Evaluation of 'non-traditional' fingerprint sensor performance

Protocol and Results

Rick Lazarick
CSRA
Chief Scientist – Biometrics

Homeland Security
Science and Technology

Funded By: Patricia Wolfhope
DHS S&T Program Manager

Acknowledgements

Special thanks to Patty Wolfhope, DHS S&T Biometrics Program Manager for sponsoring this evaluation and analysis activity

Thanks to Patrick Grother and Mei Ngan for informative guidance on large scale data processing tools

Thanks to Jacob Rose, CSRA intern who developed the data analysis processing techniques

Homeland Security

Science and Technology

Presentation Outline

- Background – Motivation
- Approach
- Experimental Design
- Data Collected
- Laboratory Activity
- Analysis Methods
- Performance Results
- Conclusions – Testing
- Conclusions – Performance
- Q&A

Homeland Security
Science and Technology

Background – Motivation

Emerging fingerprint sensors (e.g. for mobile applications: thin, light)

- Not based on traditional optical FTIR
- Not conventionally FBI certified (Appendix F or PIV)

Questions about non-traditional sensors:

1. Performance in native/closed application?
2. Performance against legacy traditional reference fingerprints?
3. Interoperability across other devices?

Approach

- Utilized NVLAP Accredited testing laboratory (iBeta Quality Assurance, Aurora, Colorado)
- Funded by DHS Science & Technology
- Technical collaboration with other USG agencies, industry and academia
- Experimental design provided in Statement of Work
- Sensors selected by DHS S&T
  - "Traditional" – 2 optical FTIR: FAP 60 and FAP 45
  - "Non-Traditional" – 4 different technologies (2 have FBI PIV certification)

[NOTE: this open presentation will not identify specific products, please don't ask]

Homeland Security
Science and Technology

Experimental Design

{0} Image Quality – Using NFIQ

{1} Native Performance

- 1.1 Proprietary (Template Generator (TG) & Matcher)
- 1.2 ISO Standards based minutiae (TG & Matcher)

{2} Traditional References (REF), Non-traditional (NT) Probes

- 2.1 Proprietary TG (NT) for REF and Probes, proprietary matcher
- 2.2 Standard: TG (NT) for REF and Probes, associated NT matcher
- 2.3 Standard: REF Traditional TG, Probe TG (NT), associated NT matcher
- 2.4 “Probe Image” from NT sensor, proprietary Traditional TG and matcher

{3} Interoperability across all devices *(all ISO Standard based)*

- 3.1 All associated-TGs, Probe associated matcher
- 3.2 All associated-TGs, Traditional matcher
- 3.3 Traditional matcher and TG (NT images only)

Homeland Security

Science and Technology

Experimental Design-Applications

{1} Native Performance = Closed system (either Proprietary or Standards based (STD))

{2} Traditional (TRAD) REF, Non-traditional (NT) Probes

- 2.1 Legacy TRAD enrollment images (only) + NT Proprietary TG/matcher
- 2.2 Legacy TRAD enrollment images (only) + NT STD TG/matcher
- 2.3 **PIV** (TRAD enrollment templates) + NT (certified/MINEX)
- 2.4 **IDENT** (Probe device image only, TRAD proprietary TG/matcher)

{3} Interoperability (I/Op) across all devices *(all ISO Standard based)*

- 3.1 **MINEX** Scenario-1 *(when using index fingers)*
- 3.2 None *(investigates I/Op independent of NT matcher)*
- 3.3 None *(investigates image level interoperability)*

Homeland Security
Science and Technology

Experimental Design - Details

		Reference		Probe		Matcher
		Sensor	TG	Sensor	TG	
Native	Exp 1.1	Vendor-i	Prop	Vendor-i	Prop	Vendor
	Exp 1.2	Vendor-i	Std	Vendor-i	Std	Vendor
Traditional Reference	Exp 2.1	TRAD	NT-Prop	NT	NT-Prop	NT Vendor
	Exp 2.2	TRAD	NT-Std	NT	NT-Std	NT Vendor
	Exp 2.3	TRAD	TRAD-Std	NT	NT-Std	NT Vendor
	Exp 2.4	TRAD	TRAD-Prop	NT	TRAD-Prop	TRAD-Prop
Interoperability	Exp 3.1	Vendor-i	Vendor-i Std	Vendor-i	Vendor-i Std	Probe Vendor
	Exp 3.2	Vendor-i	Vendor-i Std	Vendor-i	Vendor-i Std	TRAD
	Exp 3.3	Vendor-i	TRAD	Vendor-i	TRAD	TRAD

Legend
TRAD – Traditional
NT – Non-traditional

Prop – Proprietary
Std – ISO Standard based

TG – Template Generator
i - device 1-6

Homeland Security
Science and Technology

Data Collected

- 260 test subjects in crew
- Enrollment (1 or more samples, variable by device) and 6 Verification samples per finger
- 6 fingers per subject (L and R: index, middle and thumbs)
- Total number of finger prints collected ~ 11,000

Homeland Security
Science and Technology

Laboratory Activity

- Test Plan and IRB approval
- Crew recruiting (controlled for gender and age)
- Data collection- prepare test harnesses
- Data collection- one session per crew member (indoor environment, various locations)
- Data reduction, analysis and reporting

Analysis Methods

- Single finger and ALL fingers
- Single attempt and 3-attempt transactions
  - Max of 3 scores used for transaction level (genuine and imposter)
- 2-finger fusion (LRI – left & right index, RIM – right index & middle, LIM – left index & middle, LRT – left & right thumbs)
  - Simple sum fusion *(or single score if second score is missing)*
- Combined fusion and 3-attempt transactions
- For anonymous reporting:
  - **Traditional (FTIR) devices are labeled A and B**
  - **Non-traditional devices are labeled C through F**

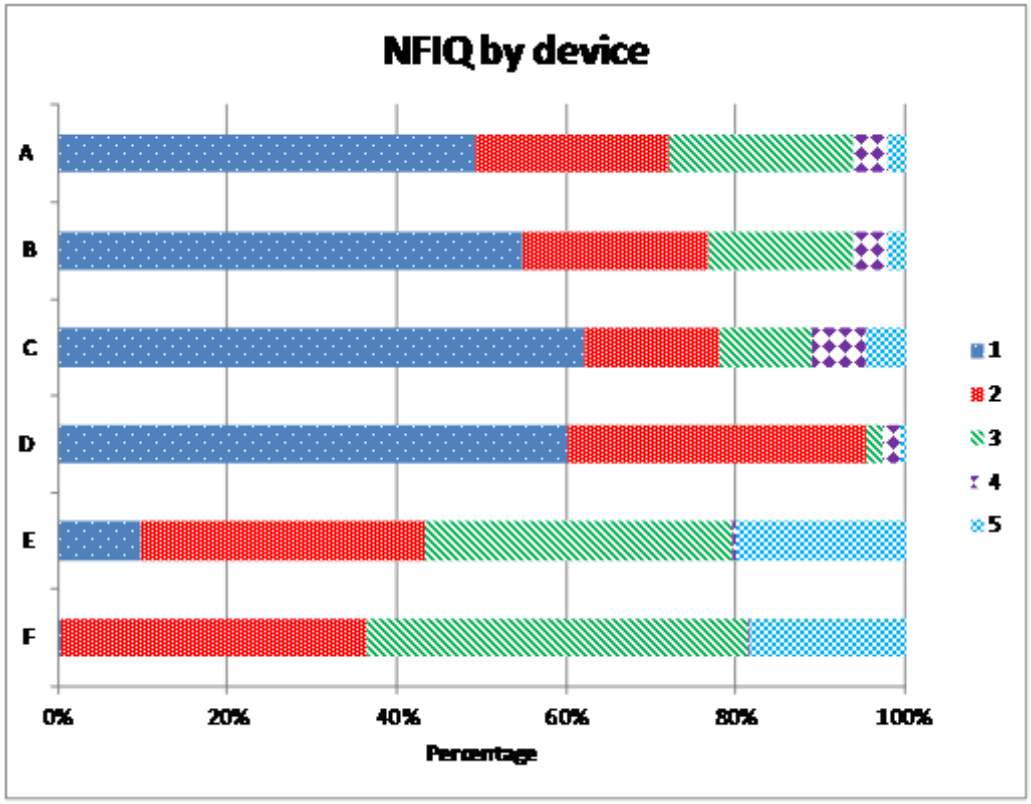
Homeland Security
Science and Technology

Performance Results

- Quality
- Native – E1
- Traditional REF – E2.x
- Interoperability – E3.1, E3.3
- Effect of fusion and 3-attempts

Quality

- Based on NIST NFIQ scores[1]

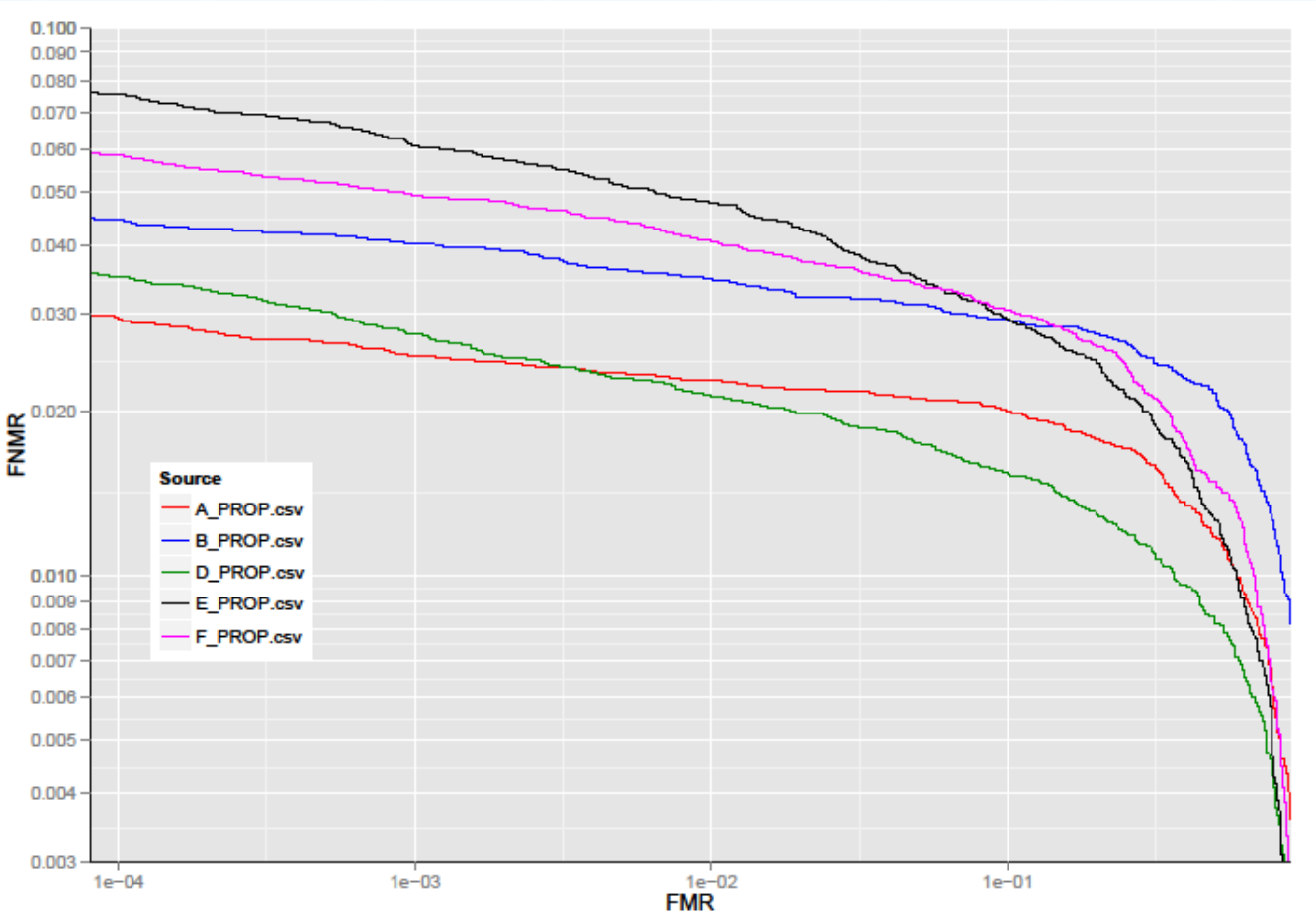


[1]Adjustments made to represent typical operational data collection

Homeland Security
Science and Technology

Native Performance – Proprietary

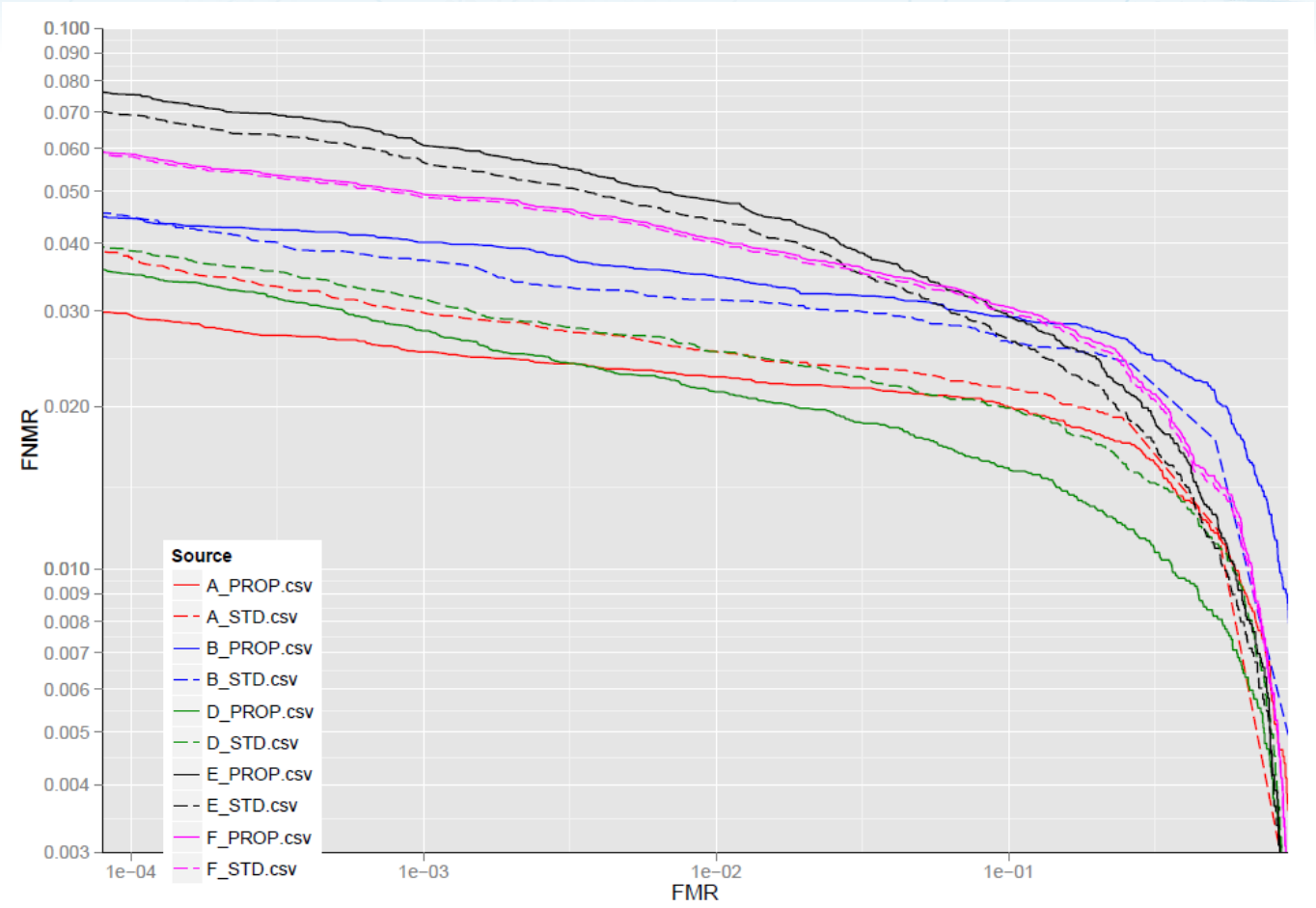
Devices A, B, D, E, F: all fingers combined



Homeland Security

Science and Technology

Native Performance – Proprietary and Standard-based



Homeland Security
Science and Technology

Native Performance – Difference due to ISO Standard Template Generation

Standard minus Proprietary FNMR – Table shows very little impact

Prop	A	B	D	E	F
0.0001	0.030	0.045	0.035	0.075	0.059
0.001	0.025	0.040	0.028	0.061	0.049
0.01	0.023	0.035	0.021	0.048	0.041
0.1	0.020	0.029	0.015	0.029	0.031
Std					
0.0001	0.038	0.045	0.039	0.069	0.058
0.001	0.030	0.037	0.032	0.057	0.049
0.01	0.025	0.032	0.025	0.044	0.040
0.1	0.022	0.026	0.020	0.027	0.030
Diff					
0.0001	0.008	0.000	0.004	-0.006	-0.001
0.001	0.005	-0.003	0.004	-0.005	0.000
0.01	0.003	-0.003	0.004	-0.004	-0.001
0.1	0.002	-0.003	0.005	-0.002	-0.001

Prop	A	B	D	E	F
0.0001	3.0%	4.5%	3.5%	7.5%	5.9%
0.001	2.5%	4.0%	2.8%	6.1%	4.9%
0.01	2.3%	3.5%	2.1%	4.8%	4.1%
0.1	2.0%	2.9%	1.5%	2.9%	3.1%
Std					
0.0001	3.8%	4.5%	3.9%	6.9%	5.8%
0.001	3.0%	3.7%	3.2%	5.7%	4.9%
0.01	2.5%	3.2%	2.5%	4.4%	4.0%
0.1	2.2%	2.6%	2.0%	2.7%	3.0%
Diff					
0.0001	0.8%	0.0%	0.4%	-0.6%	-0.1%
0.001	0.5%	-0.3%	0.4%	-0.5%	0.0%
0.01	0.3%	-0.3%	0.4%	-0.4%	-0.1%
0.1	0.2%	-0.3%	0.5%	-0.2%	-0.1%

Homeland Security

Science and Technology

Performance Data Tables

Table structure/organization

- Table values are FNMR values at 4 levels of FMR (0.0001 to 0.1)
  - For 3-Attempt transaction, values are FRR at 4 levels of FAR
- Columns are Probe devices. Blocks of 4 rows are Reference devices
- All values are decimal

Performance Data Tables

Use of shading

- As indicated in the Legend on each table, the FNMR (or FRR) values are shaded based on error level:
  - > 10% Yellow
  - > 5% Blue
  - > 2% Light Green
  - > 1% Dark Green
- This allows for a rapid visual assessment of the degree of achievement: **the more shading the better**, the **more green the better.**

Homeland Security
Science and Technology

Experiment 2 – Traditional Reference

	Ref	Probe->	C	D	E	F
		FMR	FNMR			
	A					
		0.0001	NS	NS	0.346	0.355
		0.001	NS	NS	0.277	0.300
		0.01	NS	NS	0.218	0.252
E2-1		0.1	NS	NS	0.154	0.200
	B					
		0.0001	NS	NS	0.318	0.274
		0.001	NS	NS	0.265	0.250
		0.01	NS	NS	0.214	0.226
		0.1	NS	NS	0.163	0.194
	A					
		0.0001	NS	0.180	0.346	0.360
		0.001	NS	0.130	0.277	0.305
		0.01	NS	0.095	0.218	0.257
E2-2		0.1	NS	0.065	0.154	0.204
	B					
		0.0001	NS	0.131	0.318	0.279
		0.001	NS	0.101	0.265	0.255
		0.01	NS	0.081	0.214	0.231
		0.1	NS	0.060	0.163	0.200

	Ref	Probe->	C	D	E	F
		FMR	FNMR			
	A					
		0.0001	NS	0.185	0.360	0.449
		0.001	NS	0.143	0.296	0.363
		0.01	NS	0.112	0.232	0.300
E2-3		0.1	NS	0.088	0.168	0.231
	B					
		0.0001	NS	0.155	0.347	0.422
		0.001	NS	0.118	0.289	0.341
		0.01	NS	0.097	0.230	0.276
		0.1	NS	0.079	0.167	0.219
	A					
		0.0001	0.071	0.099	0.238	0.312
		0.001	0.058	0.078	0.182	0.237
		0.01	0.049	0.067	0.134	0.181
E2-4		0.1	0.037	0.054	0.089	0.129
	B					
		0.0001	0.084	0.103	0.250	0.292
		0.001	0.071	0.086	0.204	0.231
		0.01	0.060	0.073	0.159	0.182
		0.1	0.050	0.061	0.114	0.131
		Legend	> 0.1	> 0.02	> 0.01	

NS = Not Supported (matcher or TG not provided)

Homeland Security
Science and Technology

Experiment 3.1 – Interoperability

Performance data table for Interoperability experiment, part 1, **Right IndeX** finger, **one** attempt (RIX-1), showing FNMR values at 4 levels of FMR across all device combinations.

(Color coding in accordance with the embedded legend)

E31 RIX-1						
Ref	**Probe->**	**A**	**B**	**D**	**E**	**F**
	FMR	FNMR				
A						
	0.0001	0.037	0.026	0.145	0.304	0.352
	0.001	0.031	0.019	0.102	0.218	0.277
	0.01	0.028	0.014	0.079	0.171	0.219
	0.1	0.023	0.014	0.069	0.122	0.163
B						
	0.0001	0.074	0.050	0.169	0.308	0.370
	0.001	0.062	0.045	0.133	0.247	0.289
	0.01	0.054	0.040	0.107	0.201	0.230
	0.1	0.045	0.032	0.086	0.145	0.180
D						
	0.0001	0.141	0.116	0.023	0.224	0.243
	0.001	0.115	0.092	0.021	0.172	0.192
	0.01	0.089	0.074	0.019	0.126	0.149
	0.1	0.070	0.056	0.018	0.079	0.112
E						
	0.0001	0.286	0.237	0.284	0.047	0.157
	0.001	0.221	0.193	0.214	0.035	0.133
	0.01	0.169	0.160	0.167	0.022	0.112
	0.1	0.129	0.122	0.117	0.013	0.096
F						
	0.0001	0.415	0.397	0.291	0.151	0.041
	0.001	0.318	0.297	0.248	0.131	0.036
	0.01	0.265	0.248	0.189	0.102	0.026
	0.1	0.215	0.217	0.131	0.067	0.021
	Legend	> 0.1	> 0.05	> 0.02	> 0.01	

Homeland Security
Science and Technology

Experiment 3.1 – Interoperability - 2

MINEX equivalent: For fused **Left-Right Index** fingers, **one** attempt (LRI-1), the overall error rates drop significantly from one-finger. Do not satisfy MINEX approval criteria.

E31 LRI-1						
Ref	**Probe->**	**A**	**B**	**D**	**E**	**F**
	FMR	FNMR				
A						
	0.0001	0.015	0.006	0.082	0.226	0.305
	0.001	0.015	0.003	0.055	0.163	0.248
	0.01	0.013	0.002	0.040	0.094	0.133
	0.1	0.011	0.002	0.028	0.055	0.067
B						
	0.0001	0.030	0.006	0.076	0.222	0.273
	0.001	0.024	0.006	0.055	0.157	0.222
	0.01	0.019	0.005	0.033	0.089	0.112
	0.1	0.013	0.001	0.026	0.062	0.052
D						
	0.0001	0.085	0.053	0.001	0.097	0.118
	0.001	0.064	0.036	0.001	0.072	0.094
	0.01	0.042	0.031	0.001	0.053	0.073
	0.1	0.032	0.023	0.001	0.035	0.042
E						
	0.0001	0.193	0.158	0.161	0.014	0.089
	0.001	0.148	0.121	0.120	0.009	0.078
	0.01	0.089	0.075	0.071	0.007	0.057
	0.1	0.066	0.046	0.046	0.004	0.039
F						
	0.0001	0.365	0.329	0.181	0.098	0.013
	0.001	0.304	0.236	0.138	0.078	0.010
	0.01	0.152	0.121	0.108	0.051	0.005
	0.1	0.091	0.071	0.072	0.033	0.002
	Legend	> 0.1	> 0.05	> 0.02	> 0.01	

Homeland Security
Science and Technology

Experiment 3.1 – Interoperability - 3

For fused **Left-Right Index** fingers, **three** attempts (LRI-3), some of the higher error rates drop. Indicates some "potential" for interoperability.

(this is best-case example)

E31 LRI-3						
Ref	**Probe->**	**A**	**B**	**D**	**E**	**F**
	FMR	FNMR				
A						
	0.0001	0.014	0.009	0.063	0.169	0.180
	0.001	0.014	0.006	0.046	0.133	0.169
	0.01	0.014	0.006	0.034	0.088	0.113
	0.1	0.012	0.006	0.024	0.051	0.036
B						
	0.0001	0.029	0.006	0.061	0.149	0.145
	0.001	0.023	0.006	0.042	0.107	0.117
	0.01	0.016	0.003	0.026	0.067	0.066
	0.1	0.010	0.003	0.026	0.037	0.021
D						
	0.0001	0.110	0.071	0.002	0.087	0.088
	0.001	0.076	0.052	0.002	0.066	0.067
	0.01	0.053	0.038	0.002	0.041	0.045
	0.1	0.032	0.025	0.002	0.033	0.026
E						
	0.0001	0.192	0.174	0.139	0.013	0.057
	0.001	0.157	0.143	0.097	0.013	0.049
	0.01	0.082	0.100	0.057	0.010	0.036
	0.1	0.059	0.062	0.035	0.010	0.022
F						
	0.0001	0.315	0.306	0.145	0.072	0.005
	0.001	0.268	0.221	0.119	0.061	0.002
	0.01	0.171	0.124	0.081	0.040	0.002
	0.1	0.109	0.075	0.059	0.035	0.002
	Legend	> 0.1	> 0.05	> 0.02	> 0.01	

Homeland Security
Science and Technology

Experiment 3.3 Traditional TG/Matcher

When images for all devices are processed with traditional TG and matcher, the results reflect the **utility of the images** per device. FNMR values are for LRI fusion, 3-attempts.

Devices A through D indicate potential for interoperability at the sensor image level.

E33 LRI-3							
Ref	**Probe->**	**A**	**B**	**C**	**D**	**E**	**F**
	FMR	FNMR					
A							
	0.0001	0.014	0.009	0.025	0.034	0.105	0.077
	0.001	0.014	0.006	0.022	0.032	0.096	0.075
	0.01	0.014	0.006	0.018	0.027	0.071	0.058
	0.1	0.012	0.006	0.010	0.022	0.031	0.022
B							
	0.0001	0.029	0.029	0.027	0.042	0.095	0.093
	0.001	0.023	0.023	0.025	0.029	0.073	0.081
	0.01	0.016	0.016	0.022	0.026	0.058	0.048
	0.1	0.010	0.010	0.022	0.026	0.049	0.024
C							
	0.0001	0.049	0.035	0.037	0.062	0.084	0.088
	0.001	0.042	0.033	0.027	0.056	0.071	0.081
	0.01	0.027	0.027	0.025	0.046	0.051	0.055
	0.1	0.021	0.022	0.025	0.035	0.031	0.017
D							
	0.0001	0.059	0.063	0.045	0.006	0.084	0.102
	0.001	0.049	0.038	0.036	0.006	0.069	0.079
	0.01	0.042	0.035	0.036	0.004	0.054	0.052
	0.1	0.030	0.027	0.028	0.004	0.023	0.026
E							
	0.0001	0.157	0.134	0.105	0.143	0.064	0.148
	0.001	0.127	0.112	0.090	0.108	0.056	0.131
	0.01	0.080	0.081	0.053	0.084	0.054	0.107
	0.1	0.042	0.025	0.025	0.032	0.026	0.036
F							
	0.0001	0.182	0.192	0.162	0.194	0.207	0.114
	0.001	0.170	0.158	0.149	0.162	0.202	0.100
	0.01	0.136	0.099	0.127	0.124	0.155	0.096
	0.1	0.052	0.058	0.039	0.043	0.042	0.030
	Legend	> 0.1	> 0.05	> 0.02	> 0.01		

Homeland Security
Science and Technology

Fusion Effect – across E3.x

2-finger fusion significantly reduces FNMR

Table values are the average change in FNMR for each experiment, across all devices

FUSION	E31		E32		E33	
EFFECT	1	3	1	3	1	3
LRI	-6.7%	-5.3%	-7.1%	-5.6%	-6.1%	-4.8%
LIM	-6.2%	-5.1%	-6.7%	-5.6%	-6.1%	-5.1%
RIM	-4.7%	-3.4%	-4.9%	-3.5%	-4.0%	-3.1%
LRT	-7.7%	-6.0%	-5.5%	-5.8%	-6.2%	-5.2%
		AVERAGE	-5.4%			
		AVG 1	-6.0%			
		AVG 3	-4.9%			

Homeland Security
Science and Technology

E31: Effects of Fusion and 3-attempts

Ref ↓ Probe->		A-1	A-3	B-1	B-3	D-1	D-3	E-1	E-3	F-1	F-3
		FNMR									
A	RIX	**0.028**	0.026	**0.014**	0.027	**0.079**	0.051	**0.171**	0.110	**0.219**	0.129
	LRI	0.013	0.014	0.002	0.006	0.040	0.034	0.094	0.088	0.133	0.113
	RIM	0.019	0.017	0.007	0.011	0.041	0.034	0.107	0.099	0.130	0.113
B	RIX	**0.054**	0.054	**0.040**	0.041	**0.107**	0.089	**0.201**	0.134	**0.230**	0.131
	LRI	0.019	0.016	0.005	0.003	0.033	0.026	0.089	0.067	0.112	0.066
	RIM	0.039	0.044	0.036	0.034	0.053	0.050	0.112	0.089	0.142	0.094
D	RIX	**0.089**	0.099	**0.074**	0.093	**0.019**	0.008	**0.126**	0.090	**0.149**	0.112
	LRI	0.042	0.053	0.031	0.038	0.001	0.002	0.053	0.041	0.073	0.045
	RIM	0.038	0.047	0.029	0.046	0.002	0.002	0.074	0.055	0.076	0.052
E	RIX	**0.169**	0.152	**0.160**	0.166	**0.167**	0.142	**0.022**	0.019	**0.112**	0.078
	LRI	0.089	0.082	0.075	0.100	0.071	0.057	0.007	0.010	0.057	0.036
	RIM	0.101	0.113	0.073	0.096	0.099	0.089	0.011	0.008	0.072	0.052
F	RIX	**0.265**	0.232	**0.248**	0.252	**0.189**	0.144	**0.102**	0.067	**0.026**	0.007
	LRI	0.152	0.171	0.121	0.124	0.108	0.081	0.051	0.040	0.005	0.002
	RIM	0.173	0.169	0.158	0.152	0.105	0.083	0.072	0.066	0.008	0.005

- Summary across E31 six datasets, for FNMR (or FRR) at FMR (or FAR) =0.01; the bold value indicates the single index performance.

Homeland Security

Science and Technology

Observations – Testing & Analysis

- Need for quality check during enrollment capture, to better mirror real world practices
- Variability in capture times drives equipment needs
- Analysis method for 3-attempt transaction could be improved (using fixed thresholds rather than max score)

Conclusions - Performance

- Standard template performance close to proprietary
- Native performance far better than cross-device
- Interoperability across devices is limited
- Fusion and multi-attempt transactions decrease matching error rates
- FAP 45 conducive to RIM or LIM (efficient simultaneous capture)
- As anticipated, NFIQ for NT devices does not predict matching performance or interoperability

Next steps

- for laboratories and testing
- for reusable interoperability testing protocol ??

Q&A

Homeland Security

Science and Technology

Homeland Security

Science and Technology

Abbreviation and Terms

FAR	False Accept Rate
FMR	False Match Rate
FNMR	False Non-Match Rate
FRR	False Reject Rate
FTIR	Frustrated Total Internal Reflection
IRB	Institutional Review Board
ISO	International Organization for Standardization
L	Left hand
LIM	Left index-middle fusion
LRI	Left-right index fusion
NFIQ	NIST Fingerprint Image Quality
NT	Non-traditional
Prop	Proprietary
R	Right hand
REF	Reference
RIM	Right index-middle fusion
RIX	Right index finger
Std	ISO Standard
TG	Template Generator