
Ongoing MINEX Report Card

Matcher 4X



Last Updated: October 9, 2015

Participant Details

Company: ViRDI-Tech, Inc.

Date Submitted: 1/26/2015

Date Validated: 2/5/2015

Date Completed: 2/10/2015

Library	Size (bytes)	MD5 Checksum
libminex.a	468654	decbd66577cee816d2790bb71ee74ff0

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.

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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 ($i = 1 \dots M$) be the i th mated comparison score, and n_j ($j = 1 \dots N$) the j th non-mated comparison score. Then the statistics are

$$\text{FNMR}(\tau) = \frac{1}{N} \sum_{j=1}^N \mathbb{1}\{n_j < \tau\}, \quad (1)$$

$$\text{FMR}(\tau) = \frac{1}{M} \sum_{i=1}^M \mathbb{1}\{m_i \geq \tau\}. \quad (2)$$

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

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

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 4X 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

Single 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 $\text{FNMR}_{\text{FMR}}(0.0001) \leq 0.02$.

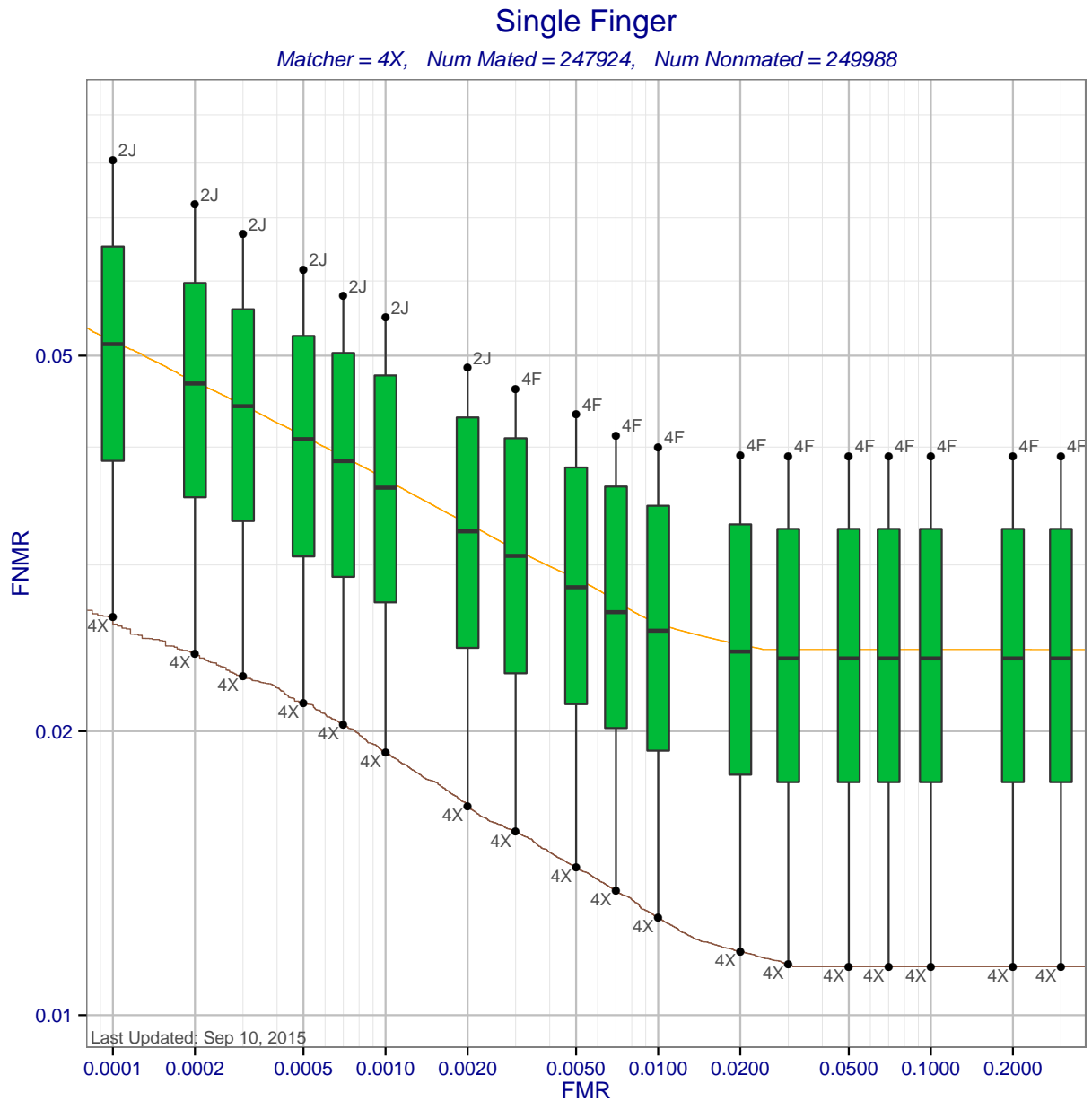


Figure 2: Single finger DET statistics for matcher 4X. Each box shows the distribution of FNMRs at a fixed FMR across all MINEX compliant template generators. The ends of the whiskers show the minimum and maximum FNMRs. The orange DET curve shows pooled performance against all template generators.

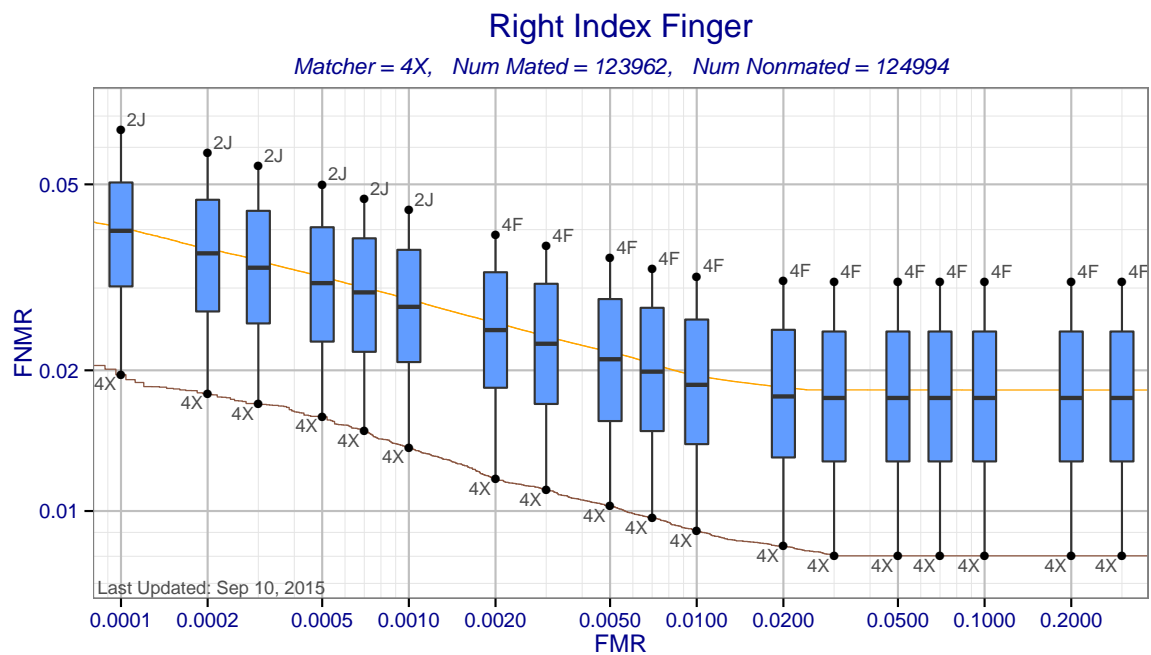


Figure 3: Right index finger DET statistics for matcher 4X. Each box shows the distribution of FNMR at a fixed FMR across all MINEX compliant template generators. The ends of the whiskers show the minimum and maximum FNMRs. The orange DET curve shows pooled performance against all template generators.

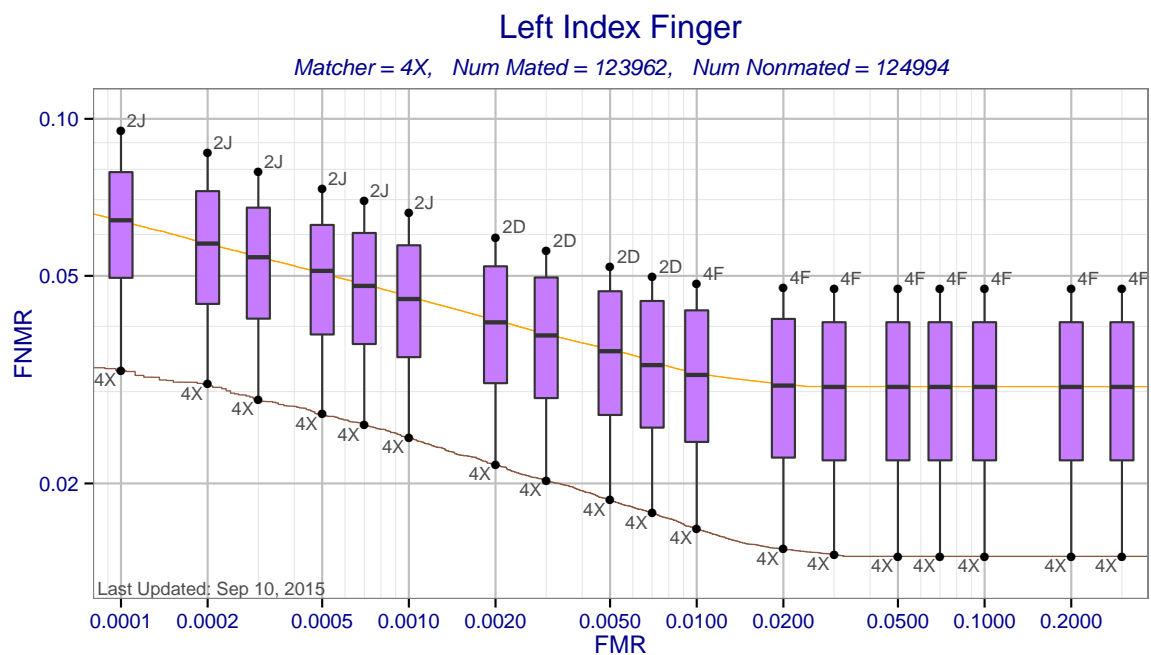


Figure 4: Left index finger DET statistics for matcher 4X. Each box shows the distribution of FNMRs at a fixed FMR across all MINEX compliant template generators. The ends of whiskers show the minimum and maximum FNMRs. The orange DET curve shows pooled performance against all template generators.

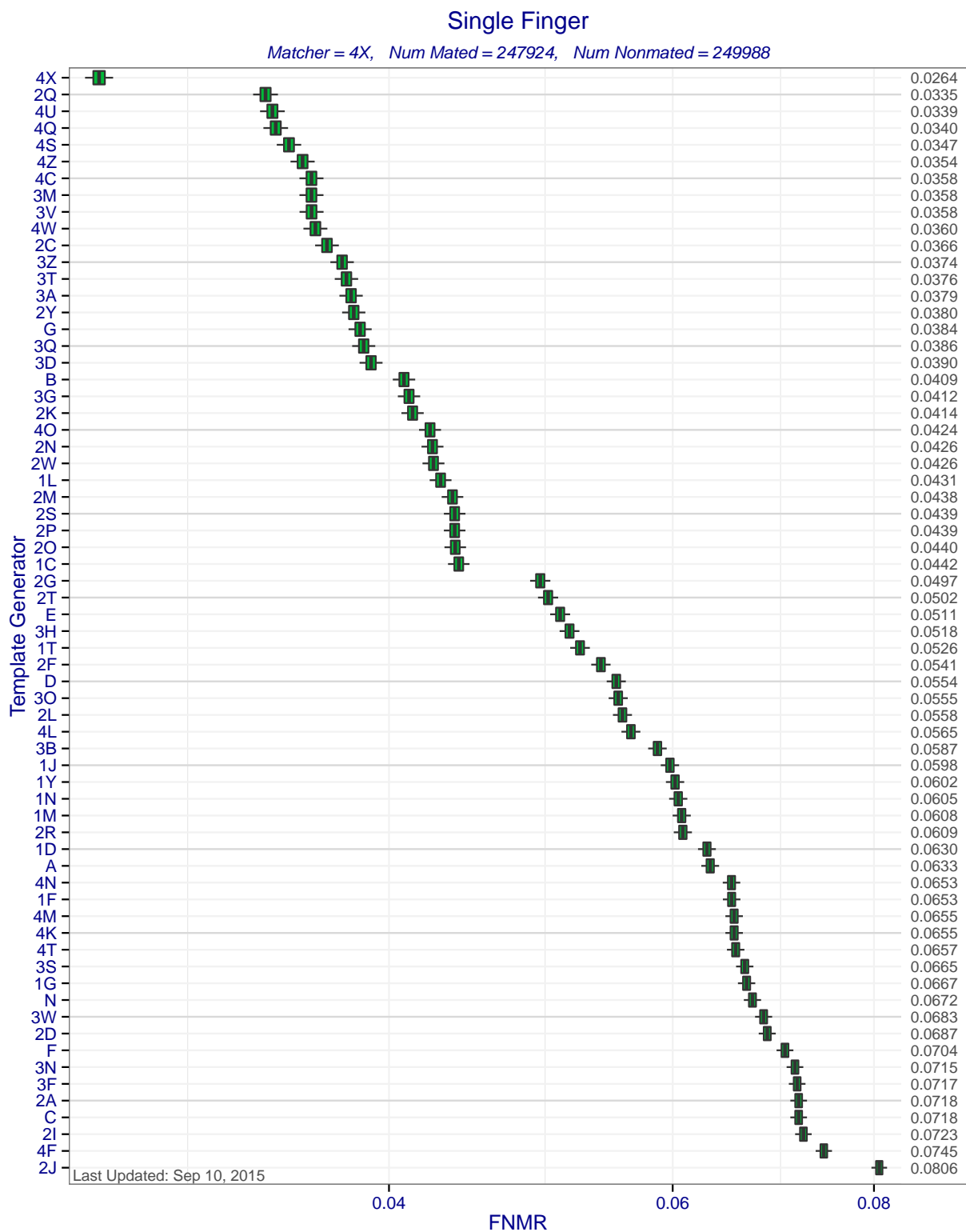


Figure 5: Single finger FNMRs at FMR = 0.0001 when matcher 4X compares templates created by different template generators. The ends of the whiskers show the minimum and maximum FNMRs. Each box represents uncertainty about the true FNMR. The box edges mark the 50% confidence intervals while the whiskers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

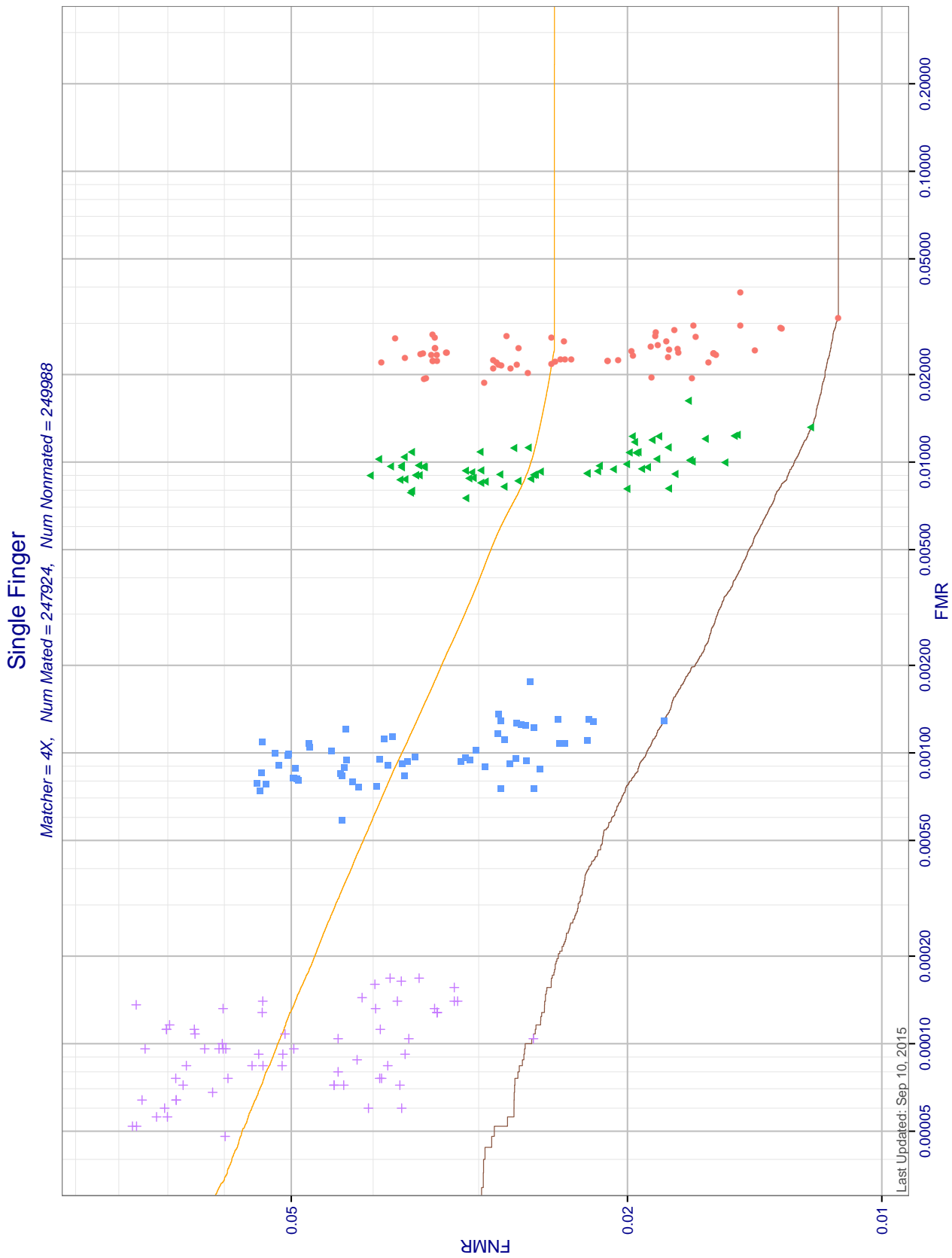


Figure 6: Single finger DET accuracy for matcher 4X. Each cluster of points represents the variation in FMR and FNMR across MINEX compliant template generators at a fixed decision threshold. Each point corresponds to an (FMR, FNMR) pair for a specific template generator at a particular decision threshold.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

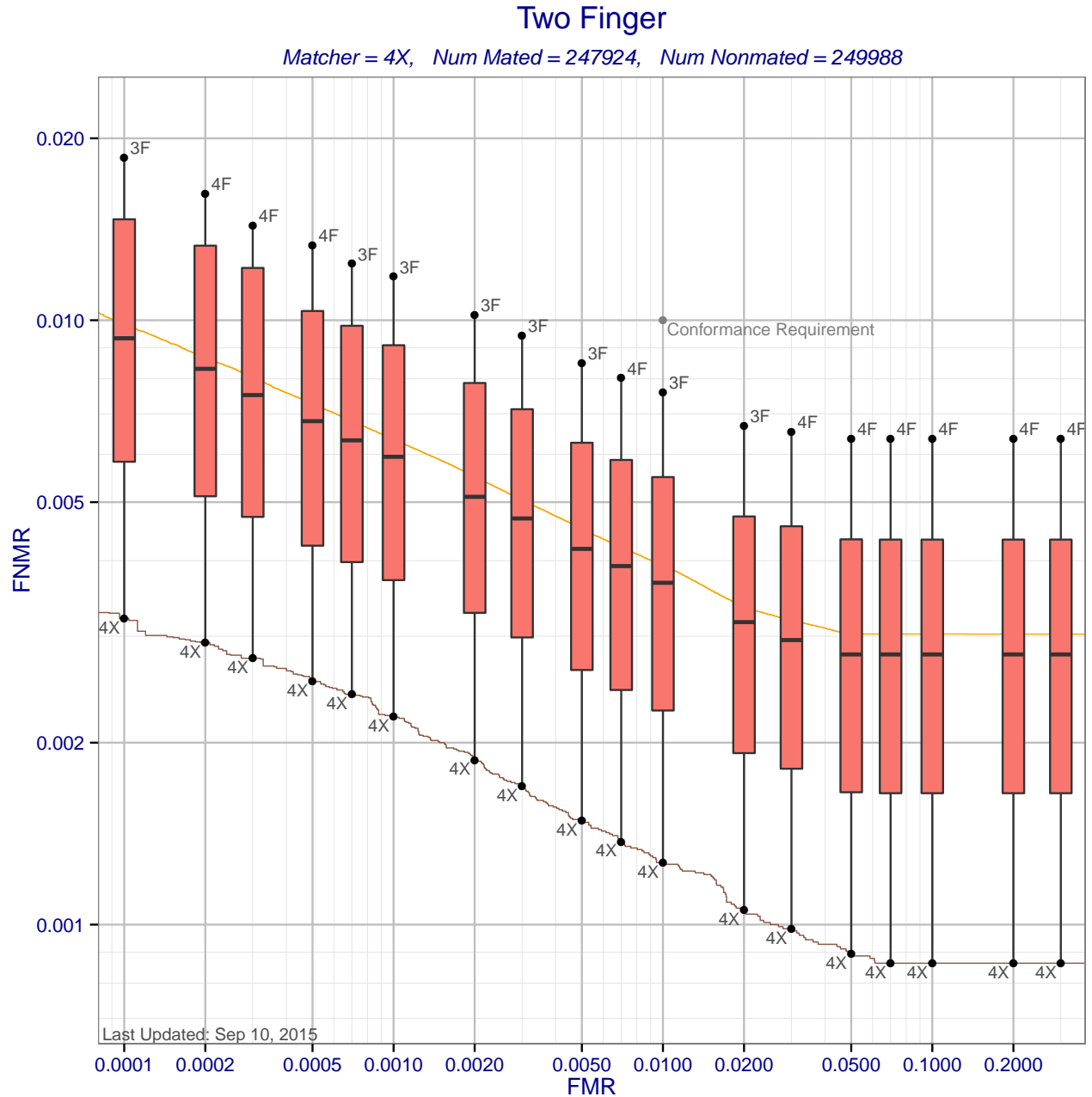


Figure 7: Two finger DET statistics for matcher 4X. Each box shows the distribution of FNMRs at a fixed FMR across all MINEX compliant template generators. The whisker ends show the minimum and maximum FNMRs. The orange DET curve shows pooled performance against all template generators. Score-level fusion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

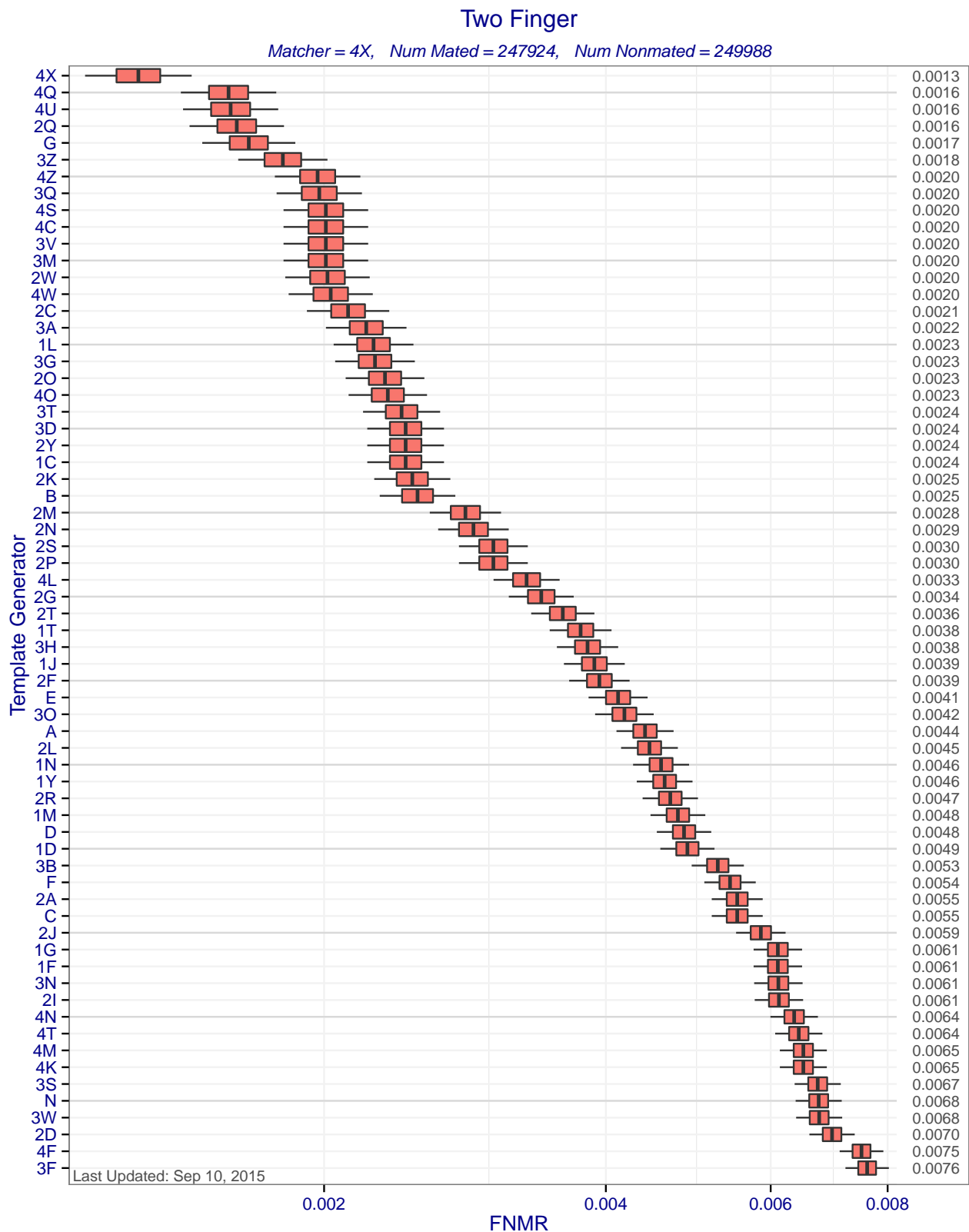


Figure 8: Two finger FNMR at FMR=0.01 when matcher 4X compares templates created by different template generators. Each box represents uncertainty about the true FNMR. The box edges mark the 50% confidence intervals while the whiskers mark the 90% confidence intervals. The numbers on the right show the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

Two Finger

Matcher = 4X, Num Mated = 247924, Num Nonmated = 249988

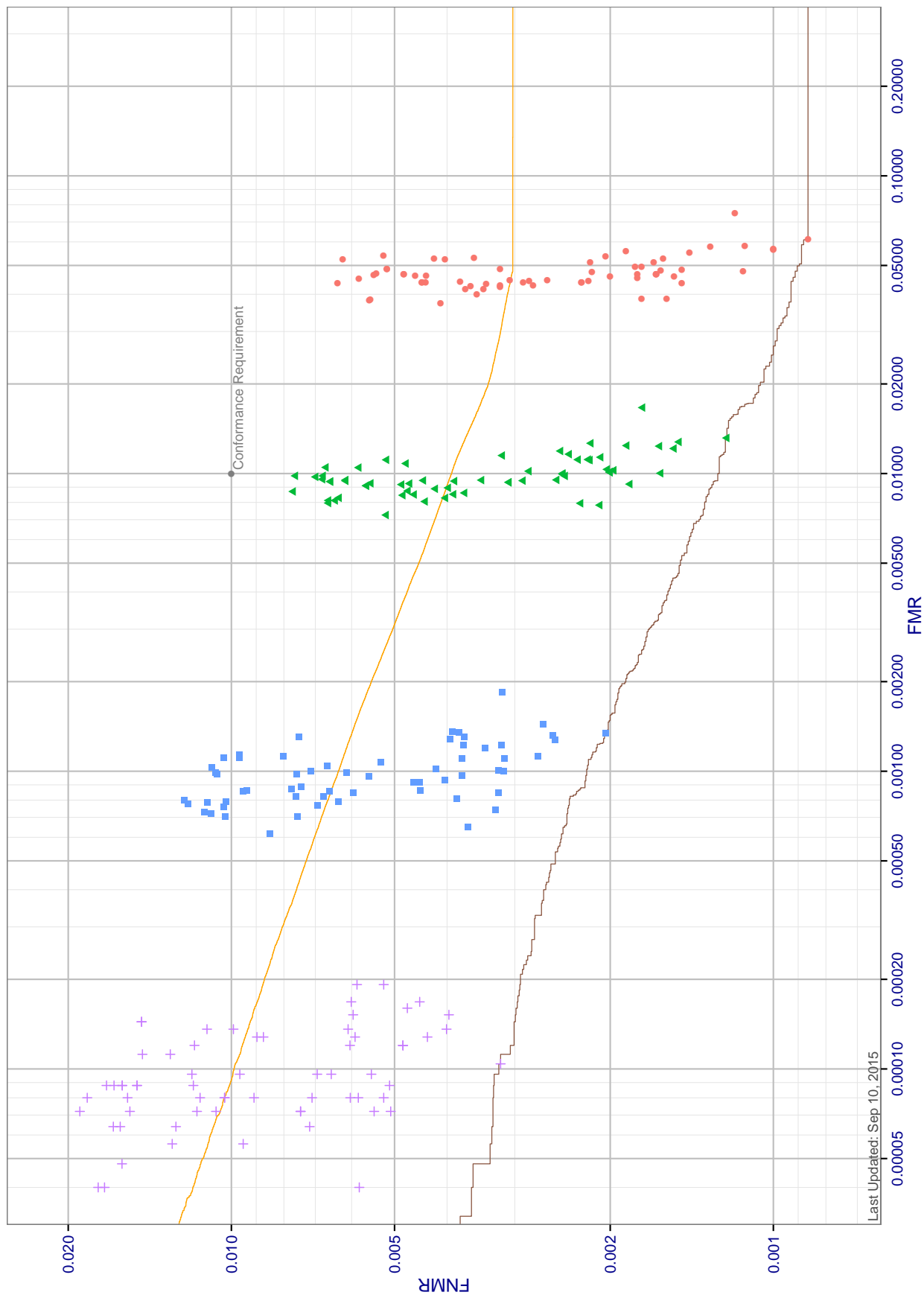


Figure 9: Two finger DET accuracy for matcher 4X. Each cluster of points represents the variation in FMR and FNMR across MINEX compliant template generators at a fixed decision threshold. Each point corresponds to an (FMR, FNMR) pair for a specific template generator at a particular decision threshold.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

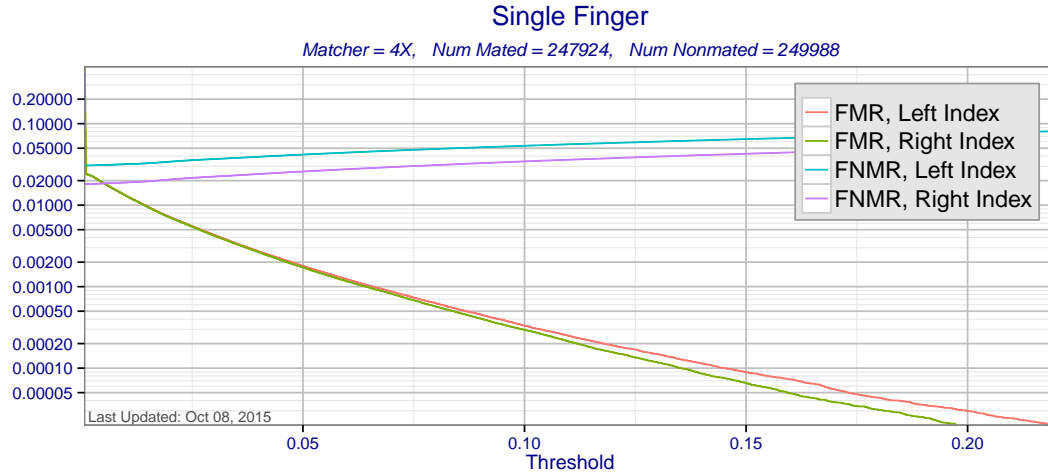


Figure 10: Single finger FMR and FNMR as a function of score threshold for matcher 4X using templates created by all MINEX compliant template generators. Separate curves are presented for left and right index fingers.

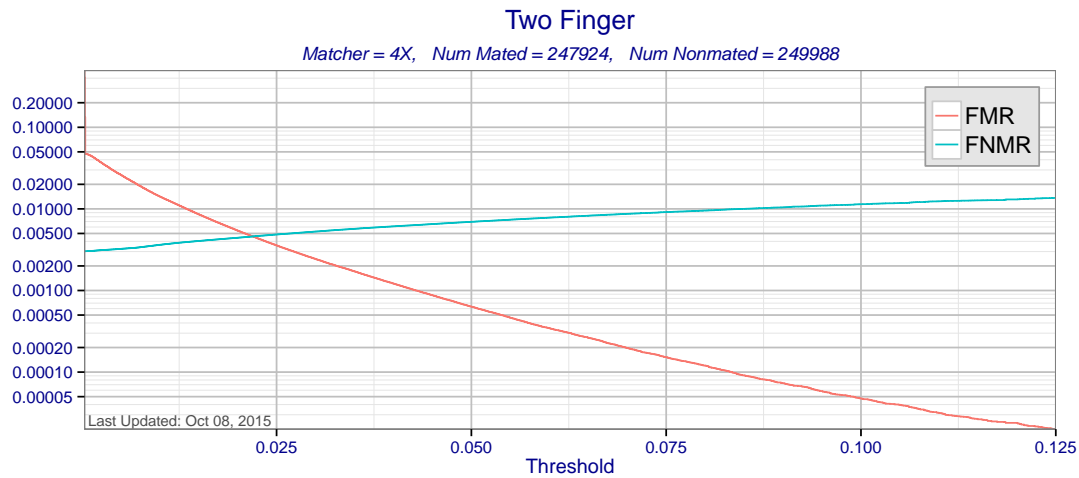


Figure 11: Two finger FMR and FNMR as a function of score threshold for matcher 4X using templates created by all MINEX compliant template generators. Score-level fusion is achieved by averaging scores for the left and right index fingers.

	FMR=0.1	FMR=0.01	FMR=0.001	FMR=0.0001
Right index finger	0.00090	0.014301	0.064406	0.135410
Left index finger	0.00090	0.014501	0.066007	0.145410
Single finger	0.00090	0.014401	0.065107	0.139310
Two finger	0.00045	0.013552	0.043054	0.083458

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 curve is indicative of discretized scores.

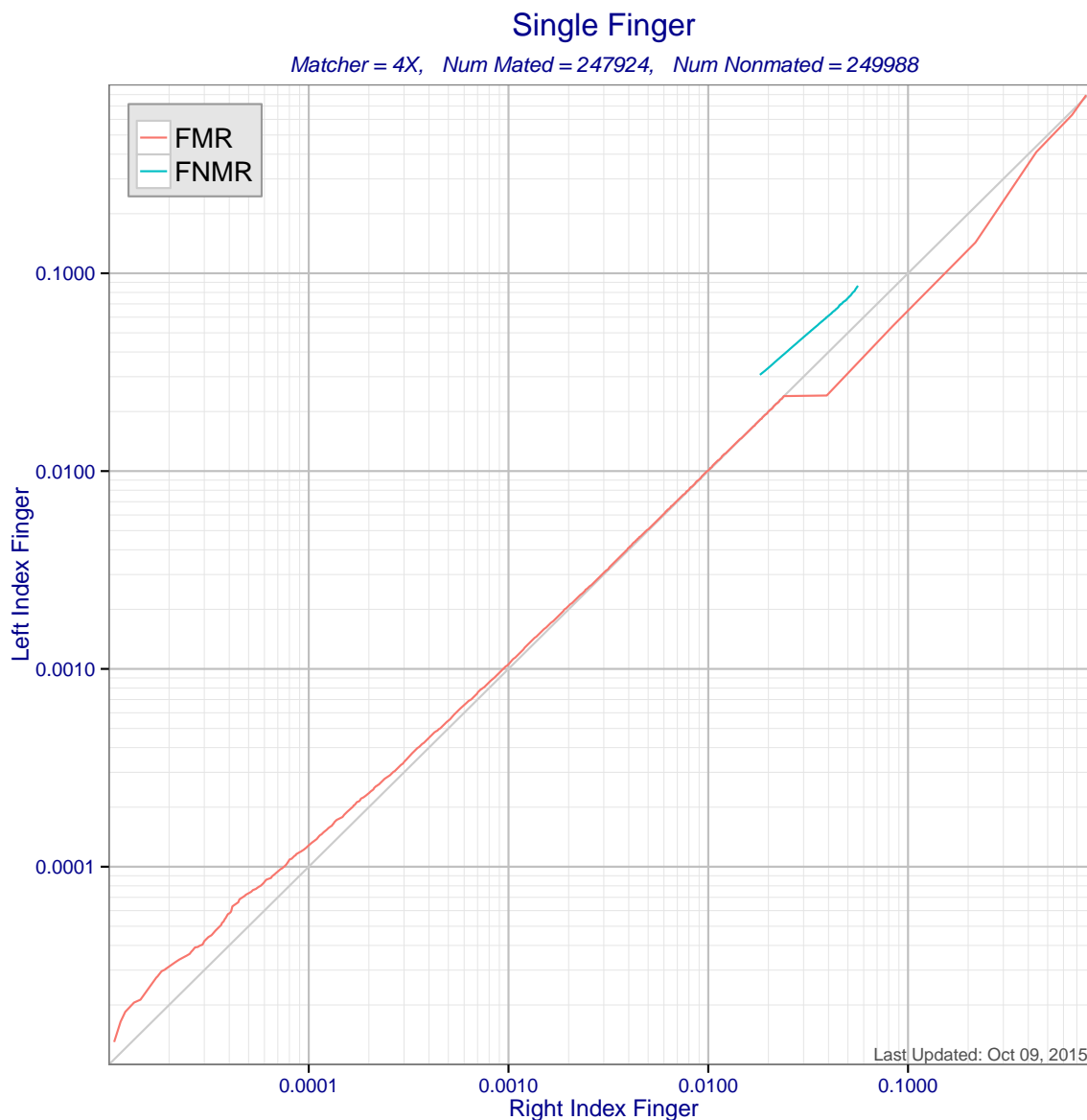


Figure 12: Q-Q plot comparing score distributions for left and right index fingers.

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.

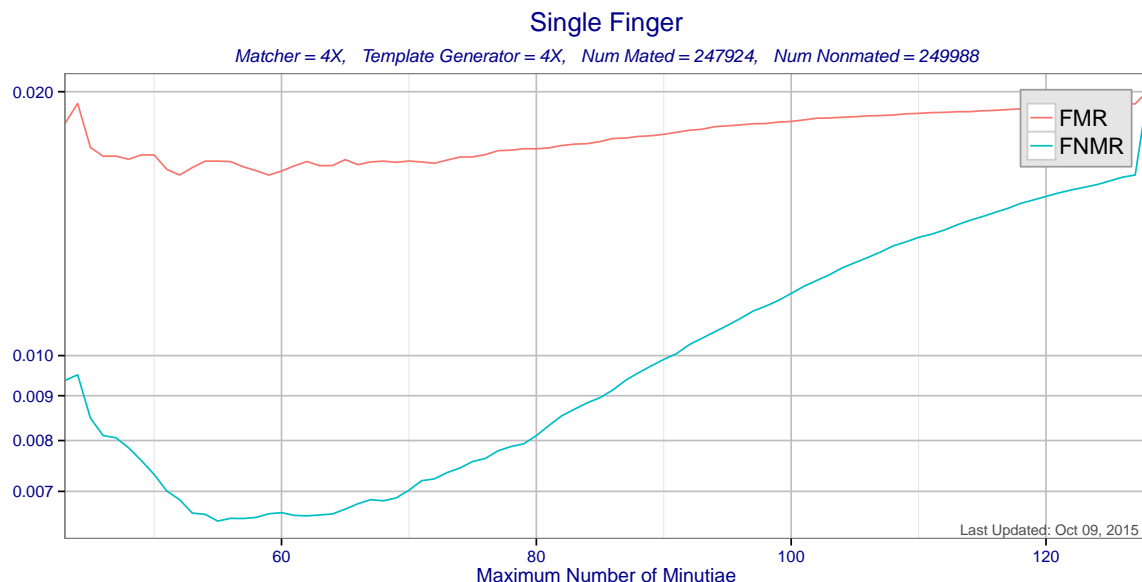


Figure 13: FNMR and FMR as a function of the number of minutia found by the template generator. The vertical axis defines a filter criterion such that FNMR and FMR are computed over only those comparisons where at least one of the compared templates has no more than the specified number of minutia. The threshold is fixed separately for FNMR and FMR to elicit an error rate of approximately 0.01 over unfiltered comparisons.

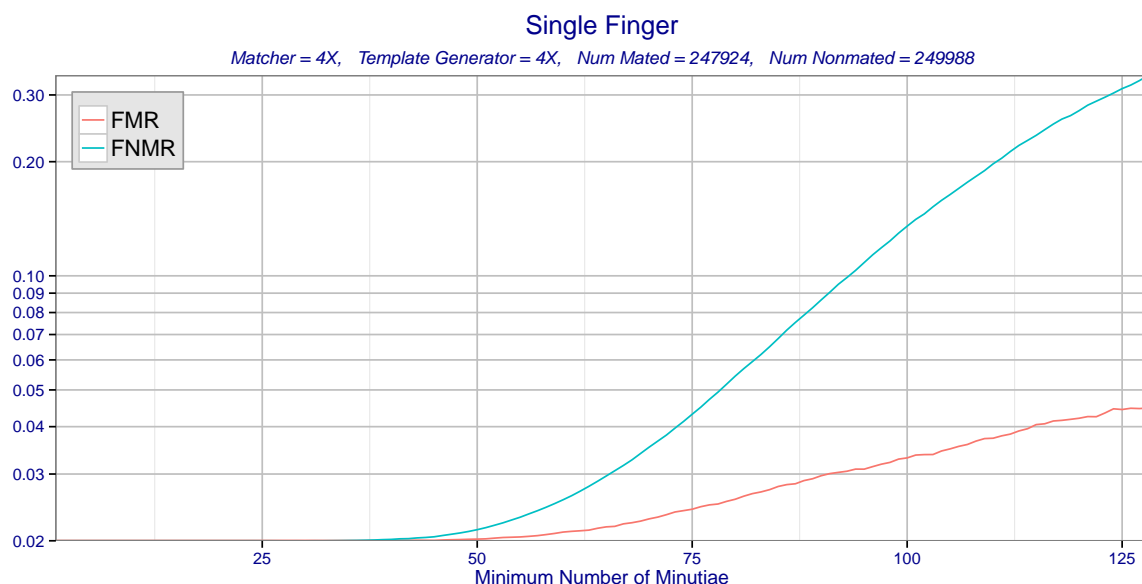


Figure 14: FNMR and FMR as a function of the number of minutia found by the template generator. The vertical axis defines a filter criterion such that FNMR and FMR are computed over only those comparisons where at least one of the compared templates has at least the indicated number of minutia. The threshold 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 4X 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	0.0308 ± 0.0006	0.0451 ± 0.0007	0.0633 ± 0.0008
B	0.0199 ± 0.0005	0.0279 ± 0.0005	0.0409 ± 0.0007
C	0.0353 ± 0.0006	0.0488 ± 0.0007	0.0718 ± 0.0009
D	0.0305 ± 0.0006	0.0407 ± 0.0007	0.0554 ± 0.0008
E	0.0254 ± 0.0005	0.0363 ± 0.0006	0.0511 ± 0.0007
F	0.0349 ± 0.0006	0.0486 ± 0.0007	0.0704 ± 0.0008
G	0.0168 ± 0.0004	0.0257 ± 0.0005	0.0384 ± 0.0006
N	0.0368 ± 0.0006	0.0504 ± 0.0007	0.0672 ± 0.0008
1C	0.0199 ± 0.0005	0.0304 ± 0.0006	0.0442 ± 0.0007
1D	0.0301 ± 0.0006	0.0441 ± 0.0007	0.0630 ± 0.0008
1F	0.0346 ± 0.0006	0.0482 ± 0.0007	0.0653 ± 0.0008
1G	0.0347 ± 0.0006	0.0485 ± 0.0007	0.0667 ± 0.0008
1J	0.0291 ± 0.0006	0.0398 ± 0.0006	0.0598 ± 0.0008
1L	0.0197 ± 0.0005	0.0296 ± 0.0006	0.0431 ± 0.0007
1M	0.0303 ± 0.0006	0.0426 ± 0.0007	0.0608 ± 0.0008
1N	0.0295 ± 0.0006	0.0427 ± 0.0007	0.0605 ± 0.0008
1T	0.0264 ± 0.0005	0.0378 ± 0.0006	0.0526 ± 0.0007
1Y	0.0299 ± 0.0006	0.0425 ± 0.0007	0.0602 ± 0.0008
2A	0.0353 ± 0.0006	0.0488 ± 0.0007	0.0718 ± 0.0009
2C	0.0182 ± 0.0004	0.0267 ± 0.0005	0.0366 ± 0.0006
2D	0.0380 ± 0.0006	0.0523 ± 0.0007	0.0687 ± 0.0008
2F	0.0280 ± 0.0005	0.0391 ± 0.0006	0.0541 ± 0.0007
2G	0.0251 ± 0.0005	0.0355 ± 0.0006	0.0497 ± 0.0007
2I	0.0366 ± 0.0006	0.0516 ± 0.0007	0.0723 ± 0.0009
2J	0.0369 ± 0.0006	0.0549 ± 0.0008	0.0806 ± 0.0009
2K	0.0206 ± 0.0005	0.0290 ± 0.0006	0.0414 ± 0.0007
2L	0.0293 ± 0.0006	0.0408 ± 0.0007	0.0558 ± 0.0008
2M	0.0215 ± 0.0005	0.0310 ± 0.0006	0.0438 ± 0.0007
2N	0.0215 ± 0.0005	0.0304 ± 0.0006	0.0426 ± 0.0007
2O	0.0204 ± 0.0005	0.0300 ± 0.0006	0.0440 ± 0.0007
2P	0.0221 ± 0.0005	0.0310 ± 0.0006	0.0439 ± 0.0007
2Q	0.0153 ± 0.0004	0.0227 ± 0.0005	0.0335 ± 0.0006
2R	0.0304 ± 0.0006	0.0424 ± 0.0007	0.0609 ± 0.0008
2S	0.0221 ± 0.0005	0.0310 ± 0.0006	0.0439 ± 0.0007
2T	0.0257 ± 0.0005	0.0356 ± 0.0006	0.0502 ± 0.0007
2W	0.0187 ± 0.0004	0.0291 ± 0.0006	0.0426 ± 0.0007
2Y	0.0188 ± 0.0004	0.0270 ± 0.0005	0.0380 ± 0.0006
3A	0.0196 ± 0.0005	0.0268 ± 0.0005	0.0379 ± 0.0006
3B	0.0278 ± 0.0005	0.0395 ± 0.0006	0.0587 ± 0.0008
3D	0.0191 ± 0.0005	0.0273 ± 0.0005	0.0390 ± 0.0006

Table 2: (continued)

Enroller	FNMR @ FMR=0.01	FNMR @ FMR=0.001	FNMR @ FMR=0.0001
3F	0.0394 ± 0.0006	0.0530 ± 0.0007	0.0717 ± 0.0009
3G	0.0196 ± 0.0005	0.0285 ± 0.0005	0.0412 ± 0.0007
3H	0.0254 ± 0.0005	0.0361 ± 0.0006	0.0518 ± 0.0007
3M	0.0169 ± 0.0004	0.0241 ± 0.0005	0.0358 ± 0.0006
3N	0.0361 ± 0.0006	0.0513 ± 0.0007	0.0715 ± 0.0009
3O	0.0274 ± 0.0005	0.0384 ± 0.0006	0.0555 ± 0.0008
3Q	0.0189 ± 0.0004	0.0278 ± 0.0005	0.0386 ± 0.0006
3S	0.0368 ± 0.0006	0.0511 ± 0.0007	0.0665 ± 0.0008
3T	0.0191 ± 0.0005	0.0273 ± 0.0005	0.0376 ± 0.0006
3V	0.0169 ± 0.0004	0.0241 ± 0.0005	0.0358 ± 0.0006
3W	0.0362 ± 0.0006	0.0504 ± 0.0007	0.0683 ± 0.0008
3Z	0.0173 ± 0.0004	0.0247 ± 0.0005	0.0374 ± 0.0006
4C	0.0169 ± 0.0004	0.0241 ± 0.0005	0.0358 ± 0.0006
4F	0.0400 ± 0.0006	0.0529 ± 0.0007	0.0745 ± 0.0009
4K	0.0352 ± 0.0006	0.0485 ± 0.0007	0.0655 ± 0.0008
4L	0.0266 ± 0.0005	0.0389 ± 0.0006	0.0565 ± 0.0008
4M	0.0352 ± 0.0006	0.0485 ± 0.0007	0.0655 ± 0.0008
4N	0.0355 ± 0.0006	0.0477 ± 0.0007	0.0653 ± 0.0008
4O	0.0201 ± 0.0005	0.0292 ± 0.0006	0.0424 ± 0.0007
4Q	0.0154 ± 0.0004	0.0231 ± 0.0005	0.0340 ± 0.0006
4S	0.0175 ± 0.0004	0.0246 ± 0.0005	0.0347 ± 0.0006
4T	0.0356 ± 0.0006	0.0476 ± 0.0007	0.0657 ± 0.0008
4U	0.0155 ± 0.0004	0.0229 ± 0.0005	0.0339 ± 0.0006
4W	0.0167 ± 0.0004	0.0243 ± 0.0005	0.0360 ± 0.0006
4X	0.0127 ± 0.0004	0.0190 ± 0.0005	0.0264 ± 0.0005
4Z	0.0185 ± 0.0004	0.0261 ± 0.0005	0.0354 ± 0.0006

Table 3: *Right index finger FNMRs at various FMRs when matcher 4X 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	0.0215 \pm 0.0007	0.0333 \pm 0.0008	0.050 \pm 0.001
B	0.0140 \pm 0.0005	0.0203 \pm 0.0007	0.0306 \pm 0.0008
C	0.0269 \pm 0.0008	0.0384 \pm 0.0009	0.058 \pm 0.001
D	0.0230 \pm 0.0007	0.0314 \pm 0.0008	0.0424 \pm 0.0009
E	0.0195 \pm 0.0006	0.0281 \pm 0.0008	0.0385 \pm 0.0009
F	0.0267 \pm 0.0008	0.0380 \pm 0.0009	0.057 \pm 0.001
G	0.0120 \pm 0.0005	0.0189 \pm 0.0006	0.0283 \pm 0.0008
N	0.0273 \pm 0.0008	0.0378 \pm 0.0009	0.051 \pm 0.001
1C	0.0159 \pm 0.0006	0.0251 \pm 0.0007	0.0378 \pm 0.0009
1D	0.0244 \pm 0.0007	0.0364 \pm 0.0009	0.053 \pm 0.001
1F	0.0256 \pm 0.0007	0.0355 \pm 0.0009	0.050 \pm 0.001
1G	0.0257 \pm 0.0007	0.0357 \pm 0.0009	0.050 \pm 0.001
1J	0.0219 \pm 0.0007	0.0306 \pm 0.0008	0.0470 \pm 0.0010
1L	0.0137 \pm 0.0005	0.0211 \pm 0.0007	0.0310 \pm 0.0008
1M	0.0225 \pm 0.0007	0.0328 \pm 0.0008	0.049 \pm 0.001
1N	0.0228 \pm 0.0007	0.0330 \pm 0.0008	0.0470 \pm 0.0010
1T	0.0202 \pm 0.0007	0.0302 \pm 0.0008	0.0437 \pm 0.0010
1Y	0.0223 \pm 0.0007	0.0330 \pm 0.0008	0.0475 \pm 0.0010
2A	0.0269 \pm 0.0008	0.0384 \pm 0.0009	0.058 \pm 0.001
2C	0.0125 \pm 0.0005	0.0189 \pm 0.0006	0.0270 \pm 0.0008
2D	0.0287 \pm 0.0008	0.0397 \pm 0.0009	0.054 \pm 0.001
2F	0.0208 \pm 0.0007	0.0291 \pm 0.0008	0.0411 \pm 0.0009
2G	0.0184 \pm 0.0006	0.0266 \pm 0.0008	0.0359 \pm 0.0009
2I	0.0293 \pm 0.0008	0.0413 \pm 0.0009	0.060 \pm 0.001
2J	0.0282 \pm 0.0008	0.0440 \pm 0.0010	0.065 \pm 0.001
2K	0.0153 \pm 0.0006	0.0222 \pm 0.0007	0.0310 \pm 0.0008
2L	0.0224 \pm 0.0007	0.0321 \pm 0.0008	0.0467 \pm 0.0010
2M	0.0167 \pm 0.0006	0.0246 \pm 0.0007	0.0349 \pm 0.0009
2N	0.0158 \pm 0.0006	0.0232 \pm 0.0007	0.0326 \pm 0.0008
2O	0.0143 \pm 0.0006	0.0222 \pm 0.0007	0.0327 \pm 0.0008
2P	0.0162 \pm 0.0006	0.0236 \pm 0.0007	0.0332 \pm 0.0008
2Q	0.0107 \pm 0.0005	0.0166 \pm 0.0006	0.0251 \pm 0.0007
2R	0.0227 \pm 0.0007	0.0322 \pm 0.0008	0.0477 \pm 0.0010
2S	0.0162 \pm 0.0006	0.0236 \pm 0.0007	0.0332 \pm 0.0008
2T	0.0184 \pm 0.0006	0.0261 \pm 0.0007	0.0361 \pm 0.0009
2W	0.0132 \pm 0.0005	0.0210 \pm 0.0007	0.0318 \pm 0.0008
2Y	0.0143 \pm 0.0006	0.0208 \pm 0.0007	0.0301 \pm 0.0008
3A	0.0139 \pm 0.0005	0.0196 \pm 0.0006	0.0277 \pm 0.0008
3B	0.0202 \pm 0.0007	0.0299 \pm 0.0008	0.0422 \pm 0.0009
3D	0.0141 \pm 0.0006	0.0209 \pm 0.0007	0.0308 \pm 0.0008

Table 3: (continued)

Enroller	FNMR @ FMR=0.01	FNMR @ FMR=0.001	FNMR @ FMR=0.0001
3F	0.0311 ± 0.0008	0.0423 ± 0.0009	0.059 ± 0.001
3G	0.0144 ± 0.0006	0.0216 ± 0.0007	0.0321 ± 0.0008
3H	0.0188 ± 0.0006	0.0273 ± 0.0008	0.0411 ± 0.0009
3M	0.0118 ± 0.0005	0.0175 ± 0.0006	0.0270 ± 0.0008
3N	0.0288 ± 0.0008	0.0410 ± 0.0009	0.059 ± 0.001
3O	0.0206 ± 0.0007	0.0303 ± 0.0008	0.0462 ± 0.0010
3Q	0.0139 ± 0.0005	0.0206 ± 0.0007	0.0299 ± 0.0008
3S	0.0287 ± 0.0008	0.0421 ± 0.0009	0.054 ± 0.001
3T	0.0144 ± 0.0006	0.0210 ± 0.0007	0.0296 ± 0.0008
3V	0.0118 ± 0.0005	0.0175 ± 0.0006	0.0271 ± 0.0008
3W	0.0285 ± 0.0008	0.0408 ± 0.0009	0.056 ± 0.001
3Z	0.0114 ± 0.0005	0.0169 ± 0.0006	0.0265 ± 0.0008
4C	0.0118 ± 0.0005	0.0175 ± 0.0006	0.0270 ± 0.0008
4F	0.0318 ± 0.0008	0.0430 ± 0.0009	0.063 ± 0.001
4K	0.0274 ± 0.0008	0.0391 ± 0.0009	0.052 ± 0.001
4L	0.0181 ± 0.0006	0.0274 ± 0.0008	0.0416 ± 0.0009
4M	0.0274 ± 0.0008	0.0391 ± 0.0009	0.052 ± 0.001
4N	0.0275 ± 0.0008	0.0381 ± 0.0009	0.052 ± 0.001
4O	0.0146 ± 0.0006	0.0223 ± 0.0007	0.0310 ± 0.0008
4Q	0.0111 ± 0.0005	0.0172 ± 0.0006	0.0258 ± 0.0007
4S	0.0125 ± 0.0005	0.0177 ± 0.0006	0.0252 ± 0.0007
4T	0.0274 ± 0.0008	0.0382 ± 0.0009	0.053 ± 0.001
4U	0.0111 ± 0.0005	0.0170 ± 0.0006	0.0248 ± 0.0007
4W	0.0120 ± 0.0005	0.0178 ± 0.0006	0.0277 ± 0.0008
4X	0.0091 ± 0.0004	0.0137 ± 0.0005	0.0196 ± 0.0006
4Z	0.0134 ± 0.0005	0.0194 ± 0.0006	0.0270 ± 0.0008

Table 4: Left index finger FNMRs at various FMRs when matcher 4X 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	0.0401 \pm 0.0009	0.057 \pm 0.001	0.074 \pm 0.001
B	0.0257 \pm 0.0007	0.0357 \pm 0.0009	0.052 \pm 0.001
C	0.0436 \pm 0.0010	0.059 \pm 0.001	0.087 \pm 0.001
D	0.0379 \pm 0.0009	0.050 \pm 0.001	0.070 \pm 0.001
E	0.0314 \pm 0.0008	0.0449 \pm 0.0010	0.065 \pm 0.001
F	0.0431 \pm 0.0009	0.059 \pm 0.001	0.086 \pm 0.001
G	0.0217 \pm 0.0007	0.0328 \pm 0.0008	0.051 \pm 0.001
N	0.0464 \pm 0.0010	0.063 \pm 0.001	0.087 \pm 0.001
1C	0.0240 \pm 0.0007	0.0358 \pm 0.0009	0.051 \pm 0.001
1D	0.0360 \pm 0.0009	0.052 \pm 0.001	0.073 \pm 0.001
1F	0.0435 \pm 0.0010	0.061 \pm 0.001	0.086 \pm 0.001
1G	0.0437 \pm 0.0010	0.062 \pm 0.001	0.086 \pm 0.001
1J	0.0364 \pm 0.0009	0.049 \pm 0.001	0.073 \pm 0.001
1L	0.0259 \pm 0.0007	0.0380 \pm 0.0009	0.054 \pm 0.001
1M	0.0381 \pm 0.0009	0.053 \pm 0.001	0.074 \pm 0.001
1N	0.0362 \pm 0.0009	0.053 \pm 0.001	0.074 \pm 0.001
1T	0.0327 \pm 0.0008	0.0454 \pm 0.0010	0.061 \pm 0.001
1Y	0.0376 \pm 0.0009	0.052 \pm 0.001	0.073 \pm 0.001
2A	0.0436 \pm 0.0010	0.059 \pm 0.001	0.087 \pm 0.001
2C	0.0238 \pm 0.0007	0.0348 \pm 0.0009	0.0461 \pm 0.0010
2D	0.0473 \pm 0.0010	0.065 \pm 0.001	0.083 \pm 0.001
2F	0.0353 \pm 0.0009	0.050 \pm 0.001	0.069 \pm 0.001
2G	0.0318 \pm 0.0008	0.0448 \pm 0.0010	0.065 \pm 0.001
2I	0.0438 \pm 0.0010	0.062 \pm 0.001	0.085 \pm 0.001
2J	0.0457 \pm 0.0010	0.066 \pm 0.001	0.095 \pm 0.001
2K	0.0260 \pm 0.0007	0.0361 \pm 0.0009	0.053 \pm 0.001
2L	0.0361 \pm 0.0009	0.050 \pm 0.001	0.065 \pm 0.001
2M	0.0262 \pm 0.0007	0.0374 \pm 0.0009	0.053 \pm 0.001
2N	0.0272 \pm 0.0008	0.0379 \pm 0.0009	0.054 \pm 0.001
2O	0.0263 \pm 0.0007	0.0377 \pm 0.0009	0.055 \pm 0.001
2P	0.0280 \pm 0.0008	0.0387 \pm 0.0009	0.056 \pm 0.001
2Q	0.0199 \pm 0.0007	0.0288 \pm 0.0008	0.0427 \pm 0.0009
2R	0.0380 \pm 0.0009	0.053 \pm 0.001	0.078 \pm 0.001
2S	0.0280 \pm 0.0008	0.0387 \pm 0.0009	0.056 \pm 0.001
2T	0.0329 \pm 0.0008	0.0452 \pm 0.0010	0.065 \pm 0.001
2W	0.0243 \pm 0.0007	0.0373 \pm 0.0009	0.055 \pm 0.001
2Y	0.0232 \pm 0.0007	0.0333 \pm 0.0008	0.0477 \pm 0.0010
3A	0.0253 \pm 0.0007	0.0340 \pm 0.0008	0.049 \pm 0.001
3B	0.0352 \pm 0.0009	0.049 \pm 0.001	0.074 \pm 0.001
3D	0.0242 \pm 0.0007	0.0337 \pm 0.0008	0.048 \pm 0.001

Table 4: (continued)

Enroller	FNMR @ FMR=0.01	FNMR @ FMR=0.001	FNMR @ FMR=0.0001
3F	0.0476 ± 0.0010	0.064 ± 0.001	0.086 ± 0.001
3G	0.0247 ± 0.0007	0.0354 ± 0.0009	0.050 ± 0.001
3H	0.0318 ± 0.0008	0.0451 ± 0.0010	0.061 ± 0.001
3M	0.0218 ± 0.0007	0.0306 ± 0.0008	0.0448 ± 0.0010
3N	0.0434 ± 0.0010	0.062 ± 0.001	0.084 ± 0.001
3O	0.0342 ± 0.0008	0.0464 ± 0.0010	0.063 ± 0.001
3Q	0.0240 ± 0.0007	0.0352 ± 0.0009	0.0478 ± 0.0010
3S	0.0449 ± 0.0010	0.060 ± 0.001	0.082 ± 0.001
3T	0.0237 ± 0.0007	0.0336 ± 0.0008	0.0462 ± 0.0010
3V	0.0218 ± 0.0007	0.0306 ± 0.0008	0.0448 ± 0.0010
3W	0.0439 ± 0.0010	0.060 ± 0.001	0.080 ± 0.001
3Z	0.0232 ± 0.0007	0.0330 ± 0.0008	0.0474 ± 0.0010
4C	0.0218 ± 0.0007	0.0306 ± 0.0008	0.0448 ± 0.0010
4F	0.048 ± 0.001	0.063 ± 0.001	0.085 ± 0.001
4K	0.0429 ± 0.0009	0.058 ± 0.001	0.079 ± 0.001
4L	0.0352 ± 0.0009	0.050 ± 0.001	0.072 ± 0.001
4M	0.0429 ± 0.0009	0.058 ± 0.001	0.079 ± 0.001
4N	0.0435 ± 0.0010	0.057 ± 0.001	0.079 ± 0.001
4O	0.0255 ± 0.0007	0.0361 ± 0.0009	0.053 ± 0.001
4Q	0.0196 ± 0.0006	0.0292 ± 0.0008	0.0430 ± 0.0009
4S	0.0224 ± 0.0007	0.0317 ± 0.0008	0.0448 ± 0.0010
4T	0.0438 ± 0.0010	0.057 ± 0.001	0.079 ± 0.001
4U	0.0199 ± 0.0007	0.0290 ± 0.0008	0.0438 ± 0.0010
4W	0.0215 ± 0.0007	0.0308 ± 0.0008	0.0440 ± 0.0010
4X	0.0164 ± 0.0006	0.0245 ± 0.0007	0.0329 ± 0.0008
4Z	0.0236 ± 0.0007	0.0328 ± 0.0008	0.0440 ± 0.0010

Table 5: *Two finger FNMRs at various FMRs when matcher 4X 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	0.0044 ± 0.0002	0.0072 ± 0.0003	0.0115 ± 0.0004
B	0.0025 ± 0.0002	0.0041 ± 0.0002	0.0072 ± 0.0003
C	0.0055 ± 0.0002	0.0091 ± 0.0003	0.0147 ± 0.0004
D	0.0048 ± 0.0002	0.0076 ± 0.0003	0.0115 ± 0.0004
E	0.0041 ± 0.0002	0.0067 ± 0.0003	0.0106 ± 0.0003
F	0.0054 ± 0.0002	0.0091 ± 0.0003	0.0152 ± 0.0004
G	0.0017 ± 0.0001	0.0028 ± 0.0002	0.0051 ± 0.0002
N	0.0068 ± 0.0003	0.0107 ± 0.0003	0.0163 ± 0.0004
1C	0.0024 ± 0.0002	0.0042 ± 0.0002	0.0069 ± 0.0003
1D	0.0049 ± 0.0002	0.0082 ± 0.0003	0.0132 ± 0.0004
1F	0.0061 ± 0.0003	0.0099 ± 0.0003	0.0154 ± 0.0004
1G	0.0061 ± 0.0003	0.0099 ± 0.0003	0.0154 ± 0.0004
1J	0.0039 ± 0.0002	0.0063 ± 0.0003	0.0102 ± 0.0003
1L	0.0023 ± 0.0002	0.0040 ± 0.0002	0.0068 ± 0.0003
1M	0.0048 ± 0.0002	0.0076 ± 0.0003	0.0124 ± 0.0004
1N	0.0046 ± 0.0002	0.0076 ± 0.0003	0.0114 ± 0.0003
1T	0.0038 ± 0.0002	0.0064 ± 0.0003	0.0102 ± 0.0003
1Y	0.0046 ± 0.0002	0.0073 ± 0.0003	0.0110 ± 0.0003
2A	0.0055 ± 0.0002	0.0091 ± 0.0003	0.0147 ± 0.0004
2C	0.0021 ± 0.0002	0.0035 ± 0.0002	0.0055 ± 0.0002
2D	0.0070 ± 0.0003	0.0109 ± 0.0003	0.0151 ± 0.0004
2F	0.0039 ± 0.0002	0.0061 ± 0.0003	0.0096 ± 0.0003
2G	0.0034 ± 0.0002	0.0055 ± 0.0002	0.0095 ± 0.0003
2I	0.0061 ± 0.0003	0.0105 ± 0.0003	0.0158 ± 0.0004
2J	0.0059 ± 0.0003	0.0106 ± 0.0003	0.0169 ± 0.0004
2K	0.0025 ± 0.0002	0.0040 ± 0.0002	0.0065 ± 0.0003
2L	0.0045 ± 0.0002	0.0072 ± 0.0003	0.0118 ± 0.0004
2M	0.0028 ± 0.0002	0.0044 ± 0.0002	0.0071 ± 0.0003
2N	0.0029 ± 0.0002	0.0045 ± 0.0002	0.0065 ± 0.0003
2O	0.0023 ± 0.0002	0.0040 ± 0.0002	0.0067 ± 0.0003
2P	0.0030 ± 0.0002	0.0046 ± 0.0002	0.0069 ± 0.0003
2Q	0.0016 ± 0.0001	0.0028 ± 0.0002	0.0045 ± 0.0002
2R	0.0047 ± 0.0002	0.0073 ± 0.0003	0.0117 ± 0.0004
2S	0.0030 ± 0.0002	0.0046 ± 0.0002	0.0069 ± 0.0003
2T	0.0036 ± 0.0002	0.0058 ± 0.0003	0.0086 ± 0.0003
2W	0.0020 ± 0.0001	0.0036 ± 0.0002	0.0059 ± 0.0003
2Y	0.0024 ± 0.0002	0.0038 ± 0.0002	0.0058 ± 0.0003
3A	0.0022 ± 0.0002	0.0035 ± 0.0002	0.0052 ± 0.0002
3B	0.0053 ± 0.0002	0.0079 ± 0.0003	0.0117 ± 0.0004
3D	0.0024 ± 0.0002	0.0041 ± 0.0002	0.0064 ± 0.0003

Table 5: (continued)

Enroller	FNMR @ FMR=0.01	FNMR @ FMR=0.001	FNMR @ FMR=0.0001
3F	0.0076 ± 0.0003	0.0118 ± 0.0004	0.0186 ± 0.0004
3G	0.0023 ± 0.0002	0.0038 ± 0.0002	0.0063 ± 0.0003
3H	0.0038 ± 0.0002	0.0061 ± 0.0003	0.0092 ± 0.0003
3M	0.0020 ± 0.0001	0.0032 ± 0.0002	0.0050 ± 0.0002
3N	0.0061 ± 0.0003	0.0104 ± 0.0003	0.0152 ± 0.0004
3O	0.0042 ± 0.0002	0.0067 ± 0.0003	0.0103 ± 0.0003
3Q	0.0020 ± 0.0001	0.0033 ± 0.0002	0.0052 ± 0.0002
3S	0.0067 ± 0.0003	0.0108 ± 0.0003	0.0150 ± 0.0004
3T	0.0024 ± 0.0002	0.0037 ± 0.0002	0.0055 ± 0.0002
3V	0.0020 ± 0.0001	0.0032 ± 0.0002	0.0050 ± 0.0002
3W	0.0068 ± 0.0003	0.0106 ± 0.0003	0.0147 ± 0.0004
3Z	0.0018 ± 0.0001	0.0032 ± 0.0002	0.0051 ± 0.0002
4C	0.0020 ± 0.0001	0.0032 ± 0.0002	0.0050 ± 0.0002
4F	0.0075 ± 0.0003	0.0115 ± 0.0004	0.0182 ± 0.0004
4K	0.0065 ± 0.0003	0.0099 ± 0.0003	0.0153 ± 0.0004
4L	0.0033 ± 0.0002	0.0054 ± 0.0002	0.0090 ± 0.0003
4M	0.0065 ± 0.0003	0.0099 ± 0.0003	0.0153 ± 0.0004
4N	0.0064 ± 0.0003	0.0098 ± 0.0003	0.0157 ± 0.0004
4O	0.0023 ± 0.0002	0.0038 ± 0.0002	0.0061 ± 0.0003
4Q	0.0016 ± 0.0001	0.0026 ± 0.0002	0.0042 ± 0.0002
4S	0.0020 ± 0.0001	0.0031 ± 0.0002	0.0048 ± 0.0002
4T	0.0064 ± 0.0003	0.0098 ± 0.0003	0.0155 ± 0.0004
4U	0.0016 ± 0.0001	0.0028 ± 0.0002	0.0043 ± 0.0002
4W	0.0020 ± 0.0001	0.0032 ± 0.0002	0.0052 ± 0.0002
4X	0.0013 ± 0.0001	0.0022 ± 0.0002	0.0032 ± 0.0002
4Z	0.0020 ± 0.0001	0.0031 ± 0.0002	0.0051 ± 0.0002

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. Classification 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](#)