.0562 ± 0.0008	0.0954 ± 0.0010
2O	0.0441 ± 0.0007	0.0801 ± 0.0009	0.125 ± 0.001
2P	0.0287 ± 0.0006	0.0560 ± 0.0008	0.0943 ± 0.0010
2Q	0.0286 ± 0.0006	0.0545 ± 0.0008	0.0899 ± 0.0009
2R	0.0453 ± 0.0007	0.0855 ± 0.0009	0.144 ± 0.001
2S	0.0287 ± 0.0006	0.0560 ± 0.0008	0.0943 ± 0.0010
2T	0.0405 ± 0.0007	0.0777 ± 0.0009	0.136 ± 0.001
2W	0.0478 ± 0.0007	0.0910 ± 0.0010	0.168 ± 0.001
2Y	0.0284 ± 0.0005	0.0566 ± 0.0008	0.104 ± 0.001
3A	0.0325 ± 0.0006	0.0642 ± 0.0008	0.111 ± 0.001
3B	0.0444 ± 0.0007	0.170 ± 0.001	1.000000 ± 0.000005
3D	0.0467 ± 0.0007	0.0826 ± 0.0009	0.145 ± 0.001

Table 2: *(continued)*

Enroller	FNMR @ FMR=0.01	FNMR @ FMR=0.001	FNMR @ FMR=0.0001
3F	0.0259 ± 0.0005	0.0518 ± 0.0007	0.0821 ± 0.0009
3G	0.0301 ± 0.0006	0.0571 ± 0.0008	0.0898 ± 0.0009
3H	0.0429 ± 0.0007	0.0806 ± 0.0009	1.000000 ± 0.000005
3M	0.0312 ± 0.0006	0.0597 ± 0.0008	0.1012 ± 0.0010
3N	0.0408 ± 0.0007	0.0739 ± 0.0009	0.139 ± 0.001
3O	0.0371 ± 0.0006	0.0708 ± 0.0008	0.131 ± 0.001
3Q	0.0361 ± 0.0006	0.0680 ± 0.0008	0.123 ± 0.001
3S	0.0242 ± 0.0005	0.0477 ± 0.0007	0.0820 ± 0.0009
3T	0.0278 ± 0.0005	0.0530 ± 0.0007	0.0928 ± 0.0010
3V	0.0312 ± 0.0006	0.0597 ± 0.0008	0.1007 ± 0.0010
3W	0.0255 ± 0.0005	0.0491 ± 0.0007	0.0900 ± 0.0009
3Z	0.0311 ± 0.0006	0.0597 ± 0.0008	0.102 ± 0.001
4C	0.0312 ± 0.0006	0.0599 ± 0.0008	0.105 ± 0.001
4F	–	–	–
4K	–	–	–
4L	–	–	–
4M	–	–	–
4N	–	–	–
4O	–	–	–
4Q	–	–	–
4S	–	–	–
4T	–	–	–
4U	–	–	–
4W	–	–	–
4X	–	–	–
4Z	–	–	–
4D	0.0255 ± 0.0005	0.0449 ± 0.0007	0.0810 ± 0.0009

Table 3: *Right index finger FNMRs at various FMRs when matcher 4D 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	0.0405 ± 0.0009	0.078 ± 0.001	0.134 ± 0.002
B	0.0291 ± 0.0008	0.057 ± 0.001	0.098 ± 0.001
C	0.0361 ± 0.0009	0.070 ± 0.001	0.126 ± 0.002
D	0.0345 ± 0.0009	0.068 ± 0.001	0.115 ± 0.001
E	0.0347 ± 0.0009	0.069 ± 0.001	1.00000 ± 0.00001
F	0.0367 ± 0.0009	0.070 ± 0.001	0.131 ± 0.002
G	0.0270 ± 0.0008	0.055 ± 0.001	0.090 ± 0.001
N	0.0437 ± 0.0010	0.080 ± 0.001	0.129 ± 0.002
1C	0.0206 ± 0.0007	0.0434 ± 0.0010	0.156 ± 0.002
1D	0.0409 ± 0.0009	0.073 ± 0.001	0.116 ± 0.001
1F	0.0460 ± 0.0010	0.087 ± 0.001	0.172 ± 0.002
1G	0.0461 ± 0.0010	0.088 ± 0.001	0.172 ± 0.002
1J	0.0362 ± 0.0009	0.067 ± 0.001	0.117 ± 0.002
1L	0.0305 ± 0.0008	0.061 ± 0.001	0.145 ± 0.002
1M	0.0385 ± 0.0009	0.078 ± 0.001	1.00000 ± 0.00001
1N	0.0260 ± 0.0007	0.050 ± 0.001	0.099 ± 0.001
1T	0.0288 ± 0.0008	0.057 ± 0.001	0.147 ± 0.002
1Y	0.0385 ± 0.0009	0.078 ± 0.001	1.00000 ± 0.00001
2A	0.0361 ± 0.0009	0.070 ± 0.001	0.126 ± 0.002
2C	0.0315 ± 0.0008	0.063 ± 0.001	0.122 ± 0.002
2D	0.0428 ± 0.0009	0.078 ± 0.001	0.129 ± 0.002
2F	0.0324 ± 0.0008	0.062 ± 0.001	0.102 ± 0.001
2G	0.0302 ± 0.0008	0.059 ± 0.001	0.097 ± 0.001
2I	0.0311 ± 0.0008	0.059 ± 0.001	0.114 ± 0.001
2J	0.0481 ± 0.0010	0.092 ± 0.001	0.154 ± 0.002
2K	0.0228 ± 0.0007	0.0459 ± 0.0010	0.076 ± 0.001
2L	0.0308 ± 0.0008	0.060 ± 0.001	0.108 ± 0.001
2M	0.0219 ± 0.0007	0.0451 ± 0.0010	0.091 ± 0.001
2N	0.0221 ± 0.0007	0.0454 ± 0.0010	0.077 ± 0.001
2O	0.0342 ± 0.0008	0.066 ± 0.001	0.102 ± 0.001
2P	0.0217 ± 0.0007	0.0449 ± 0.0010	0.077 ± 0.001
2Q	0.0216 ± 0.0007	0.0436 ± 0.0010	0.072 ± 0.001
2R	0.0366 ± 0.0009	0.072 ± 0.001	0.136 ± 0.002
2S	0.0217 ± 0.0007	0.0449 ± 0.0010	0.077 ± 0.001
2T	0.0323 ± 0.0008	0.066 ± 0.001	0.108 ± 0.001
2W	0.0375 ± 0.0009	0.075 ± 0.001	0.127 ± 0.002
2Y	0.0213 ± 0.0007	0.0459 ± 0.0010	0.088 ± 0.001
3A	0.0263 ± 0.0007	0.054 ± 0.001	0.105 ± 0.001
3B	0.0354 ± 0.0009	0.097 ± 0.001	1.00000 ± 0.00001
3D	0.0377 ± 0.0009	0.069 ± 0.001	0.110 ± 0.001

Table 3: *(continued)*

Enroller	FNMR @ FMR=0.01	FNMR @ FMR=0.001	FNMR @ FMR=0.0001
3F	0.0200 ± 0.0007	0.0412 ± 0.0009	0.068 ± 0.001
3G	0.0221 ± 0.0007	0.0447 ± 0.0010	0.076 ± 0.001
3H	0.0335 ± 0.0008	0.066 ± 0.001	0.217 ± 0.002
3M	0.0241 ± 0.0007	0.049 ± 0.001	0.095 ± 0.001
3N	0.0315 ± 0.0008	0.059 ± 0.001	0.117 ± 0.001
3O	0.0292 ± 0.0008	0.057 ± 0.001	0.110 ± 0.001
3Q	0.0279 ± 0.0008	0.055 ± 0.001	0.099 ± 0.001
3S	0.0181 ± 0.0006	0.0368 ± 0.0009	0.065 ± 0.001
3T	0.0216 ± 0.0007	0.0421 ± 0.0009	0.076 ± 0.001
3V	0.0239 ± 0.0007	0.049 ± 0.001	0.095 ± 0.001
3W	0.0192 ± 0.0006	0.0389 ± 0.0009	0.075 ± 0.001
3Z	0.0236 ± 0.0007	0.049 ± 0.001	0.078 ± 0.001
4C	0.0240 ± 0.0007	0.049 ± 0.001	0.103 ± 0.001
4F	–	–	–
4K	–	–	–
4L	–	–	–
4M	–	–	–
4N	–	–	–
4O	–	–	–
4Q	–	–	–
4S	–	–	–
4T	–	–	–
4U	–	–	–
4W	–	–	–
4X	–	–	–
4Z	–	–	–
4D	0.0197 ± 0.0006	0.0361 ± 0.0009	0.067 ± 0.001

Table 4: *Left index finger FNMRs at various FMRs when matcher 4D 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	0.064 ± 0.001	0.112 ± 0.001	0.181 ± 0.002
B	0.0435 ± 0.0010	0.083 ± 0.001	0.126 ± 0.002
C	0.058 ± 0.001	0.110 ± 0.001	0.181 ± 0.002
D	0.050 ± 0.001	0.091 ± 0.001	0.148 ± 0.002
E	0.052 ± 0.001	0.101 ± 0.001	1.00000 ± 0.00001
F	0.058 ± 0.001	0.111 ± 0.001	0.183 ± 0.002
G	0.0435 ± 0.0010	0.082 ± 0.001	0.132 ± 0.002
N	0.069 ± 0.001	0.123 ± 0.002	0.210 ± 0.002
1C	0.0325 ± 0.0008	0.061 ± 0.001	0.121 ± 0.002
1D	0.059 ± 0.001	0.098 ± 0.001	0.150 ± 0.002
1F	0.072 ± 0.001	0.128 ± 0.002	0.212 ± 0.002
1G	0.072 ± 0.001	0.128 ± 0.002	0.212 ± 0.002
1J	0.058 ± 0.001	0.104 ± 0.001	0.161 ± 0.002
1L	0.049 ± 0.001	0.097 ± 0.001	0.220 ± 0.002
1M	0.056 ± 0.001	0.103 ± 0.001	0.228 ± 0.002
1N	0.0441 ± 0.0010	0.081 ± 0.001	0.150 ± 0.002
1T	0.0449 ± 0.0010	0.087 ± 0.001	0.158 ± 0.002
1Y	0.056 ± 0.001	0.102 ± 0.001	0.184 ± 0.002
2A	0.058 ± 0.001	0.110 ± 0.001	0.181 ± 0.002
2C	0.049 ± 0.001	0.093 ± 0.001	0.150 ± 0.002
2D	0.069 ± 0.001	0.123 ± 0.002	0.200 ± 0.002
2F	0.054 ± 0.001	0.100 ± 0.001	0.159 ± 0.002
2G	0.050 ± 0.001	0.092 ± 0.001	0.162 ± 0.002
2I	0.050 ± 0.001	0.090 ± 0.001	0.170 ± 0.002
2J	0.071 ± 0.001	0.131 ± 0.002	0.216 ± 0.002
2K	0.0377 ± 0.0009	0.069 ± 0.001	0.121 ± 0.002
2L	0.0472 ± 0.0010	0.090 ± 0.001	0.221 ± 0.002
2M	0.0340 ± 0.0008	0.063 ± 0.001	0.107 ± 0.001
2N	0.0358 ± 0.0009	0.068 ± 0.001	0.119 ± 0.002
2O	0.054 ± 0.001	0.095 ± 0.001	0.145 ± 0.002
2P	0.0357 ± 0.0009	0.068 ± 0.001	0.118 ± 0.002
2Q	0.0354 ± 0.0009	0.066 ± 0.001	0.108 ± 0.001
2R	0.054 ± 0.001	0.102 ± 0.001	0.154 ± 0.002
2S	0.0357 ± 0.0009	0.068 ± 0.001	0.118 ± 0.002
2T	0.049 ± 0.001	0.091 ± 0.001	0.165 ± 0.002
2W	0.059 ± 0.001	0.107 ± 0.001	0.206 ± 0.002
2Y	0.0353 ± 0.0009	0.068 ± 0.001	0.122 ± 0.002
3A	0.0391 ± 0.0009	0.074 ± 0.001	0.121 ± 0.002
3B	0.054 ± 0.001	1.00000 ± 0.00001	1.00000 ± 0.00001
3D	0.053 ± 0.001	0.095 ± 0.001	0.177 ± 0.002

Table 4: *(continued)*

Enroller	FNMR @ FMR=0.01	FNMR @ FMR=0.001	FNMR @ FMR=0.0001
3F	0.0318 ± 0.0008	0.062 ± 0.001	0.110 ± 0.001
3G	0.0382 ± 0.0009	0.069 ± 0.001	0.104 ± 0.001
3H	0.053 ± 0.001	0.095 ± 0.001	1.00000 ± 0.00001
3M	0.0384 ± 0.0009	0.070 ± 0.001	0.113 ± 0.001
3N	0.050 ± 0.001	0.089 ± 0.001	0.151 ± 0.002
3O	0.0447 ± 0.0010	0.085 ± 0.001	0.150 ± 0.002
3Q	0.0443 ± 0.0010	0.081 ± 0.001	0.148 ± 0.002
3S	0.0309 ± 0.0008	0.061 ± 0.001	0.099 ± 0.001
3T	0.0343 ± 0.0009	0.066 ± 0.001	0.109 ± 0.001
3V	0.0384 ± 0.0009	0.072 ± 0.001	0.113 ± 0.001
3W	0.0318 ± 0.0008	0.061 ± 0.001	0.108 ± 0.001
3Z	0.0387 ± 0.0009	0.072 ± 0.001	0.126 ± 0.002
4C	0.0384 ± 0.0009	0.072 ± 0.001	0.115 ± 0.001
4F	–	–	–
4K	–	–	–
4L	–	–	–
4M	–	–	–
4N	–	–	–
4O	–	–	–
4Q	–	–	–
4S	–	–	–
4T	–	–	–
4U	–	–	–
4W	–	–	–
4X	–	–	–
4Z	–	–	–
4D	0.0313 ± 0.0008	0.054 ± 0.001	0.094 ± 0.001

Table 5: *Two finger FNMRs at various FMRs when matcher 4D 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	0.0092 ± 0.0003	0.0199 ± 0.0005	0.0372 ± 0.0006
B	0.0066 ± 0.0003	0.0150 ± 0.0004	0.0274 ± 0.0005
C	0.0092 ± 0.0003	0.0203 ± 0.0005	0.0396 ± 0.0006
D	0.0081 ± 0.0003	0.0174 ± 0.0004	0.0341 ± 0.0006
E	0.0094 ± 0.0003	0.0251 ± 0.0005	1.000000 ± 0.000005
F	0.0090 ± 0.0003	0.0206 ± 0.0005	0.0421 ± 0.0007
G	0.0058 ± 0.0003	0.0131 ± 0.0004	0.0310 ± 0.0006
N	0.0124 ± 0.0004	0.0280 ± 0.0005	1.000000 ± 0.000005
1C	0.0041 ± 0.0002	0.0087 ± 0.0003	1.000000 ± 0.000005
1D	0.0122 ± 0.0004	0.0241 ± 0.0005	0.0440 ± 0.0007
1F	0.0132 ± 0.0004	0.0299 ± 0.0006	1.000000 ± 0.000005
1G	0.0132 ± 0.0004	0.0300 ± 0.0006	1.000000 ± 0.000005
1J	0.0089 ± 0.0003	0.0197 ± 0.0005	0.0346 ± 0.0006
1L	0.0065 ± 0.0003	0.0156 ± 0.0004	1.000000 ± 0.000005
1M	0.0092 ± 0.0003	0.0228 ± 0.0005	1.000000 ± 0.000005
1N	0.0062 ± 0.0003	0.0132 ± 0.0004	0.0634 ± 0.0008
1T	0.0065 ± 0.0003	0.0147 ± 0.0004	1.000000 ± 0.000005
1Y	0.0090 ± 0.0003	0.0217 ± 0.0005	1.000000 ± 0.000005
2A	0.0092 ± 0.0003	0.0203 ± 0.0005	0.0396 ± 0.0006
2C	0.0073 ± 0.0003	0.0166 ± 0.0004	0.0334 ± 0.0006
2D	0.0126 ± 0.0004	0.0265 ± 0.0005	0.0483 ± 0.0007
2F	0.0074 ± 0.0003	0.0169 ± 0.0004	0.0308 ± 0.0006
2G	0.0068 ± 0.0003	0.0152 ± 0.0004	0.0352 ± 0.0006
2I	0.0076 ± 0.0003	0.0162 ± 0.0004	0.0528 ± 0.0007
2J	0.0134 ± 0.0004	0.0288 ± 0.0006	0.0589 ± 0.0008
2K	0.0049 ± 0.0002	0.0109 ± 0.0003	0.0213 ± 0.0005
2L	0.0072 ± 0.0003	0.0154 ± 0.0004	1.000000 ± 0.000005
2M	0.0042 ± 0.0002	0.0095 ± 0.0003	0.0233 ± 0.0005
2N	0.0042 ± 0.0002	0.0098 ± 0.0003	0.0223 ± 0.0005
2O	0.0084 ± 0.0003	0.0185 ± 0.0004	0.0360 ± 0.0006
2P	0.0041 ± 0.0002	0.0097 ± 0.0003	0.0204 ± 0.0005
2Q	0.0042 ± 0.0002	0.0098 ± 0.0003	0.0213 ± 0.0005
2R	0.0088 ± 0.0003	0.0192 ± 0.0005	0.0412 ± 0.0007
2S	0.0041 ± 0.0002	0.0097 ± 0.0003	0.0204 ± 0.0005
2T	0.0072 ± 0.0003	0.0170 ± 0.0004	0.0338 ± 0.0006
2W	0.0086 ± 0.0003	0.0193 ± 0.0005	1.000000 ± 0.000005
2Y	0.0045 ± 0.0002	0.0102 ± 0.0003	0.0210 ± 0.0005
3A	0.0047 ± 0.0002	0.0105 ± 0.0003	0.0213 ± 0.0005
3B	0.0089 ± 0.0003	1.000000 ± 0.000005	1.000000 ± 0.000005
3D	0.0106 ± 0.0003	0.0226 ± 0.0005	0.0423 ± 0.0007

Table 5: *(continued)*

Enroller	FNMR @ FMR=0.01	FNMR @ FMR=0.001	FNMR @ FMR=0.0001
3F	0.0036 ± 0.0002	0.0083 ± 0.0003	0.0180 ± 0.0004
3G	0.0049 ± 0.0002	0.0114 ± 0.0003	0.0222 ± 0.0005
3H	0.0080 ± 0.0003	0.0180 ± 0.0004	1.000000 ± 0.000005
3M	0.0043 ± 0.0002	0.0098 ± 0.0003	0.0182 ± 0.0004
3N	0.0075 ± 0.0003	0.0166 ± 0.0004	0.0420 ± 0.0007
3O	0.0066 ± 0.0003	0.0154 ± 0.0004	0.0300 ± 0.0006
3Q	0.0059 ± 0.0003	0.0135 ± 0.0004	1.000000 ± 0.000005
3S	0.0033 ± 0.0002	0.0077 ± 0.0003	0.0149 ± 0.0004
3T	0.0042 ± 0.0002	0.0094 ± 0.0003	0.0192 ± 0.0005
3V	0.0043 ± 0.0002	0.0096 ± 0.0003	0.0181 ± 0.0004
3W	0.0036 ± 0.0002	0.0079 ± 0.0003	0.0181 ± 0.0004
3Z	0.0044 ± 0.0002	0.0098 ± 0.0003	0.0247 ± 0.0005
4C	0.0043 ± 0.0002	0.0099 ± 0.0003	0.0240 ± 0.0005
4F	–	–	–
4K	–	–	–
4L	–	–	–
4M	–	–	–
4N	–	–	–
4O	–	–	–
4Q	–	–	–
4S	–	–	–
4T	–	–	–
4U	–	–	–
4W	–	–	–
4X	–	–	–
4Z	–	–	–
4D	0.0036 ± 0.0002	0.0074 ± 0.0003	0.0165 ± 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