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Author(s):	**Lars Ericson, Ph.D., Stephen Shine**
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Evaluation of Contactless versus Contact Fingerprint Data, Phase 2

(Version 1.1)

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Prepared for

Defense Biometrics & Forensics
OSD AT&L, ASD(R&E)

Prepared by

ManTech Advanced Systems International
1000 Technology Drive, Suite 3310
Fairmont, West Virginia 26554
Telephone: (304) 368-4120
Fax: (304) 366-8096

Dr. Lars Ericson, Director

Stephen Shine (Azimuth, Inc.)

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EXECUTIVE SUMMARY

The National Institute of Justice (NIJ) Sensor, Surveillance, and Biometric Technologies (SSBT) Center of Excellence (CoE) has undertaken an evaluation of fingerprint data gathered from traditional contact-based legacy fingerprint (LFP) devices versus fingerprint data generated by next-generation contactless fingerprint (CFP) scanners. In 2012, the NIJ SSBT CoE evaluated a biometric collection of fingerprint data from traditional scanners and next generation contactless devices – Contactless Fingerprint Collection, Round 1 (CFPv1). Based on the success of CFPv1 and its value to the biometrics research community, a second collection of contact and contactless fingerprint data has been performed (CFPv2).[1] This report details experiments and analysis using the Phase 2 fingerprint data to investigate matching performance and interoperability of contact and contactless fingerprint devices. The analysis is focused on addressing the following objectives:

1. Determine the interoperability and match performance of CFP data against traditional LFP databases.
2. Investigate the performance and feasibility of a contactless fingerprint database for matching LFP and CFP systems against.
3. Evaluate the performance of criminal justice and/or defense relevant systems – fixed (i.e., livescan) and mobile devices.
4. Compare the match performance of data from CFPv2 with CFPv1.

Data

Data analysis was conducted using a fingerprint dataset collected by West Virginia University (WVU). The dataset is available for use by third-party research organizations. For comparison purposes, data from the CFPv1 collection was also used from certain devices (designated CFPv1 below). Fingerprint data used in this analysis was collected from the following devices:

1. Traditional Contact Fingerprint Devices:
    a. Cross Match Guardian R2 (CMR2) – Rolled and plain
    b. Cross Match SEEK Avenger (SEEK) – Rolled and plain
    c. MorphoTrak MorphoIDent (MID) – Prints
    d. MorphoTrust TouchPrint 5300 – Rolled and plain
    e. Northrop Grumman BioSled – Rolled and plain
    f. CMR2 (CFPv1) – Rolled
    g. TouchPrint 5300 (CFPv1) – Rolled
    h. SEEK II (CFPv1) – Rolled
2. Contactless Fingerprint Devices
    a. Advanced Optical Systems (AOS) ANDI On-The-Go (OTG) – Individual
    b. MorphoTrak Finger-On-The-Fly (FOTF) – Individual
    c. IDair innerID on iPhone 4 – Individual
    d. Touchless Biometric Systems (TBS) 3D Enroll – Individual

Experiments

The fingerprint image datasets were submitted as probes against enrollment galleries using the Neurotechnology MegaMatcher (MM) version 4.5 matching algorithm to determine the matching performance of images captured by different fixed and mobile biometric systems.

Table 1: Summary of Matching Runs

Probe Set	Enrollment	Gallery Set	Enrollment	True Match Rank 1	Score, Mean	Score, Std Dev
CMR2 Rolled	538	CMR2 Rolled	538	100.0%	2403	859
FOTF	537	FOTF	537	99.8%	3088	961
CMR2 Rolled (CFPv1)	4868	CMR2 Rolled (CFPv1)	4868	100.0%	2501	957
SEEK Rolled	537	CMR2 Rolled	538	97.8%	427	198
SEEK Plain	536	CMR2 Rolled	538	95.0%	296	152
MID	538	CMR2 Rolled	538	96.5%	247	120
TouchPrint Rolled	538	CMR2 Rolled	538	97.0%	447	201
TouchPrint Plain	538	CMR2 Rolled	538	96.7%	313	153
BioSled Rolled	537	CMR2 Rolled	538	96.3%	400	212
BioSled Plain	537	CMR2 Rolled	538	94.2%	278	156
ANDI OTG Grayscale	538	CMR2 Rolled	538	76.0%	72	44
ANDI OTG Binary	538	CMR2 Rolled	538	83.6%	110	68
FOTF	537	CMR2 Rolled	538	92.4%	144	78
innerID	537	CMR2 Rolled	538	2.2%	19	4
CMR2 Rolled	537	FOTF	537	92.0%	145	78
SEEK Plain	535	FOTF	537	87.2%	158	93
ANDI OTG Grayscale	537	FOTF	537	79.5%	123	72
ANDI OTG Binary	537	FOTF	537	83.2%	142	85
innerID	536	FOTF	537	2.0%	24	4
innerID Set 2	1579	innerID Set 1	1584	66.4%	188	141
SEEK II Rolled (CFPv1)	4868	CMR2 Rolled (CFPv1)	4868	97.7%	445	215
TouchPrint Rolled (CFPv1)	4866	CMR2 Rolled (CFPv1)	4868	96.5%	386	197
TBS HT1 (CFPv1)	4868	CMR2 Rolled (CFPv1)	4868	91.5%	215	136

Conclusions

In general, several key observations/conclusions were identified as a result of this analysis effort:

- This effort is the second quantitative demonstration by a third party that fingerprints collected under ideal conditions from LFP and CFP devices can be matched against each other in a statistically meaningful way.
  - **Conclusion:** The experimental methodology employed (data collection and analysis) can be used to determine a comparative match performance among LFP and CFP using two dimensional (2D) projections.

- The CFPv2 dataset possesses sufficient breadth and depth for investigating the performance and interoperability of CFP and LFP devices. Few biometric dataset resources exist that cover as many devices capturing the same subject pool.
  - **Conclusion:** The CFPv2 dataset is a unique and useful resource for biometric researchers that can further the understanding, performance, and adoption of CFP systems, as well as inter-device matching.

- The FOTF and OTG performed well against a LFP (see Section 5.4.1 Fixed System Results). Using single finger matching, the FOTF demonstrated a True Match Rate at Rank 1 (TMR) > 90% and Very Good quality images; the OTG produced TMR > 83% and Very Good – Excellent quality images.
  - **Conclusion:** The FOTF is a mature system and a possible candidate for operational environments.
  - **Conclusion:** The OTG is near production ready and with minor improvements in capture and image processing will be ready for operational consideration.

- The contact mobile devices performed well (both plain and rolled printed). The results were comparable to fixed livescan systems (see Section 5.4.2 Mobile Device Results).
  - **Conclusion:** The SEEK and BioSled are suitable for field enrollments, and are more than adequate for field queries.
  - **Conclusion:** The MID is well suited for field queries.

- The matching accuracy of a probe set was highest when matched against its same type (see Sections 5.4 LFP Gallery Results and 5.5 CFP Gallery). The OTG Grayscale images performed better against the CFP than they did against the LFP (TMR = 79.5% vs. 76.0%) and the SEEK Plain images performed worse against CFP than LFP (TMR = 87.2% vs. 95%).
  - **Conclusion:** The feature extraction process for MM (and possibly other matchers) may be different for CFP images than LFP images due to image characteristics and common image defects.

- The OTG Binary images led to a higher match accuracy than OTG Grayscale images (see Section 5.4.1 Fixed System Results). OTG Binary probes matched against the LFP resulted in a TMR = 83.6%, as compared to TMR = 76.0% for Grayscale images.
    - **Conclusion:** The use of a vendor-optimized binarization processing step after image capture could increase matching accuracy prior to submission to an agnostic third party Automated Fingerprint Identification System (AFIS) matcher, even if that matcher includes a standard binarization stage.

- The NIST Fingerprint Image Quality (NFIQ) score distributions of some CFP datasets were not fully consistent with the resulting match accuracy (see Section 5.4 LFP Gallery Results). The OTG Grayscale probe set had a high mean image quality ($NFIQ_{avg}$ = 1.9), but the lowest TMR of the datasets. The innerID probe set had an Average overall image quality ($NFIQ_{avg}$ = 2.7), but extremely low TMR.
    - **Conclusion:** The NFIQ algorithm may not be optimized for predicting match performance for certain kinds of CFP images.

- The innerID produced very low matching accuracy submitted against LFP or CFP galleries, but significantly higher matching when submitted against a second innerID gallery (see Section 5.6 innerID Comparison). Against a second device gallery, TMR = ~2% but against innerID Set 2 TMR = 66.4%.
    - **Conclusion:** Some CFP capture devices that perform poorly against third party databases may have a role in low security verification applications.
    - **Conclusion:** Test parameters need to mirror operational end-use rather than relying solely on simplified generic test procedures.

1.0 INTRODUCTION

The NIJ SSBT CoE has undertaken an evaluation of fingerprint data gathered from traditional contact-based fingerprint devices versus fingerprint data generated by next-generation contactless fingerprint scanners. The evaluation investigates the comparative match performance of LFP data and CFP data, for the purposes of exploring interoperability, technology viability, and challenges to operational deployment of next-generation contactless fingerprint systems.

In 2012, the NIJ SSBT CoE undertook a biometric collection of fingerprint data from traditional scanners and next generation contactless devices – Contactless Fingerprint Collection, Round 1 (CFPv1). This data was the first of its kind across the two classes of scanners using the same subject population. The data was used to evaluate the match performance and interoperability of contactless versus contact fingerprint data. These results were published in a 2014 report – *Evaluation of Contact versus Contactless Fingerprint Data*.[2] Based on the success of CFPv1 and its value to the biometrics research community, a second collection of contact and contactless fingerprint data has been performed (CFPv2).[1] This report details experiments and analysis using the Phase 2 fingerprint data to investigate matching performance and interoperability of contact and contactless fingerprint devices. The analysis is focused on addressing the following objectives:

1. Determine the interoperability and match performance of CFP data against traditional LFP databases.
2. Investigate the performance and feasibility of a contactless fingerprint database for matching LFP and CFP systems against.
3. Evaluate the performance of criminal justice and/or defense relevant systems – fixed (i.e., livescan) and mobile devices.
4. Compare the match performance of data from CFPv2 with CFPv1.

1.1 About the SSBT CoE

The NIJ SSBT CoE is a center within the National Law Enforcement and Corrections Technology Center (NLECTC) System.[3] The Center provides scientific and technical support to NIJ's research and development efforts. The Center also provides technology assistance, information, and support to criminal justice agencies. The Center supports the sensor and surveillance portfolio and biometrics portfolio. The CoEs are the authoritative resource within the NLECTC System for both practitioners and developers in their technology area(s) of focus. The primary role of the CoEs is to assist in the transition of law enforcement technology from the laboratory into practice by first adopters.

1.2 Disclaimers and Notices

DISCLAIMER: This project was supported by Award No. 2010-IJ-CX-K024 and 2014-ZD-CX-K001, awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice. The opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect those of the Department of Justice.

DISCLAIMER: The product information contained in this appendix has been provided by vendors. Commercial products included herein do not constitute an endorsement by NIJ, DOJ, NLECTC or ManTech. NIJ, DOJ, NLECTC and ManTech assume no liability for any use of this content. Product information is included for educational and reference purposes only. None of the claims contained in product summaries herein have been verified or validated. Any questions regarding a device should be directed to the vendor.

NOTE: The lack of available three dimensional (3D) matchers and varying collection methodologies and data formats used among 3D collection devices required the evaluation to focus on a format common to all devices: the 2D legacy fingerprint image. Due to the limitations of 3D images converted to 2D images, the quality or efficacy of the 3D contactless fingerprint devices in capturing topological fingerprint details was not investigated.

NOTE: Raw 3D images generated from optical structured light (e.g., Morpho Finger-On-The-Fly) and other methods are not directly compatible with existing fingerprint matching algorithms. As a result, all analysis discussed in this report does not utilize this 3D fingerprint data directly, rather the analysis is performed on images obtained from each 3D system's transformation of the scanned data into 2D grayscale images that are intended by their vendors to be matchable against existing fingerprint databases.

NOTE: No fusion techniques have been incorporated into the matching runs or analyses. In operational deployments, some systems may utilize multi-finger fusion methods as a standard part of the identification process when communicating with an AFIS database (local or remote) to improve match performance. Operational testing is strongly recommended to better reflect real-world performance.

NOTE: Matching results are strongly dependent on the type of matching algorithm utilized and any optimization performed in configuring the matcher for a specific application. Neurotechnology MegaMatcher is an average matcher (as reported in National Institute of Standards and Technology (NIST) testing), but other matchers have been shown to provide more accurate results.[4]

NOTE: Fingerprint images contained in this report are reproduced with permission from the collected subjects for research reporting purposes in accordance with Institutional Review Board (IRB) approved protocols.

2.0 BACKGROUND

2.1 Data Source: WVU Fingerprint Collection, Phase 2

The data analysis was conducted using a fingerprint dataset collected by WVU. For WVU IRB and data request purposes, the collection, protocol, and dataset are formally titled "ManTech Innovations Fingerprint Study Phase 2." The dataset is available for use by third-party research organizations by submitting an email request to wvubiometricdata@mail.wvu.edu. The full report detailing the WVU fingerprint collection is included in APPENDIX A: WVU COLLECTION REPORT for reference. Fingerprint data was collected from 450 unique subjects in a controlled, sterile environment during the time period of November 2014 – April 2015 on the following devices:

1. Rolled-ink fingerprint cards – Rolled and prints, 500 and 1000 dpi scans, 10 fingers
2. Traditional Contact Fingerprint Devices:
    a. Cross Match Guardian R2 (CMR2) – Rolled and plain, 10 fingers
    b. Cross Match SEEK Avenger (SEEK) – Rolled and plain, 10 fingers
    c. MorphoTrak MorphoIDent (MID) – Prints, 10 fingers
    d. MorphoTrust TouchPrint 5300 – Rolled and plain, 10 fingers
    e. Northrop Grumman BioSled – Rolled and plain, 10 fingers
3. Contactless Fingerprint Devices
    a. AOS ANDI On-The-Go (OTG) – Individual, Right hand 4 fingers
    b. MorphoTrak Finger-On-The-Fly (FOTF) – Individual, 8 fingers no thumbs
    c. IDair innerID on iPhone 4 – Individual, 10 fingers
        i. *Due to technical issues, the innerID was not operational during the entire collection. As a result, data from only a third of the subjects was collected.*

2.2 Fingerprint Scanners

Eight fingerprint scanners were included in this effort – 5 traditional contact-based devices and 3 contactless devices. The devices were chosen to satisfy a combination of factors:

1. Provide a link to Phase 1 efforts so as to provide a context to previous results for comparison purposes (e.g., CMR2, TouchPrint 5300).
2. Operate within resource and schedule constraints.
3. Accommodate integration into a laboratory collection infrastructure with custom database and the lack of an AFIS server.
4. Contribute to stakeholder biometric RDT&E and acquisition efforts currently underway.
5. Facilitate multiple research investigations (e.g., Contact vs. Contactless, Differing Mobile Platforms).
6. Utilize available systems.

Efforts were made to contact all known contactless fingerprint device developers and vendors. Many were unresponsive. Some were supportive, but their devices were not at a suitable development stage for inclusion in the collection. Vendors were allowed to submit device summaries for inclusion in this report. Rather than repeating that information, readers are directed to review APPENDIX B: COLLECTION DEVICE SUMMARIES for more information on the devices. Some results from CFPv1 are utilized for comparison purposes. Summaries of those devices can be found in APPENDIX C: COLLECTION DEVICE SUMMARIES – CFPv1.

2.3 Evaluation of Contactless vs. Contact Fingerprint Data, Phase 1

In 2012, the SSBT CoE undertook a biometric collection of fingerprint data from traditional scanners and next generation contactless devices. This effort is referred to as CFPv1 (contactless fingerprint project version 1). This data was the first of its kind across the two classes of scanners using the same subject population. The data was used to evaluate the match performance and interoperability of contactless versus contact fingerprint data. These results were published in a 2014 report – *Evaluation of Contact versus Contactless Fingerprint Data*.[2] A summary of those evaluation results and conclusions is included here for reference.

Phase 1 utilized a dataset collected by WVU in 2012 under an earlier SSBT CoE initiative. For WVU IRB and data request purposes, the collection, protocol, and dataset are formally titled "ManTech Innovations Fingerprint Study." The dataset is available for use by third-party research organizations by submitting an email request to wvubiometricdata@mail.wvu.edu. The full report detailing the WVU fingerprint collection is publically available.[5] Fingerprint data was collected from 500 unique subjects in a controlled, sterile environment during the time period of April – July 2012 on the following devices:

4. Rolled-ink fingerprint cards – Digitized at 500 dpi and 1000 dpi
5. Legacy Fingerprint Devices:
    a. Cross Match Guardian R2 – Rolled fingers and slaps
    b. i3 DigID Mini – Rolled fingers and slaps
    c. L1 TouchPrint 5300 – Rolled fingers and slaps
    d. SEEK II – Rolled fingers and prints
6. Contactless Fingerprint Devices
    a. Touchless Biometric Systems (TBS) 3D Enroll Device – Individual fingers
    b. FlashScan 3D Single Finger Scanner – Individual fingers
    c. FlashScan 3D 4-Finger Slap D4 Scanner – Slaps
        i. *Due to technical issues, the D4 was not operational during the entire collection. As a result, data from only 184 subjects was collected on the FS3D D4.*

Twenty matching runs were performed on the rolled and 2D grayscale rolled-equivalent fingerprint data collected from devices and card-scans using the Neurotechnology MM Suite fingerprint algorithm (version 4.2) software. The various matching efforts are organized into the following categories:

- Galleries were matched against themselves to establish ground truth performance
- LFP datasets were matched against LFP galleries

- CFP datasets were matched against LFP galleries
- CFP dataset were matched against CFP galleries
- Select LFP datasets were matched against a CFP gallery

Matching results were analyzed and compared based on True Accept Rate (TAR) and NFIQ score. A summary of matching results is included here:

Table 2: CFPv1 Matching Runs Results

MATCHING RUNS	True Match at Rank 1 (Based on Matched Pairs)	False Match at Rank 1 (Based on Matched Pairs)
Gallery Runs		
GR1- Cross Match R2 Set 1 vs. Set 1	100%	0%
GR2- Cross Match R2 Set 2 vs. Set 2	100%	0%
GR3- Card Scan 500 dpi vs. 500 dpi	100%	0%
GR4- FlashScan Single vs. Single	100%	0%
GR5- TBS (HT1) vs. TBS (HT1)	100%	0%
2D LFP Runs		
LFPR1- I3 vs. G1	92.66%	7.34%
LFPR2- L1 vs. G1	96.58%	3.42%
LFPR3- Card Scan 500 dpi vs. G1	91.34%	8.66%
LFPR4- Cross Match SEEK vs. G1	97.80%	2.20%
CFP to LFP Runs		
CFPR1- FlashScan Single vs. G1	71.40%	28.60%
CFPR2- FlashScan D4 vs. G1	17.05%	82.95%
CFPR3- TBS (HT1) vs. G1	91.15%	8.85%
CFPR4- TBS (HT2) vs. G1	85.67%	14.33%
CFPR5- TBS (HT6) vs. G1	86.42%	13.58%
CFP to CFP Runs		
CFPR6- FlashScan D4 vs. G4	11.80%	88.20%
CFPR7- TBS (HT1) vs. G4	65.75%	34.25%
CFPR8- TBS (HT2) vs. G4	56.53%	43.47%
Additional GR5 Runs		
AR1- FlashScan Single vs. G5	65.64%	34.36%
AR2- Cross Match R2 Set 1 vs. G5	90.73%	9.27%
AR3- Cross Match SEEK vs. G5	91.20%	8.80%

In general, seven key observations/conclusions were identified as a result of this evaluation effort:

- This effort is the first quantitative demonstration by a third party that fingerprints collected under ideal conditions from LFP and CFP devices can be matched against each other in a statistically meaningful way.
    - Conclusion: The experimental methodology employed (data collection and analysis) can be used to determine a comparative match performance among LFP and CFP using 2D projections.

- Matching CFP legacy-equivalent images to LFP images provides less match performance than LFP images to LFP images.
    - Conclusion: More work is needed to improve the quality of captured images or the quality of 2D legacy-equivalent conversions. Additional research opportunities may exist in developing or modifying fingerprint matching algorithms that are less sensitive to skin elasticity.

- Matching CFP legacy-equivalent images between the various contactless devices provided very poor results as compared to currently available technologies.
    - Conclusion: Additional research may be necessary to provide better CFP to LFP conversion algorithm accuracy.

- The ink and paper collection provided lower similarity scores from the fingerprint matcher and had poorer NFIQ scores. We assume from this finding that ink and paper fingerprinting requires more skill and experience than collecting on live scan devices. Additionally, live scan fingerprint collection devices generally provide immediate quality feedback and the opportunity to recollect a poor fingerprint.
    - Conclusion: Rolled-ink tenprint cards may not be the "gold standard" ground-truth gallery for biometric testing or research

- The Cross Match SEEK II performed better than expected as a livescan collection device, as compared to the other legacy CFP systems. The reason for expectations of lower match performance was due to the smaller platen surface area.
    - Conclusion: SEEK may be suitable for field enrollments, and is more than adequate for field queries.

- The FlashScan D4 performed very poorly. The device had several failures during collection efforts and required vendor support. Also, due to the failures this device had the fewest number of collection subjects.
    - Conclusion: Data from prototypes can be significantly poorer than commercial systems using similar capture approaches, and therefore the purpose/objective of data collections should be taken into account when considering the inclusion of prototypes.

- The images collected by the TBS 3D Enroll are mirrored along the vertical axis, causing an inability to match against standard datasets. The Test Team corrected the images locally prior to testing. Images in the WVU dataset remain unchanged.
    - Conclusion: Devices developed for civilian access control applications, or for foreign markets, may not follow standard Appendix F requirements. RDT&E must be aware of potential issues.

3.0 TEST ENVIRONMENT & APPROACH

3.1 System Test Environment

The lab evaluation environment consisted of the resources needed to evaluate the fingerprint images collected from the devices in the WVU dataset. The hardware environment for the evaluation consisted of a Windows 7 (64 bit) operating system executing on a Dell Precision T7500 64-bit with a dual quad core processor. It has 12 Gigabytes (GB) of system RAM, a 256 GB solid state drive, and two 1 Terabyte (TB) hard drives configured as a RAID 1 drive. The image datasets were temporarily hosted on the computers during matching run processing, but are permanently stored on an encrypted external hard drive for archival and security purposes. These computers hosted the Neurotechnology's MM algorithm and gallery manager.

The algorithm selected to verify and evaluate the performance of the matching was Neurotechnology MM version 4.5. The MM was utilized in the CFPv1 evaluations previously conducted; it was also selected based on its low cost, product maturity, performance, and experience integrating it into many products.

NOTE: Matching results are strongly dependent on the type of matching algorithm utilized and any optimization performed in configuring the matcher for a specific application. Neurotechnology MegaMatcher is an average matcher (as reported in NIST testing), but other matchers have been shown to provide more accurate results.[4]

3.2 Fingerprint Data

The fingerprint data used by this evaluation consisted of finger images collected in the CFPv2 WVU biometric collection detailed previously (see Section 2.1 Data Source: WVU Fingerprint Collection, Phase 2). Two sets of fingerprint data were captured from each device and are contained in the WVU collection dataset. The data was captured on contactless and contact devices alike. Although the device collections contain multiple datasets, due to time and resource constraints only one set from each device was used in this evaluation. In the case of the Morpho FOTF, the capture process involved collecting two sets of prints for a single session. However, the output files are organized as separate image folders. The folder with the most images was selected for these evaluations. Note that in an operational setting, these two image sets would likely be combined using a fusion approach to improve the device match performance. The images underwent several processing and data integrity steps before use in the matching runs and analysis contained herein.

1. The data received from WVU was organized by subject ID and collection session. To enable batch matching, the files were binned into folders designating device and capture type (i.e., rolled or print).

2. All file names were reviewed to ensure that they followed a standard naming format. If the files could not be readily identified, then the files were discarded for data integrity purposes. This was only necessary on one or two instances. This was important because the biometric test environment developed to executing matching runs used the filename to extra matching run parameters, such as finger position and subject ID.

3. In a couple of device datasets, it was clear that a couple of images had not been captured during set 1 (e.g., 2399 images for 240 subjects with 10 fingers each). When possible, the Set 2 was examined to determine if that missing subject/finger image was present and, if so, included in the device data set for these evaluations. Since the TMR for matching runs is calculated using captured images and not subject finger presentations to the device, this does not affect the metrics only the available data.

4. Devices that captured plain images (i.e., slaps) were often output by the device as a combined image (e.g., all four fingerprints from one hand as a single image). To facilitate individual finger matching, those images were segmented using a photo processing tool and saved as individual fingerprint images.

5. A custom batch utility was used to correct the image file header information to specify 500 dpi. Several devices are known to capture images at 500 dpi (according to vendor product specifications), however that information is not properly contained in the image file. MM utilizes that information when evaluating an image's suitability for ingestion during the matching process.

6. A custom batch utility was used to compare all the data subsets and then create a duplicate folder that contained only files where the subject ID and finger position was common across all subsets. This ensures that ever image has a counterpart in ever device/print type dataset. Two datasets contributed the primary filtering factors in the final matching dataset:
    a. ANDI OTG was only designed to capture the four fingers on the right hand.
    b. InnerID became inoperable part way during the collection, reducing the number of captured subjects.

After following the data processing steps outlined above, the resulting data consisted of thirteen datasets for eight (8) devices plus ink cards. Each dataset contained 538 images of the four fingers on the right hand from 135 subjects for 100% N:N compatibility.

- Data Sets
    - CMR2 rolled prints
    - SEEK rolled and plain prints
    - TouchPrint rolled and plain prints
    - innerID plain fingers
    - BioSled rolled and plain prints
    - Tenprint card rolled prints
    - MorphoIDent plain prints
    - Morpho FOTF plain prints
    - ANDI OTG plain prints, grayscale and binary

3.2.1 CFPv1 Collection Data

For comparison purposes, some matching runs were performed using datasets from the Phase 1 CFPv1 WVU collection (see Section 2.3 Evaluation of Contactless vs. Contact Fingerprint Data, Phase 1). A detailed description of the collection and data preparations can be found in the 2014 report – *Evaluation of Contact versus Contactless Fingerprint Data*.[2] This work did not simply repurpose the results from those evaluations because the MM algorithm had updated from version 4.2 to 4.5 in the interim time. As a result, the data was used to rerun matching runs for a more accurate comparison.

3.3 Matching Run Evaluation Methodology

The MM algorithm was utilized to evaluate the match performance of the baseline processed fingerprint data and minutia deviation-filtered datasets. The focus of the evaluation was on the comparative performance of the fingerprint data from different devices and not the performance of the well-established biometric matching algorithm. In addition, the evaluation was also focused on data interoperability and match performance and not device function and operational suitability. A custom-made biometric test environment was utilized that incorporated the matcher software development kit (SDK) with an SQL database for storing matching run results. This test environment had the same framework as the one used in CFPv1, but modified to utilize MM 4.5 (vs. MM 4.2 in previous work) to be able to accept gallery and probe submissions.

For a given matching run, the gallery was created by enrolling a set of images. MM had no issues with enrolling the pre-determined images and it was a relatively straightforward process. The SQL gallery database was double checked to confirm that there were no duplicate enrollments. The probe datasets were submitted using the same biometric test environments against the previously loaded gallery. A new gallery was created for each probe set to ensure a blank slate for matching activities. MM did not accept probe submissions that did not possess a fingerprint, as determined by its own internal quality checks.

The output of a matching run was an SQL database populated with matching results and data parameters. The database was used to generate matching run reports that were used as inputs to a robust excel spreadsheet used to generate matching run statistics and analyses. Data integrity checks were used in all matching runs to ensure that the results were consistent with the known probe and gallery image set inputs and that all subjects present in the probe set also existed in the gallery set. The primary matching run metrics used in subsequent analyses were the True Match Rate at Rank 1 (TMR), False Match Rate at Rank 1 (FMR), Similarity Score Mean, Similarity Score Standard Deviation, and True Match (TM) rate at ranks 1 – 10.

3.3.1 Match Rates

The number of TMs was calculated as the number of matches at rank 1 returned by the algorithm where the probe ID number was equal to the gallery ID number and the probe finger position number was equal to the gallery finger position number. Similarly the number of False Matches (FMs) was the number of matches at rank 1 where the ID numbers and/or finger position numbers were not equal. The TMR and FMR were determined by dividing the number of matches in each case by the total number of probe submissions.

3.3.2 Similarity Score

The similarity score is a metric for the probability that a matched pair of biometrics originated from the same person. Each algorithm utilizes its own (proprietary) method to arrive at a similarity score, thus resulting in different scales and common values. Based on the Gallery vs. Gallery matches (see Section 4.1 Gallery Matching Runs) the scores for CFPv2 range from 0 – 6,300 for MM, with a higher score indicating a higher confidence of the match being a TM. For each matching run, the mean similarity score and its standard deviation were calculated for comparison purposes. Generally, a matcher threshold (specific similarity score value) is used to truncate all matches below the threshold to a null value to guarantee a non-match result. Because the matcher similarity score threshold was set to zero all matches returned a similarity score value that was needed and used in this analysis.

To aid in visualization, the scores were binned across the range of common values as determined by the maximum scores observed in the various matching runs. In this evaluation the CMR2 Rolled Gallery vs. Gallery matching results produced the largest similarity scores and thus provided a guideline for the axis settings and bin values for created the graphs. According to MM documentation, the matching threshold of its system is directly linked to the False Accept Rate (FAR), the probability that biometrics from different subjects are erroneously accepted as a TM. Neurotechnology provides an equation and resulting FAR-Threshold equivalence table in the SDK documentation.[6]

Table 3: MegaMatcher False Accept Rate vs. Similarity Score

FAR	Matching Threshold Score
100%	0
10%	12
1%	24
0.1%	36
0.01%	48
0.001%	60
0.0001%	72
0.00001%	84
0.000001%	96

4.0 EXPERIMENT RESULTS

The fingerprint image datasets were submitted as probe sets against enrollment galleries using the MM matching algorithms to determine the matching performance of images captured by different fixed and mobile biometric systems. The details of the evaluation methodology are provided in Section 3.3 Matching Run Evaluation Methodology. The following matching runs were conducted, for a total of 18 runs:

- Gallery vs. Gallery
  - CMR2 Rolled
  - FOTF
- LFP Gallery (CMR2 Rolled)
  - SEEK Rolled and Plain
  - MID
  - TouchPrint Rolled and Plain
  - BioSled Rolled and Plain
  - ANDI OTG Grayscale and Binary
  - FOTF
  - innerID
- CFP Gallery (FOTF)
  - CMR2 Rolled
  - SEEK Plain
  - ANDI OTG Grayscale and Binary
- innerID Set 2 vs. innerID Set 1

To aid in the evaluation of the CFPv2 data, the following matching runs were performed using the previous CFPv1 data to provide a more direct comparison:

- CMR2 Rolled vs. CMR2 Rolled (cfpv1)
- SEEK II Rolled vs. CMR2 Rolled (cfpv1)
- TouchPrint Rolled vs. CMR2 Rolled (cfpv1)
- TBS HT1 vs. CMR2 Rolled (cfpv1)

Results from each of the matching runs were used to calculate the following metrics and matching run statistics. To simplify results reporting, a description of these items is provided here, but not repeated in each of the individual matching runs.

- **Total Enrollments –** Number of images enrolled in the gallery
- **Unique Subjects –** Number of unique subjects represented in the gallery
- **Submissions –** Number of probe images submitted to the matcher
- **Probes Accepted –** Number of probe images processed by the matcher and subsequently matched against the enrollment gallery
- **Unique Subjects –** Number of unique subjects represented in the Probes Accepted data set
- **True Matches (TMs) –** Number of rank 1 match results returned by the matcher where the probe ID and finger position is the same as the gallery ID and finger position

- **False Matches (FMs) –** Number of rank 1 match results returned by the matcher where the probe ID and finger position are NOT the same as the gallery ID and finger position
- **Total Matches (TMs) –** Total number of matches performed by the algorithm with a given probe set and gallery set in which all probes are matched against all gallery images
- **Percent –** TMR or FMR for a given matching run; the fraction of probe submissions returned as True Matches or False Matches
- **Score, Mean –** The mean average similarity score for either the set of TMs or FMs
- **Score, Std Dev –** The standard deviation of the similarity scores for either the set of TMs or FMs
- **Non-Match Rate –** The fraction of probe submissions that are NOT accepted by the matcher and therefore not pitted against the enrollment gallery

In addition to the matching run statistics, a graphical plot is provided for each matching run that depicts the TMR vs. Frequency for a given matching run. This graph depicts how often the TM was returned at a given rank for an entire probe submission set. Note that this TMR is calculated based on initial number of probe submissions and not total number of accepted probes.

The second graphic for each matching run (except for gallery vs. gallery runs) is the frequency distribution of similarity scores for the TMs and FMs returned in the rank 1 position. To aid in visualization, the MM matcher scores were sorted with a bin size of 10 (or bin size of 50 for gallery vs. gallery runs). This was chosen simply based on the range of scores returned for the non-gallery matching runs.

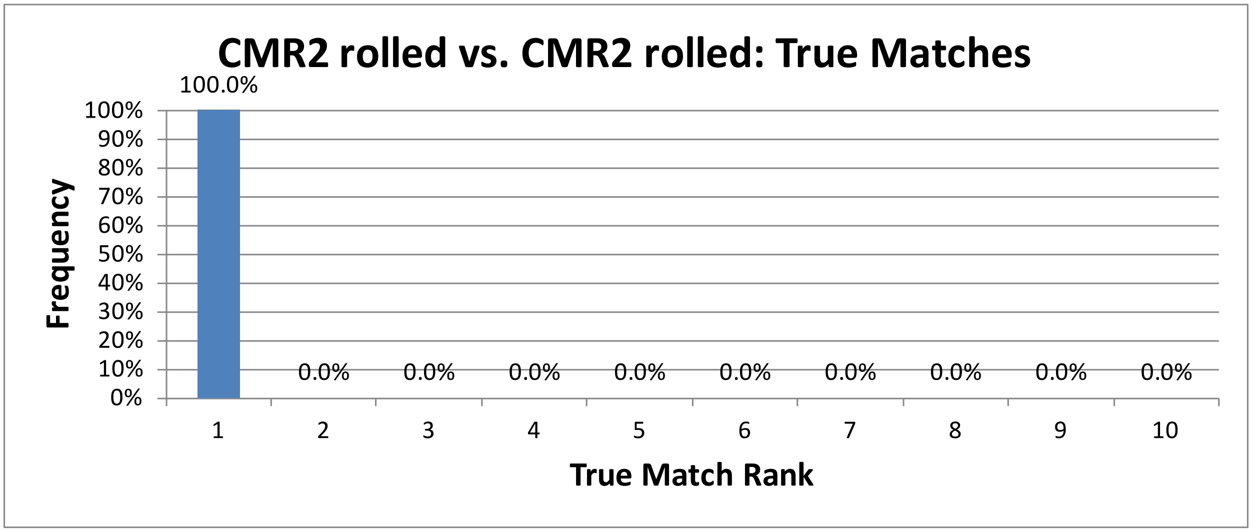
Table 4: Summary of Matching Runs

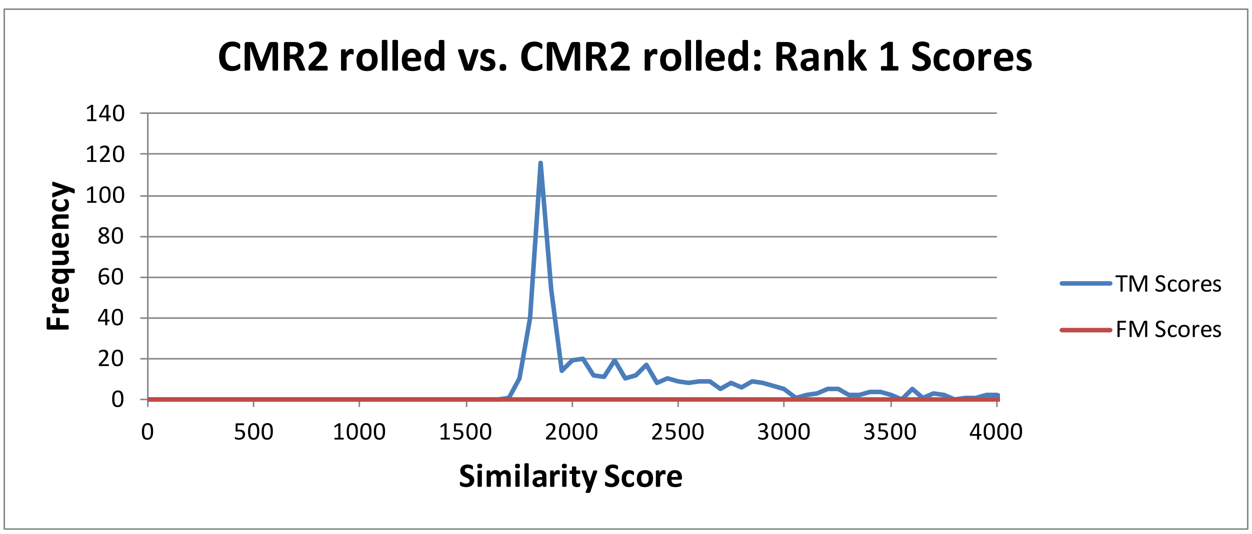
Probe Set	Enrollment	Gallery Set	Enrollment	TM Rank 1	Score, Mean	Score, Std Dev
CMR2 Rolled	538	CMR2 Rolled	538	100.0%	2403	859
FOTF	537	FOTF	537	99.8%	3088	961
CMR2 Rolled (CFPv1)	4868	CMR2 Rolled (CFPv1)	4868	100.0%	2501	957
SEEK Rolled	537	CMR2 Rolled	538	97.8%	427	198
SEEK Plain	536	CMR2 Rolled	538	95.0%	296	152
MID	538	CMR2 Rolled	538	96.5%	247	120
TouchPrint Rolled	538	CMR2 Rolled	538	97.0%	447	201
TouchPrint Plain	538	CMR2 Rolled	538	96.7%	313	153
BioSled Rolled	537	CMR2 Rolled	538	96.3%	400	212
BioSled Plain	537	CMR2 Rolled	538	94.2%	278	156
ANDI OTG Grayscale	538	CMR2 Rolled	538	76.0%	72	44
ANDI OTG Binary	538	CMR2 Rolled	538	83.6%	110	68
FOTF	537	CMR2 Rolled	538	92.4%	144	78
innerID	537	CMR2 Rolled	538	2.2%	19	4
CMR2 Rolled	537	FOTF	537	92.0%	145	78
SEEK Plain	535	FOTF	537	87.2%	158	93
ANDI OTG Grayscale	537	FOTF	537	79.5%	123	72
ANDI OTG Binary	537	FOTF	537	83.2%	142	85
innerID	536	FOTF	537	2.0%	24	4
innerID Set 2	1579	innerID Set 1	1584	66.4%	188	141
SEEK II Rolled (CFPv1)	4868	CMR2 Rolled (CFPv1)	4868	97.7%	445	215
TouchPrint Rolled (CFPv1)	4866	CMR2 Rolled (CFPv1)	4868	96.5%	386	197
TBS HT1 (CFPv1)	4868	CMR2 Rolled (CFPv1)	4868	91.5%	215	136

4.1 Gallery Matching Runs

4.1.1 CMR2 Rolled vs. CMR2 Rolled

MegaMatcher		Results	Percent	Score, Mean	Score, Std Dev
Gallery	**Total**	538			
CMR2 Rolled	**Unique Galleries**	538			
Probe	**Submissions**	538			
CMR2 Rolled	**Total Qualified**	538	100.0%		
	Unique Probes	538			
Matches	**True Matches**	538	100.0%	2403	859
	False Matches	0	0.0%	#DIV/0!	#DIV/0!
	Total Matches	289444			

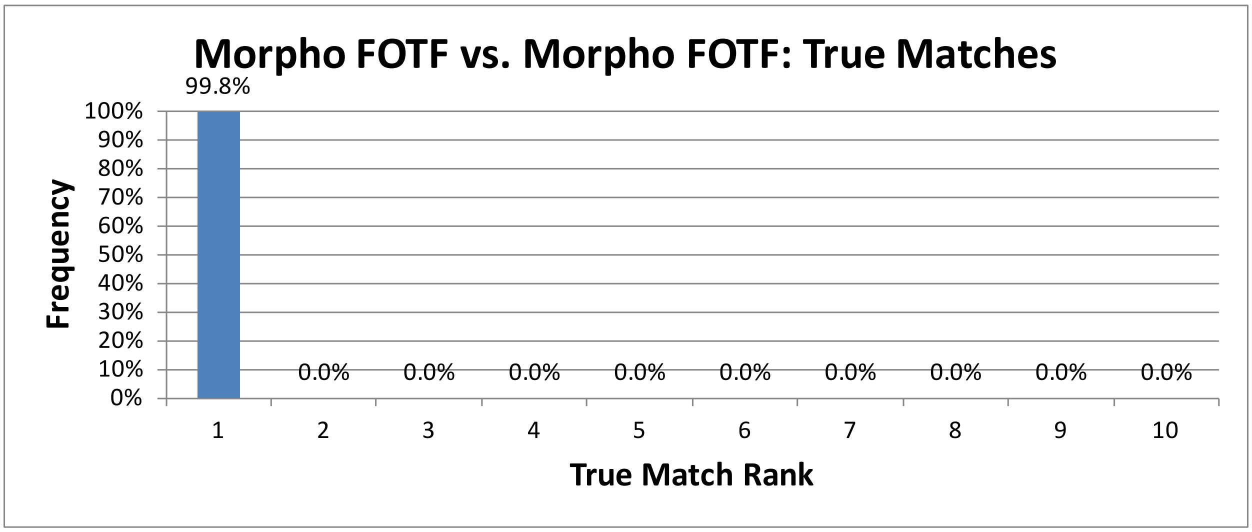


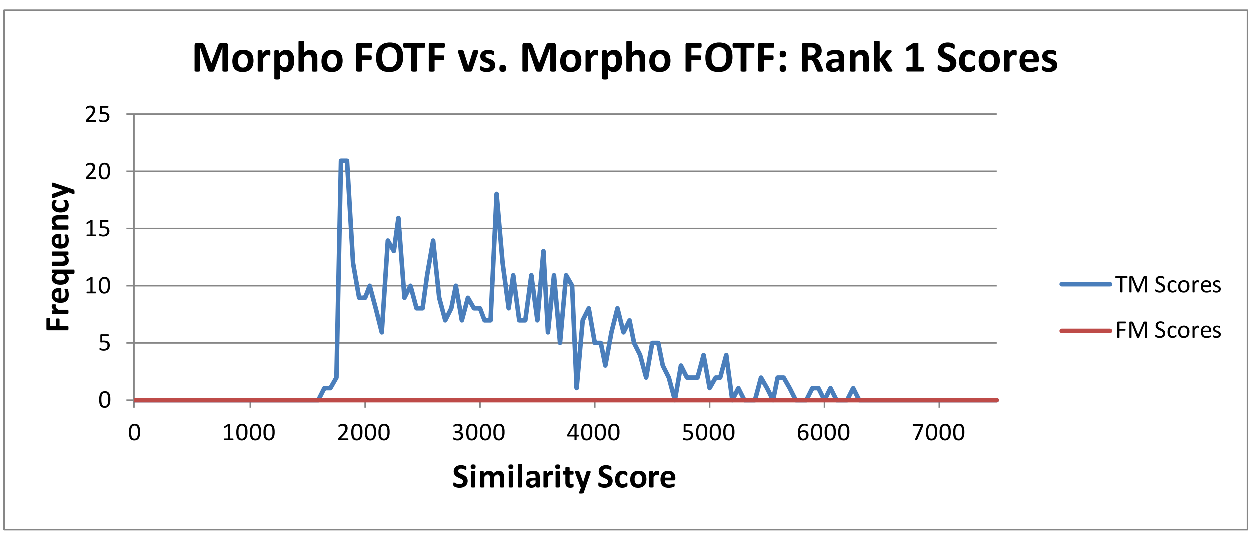


4.1.2 FOTF vs. FOTF

One of the FOTF images failed to enroll due to image quality. As a result, all matches against the FOTF gallery excluded that subject ID/finger position from the probe set to ensure 100% correspondence between probes and gallery images.

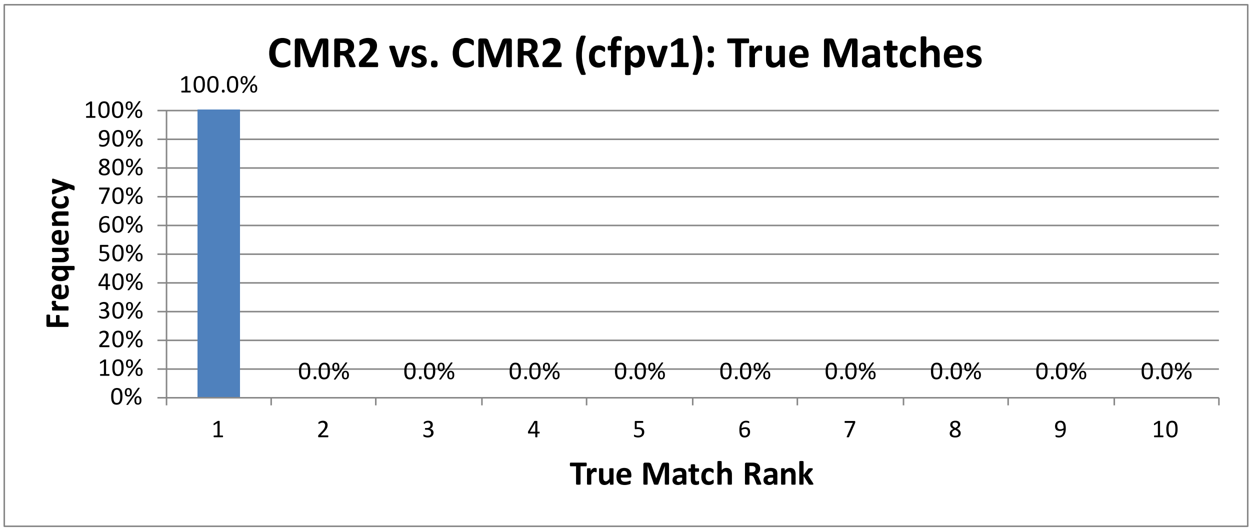
MegaMatcher		Results	Percent	Score, Mean	Score, Std Dev
Gallery	**Total**	537			
Morpho FOTF	**Unique Galleries**	537			
Probe	**Submissions**	538			
Morpho FOTF	**Total Qualified**	537	99.8%		
	UniqueProbes	537			
Matches	**True Matches**	537	99.8%	3088	961
	False Matches	0	0.0%	#DIV/0!	#DIV/0!
	Total Matches	288369			

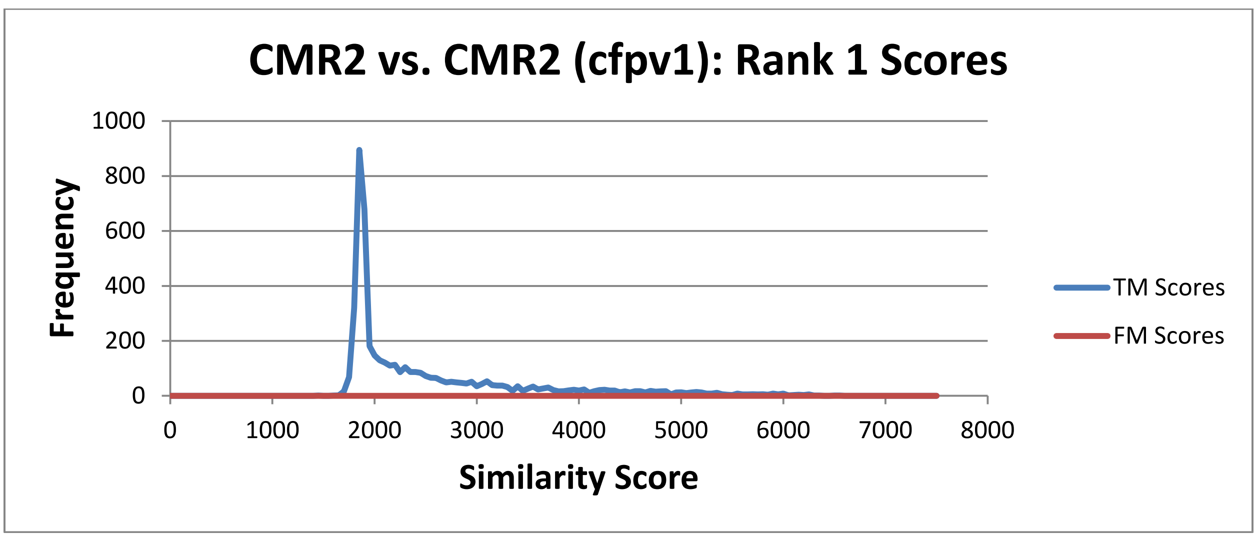




4.1.3 CMR2 Rolled (CFPv1) vs. CMR2 Rolled (CFPv1)

MegaMatcher		Results	Percent	Score, Mean	Score, Std Dev
Gallery	**Total**	4868			
CMR2 Set1	**Unique Galleries**	4868			
Probe	**Submissions**	4868			
CMR2 Set1	**Total Qualified**	4868	100%		
All images uniform	**Unique Probes**	4868			
Matches	**True Matches**	4868	100%	2501	957
	False Matches	0	0%	#DIV/0!	#DIV/0!
	Total Matches	23697424			

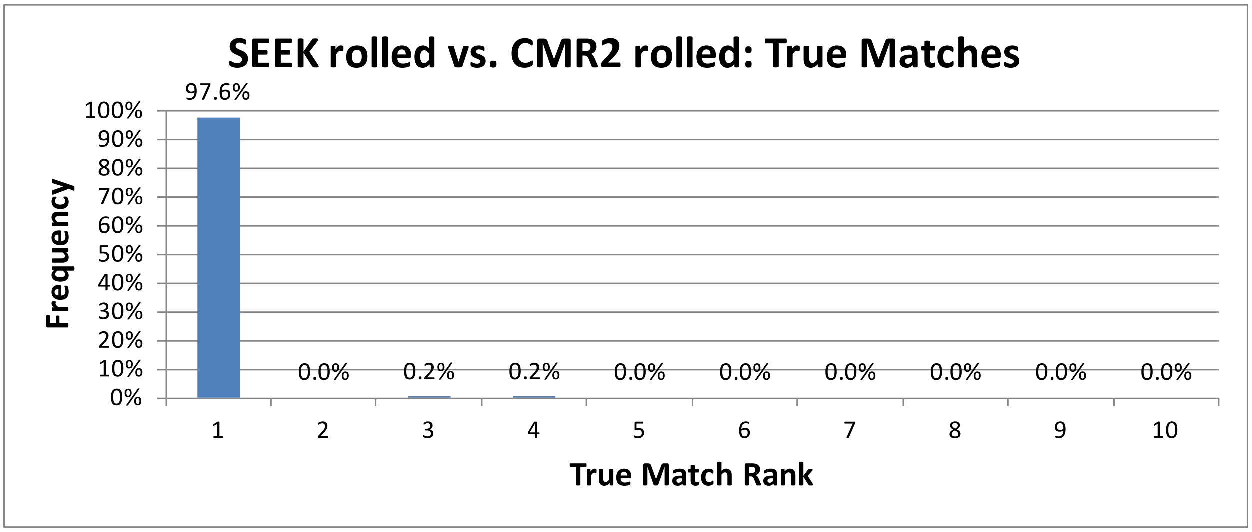


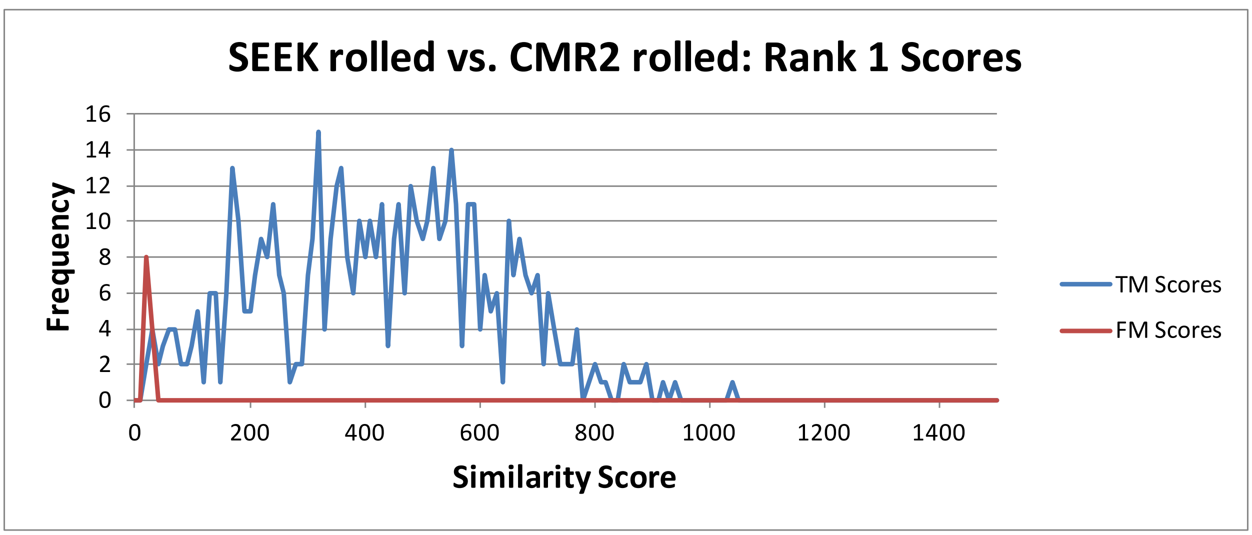


4.2 CMR2 Rolled Gallery Matching Runs

4.2.1 SEEK Rolled vs. CMR2 Rolled

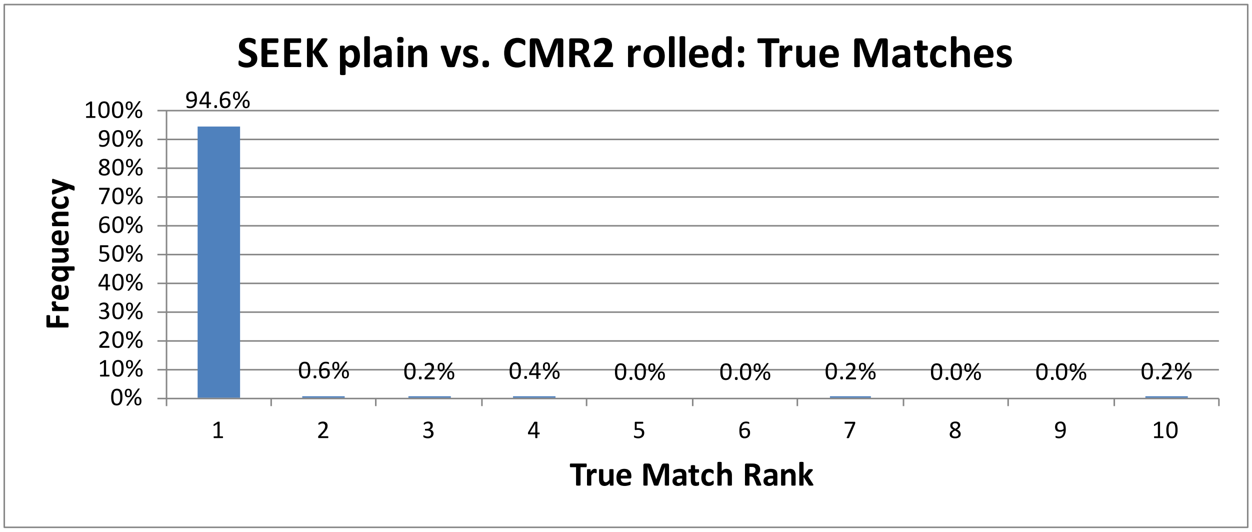
MegaMatcher		Results	Percent	Score, Mean	Score, Std Dev
Gallery	**Total**	538			
CMR2 Rolled	**Unique Galleries**	538			
Probe	**Submissions**	538			
SEEK Rolled	**Total Qualified**	537	99.8%		
	UniqueProbes	537			
Matches	**True Matches**	525	97.6%	427	198
	False Matches	12	2.2%	23	4
	Total Matches	288906			

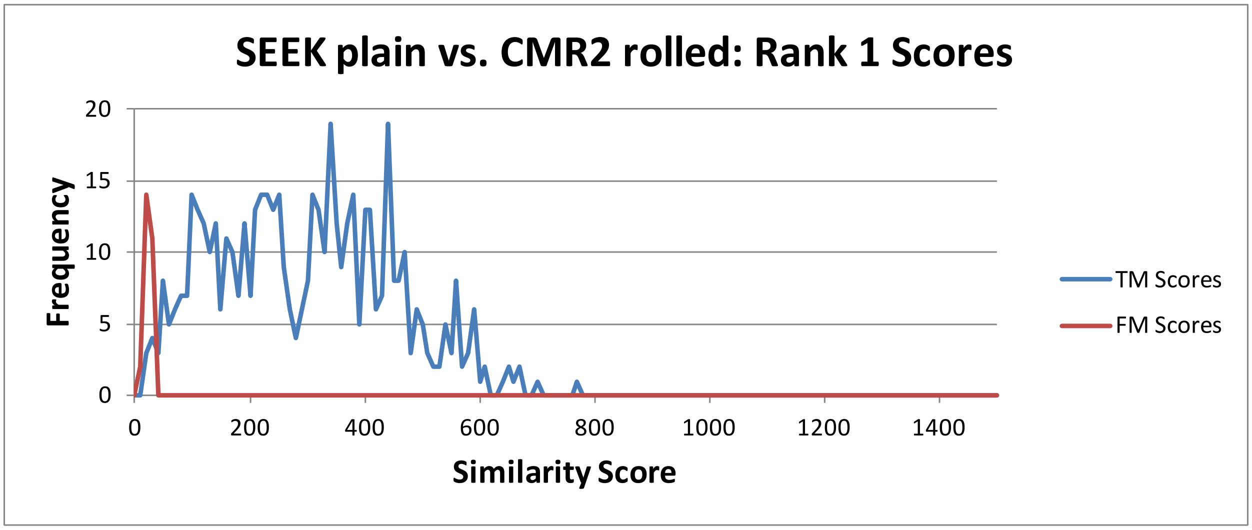




4.2.2 SEEK Plain vs. CMR2 Rolled

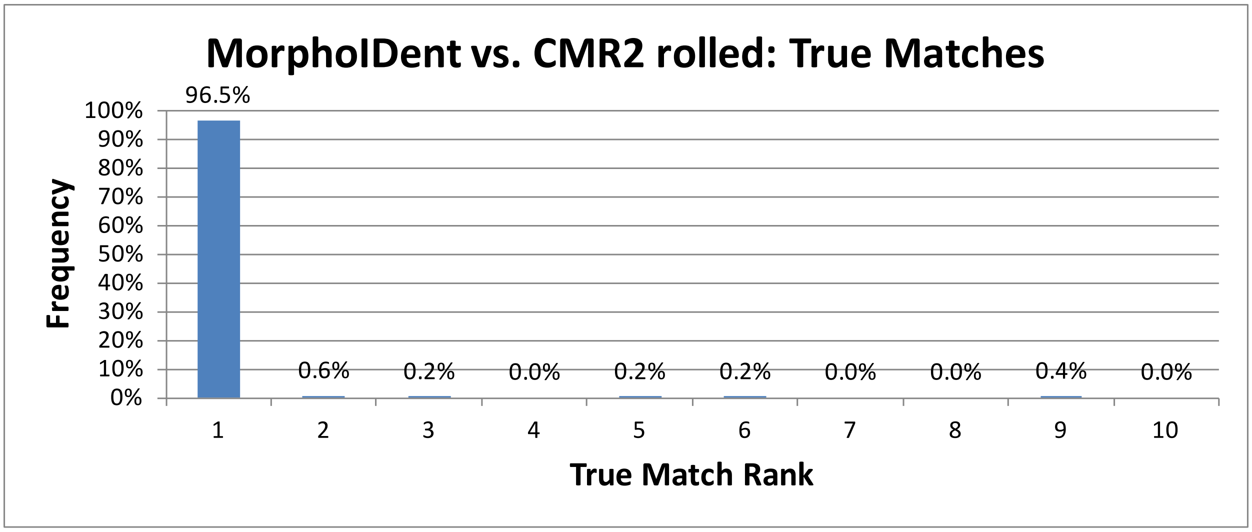
MegaMatcher		Results	Percent	Score, Mean	Score, Std Dev
Gallery	**Total**	538			
CMR2 Rolled	**Unique Galleries**	538			
Probe	**Submissions**	538			
SEEK Plain	**Total Qualified**	536	99.6%		
	UniqueProbes	536			
Matches	**True Matches**	509	94.6%	296	152
	False Matches	27	5.0%	23	5
	Total Matches	288368			

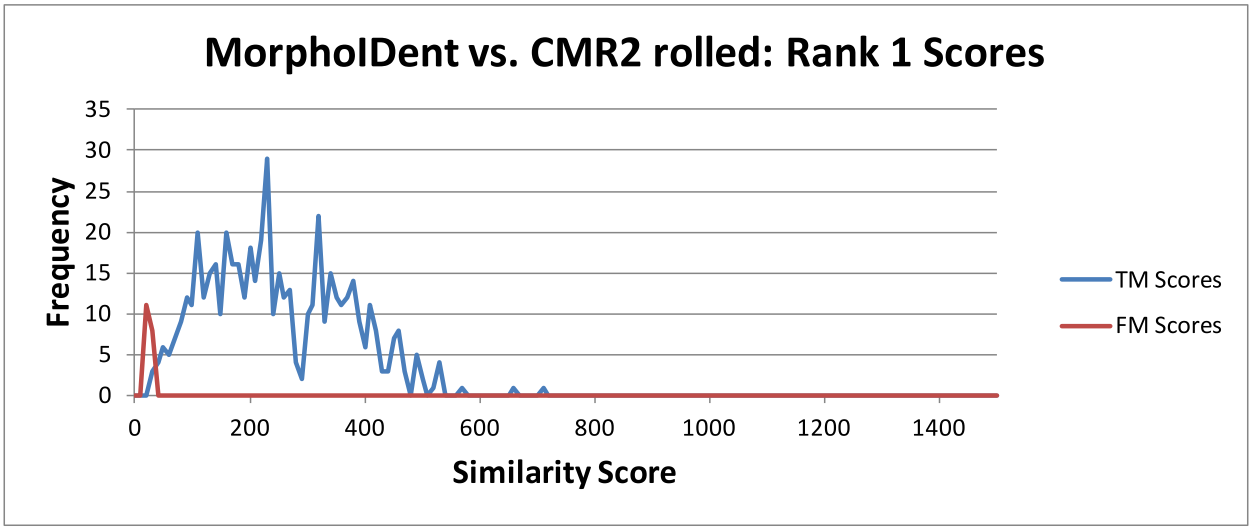




4.2.3 MorphoIDent vs. CMR2 Rolled

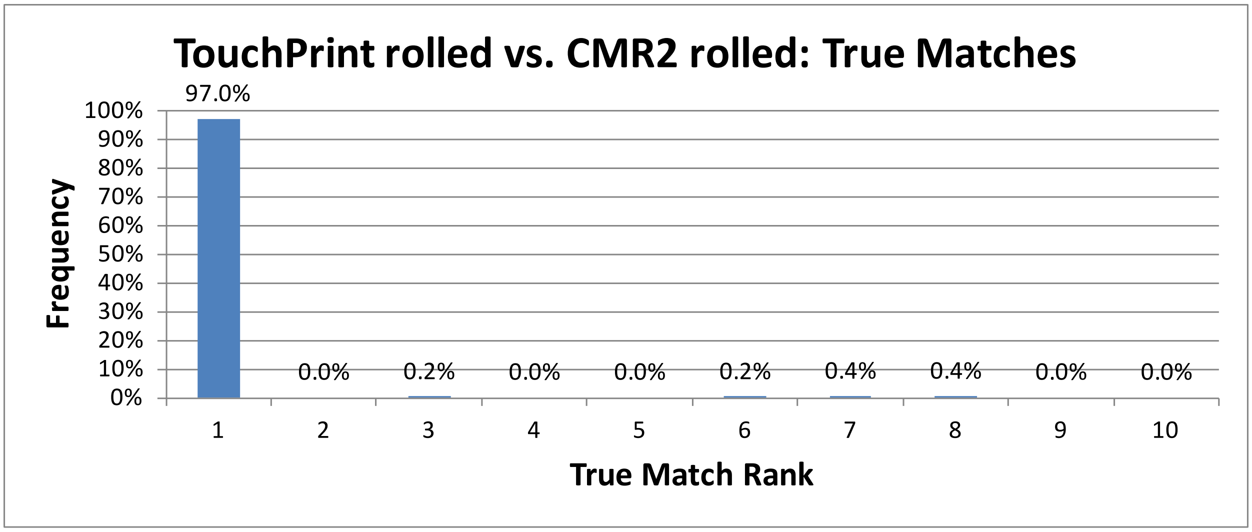
MegaMatcher		Results	Percent	Score, Mean	Score, Std Dev
Gallery	**Total**	538			
CMR2 Rolled	**Unique Galleries**	538			
Probe	**Submissions**	538			
MorphoIDent	**Total Qualified**	538	100.0%		
	UniqueProbes	538			
Matches	**True Matches**	519	96.5%	247	120
	False Matches	19	3.5%	24	4
	Total Matches	289444			

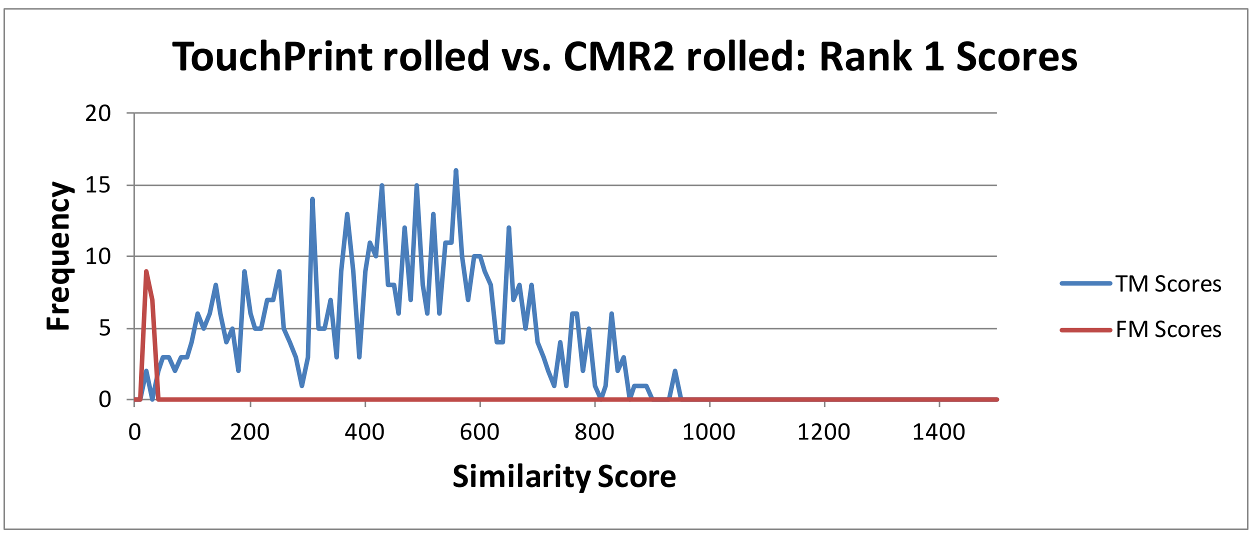




4.2.4 TouchPrint Rolled vs. CMR2 Rolled

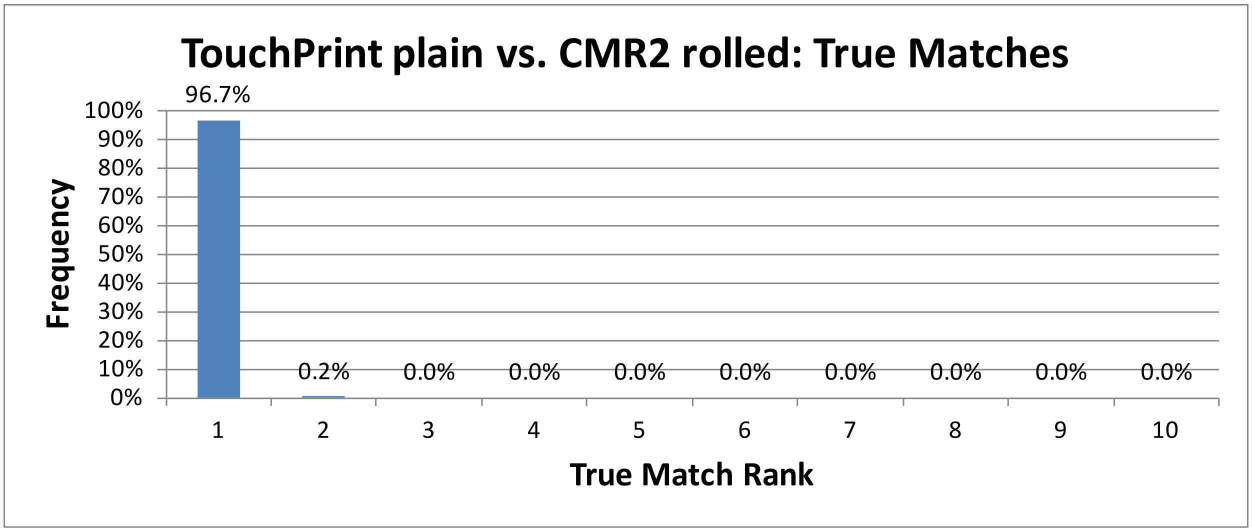
MegaMatcher		Results	Percent	Score, Mean	Score, Std Dev
Gallery	**Total**	538			
CMR2 Rolled	**Unique Galleries**	538			
Probe	**Submissions**	538			
TouchPrint Rolled	**Total Qualified**	538	100.0%		
	UniqueProbes	538			
Matches	**True Matches**	522	97.0%	447	201
	False Matches	16	3.0%	24	4
	Total Matches	289444			

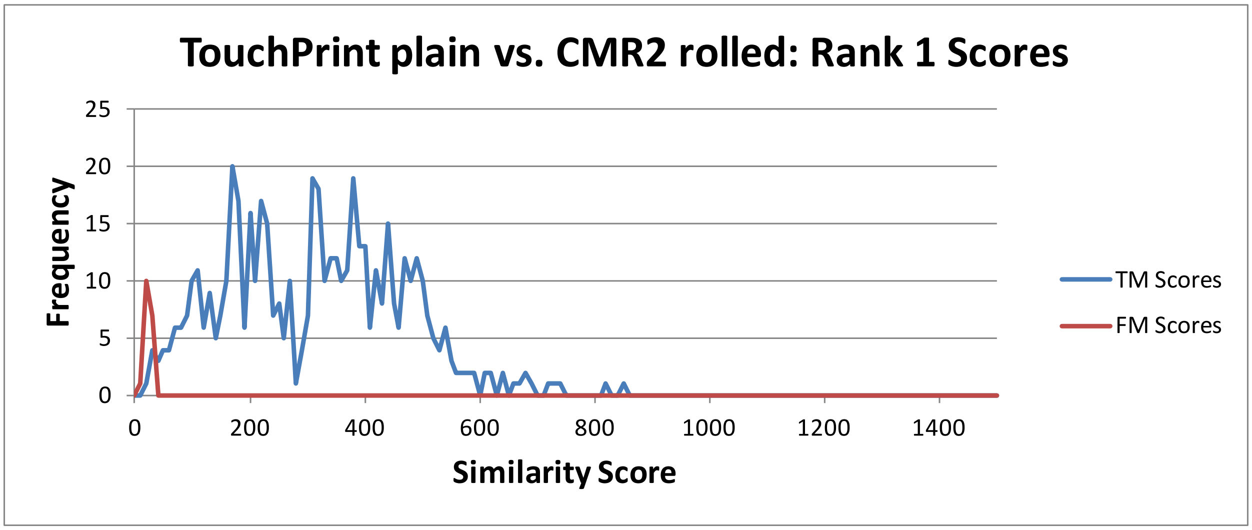




4.2.5 TouchPrint Plain vs. CMR2 Rolled

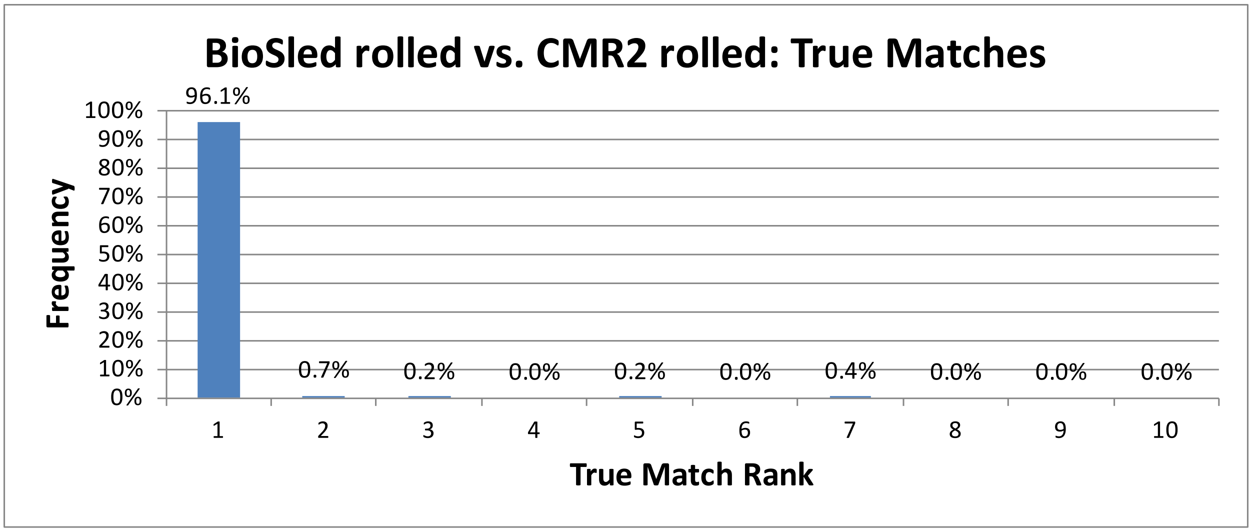
MegaMatcher		Results	Percent	Score, Mean	Score, Std Dev
Gallery	**Total**	538			
CMR2 Rolled	**Unique Galleries**	538			
Probe	**Submissions**	538			
TouchPrint Plain	**Total Qualified**	538	100.0%		
	UniqueProbes	538			
Matches	**True Matches**	520	96.7%	313	153
	False Matches	18	3.3%	23	4
	Total Matches	289444			

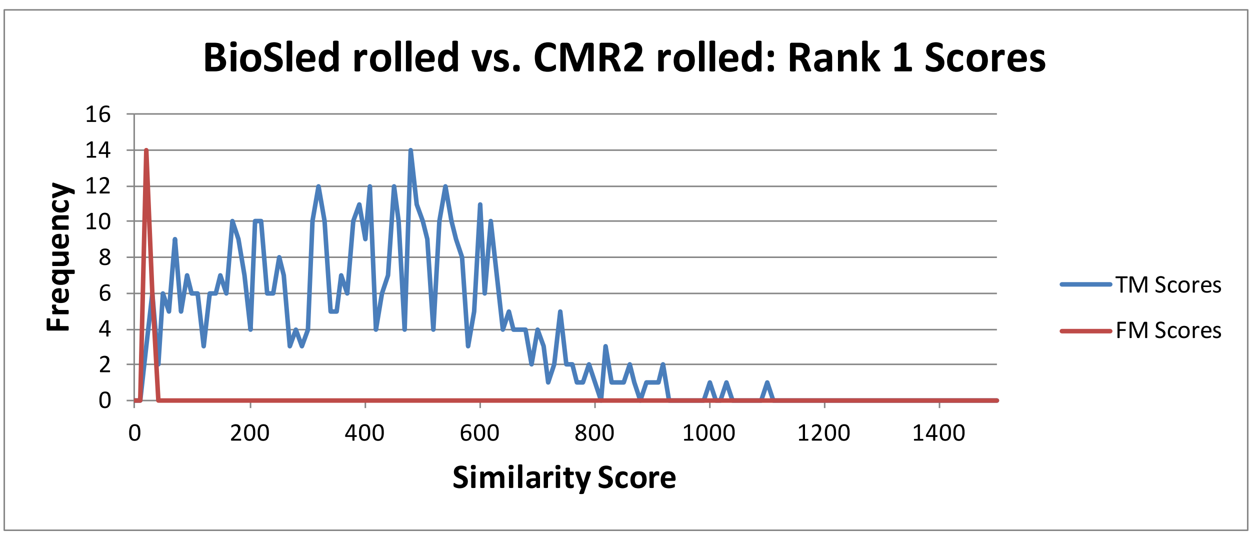




4.2.6 BioSled Rolled vs. CMR2 Rolled

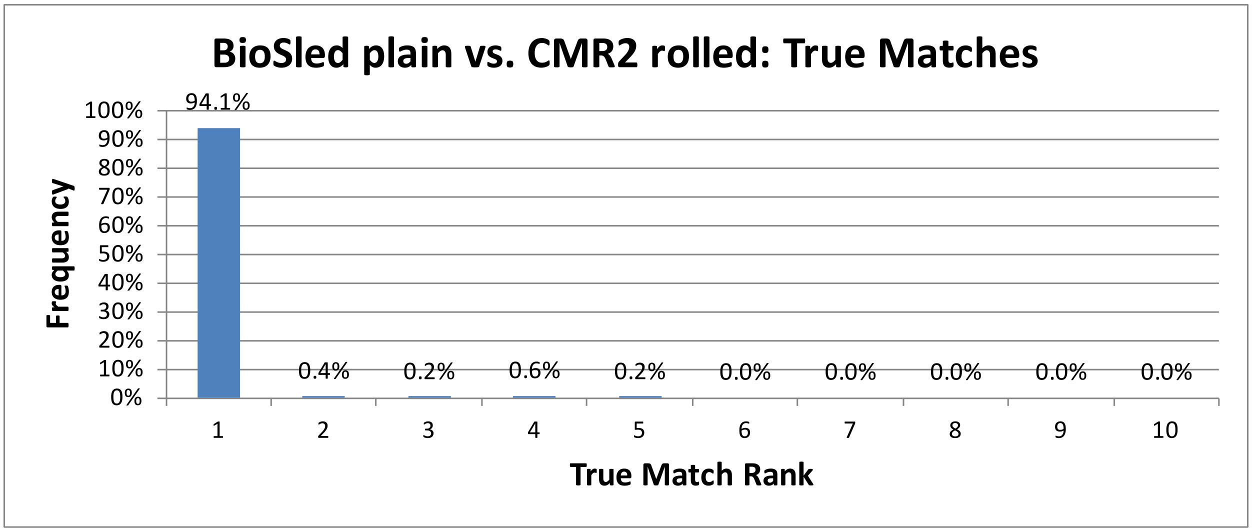
MegaMatcher		Results	Percent	Score, Mean	Score, Std Dev
Gallery	**Total**	538			
CMR2 Rolled	**Unique Galleries**	538			
Probe	**Submissions**	538			
BioSled Rolled	**Total Qualified**	537	99.8%		
	UniqueProbes	537			
Matches	**True Matches**	517	96.1%	400	212
	False Matches	20	3.7%	23	4
	Total Matches	288906			

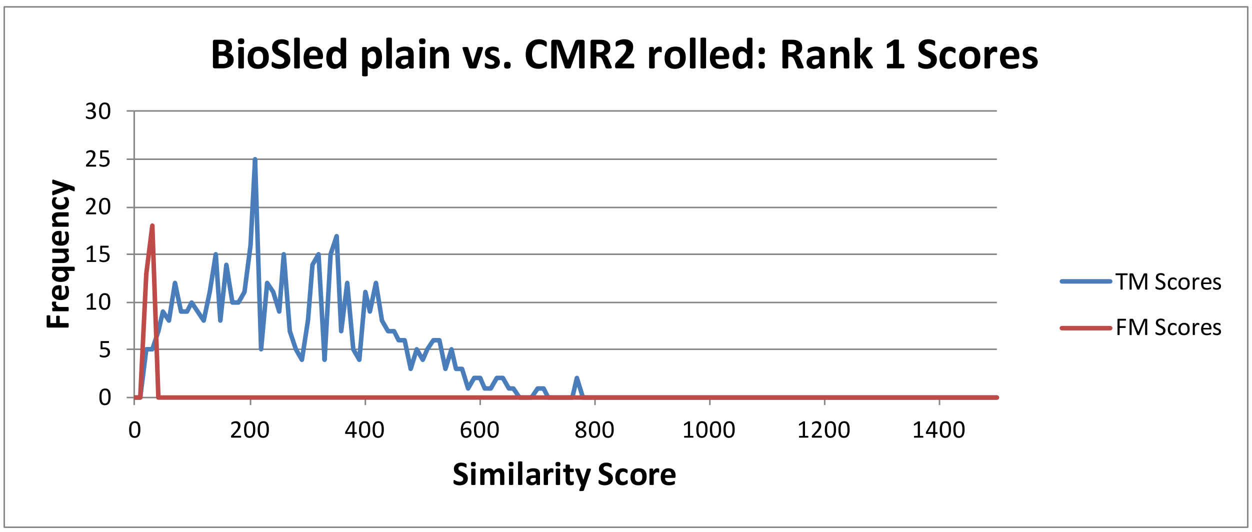




4.2.7 BioSled Plain vs. CMR2 Rolled

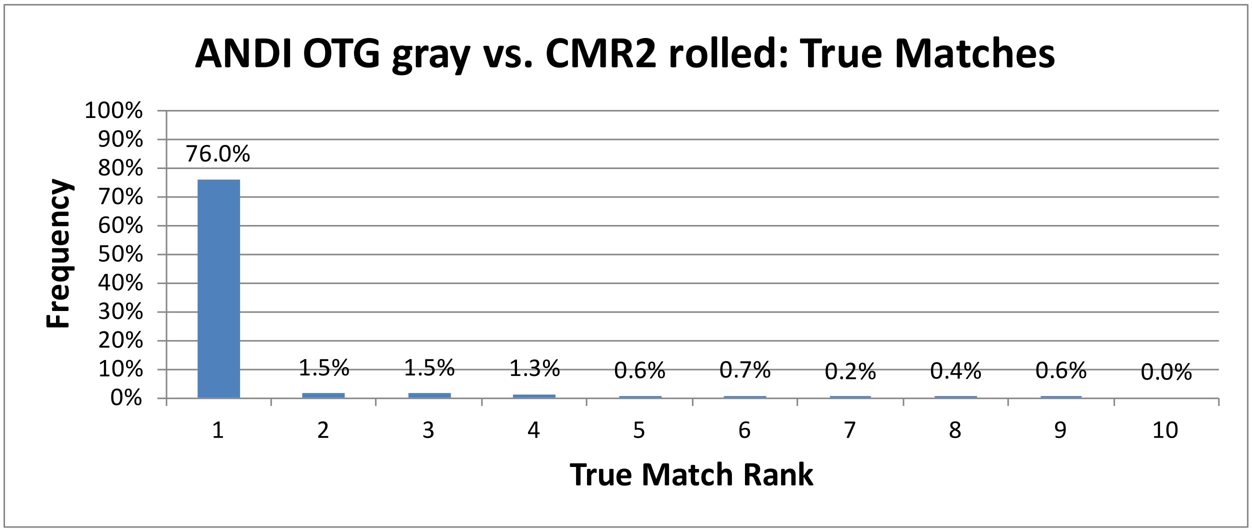
MegaMatcher		Results	Percent	Score, Mean	Score, Std Dev
Gallery	**Total**	538			
CMR2 Rolled	**Unique Galleries**	538			
Probe	**Submissions**	538			
BioSled Plain	**Total Qualified**	537	99.8%		
	UniqueProbes	537			
Matches	**True Matches**	506	94.1%	278	156
	False Matches	31	5.8%	24	3
	Total Matches	288906			

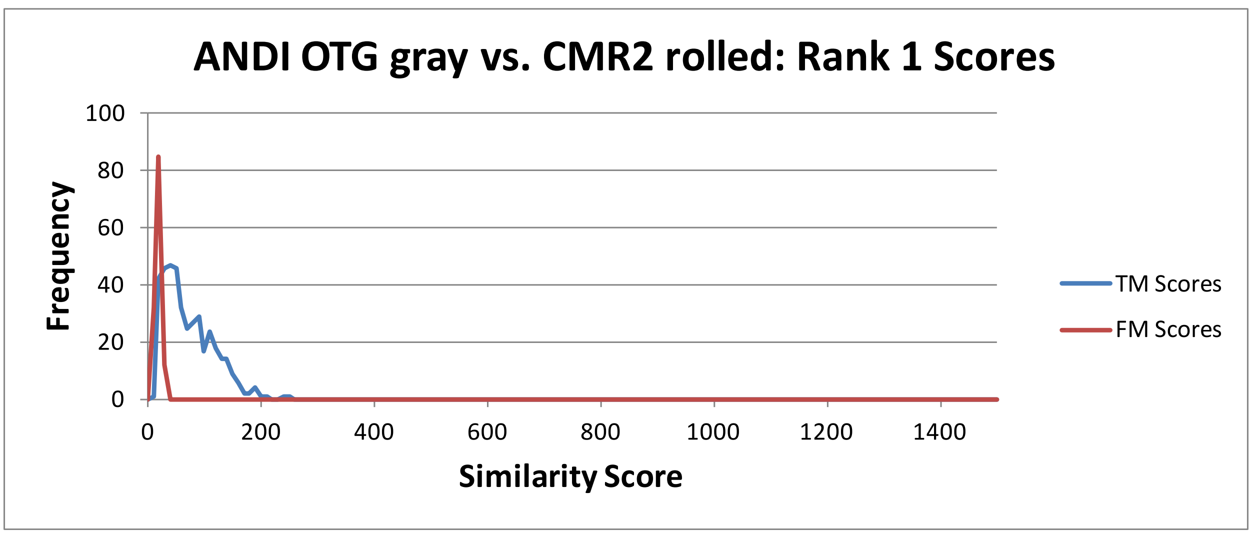




4.2.8 ANDI OTG Grayscale vs. CMR2 Rolled

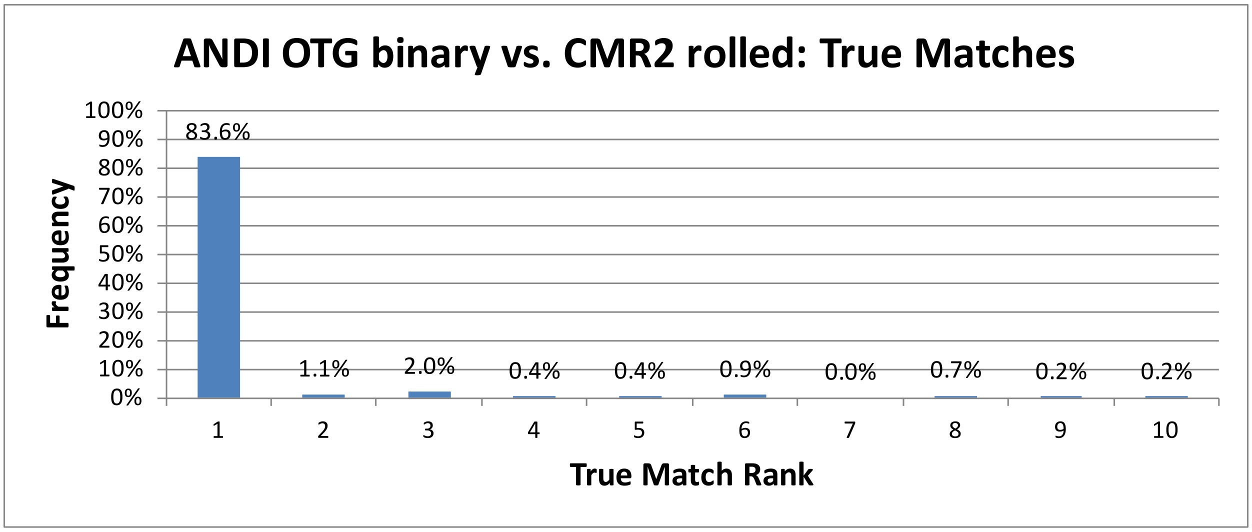
MegaMatcher		Results	Percent	Score, Mean	Score, Std Dev
Gallery	**Total**	538			
CMR2 Rolled	**Unique Galleries**	538			
Probe	**Submissions**	538			
ANDI OTG	**Total Qualified**	538	100.0%		
Grayscale Images	**UniqueProbes**	538			
Matches	**True Matches**	409	76.0%	72	44
	False Matches	129	24.0%	18	5
	Total Matches	289444			

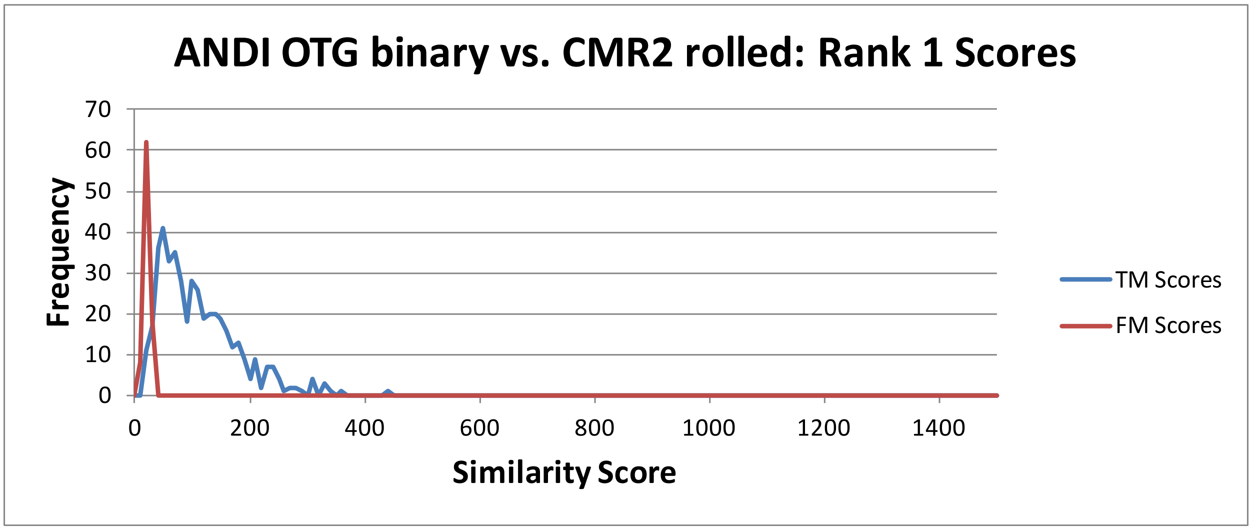




4.2.9 ANDI OTG Binary vs. CMR2 Rolled

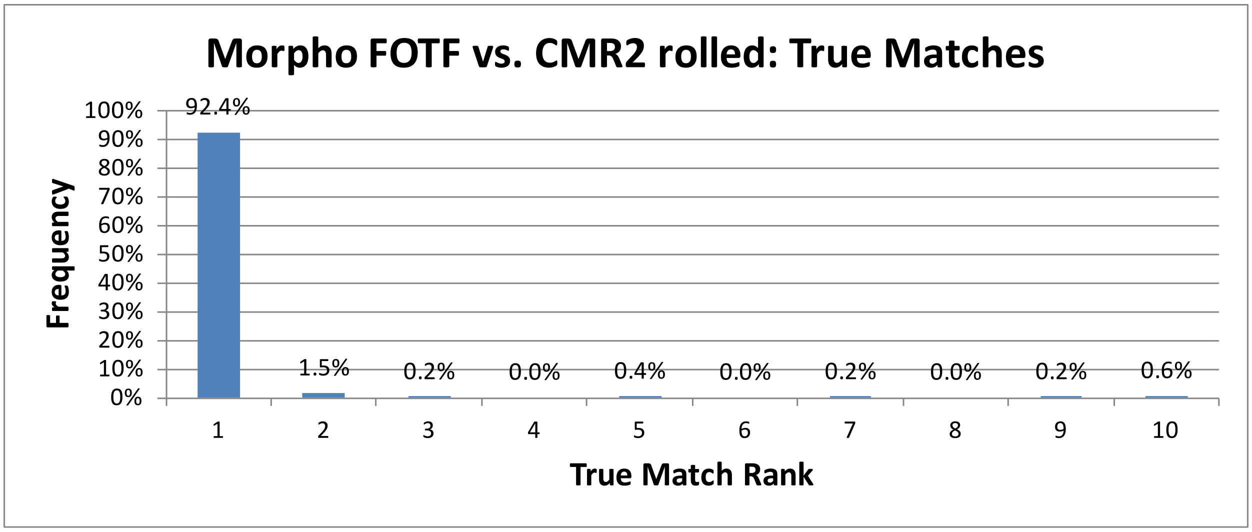
MegaMatcher		Results	Percent	Score, Mean	Score, Std Dev
Gallery	**Total**	538			
CMR2 Rolled	**Unique Galleries**	538			
Probe	**Submissions**	538			
ANDI OTG binary	**Total Qualified**	538	100.0%		
	UniqueProbes	538			
Matches	**True Matches**	450	83.6%	110	68
	False Matches	88	16.4%	21	4
	Total Matches	289444			

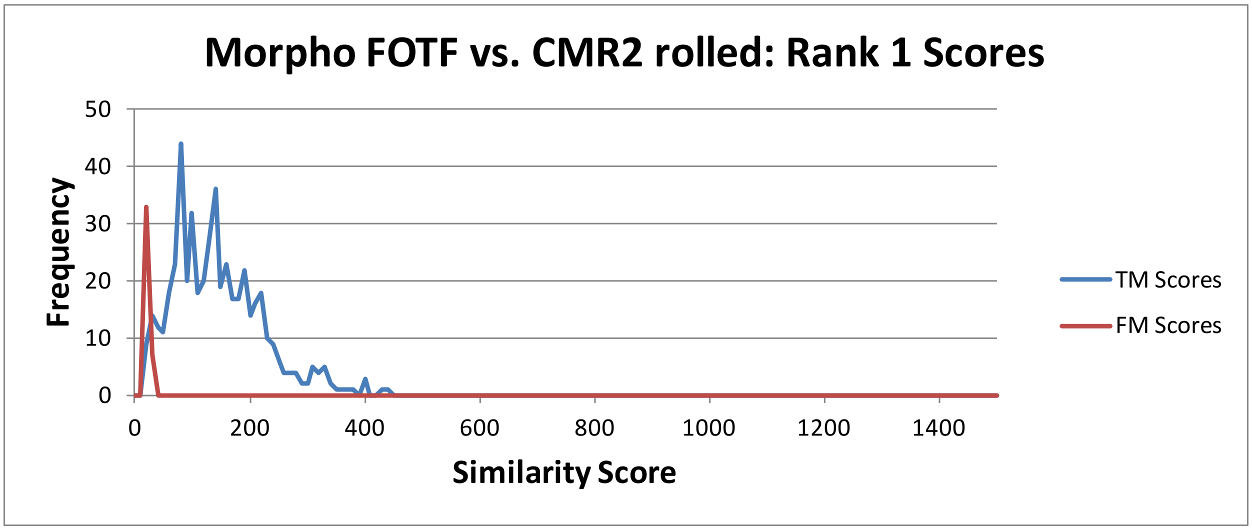




4.2.10 FOTF vs. CMR2 Rolled

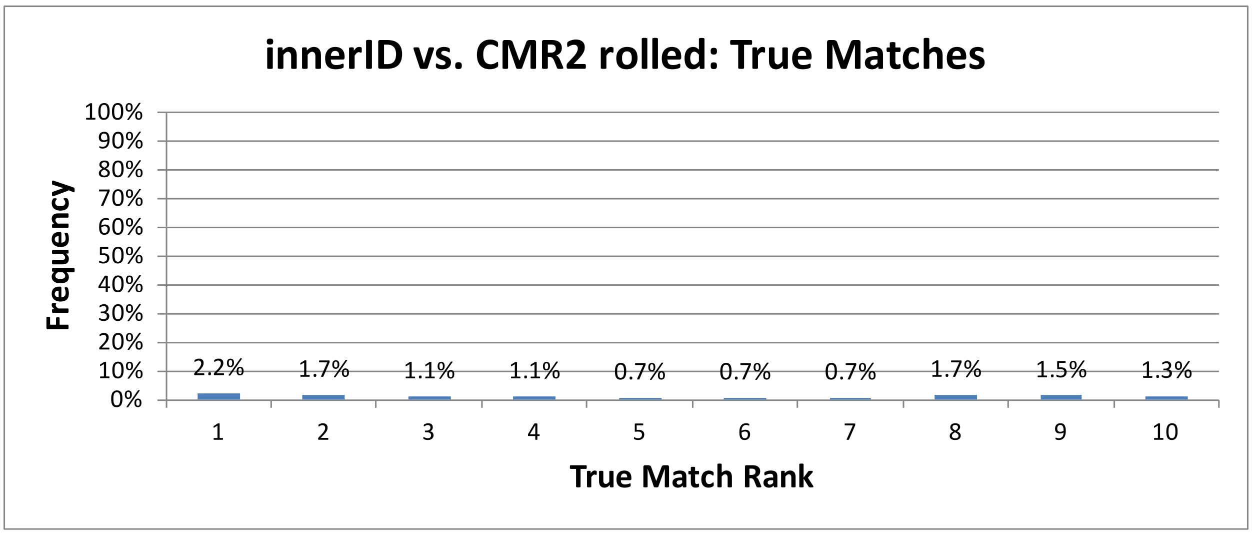
MegaMatcher		Results	Percent	Score, Mean	Score, Std Dev
Gallery	**Total**	538			
CMR2 Rolled	**Unique Galleries**	538			
Probe	**Submissions**	538			
Morpho FOTF	**Total Qualified**	537	99.8%		
	Unique Probes	537			
Matches	**True Matches**	497	92.4%	144	78
	False Matches	40	7.4%	22	4
	Total Matches	288906			

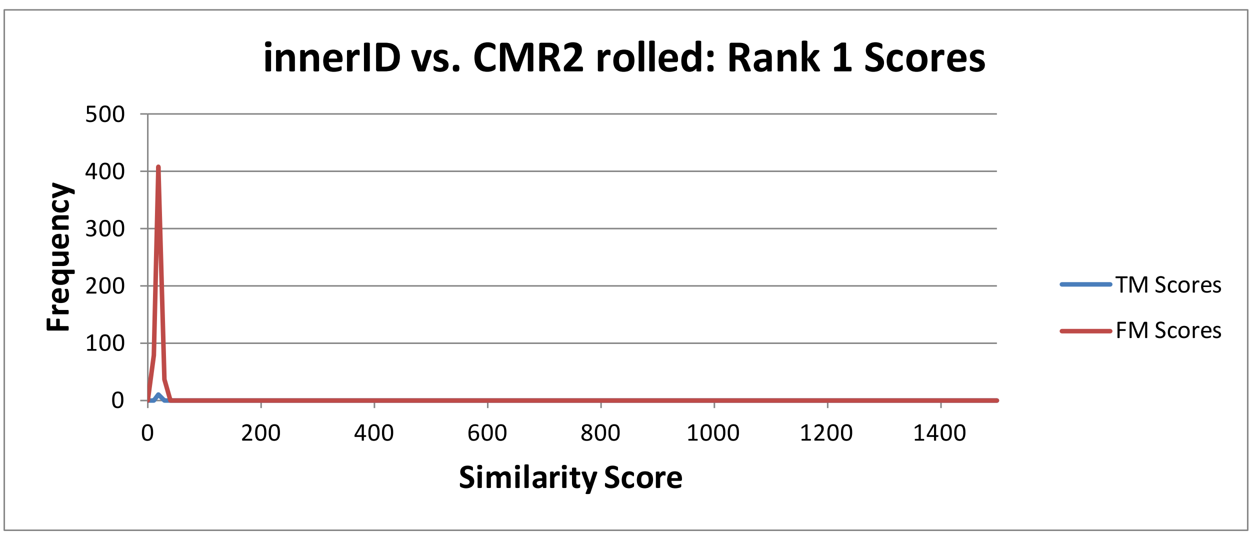




4.2.11 innerID vs. CMR2 Rolled

MegaMatcher		Results	Percent	Score, Mean	Score, Std Dev
Gallery	**Total**	538			
CMR2 Rolled	**Unique Galleries**	538			
Probe	**Submissions**	538			
innerID	**Total Qualified**	537	99.8%		
	UniqueProbes	537			
Matches	**True Matches**	12	2.2%	19	4
	False Matches	525	97.6%	19	4
	Total Matches	288906			

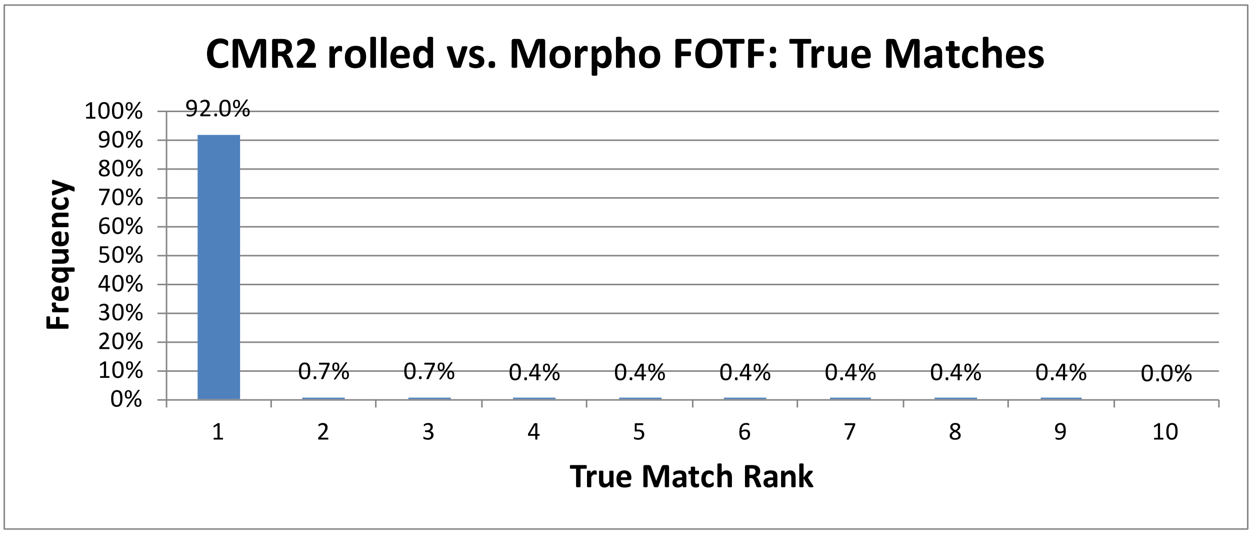


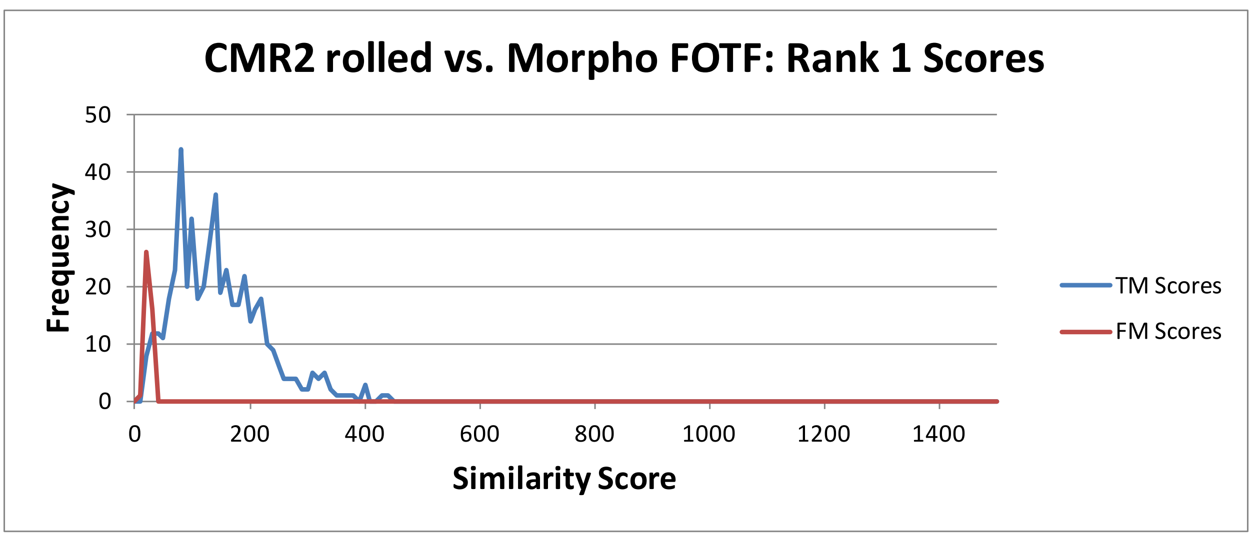


4.3 FOTF Gallery Matching Runs

4.3.1 CMR2 Rolled vs. FOTF

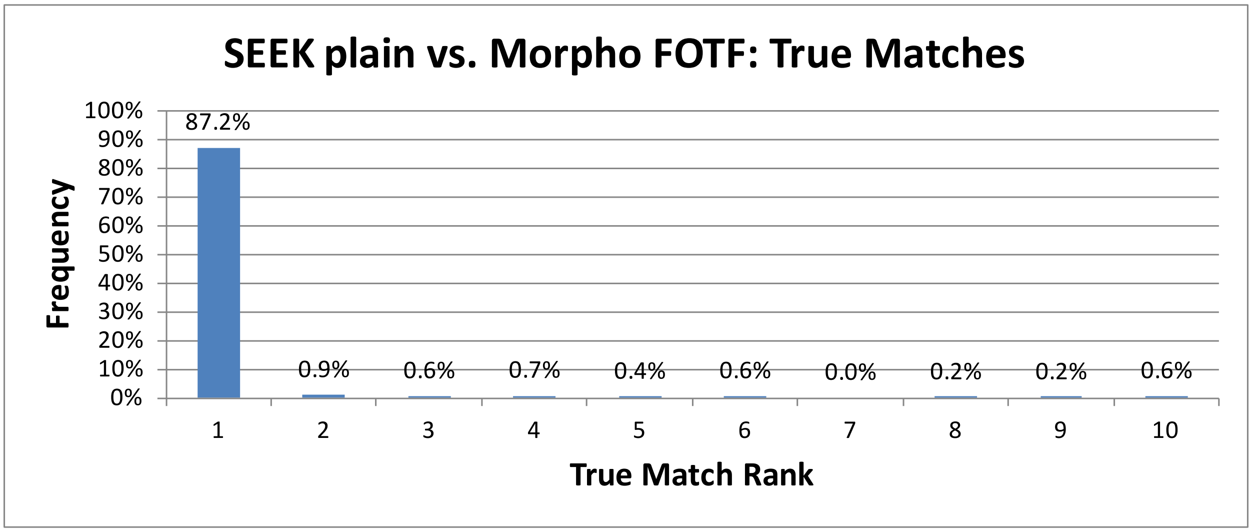
MegaMatcher		Results	Percent	Score, Mean	Score, Std Dev
Gallery	**Total**	537			
FOTF	**Unique Galleries**	537			
Probe	**Submissions**	537			
CMR2 Rolled	**Total Qualified**	537	100.0%		
	UniqueProbes	537			
Matches	**True Matches**	494	92.0%	145	78
	False Matches	43	8.0%	23	4
	Total Matches	288369			

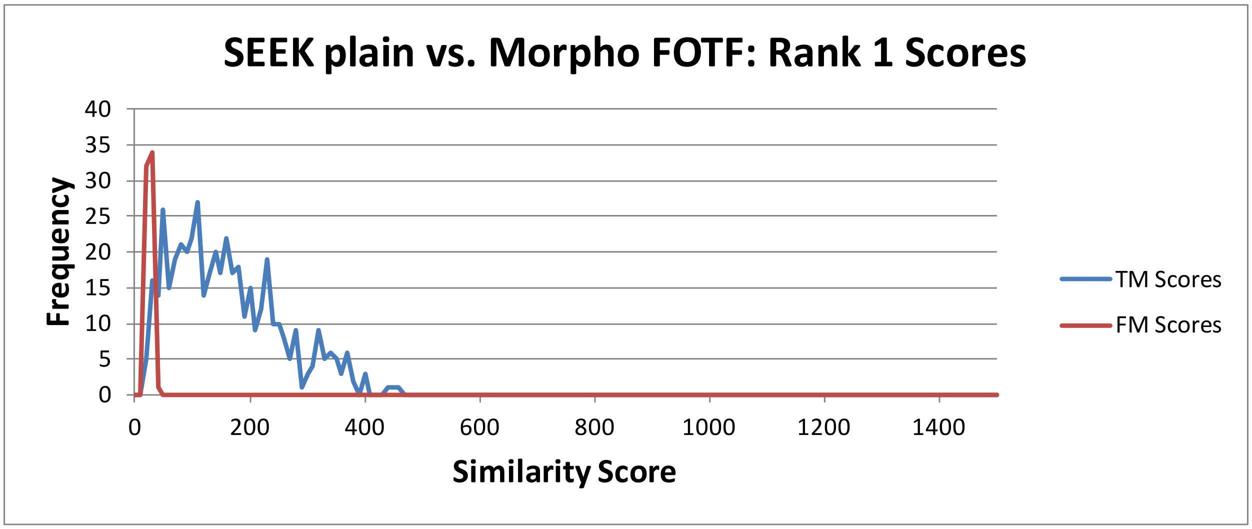




4.3.2 SEEK Plain vs. FOTF

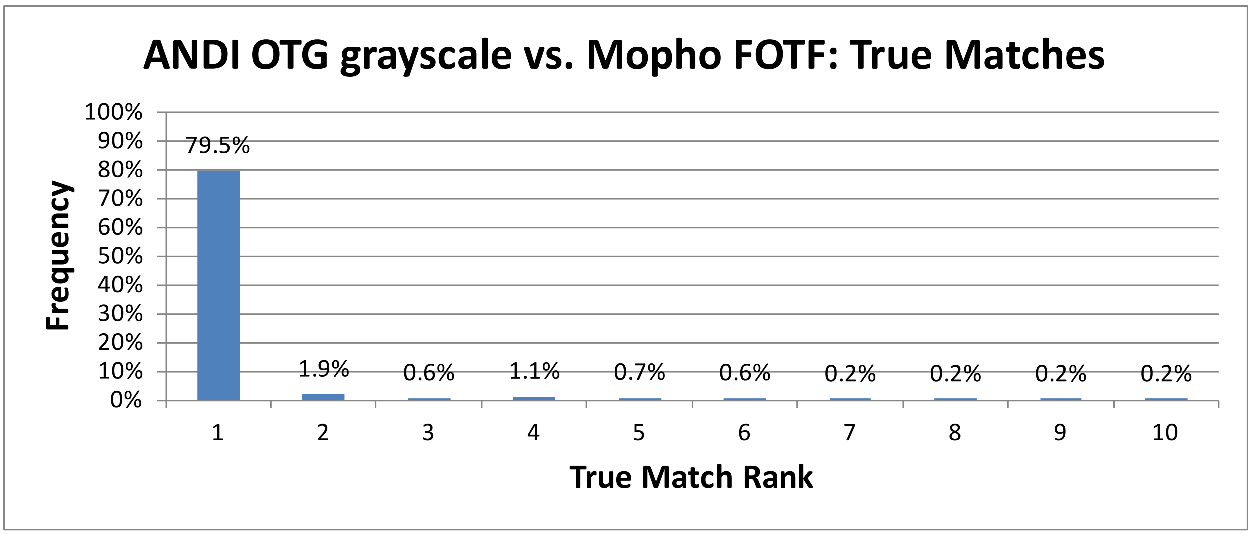
MegaMatcher		Results	Percent	Score, Mean	Score, Std Dev
Gallery	**Total**	537			
Morpho FOTF	**Unique Galleries**	537			
Probe	**Submissions**	537			
SEEK Plain	**Total Qualified**	535	99.6%		
	UniqueProbes	535			
Matches	**True Matches**	468	87.2%	158	93
	False Matches	67	12.5%	24	4
	Total Matches	287295			

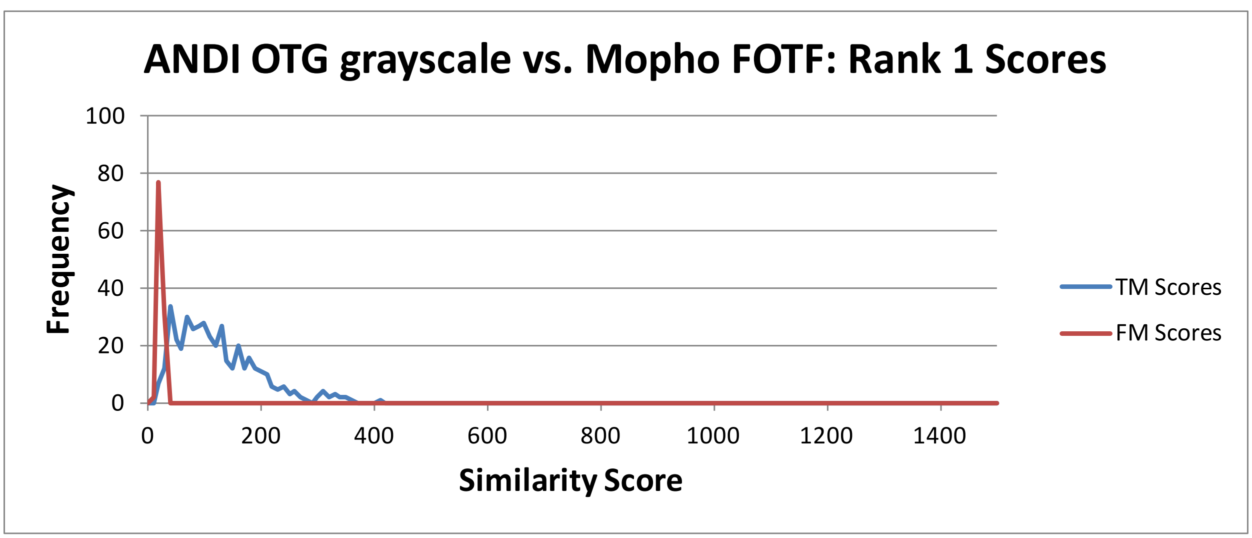




4.3.3 ANDI OTG Grayscale vs. FOTF

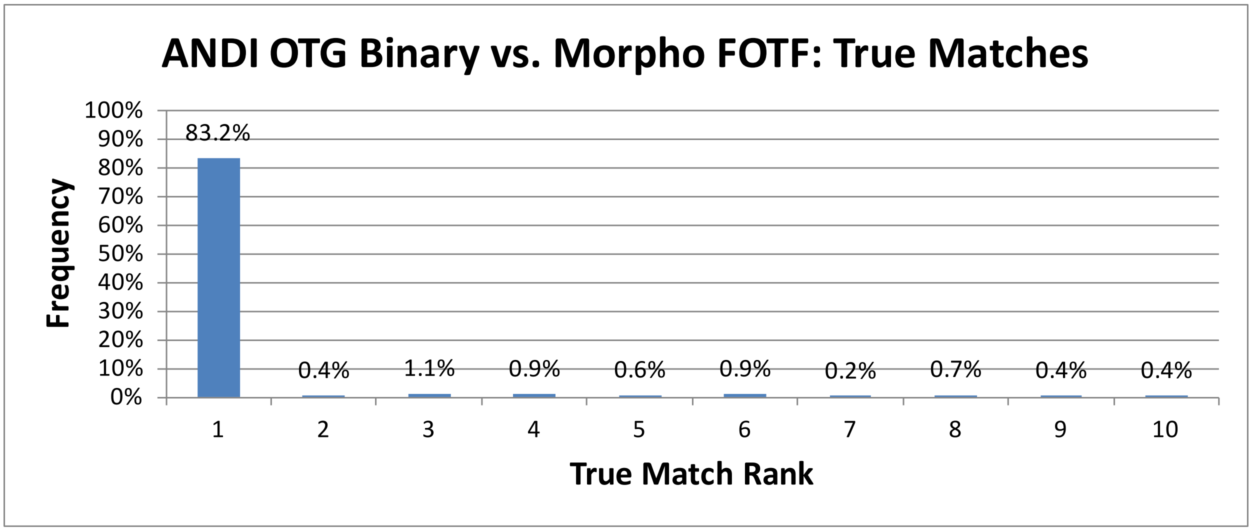
MegaMatcher		Results	Percent	Score, Mean	Score, Std Dev
Gallery	**Total**	537			
FOTF	**Unique Galleries**	537			
Probe	**Submissions**	537			
ANDI OTG Grayscale	**Total Qualified**	537	100.0%		
	UniqueProbes	537			
Matches	**True Matches**	427	79.5%	123	72
	False Matches	110	20.5%	22	4
	Total Matches	288369			

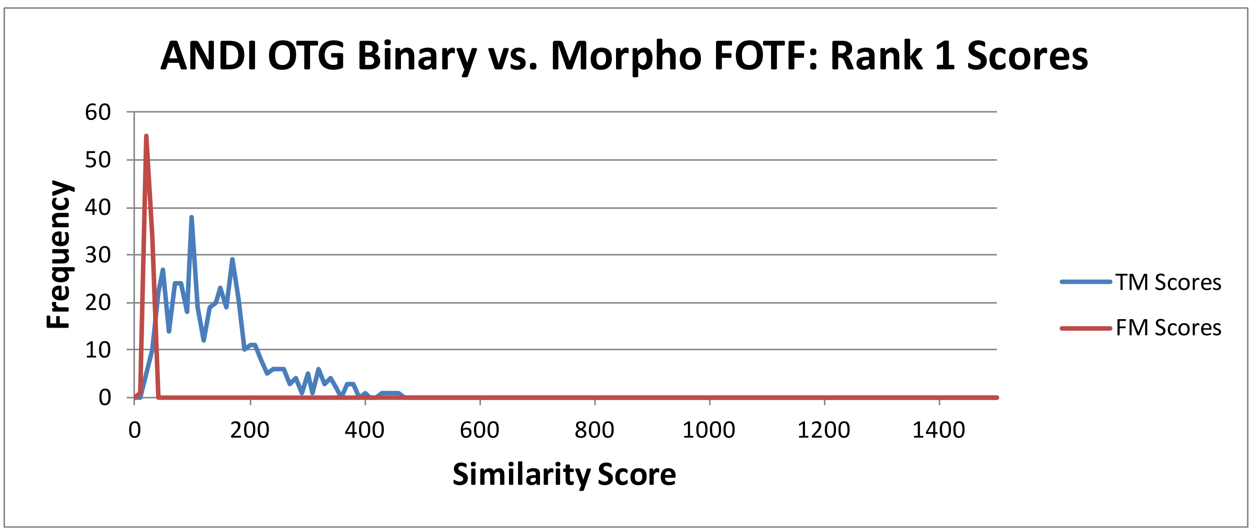




4.3.4 ANDI OTG Binary vs. FOTF

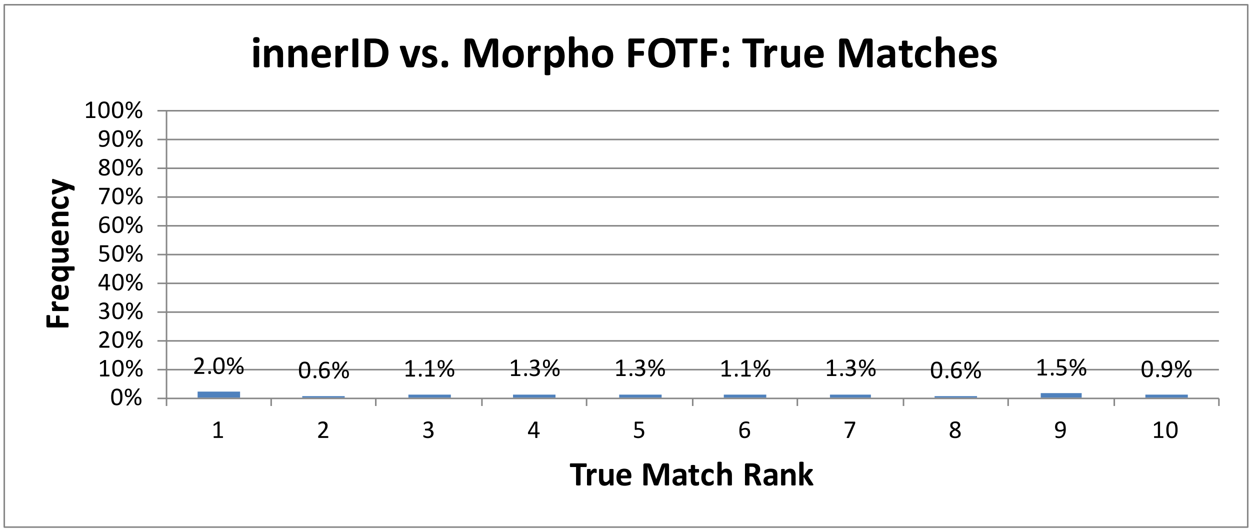
MegaMatcher		Results	Percent	Score, Mean	Score, Std Dev
Gallery	**Total**	537			
FOTF	**Unique Galleries**	537			
Probe	**Submissions**	537			
ANDI OTG Binary	**Total Qualified**	537	100.0%		
	UniqueProbes	537			
Matches	**True Matches**	447	83.2%	142	85
	False Matches	90	16.8%	23	4
	Total Matches	288369			

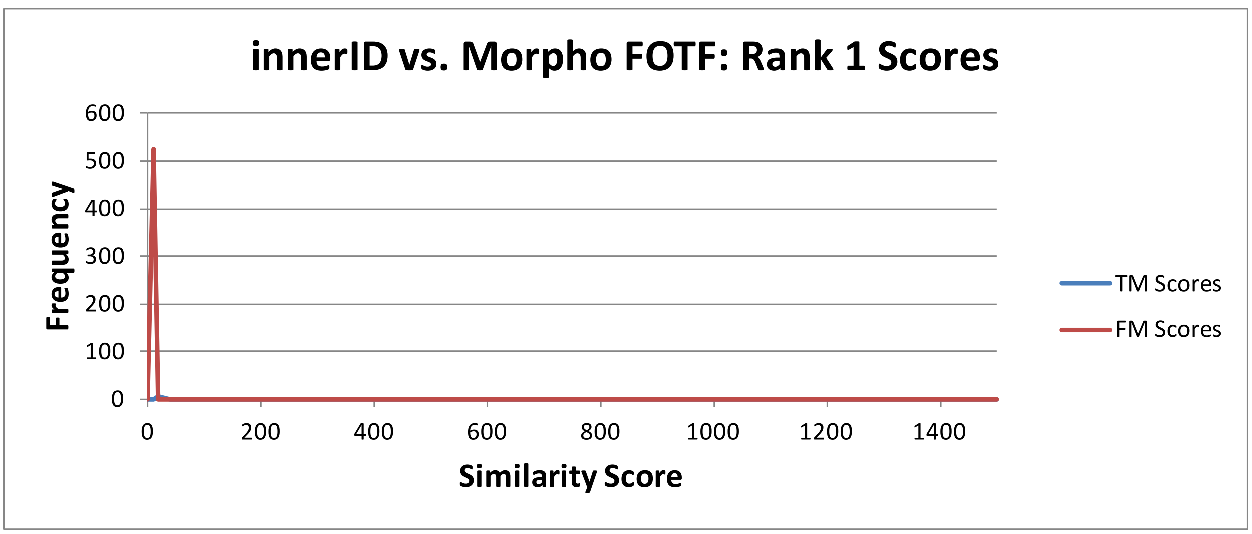




4.3.5 innerID vs. FOTF

MegaMatcher		Results	Percent	Score, Mean	Score, Std Dev
Gallery	**Total**	537			
FOTF	**Unique Galleries**	537			
Probe	**Submissions**	537			
innerID	**Total Qualified**	536	99.8%		
	UniqueProbes	536			
Matches	**True Matches**	11	2.0%	24	4
	False Matches	525	97.8%	21	4
	Total Matches	287832			

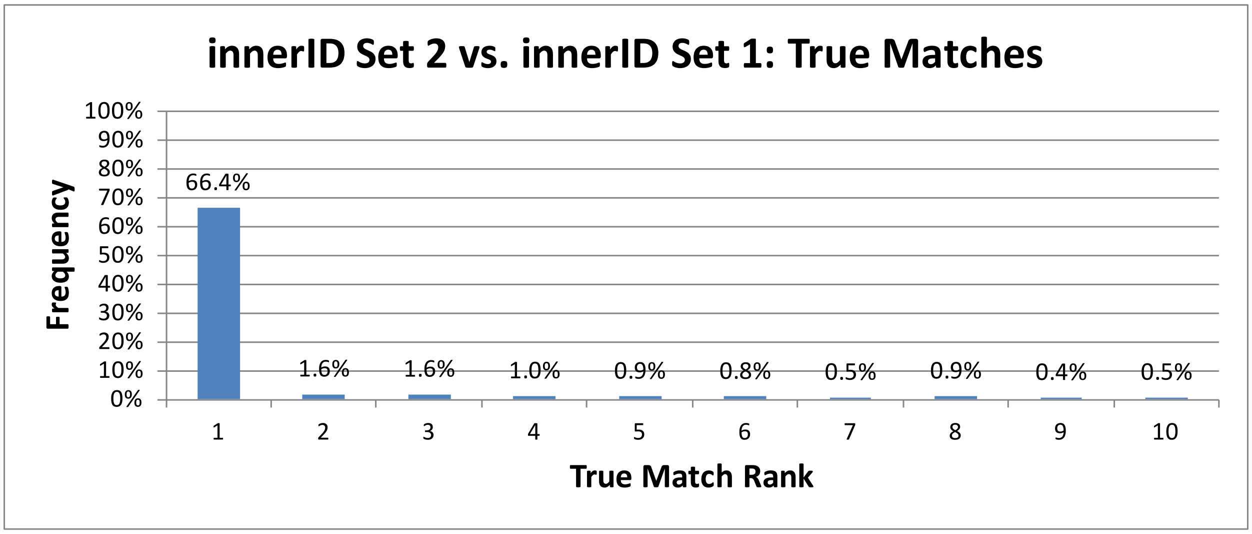


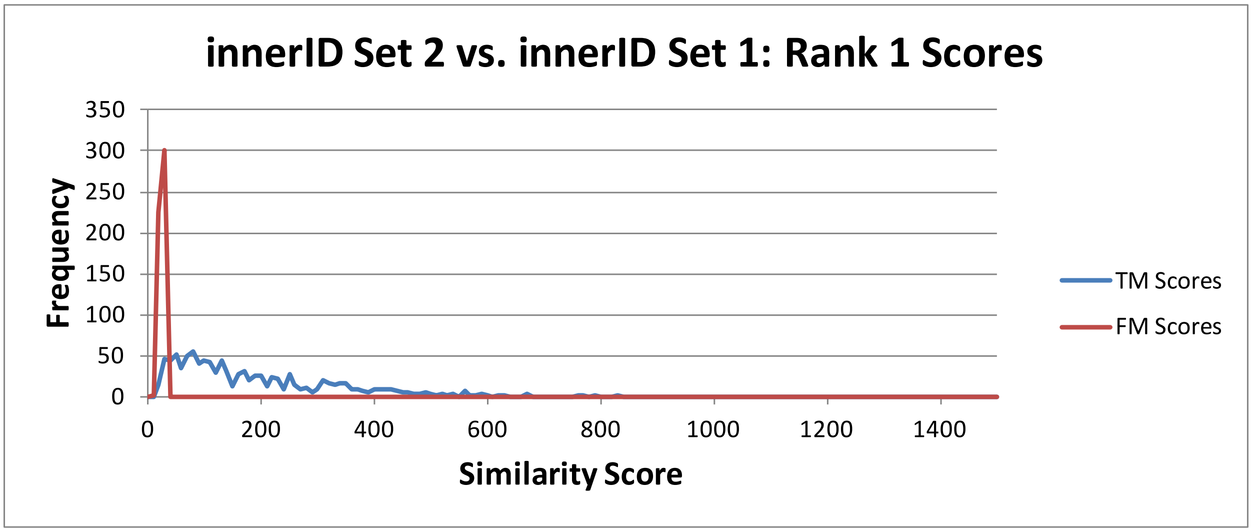


4.4 innerID Verification Run

Nine images from the innerID Set 1 dataset failed to enroll due to image quality. As a result, all matches against the gallery excluded those subject ID/finger position from the probe set to ensure 100% correspondence between probes and gallery images.

MegaMatcher		Results	Percent	Score, Mean	Score, Std Dev
Gallery	**Total**	1584			
innerID Set 1	**Unique Galleries**	1584			
Probe	**Submissions**	1584			
Inner ID Set 2	**Total Qualified**	1579	99.7%		
	UniqueProbes	1579			
Matches	**True Matches**	1051	66.4%	188	141
	False Matches	528	33.3%	25	3
	Total Matches	2501136			

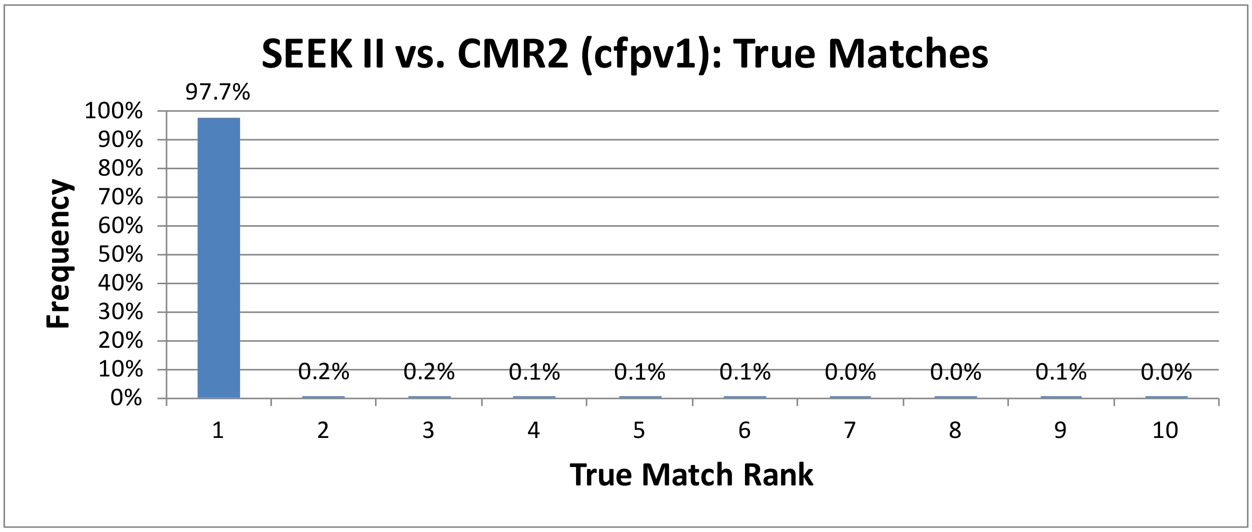


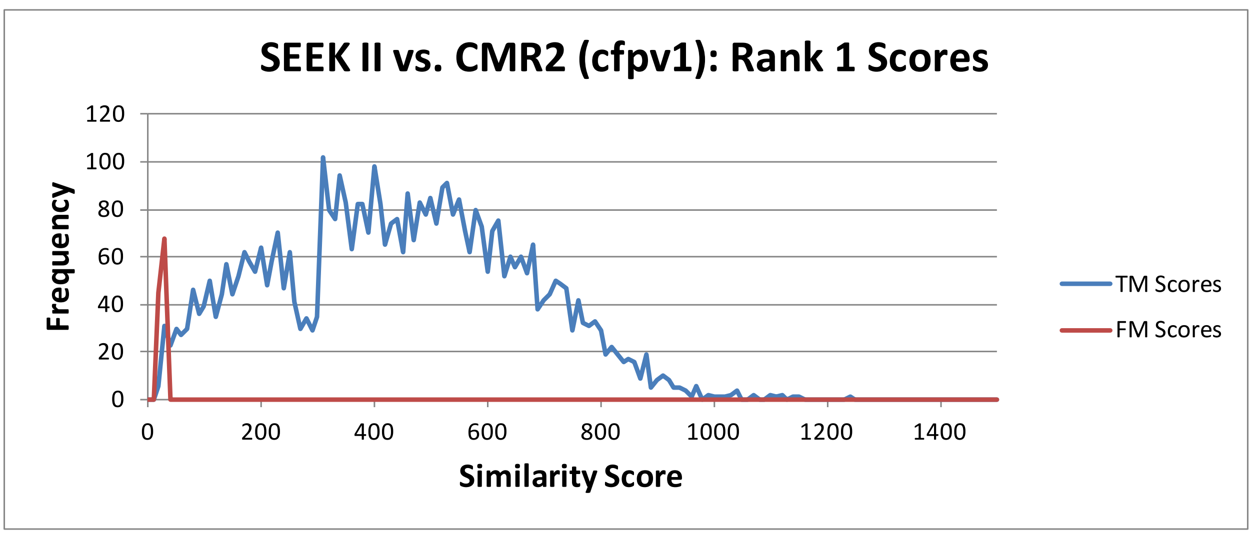


4.5 CFPv1 Matching Runs

4.5.1 SEEK II Rolled vs. CMR2 Rolled (cfpv1)

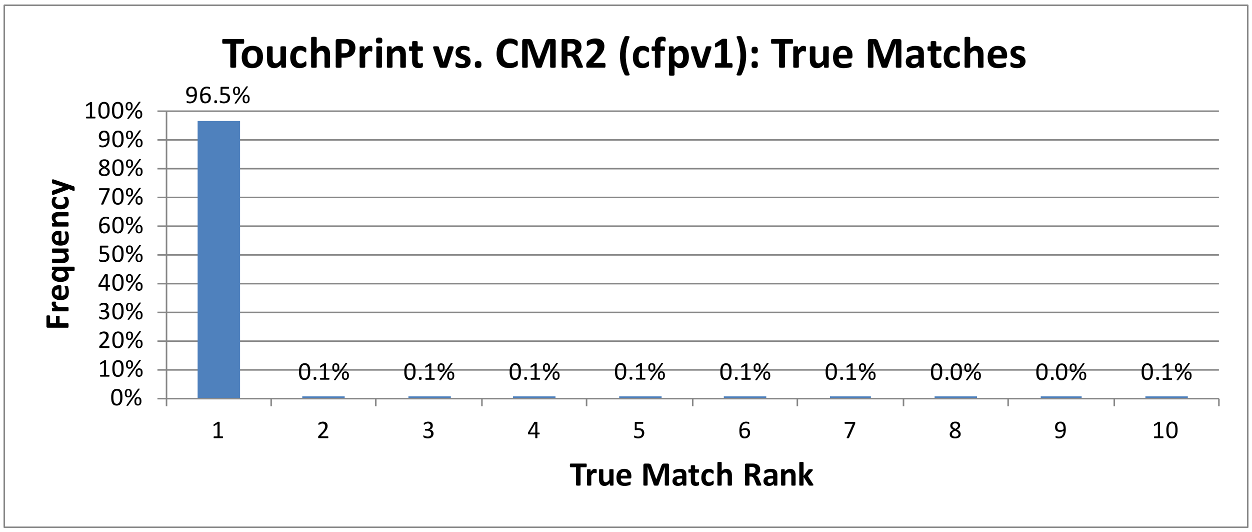
MegaMatcher		Results	Percent	Score, Mean	Score, Std Dev
Gallery	**Total**	4868			
CMR2 Set1	**Unique Subjects**	4868			
Probe	**Submissions**	4868			
SEEK II Set1	**Total Qualified**	4868	100.0%		
All Image uniform	**Unique Subjects**	4868			
Matches	**True Matches**	4755	97.7%	445	215
	False Matches	113	2.3%	26	3
	Total Matches	23697424			

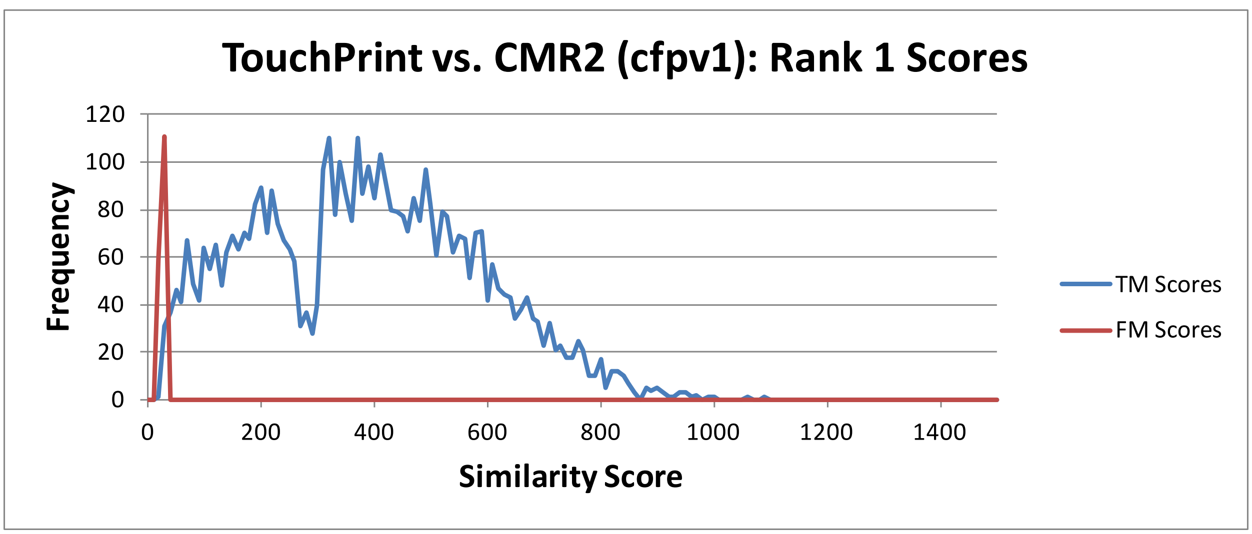




4.5.2 TouchPrint Rolled vs. CMR2 Rolled (cfpv1)

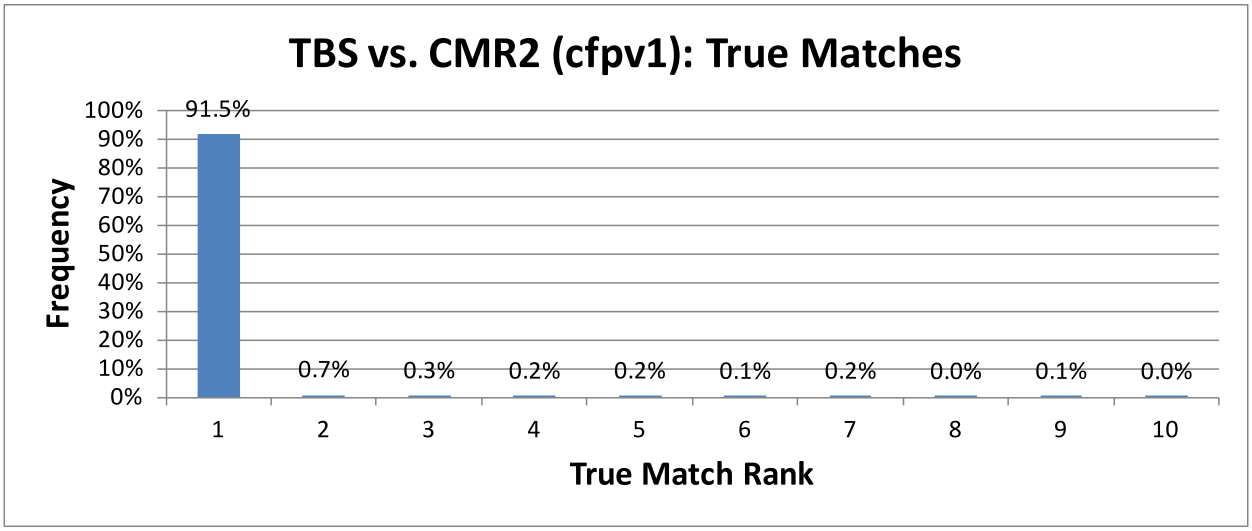
MegaMatcher		Results	Percent	Score, Mean	Score, Std Dev
Gallery	**Total**	4868			
CMR2 Set1	**Unique Galleries**	4868			
Probe	**Submissions**	4868			
TouchPrint Set1	**Total Qualified**	4866	99.96%		
All images uniform	**Unique Probes**	4866			
Matches	**True Matches**	4696	96.5%	386	197
	False Matches	170	3.5%	26	3
	Total Matches	23687688			

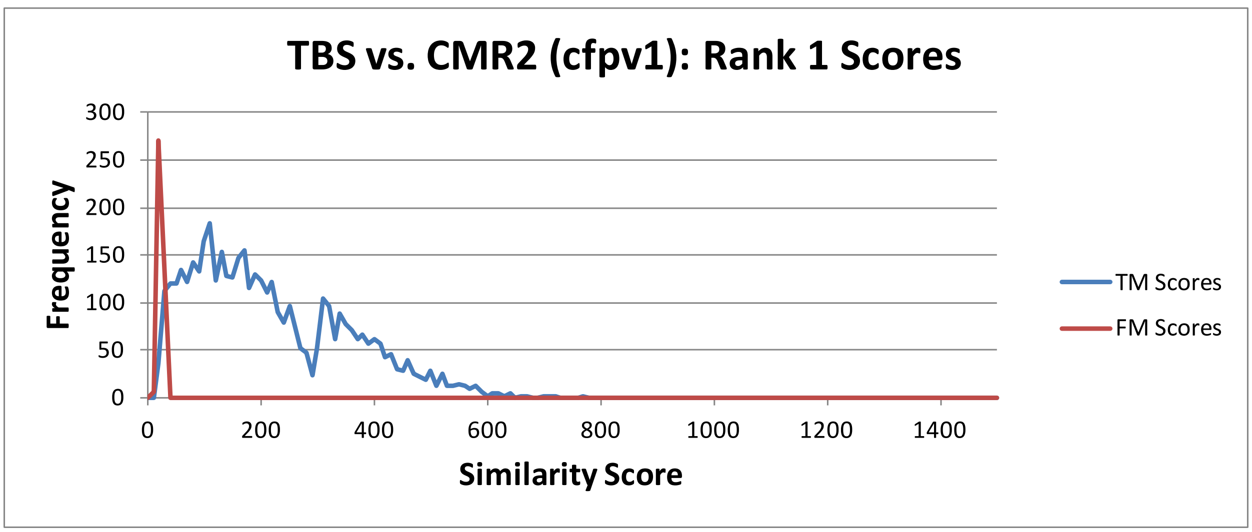




4.5.3 TBS vs. CMR2 Rolled (cfpv1)

MegaMatcher		Results	Percent	Score, Mean	Score, Std Dev
Gallery	**Total**	4868			
CMR2 Set1	**Unique Subjects**	4868			
Probe	**Submissions**	4868			
TBS HT1 Set1	**Total Qualified**	4868	100.0%		
All image uniform	**Unique Subjects**	4868			
Matches	**True Matches**	4456	91.5%	215	136
	False Matches	412	8.5%	23	4
	Total Matches	23697424			





5.0 ANALYSIS & DISCUSSIONS

The biometric fingerprint image dataset (see Section 3.2 Fingerprint Data) was used to conduct matching runs using the MM algorithm. The resulting matching run results have been used to investigate and analyze the performance and interoperability of fingerprint data from a variety of contact and contactless devices. The analysis is focused on addressing the following objectives:

1. Determine the interoperability and match performance of CFP data against traditional LFP databases.
2. Investigate the performance and feasibility of a contactless fingerprint database for matching LFP and CFP systems against.
3. Evaluate the performance of criminal justice and/or defense relevant systems – fixed (i.e., livescan) and mobile devices.
4. Compare the match performance of data from CFPv2 with CFPv1.

NOTE: The lack of available 3D matchers and varying collection methodologies and data formats used among 3D collection devices required the evaluation to focus on a format common to all devices: the 2D legacy fingerprint image. Due to the limitations of 3D images converted to 2D images, the quality or efficacy of the 3D contactless fingerprint devices in capturing topological fingerprint details was not investigated.

NOTE: Raw 3D images generated from optical structured light (e.g., Morpho FOTF) and other methods are not directly compatible with existing fingerprint matching algorithms. As a result, all analysis discussed in this report does not utilize this 3D fingerprint data directly, rather the analysis is performed on images obtained from each 3D system's transformation of the scanned data into 2D grayscale images that are intended by their vendors to be matchable against existing fingerprint databases.

NOTE: No fusion techniques have been incorporated into the matching runs or analysis. In operational deployments, some systems may utilize multi-finger fusion methods as a standard part of the identification process when communicating with an AFIS database (local or remote) to improve match performance. Operational testing is strongly recommended to better reflect real-world performance.

NOTE: Matching results are strongly dependent on the type of matching algorithm utilized and any optimization performed in configuring the matcher for a specific application. Neurotechnology MM is an average matcher (as reported in NIST testing), but other matchers have been shown to provide more accurate results.[4]

5.1 Comparison of Fingerprint Images

An example fingerprint image from each device dataset is shown in Figure 1. The images produced a TM at Rank 1 when matched against the LFP gallery. Images were selected that possess an NFIQ score equal to the most prevalent score in the probe dataset. The one exception is the innerID image; a TM image with NFIQ = 4 was unavailable.

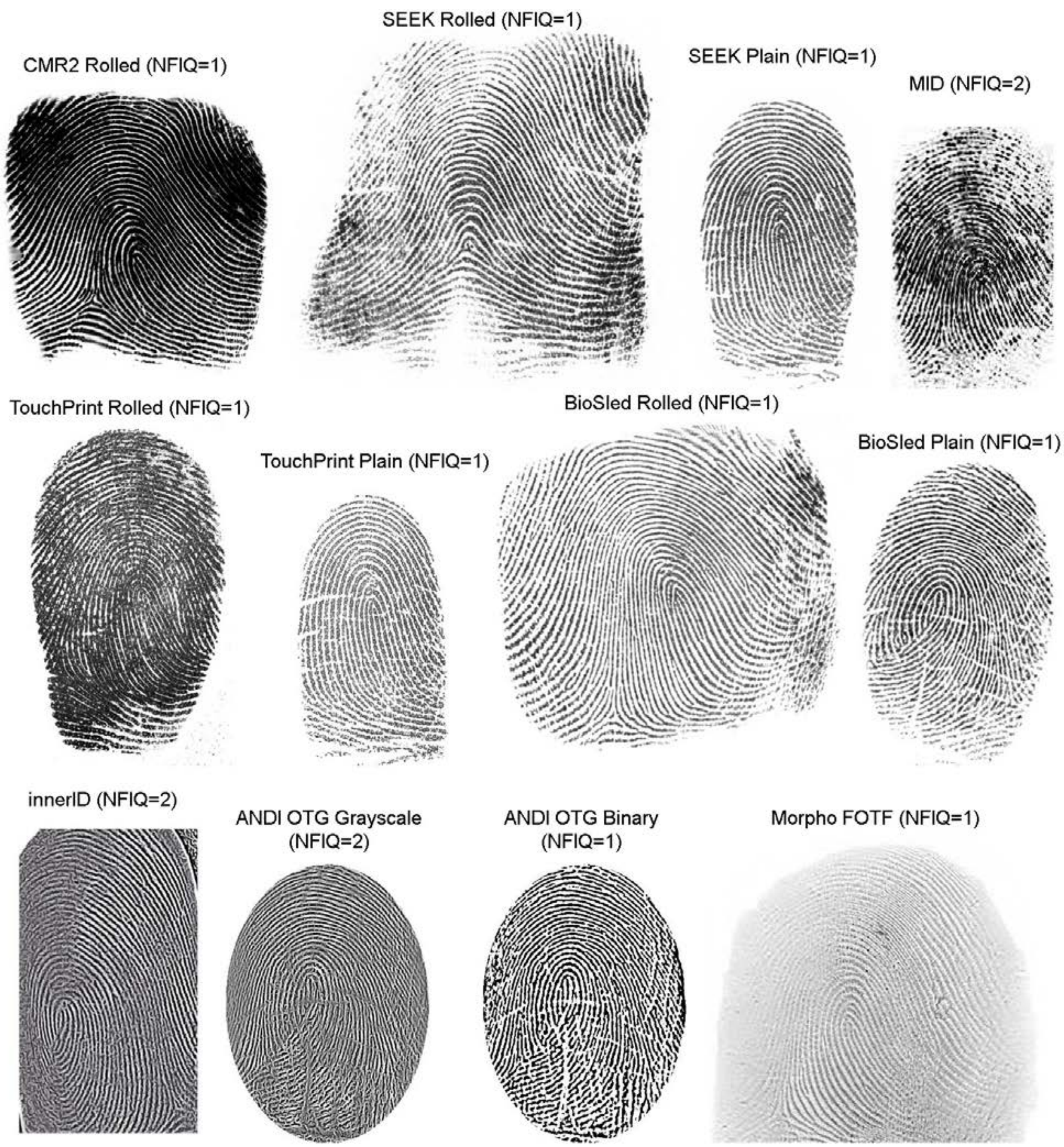


Figure 1: Example Fingerprint Images

Example fingerprint images from each device dataset with the NFIQ score of the image. Note that the images have been reduced in resolution for publication in the report.

The CMR2, TouchPrint, and MID all use a traditional optical platen for fingerprint capture. These are typical images, with variations in ridge density resulting from differing pressure applied during capture session and technique (rolled vs. plain). The SEEK and BioSled both possess a thin-film sold state platen. Qualitatively, they have an improved appearance with cleaner ridge lines and features. The innerID uses special software on an iPhone 4 to capture fingerprints using the onboard phone's camera. The image has contrast issues and a reduced capture area. The OTG system uses a high speed camera to capture all four fingers and segment them in the software. The output is a binary image by default, but for comparison purposes, the system used in this collection also output the raw grayscale images prior to undergoing any onboard image processing. Since grayscale images are the preferred submission to an AFIS and other systems in the collection do not incorporate image processing, this is a more direct comparison. The OTG images have a reduced fingerprint area, which is the result of cropping performed during the system's fingerprint segmentation. It is possible that the match performance of the OTG images could be improved by relaxing the segmentation/cropping conditions or by employing a more optimized cropping algorithm. Finally, the Morpho FOTF image is a 2D grayscale rolled-equivalent image produced from a 3D fingerprint image through a proprietary unwrapping transformation technique. FOTF utilizes proprietary advanced optical methods involving structured light to capture a 3D contactless fingerprint. Note that the 3D fingerprint was not available to operators during the CFPv2 collection, but given the project focus on interoperability to LFPs that was acceptable. The FOTF image has sufficient contrast and fidelity such that the majority of the fingerprint features are easily resolved upon viewing, but the edges of the finger are slightly unresolved. Whether this is due to the 2D transformation or present in the native 3D image is unknown.

5.2 Gallery vs. Gallery

Three datasets were used as galleries in the matching experiments. To measure their suitability as galleries, they were matched against themselves. A summary of the matching runs is provided in Table 5. The two CMR2 gallery runs produced 100% TAR with high average similarity scores. The FOTF dataset had one image that did not enroll due to image quality. As a result, all matches against the FOTF gallery excluded that subject ID/finger position from the probe set to ensure 100% correspondence between probes and gallery images.

Table 5: Gallery Matching Run Results

Probe Set	Enrollment	Gallery Set	Enrollment	TM Rank 1	Score, Mean	Score, Std Dev
CMR2 Rolled	538	CMR2 Rolled	538	100.0%	2403	859
FOTF	537	FOTF	537	99.8%	3088	961
CMR2 Rolled (CFPv1)	4868	CMR2 Rolled (CFPv1)	4868	100.0%	2501	957

Figure 2 shows the NFIQ score distributions for the three gallery datasets. In all three, the majority of images possess Excellent (NFIQ = 1) image quality with only a small percentage considered Poor (NFIQ = 5). The FOTF dataset has a slightly lower average image quality than the other two. Given that the NFIQ score algorithm was developed and optimized using sample datasets of traditional contact captured images, this is not surprising. The previous CFPv1 CMR2 dataset is slightly poorer than the current CMR2 set. This is likely due to improved collection practices and/or more experienced operators at WVU since ambient environment factors would tend to favor CFPv1, which was collected in the Spring (higher humidity), rather than CFPv2, which occurred in the winter.

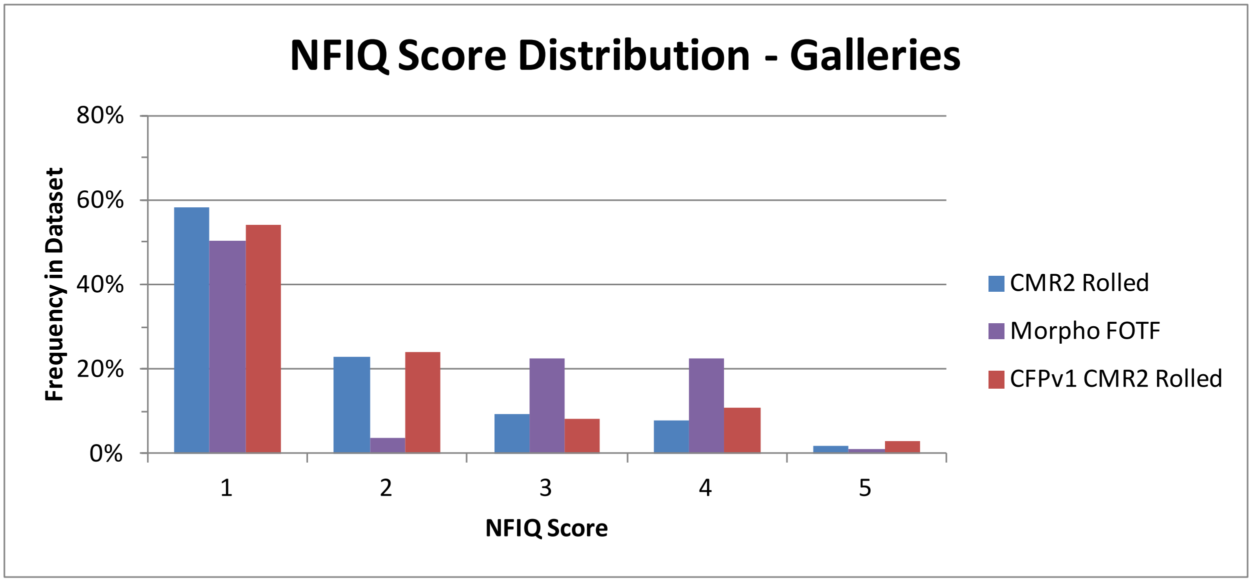


Figure 2: NFIQ Score Distributions - Galleries

Figure 3 shows the similarity score distributions of the TMs for the Gallery vs. Gallery matching runs. They are well above the score range for typical FMs (< 100). One interesting observation is that the contactless FOTF actually has a higher average score than either of the CMR2 probe sets.

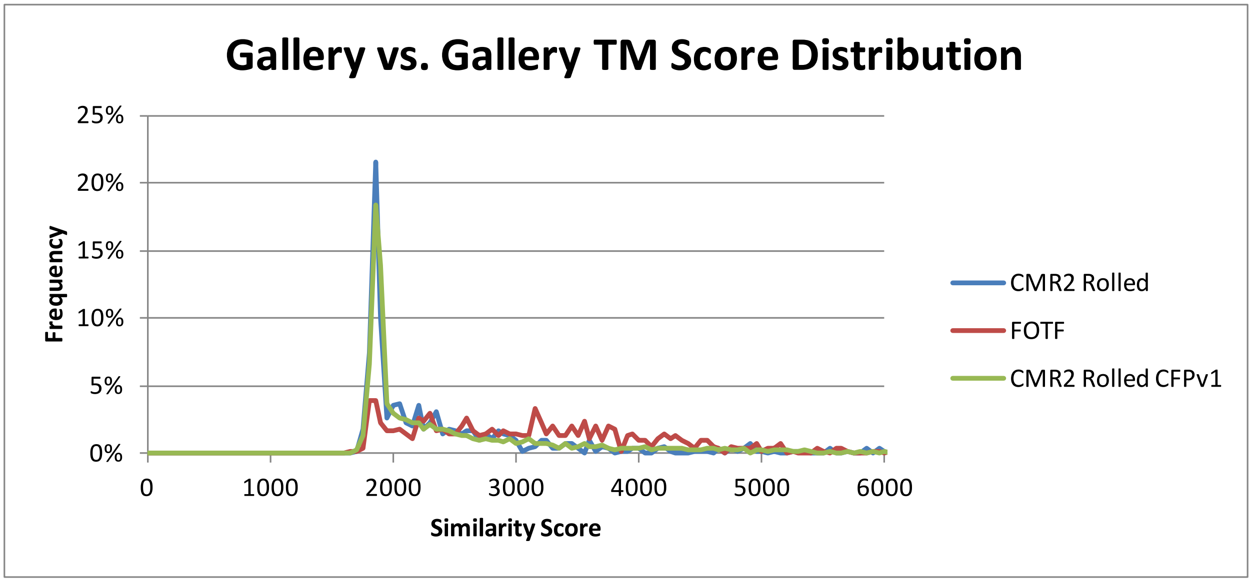


Figure 3: Gallery vs. Gallery Score Distributions

5.3 TouchPrint CFPv1 vs. CFPv2

The same specific TouchPrint and CMR2 devices were involved in the CFPv1 and CFPv2 collections. Examining the resulting dataset properties and match performances provides a useful validation of the collection processes used by WVU and, by extension, the feasibility of comparing the CFPv1 dataset results with those from this collection. Table 6 shows the matching results from the two TouchPrint datasets matched against their respective CMR2 galleries. The matching runs show almost the same TMR and average Scores.

Table 6: TouchPrint CFPv1 vs. CFPv2 Results

Probe Set	Enrollment	Gallery Set	Enrollment	TM Rank 1	Score, Mean	Score, Std Dev
TouchPrint Rolled	538	CMR2 Rolled	538	97.0%	447	201
TouchPrint Rolled (CFPv1)	4866	CMR2 Rolled (CFPv1)	4868	96.5%	386	197

Figure 4 shows the NFIQ score distributions for the TouchPrint and CMR2 datasets from each collection. The frequency composition at each quality classification is similar between CFPv1 and CFPv2 for both of the devices. In addition, the similarity score distributions for the two TouchPrint-CMR2 matching runs is almost the same (see Figure 5). Based on these results, it is reasonable to use the datasets collected under CFPv1 and compare their performance to those of CFPv2. For analysis and discussion purposes, this approach will be extended to the TBS and SEEK II datasets even though there is not a direct repeat of those device collections.

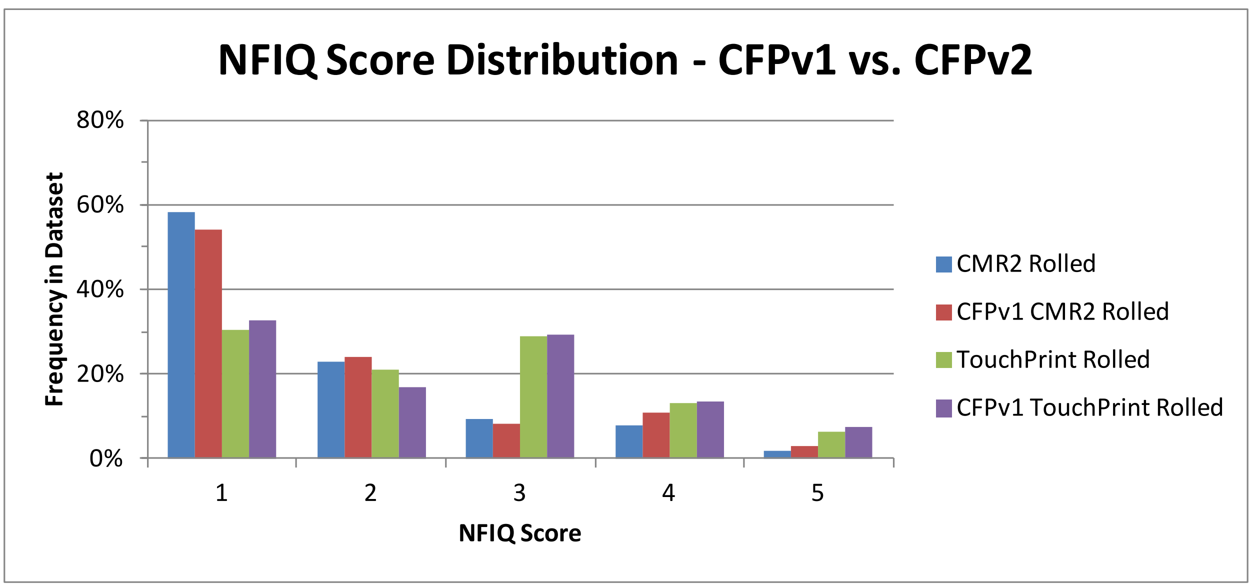


Figure 4: NFIQ Score Distributions - CFPv1 vs. CFPv2

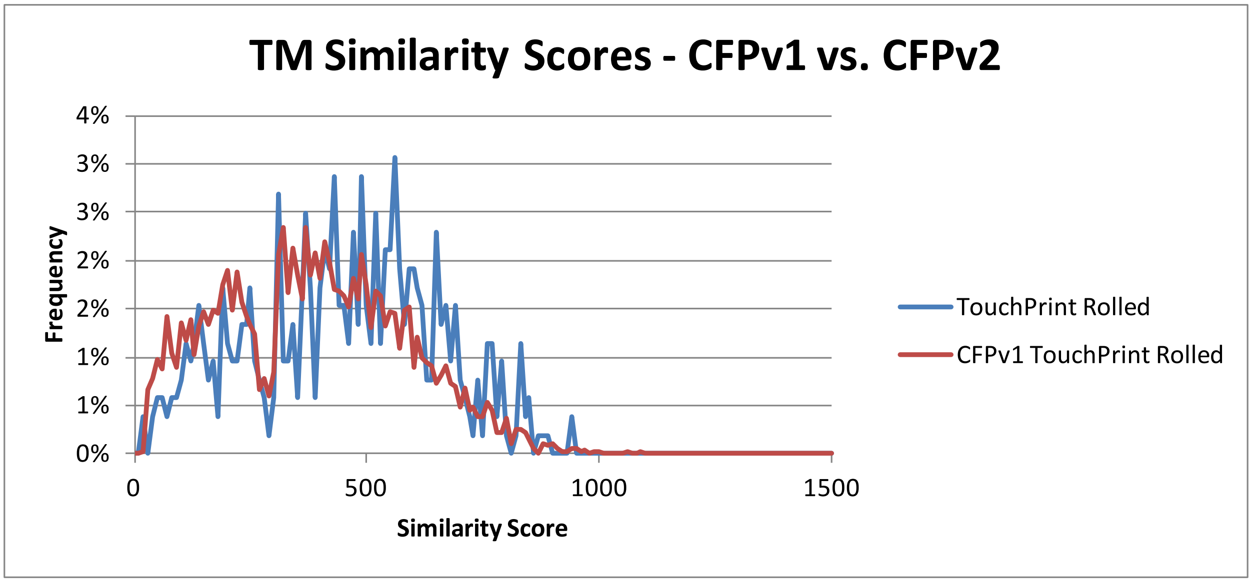


Figure 5: Similarity Score Distributions - CFPv1 vs. CFPv2

5.4 LFP Gallery Results

All of the datasets were matched against a LFP gallery represented by the CMR2 Rolled dataset. For comparison purposes and ease of reference, analysis and discussion has been divided into Fixed Systems and Mobile Devices. The two classes have differing deployment requirements and constraints.

5.4.1 Fixed System Results

Fixed systems are stationary (or portable) biometric scanners used primarily for booking, enrollment, or access control. The collected fingerprint data from a variety of fixed systems was matched against a typical LFP database gallery. In this case, the CMR2 Guardian was used as the gallery. Table 7 summarizes the match performance of various probe sets matched against the LFP database using the MM algorithm. More detailed match results can be found in Section 4.2 CMR2 Rolled Gallery Matching Runs.

The TouchPrint data performed well against the LFP gallery, with little difference between rolled and plain prints (TMR = ~97%). This can be considered the benchmark to compare other systems to, as the TouchPrint is currently deployed in many criminal justice agencies, as well as part of the suite of systems used by the Department of Defense (DOD) at various fixed position deployments. For the CFP systems, the FOTF and the TBS (from CFPv1) both performed similarly with a ~92% TMR. However, this FOTF rating is from individual fingers separately matched without multi-finger fusion, something that it is capable of doing through the capture of four fingers at a single hand swipe. The ANDI OTG is the third CFP system, which is a gate kiosk that captures four fingers from a moving subject. Its performance was notably lower than the FOTF or TBS, but through the use of multi-finger fusion, it might meet operational requirements. Of note is that the on system-generated binary images performed notably better than grayscale. This is unexpected since MM utilizes binarization as part of its image ingestion and feature extraction process. One would expect that it would be optimized for use with grayscale images. However, the low contrast of the OTG grayscale images (see Figure 1) likely contributed to this lower match rate. This suggests that CFP device vendors might benefit from utilizing their own optimized binarization processing for output images prior to submission to an agnostic third party AFIS. However, more data and test cases would be needed to confirm this trend.

Table 7: LFP Gallery Matching Results – Fixed Systems

Probe Set	Enrollment	Gallery Set	Enrollment	TM Rank 1	Score, Mean	Score, Std Dev
TouchPrint Rolled	538	CMR2 Rolled	538	97.0%	447	201
TouchPrint Plain	538	CMR2 Rolled	538	96.7%	313	153
ANDI OTG Grayscale	538	CMR2 Rolled	538	76.0%	72	44
ANDI OTG Binary	538	CMR2 Rolled	538	83.6%	110	68
FOTF	537	CMR2 Rolled	538	92.4%	144	78
TBS HT1 (CFPv1)	4868	CMR2 Rolled (CFPv1)	4868	91.5%	215	136

The NFIQ score distributions for the various fixed systems are summarized in Figure 6. The TouchPrint data had predominantly Excellent (NFIQ = 1) quality images. Interestingly, OTG Grayscale images had high image quality, as determined by NFIQ, but the lowest TMR of these datasets. This suggests that the NFIQ algorithm may not be optimized for predicting match performance for certain kinds of contactless fingerprint images. For example, the TBS had an average score of 2.9 while OTG Gray had an average score of 1.9. Therefore one would expect OTG Gray to outperform TBS in matching accuracy, but the opposite is true. However, the discrepancy might be explained by the difference in fingerprint image area size. OTG uses an internal cropping/segmentation process that results in oval shaped images of the center of the finger, while TBS is a nail-to-nail fingerprint image. This might also be why OTG Binary only has a TMR = 83.6% while it has an average NFIQ score of 1.6 with the majority of images classified as Excellent. However, from a holistic perspective NFIQ should take the image surface area into account to predict match accuracy. The TouchPrint Plain dataset has a very similar NFIQ distribution as OTG Binary but almost 15% points better matching accuracy. Improvements to the OTG capture area and/or segmentation process would likely lead to significant increases in accuracy. Finally, the FOTF is shown to have a good level of quality, with half of the images classified as Excellent. Interestingly, there is not a uniform sampling distribution, but instead the images seem to either be Excellent or Good – Fair, with a lack of Very Good images. This is not necessarily the result of the subject population's physical finger properties since the CMR2 and TouchPrint datasets have a more even distribution across the categories, including many with NFIQ = 2 (see Figure 4). This is likely the result of the use of an optical capture in which the subject's fingers are either cleanly aligned with the plane of capture (resulting in Excellent images) or misaligned (resulting in images with defects such as regions out of focus or a reduced capture area).

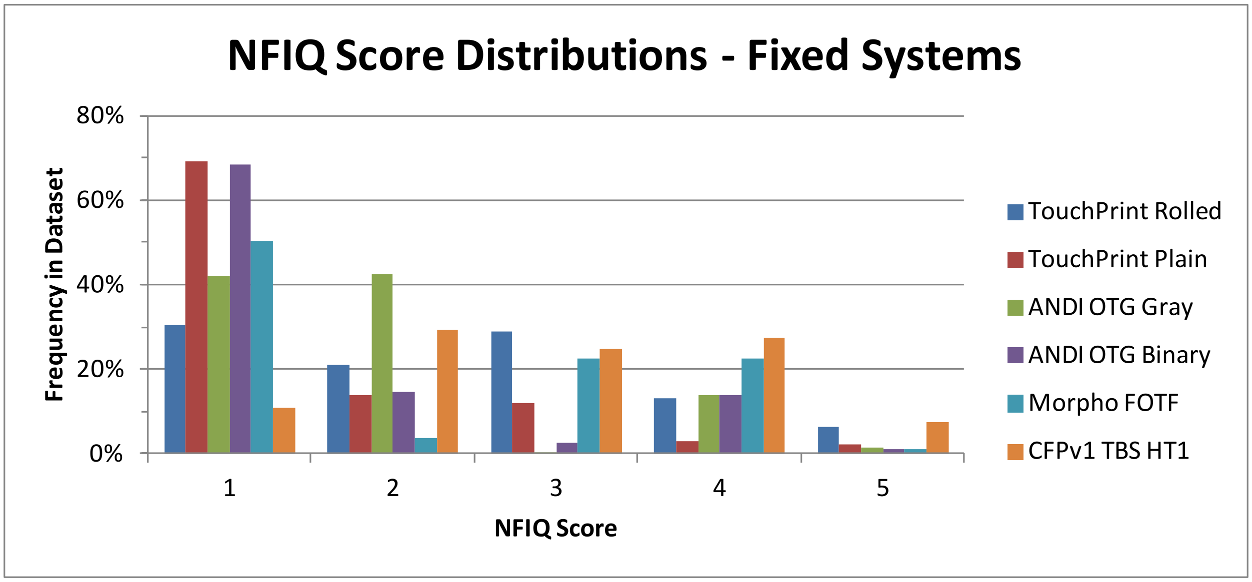


Figure 6: NFIQ Score Distributions – Fixed Systems

An aggregation of the TM similarity score distributions for each of the fixed system datasets is included in Figure 7. The distributions are aligned with the TMR accuracies previously mentioned in Table 7, with lower average scores resulting in lower accuracies. The TouchPrint datasets and TBS all have broader distributions with a higher standard deviation, as compared to the FOTF and OTG, which have narrower distributions on the low end. One anomaly is of interest. The FOTF dataset had a comparable, if slightly better, TMR as compared with the TBS; however, its similarity score distribution was notably lower. One would not have expected the FOTF to perform as well as it did comparing its similarity scores to TBS. This is likely attributed less to the FOTF and more to the atypical image appearance of TBS fingerprint images. Figure 8 shows an example fingerprint image possessing the most common NFIQ score (NFIQ = 2); the image also produced a TM and Rank 1.

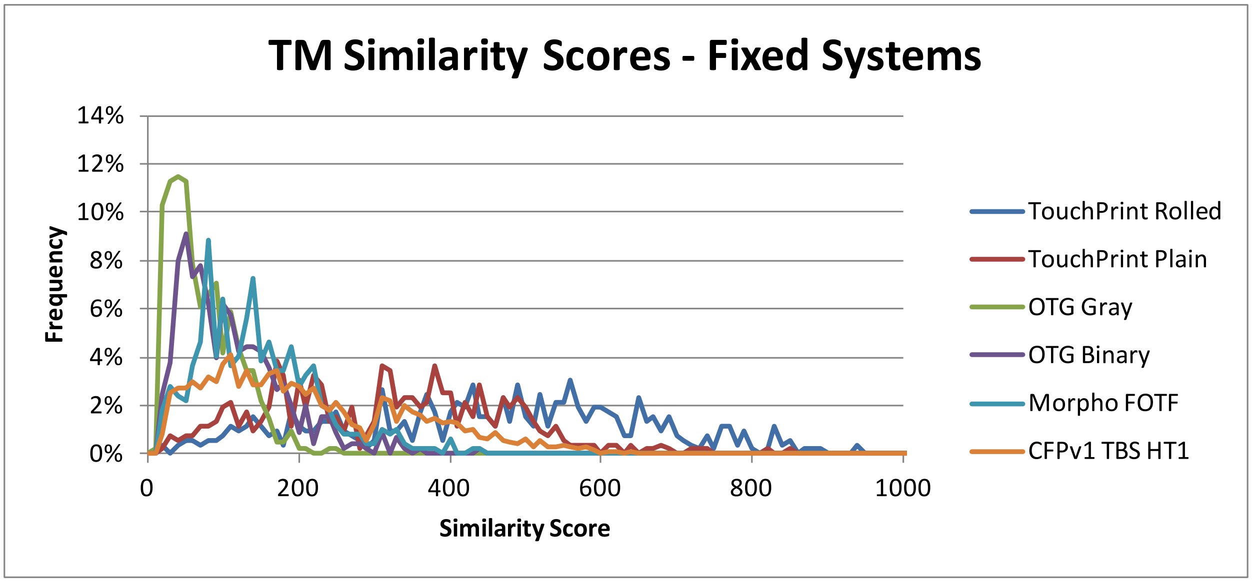


Figure 7: Similarity Score Distributions – Fixed Systems

Figure 8: Example TBS Fingerprint Image

5.4.2 Mobile Device Results

Mobile devices are handheld biometric scanners used primarily in the field for subject identification, verification, or tactical enrollment. The collected fingerprint data from a variety of mobile devices was matched against a typical LFP database gallery. In this case, the CMR2 Rolled prints were used as the gallery. Table 8 summarizes the match performance of various probe sets matched against the LFP database using the MM algorithm. More detailed match results can be found in Section 4.2 CMR2 Rolled Gallery Matching Runs.

The SEEK, BioSled, and SEEK II are direct comparisons. They all possess a Fingerprint Application Profile (FAP)[7] 45 sized sensor platen and are all medium to large handheld devices. The SEEK Rolled dataset resulted in the highest level of match accuracy of all the datasets (fixed or mobile) that was tested here, TMR = 97.8%. Considering that fixed systems have more stability, are easier for operator assistance, and a much larger platen size, that is a noteworthy result. The SEEK II was about the same as the SEEK. In a sterile laboratory environment, the evolution of the sensor (optical to LES thin film) did not yield improvements in data match performance using MM. However, improvements under more taxing operational settings might exist, but cannot be speculated in these analyses. The BioSled Rolled performed excellently as well (TMR = 96.5%), slightly below the two SEEK systems. The plain image sets for the medium-sized devices all showed an expected, but minor, drop in TMR compared to their rolled counterparts. Interestingly, the SEEK had more of a decrease than the BioSled. Given that they use the same OEM sensor component, this is likely due to either internal quality checks on the BioSled that would prompt an operator to recapture under stricter conditions, or is the result of a more ergonomic form factor that allows better interactions between the operator, device, and subject. These explanations are speculative, but reasonable possibilities. One interesting result is that the MID device, which is notable smaller than the other handhelds, resulted in better plain image accuracy (TMR = 96.5%) than either the SEEK or BioSled. The MID has a FAP 20 sensor (vs. FAP 45 for the other two). These results highlight the importance of marrying the right biometric device with the intended operational application. Finally, the innerID on an iPhone was found to produce exceptionally poorly matching results (TMR = 2.2%). This match rate all but disqualifies this mobile capture approach from any identification applications that match against a source database. However, it may be suitable for other constrained limited scope applications (see Section 5.6 innerID Comparison).

Table 8: LFP Gallery Matching Results – Mobile Devices

Probe Set	Enrollment	Gallery Set	Enrollment	TM Rank 1	Score, Mean	Score, Std Dev
SEEK Rolled	537	CMR2 Rolled	538	97.8%	427	198
SEEK Plain	536	CMR2 Rolled	538	95.0%	296	152
MID	538	CMR2 Rolled	538	96.5%	247	120
BioSled Rolled	537	CMR2 Rolled	538	96.3%	400	212
BioSled Plain	537	CMR2 Rolled	538	94.2%	278	156
innerID	537	CMR2 Rolled	538	2.2%	19	4

Probe Set	Enrollment	Gallery Set	Enrollment	TM Rank 1	Score, Mean	Score, Std Dev
SEEK II Rolled (CFPv1)	4868	CMR2 Rolled (CFPv1)	4868	97.7%	445	215

Figure 9 shows the NFIQ score distributions for the mobile device datasets. The SEEK and BioSled both produced Excellent images (NFIQ = 1) with few images of lower quality. Interestingly, the SEEK II dataset from CFPv1 had a lower frequency of Excellent images, with many more in the Very Good (NFIQ = 2) category. This indicates that, although the TMR did not see much improvement from SEEK II to SEEK (i.e., SEEK Avenger) using MM, the overall data captured was improvement. Using different matchers, the SEEK (and BioSled) datasets might be found to have an improved accuracy over SEEK II. These datasets should also be more forgiving of lower performing matchers, still providing acceptable match rates, and/or the TMR might further improve from the ~97% using the top tier matchers (e.g., 3M Cogent, NEC, Morpho[4]). The MID has its quality peak at Very Good. This is likely the result of the reduced platen size and/or the optical capture method. The other lower quality categories are infrequent – the MID has produced a quality dataset. The innerID score distribution is worse than the others, with its most frequency category being Good ($NFIQ_{avg}$ = 2.7). However, it does have a reasonable number of Excellent and Very Good quality images. Starting from this NFIQ score distribution, one would not expect the poor TMR accuracy (TMR = 2.2%) from the matching experiments. One could conclude that the either NFIQ is not providing an accurate prediction of the matching performance or the MM is ill suited to accepting the types of images captured using innerID. Given the likely increasing prevalence of smartphone capture fingerprint images, improvements in both areas are needed. Further matching experiments using the innerID data but with other matchers would identify if this issue is specific to MM or a more general problem with these types of contactless images.

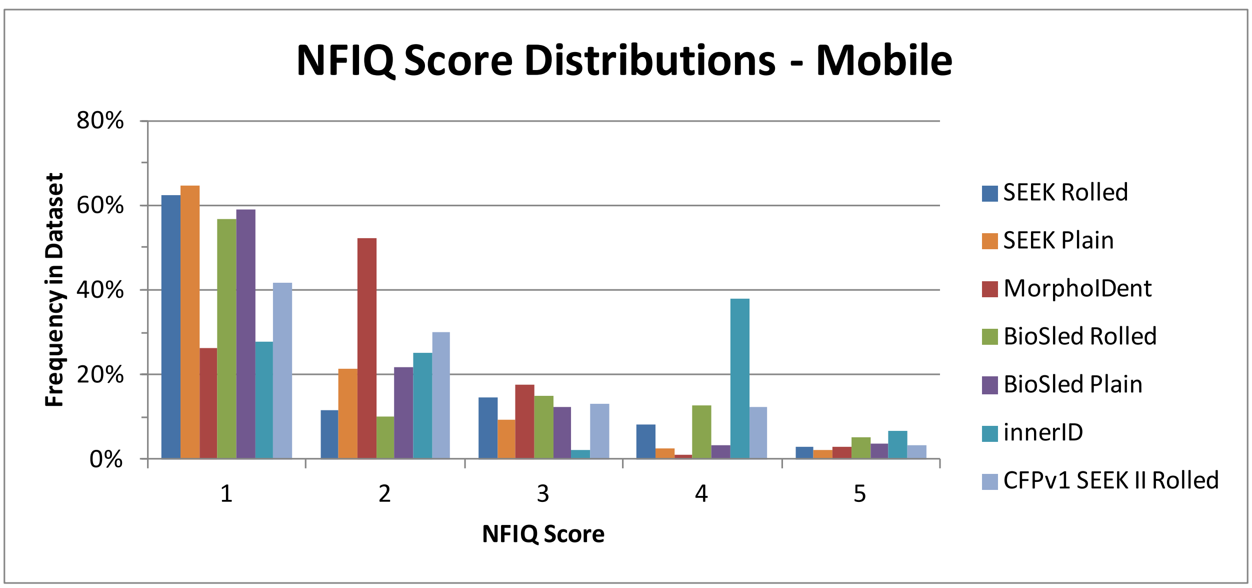


Figure 9: NFIQ Score Distributions – Mobile Devices

The TM similarity score distributions for the various mobile device matching runs are presented in Figure 10 and Figure 11. Neither figure provides interesting results or insight, but is included here for reference and completeness. The rolled print datasets all result in similar distributions, even down to the dip around ~280. They are well above the FM similarity scores, which are less than 20. The plain print dataset distributions are similar for SEEK, MID, and BioSled. Given the similar TMR, this is expected. The innerID has a very low TM distribution, which effectively overlaps the FM scores (see Section 4.2.11 innerID vs. CMR2 Rolled).

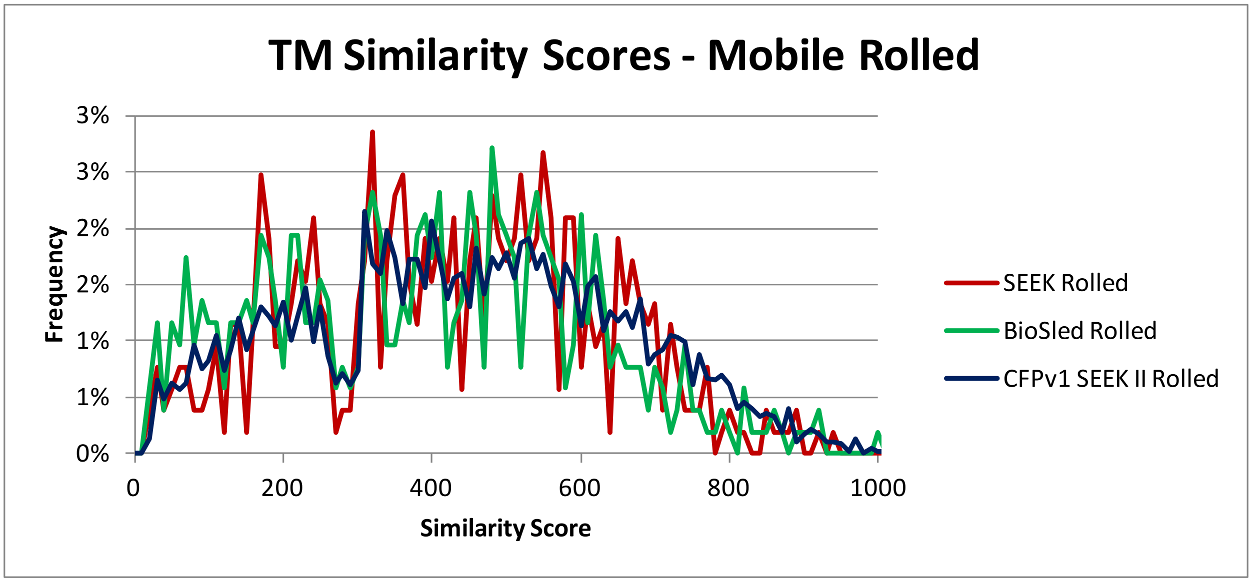


Figure 10: Similarity Score Distributions – Mobile Rolled

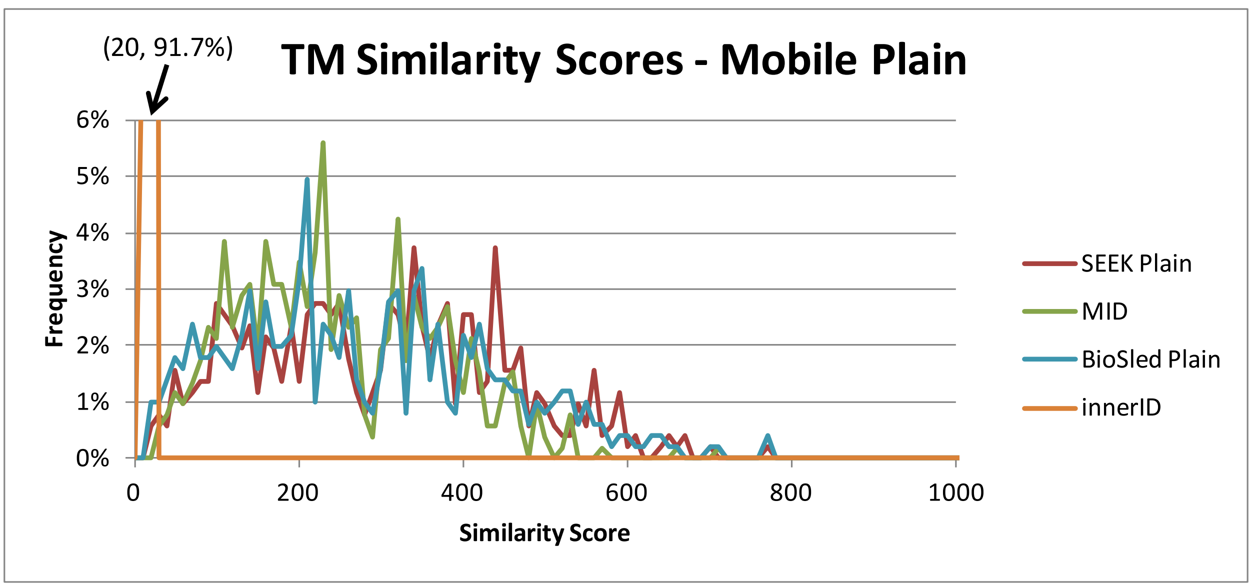


Figure 11: Similarity Score Distributions – Mobile Plain

5.5 CFP Gallery

In addition to matching against traditional LFP databases, several systems' data was matched against a CFP gallery. As CFP systems begin deploying in more locations and environments, they could become the primary enrollment system for some subjects. In particular, applications where subjects utilize biometrics in limited capacities and for singular purposes (e.g., facility access control), these CFP fingerprint images may serve as the only exemplar to match against. The FOTF was selected as the CFP gallery because it is a fixed system and produced the highest mean similarity score when matched against the CMR2. Note that one image did not enroll in the FOTF resulting in a CFP gallery size of 537 (vs. 538 for LFP); that subject/finger was excluded from the probe datasets.

Table 9 summarizes the matching results from fixed and mobile systems matched against FOTF using the MM algorithm. The CMR2 Rolled match results were the same as the flipped condition of FOTF as probes against CMR2, both in TMR and average similarity score. Interestingly, the OTG Grayscale images performed better against the FOTF than they did against the LFP (TMR = 79.5% vs. 76.0%) with notably higher similarity scores. The OTG Binary images performed at about the same level. In contrast, the SEEK Plain images performed worse against FOTF than CMR2 (TMR = 87.2% vs. 95%). These two results suggest that the MM feature extraction is different enough when processing CFP images than LFP images to impact the match performance. CFP images will have a greater affinity for matching other CFP images than LFP, and vice a versa. This is likely due to differences in image characteristics from contactless capture, such as a higher probability of certain types of image defects (e.g., blurriness, distortion) over other image defects (e.g., contrast gradients). These results have implications for improving the integration and interoperability of CFP data with LFP, such as using multiple feature extractors or changing the optimization of the extractor. The innerID dataset did not improve its matching accuracy when submitted against a CFP gallery. One might expect an improvement based on the previous logic of CFP being more prone to match CFP. However, the qualitative image appearance is notably different between FOTF and innerID (see Figure 1).

Table 9: CFP Gallery Matching Results

Probe Set	Enrollment	Gallery Set	Enrollment	TM Rank 1	Score, Mean	Score, Std Dev
CMR2 Rolled	537	FOTF	537	92.0%	145	78
SEEK Plain	535	FOTF	537	87.2%	158	93
ANDI OTG Grayscale	537	FOTF	537	79.5%	123	72
ANDI OTG Binary	537	FOTF	537	83.2%	142	85
innerID	536	FOTF	537	2.0%	24	4

The TM similarity score distributions for the CFP gallery matching runs are provided in Figure 12. No noteworthy observations or results have been provided; they are included for reference and completeness.

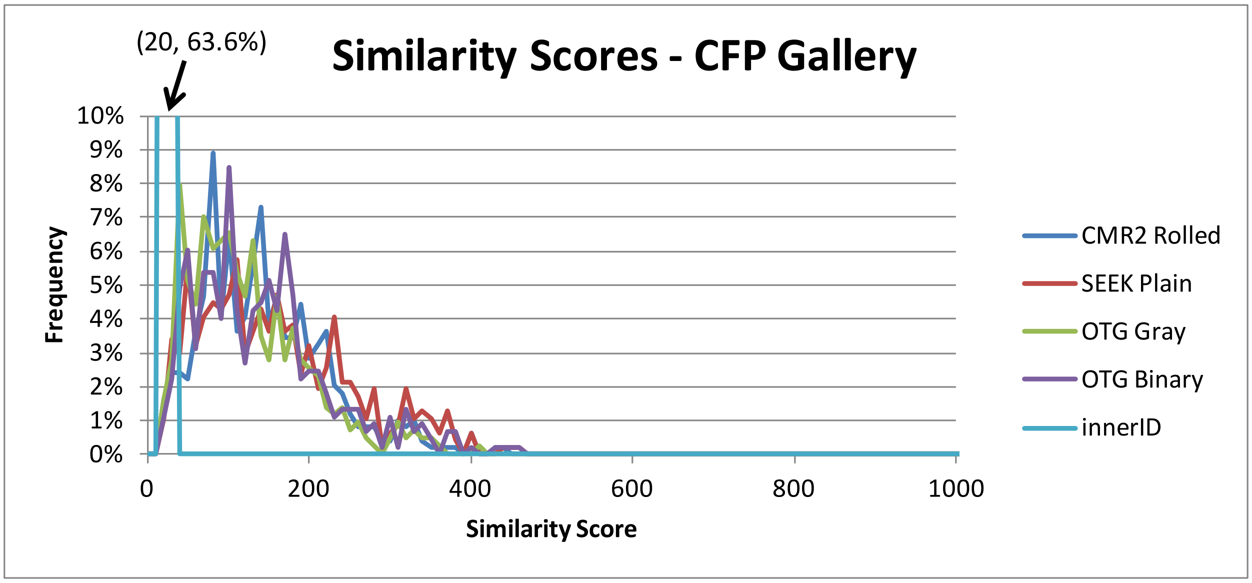


Figure 12: Similarity Score Distributions – CFP Gallery

5.6 innerID Comparison

The innerID probe set produced poor matching results when submitted against both the LFP and CFP galleries. However, the primary cause of the mismatch was hypothesized to be differences in the image composition/characteristics due to the capture method and not just due to poor image quality. This hypothesis was supported by the seemingly acceptable NFIQ score distribution (see Figure 9), in which the dataset has an average NFIQ score of 2.7. This average is actually lower (i.e., better quality) than the TBS dataset, which has an average score of 2.9. That dataset produced a matching accuracy against a CMR2 LFP gallery of TMR = 91.5%. To explore this hypothesis further, the innerID Set 2 dataset was matched against the innerID Set 1 gallery (see Section 4.4 innerID Verification Run for matching run details). Recall that each subject had two collections performed with each device. As a result, these were different images of the same subject/finger. Subject/fingers from Set 1 that were not enrolled due to image quality issues were similarly excluded from the Set 2 probes. This matching run follows a verification application scenario in which a subject was enrolled using the innerID on a device (e.g., smart phone) and then uses a future capture on the same device to verify identity and gain access.

Table 10 shows the matching run results from the three runs in which an innerID dataset was submitted as a probe set. As has been discussed previously, against a second system LFP or CFP gallery, the innerID images produce poor matching. However, when the gallery is another innerID dataset, the TMR increases dramatically to 66.4% and the average TM similarity score increases by almost an order of magnitude. With these results, the innerID becomes a viable system for verification in low security settings. In addition, if two factor authentication was employed whereby two fingers were required, the TMR would likely increase even further to ~89%. These results highlight the importance of designing experiments that mirror operational scenarios or use cases when determining suitability. In addition, it is worth noting that the other CFP systems (i.e., FOTF and OTG) might exhibit similar improvements in match performance when utilizing probes and galleries from their same systems. For access control scenarios where biometric use might be localized, enrollment on the same system used for identification/verification is a good best practice to follow if possible.

Table 10: innerID Matching Results

Probe Set	Enrollment	Gallery Set	Enrollment	TM Rank 1	Score, Mean	Score, Std Dev
innerID	537	CMR2 Rolled	538	2.2%	19	4
innerID	536	FOTF	537	2.0%	24	4
innerID Set 2	1579	innerID Set 1	1584	66.4%	188	141

The NFIQ score distributions for both innerID datasets is shown in Figure 13. The figure confirms that Set 1 has a similar distribution as Set 1 and that the higher TMR is not the result of dramatically improved NFIQ scores.

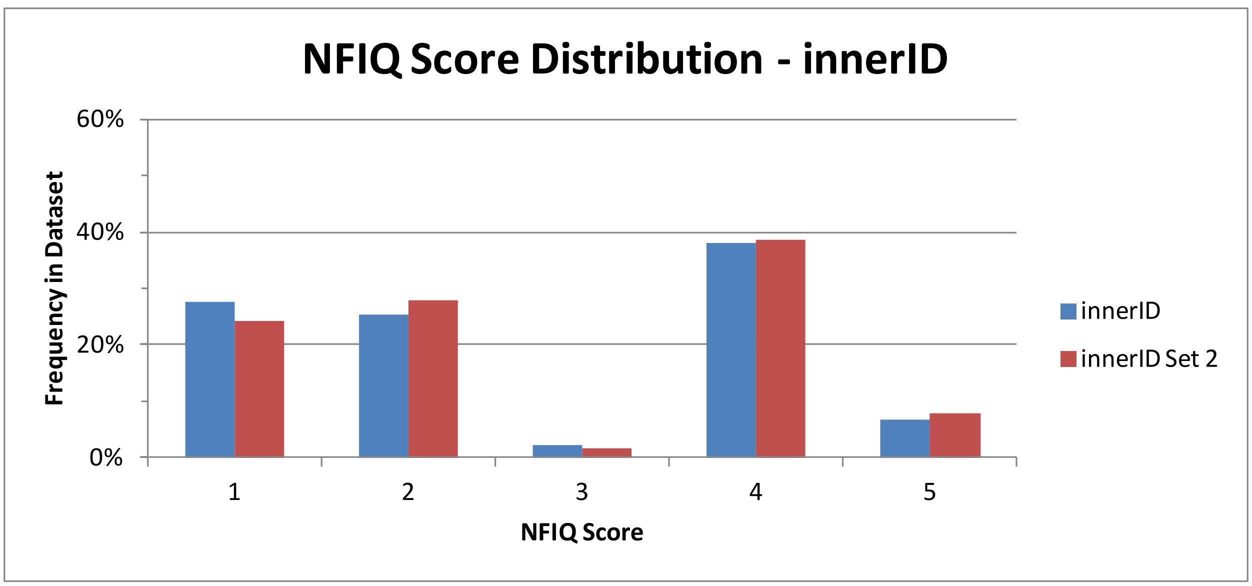


Figure 13: NFIQ Score Distributions – innerID

The TM similarity score distributions for the three innerID matching runs are shown in Figure 14. Consistent with the higher TMR, the similarity scores are much higher on average, but also have a broad sampling from 0 all the way into the 400s. The FM scores for the innerID vs. innerID matching run were similar to the other two runs.

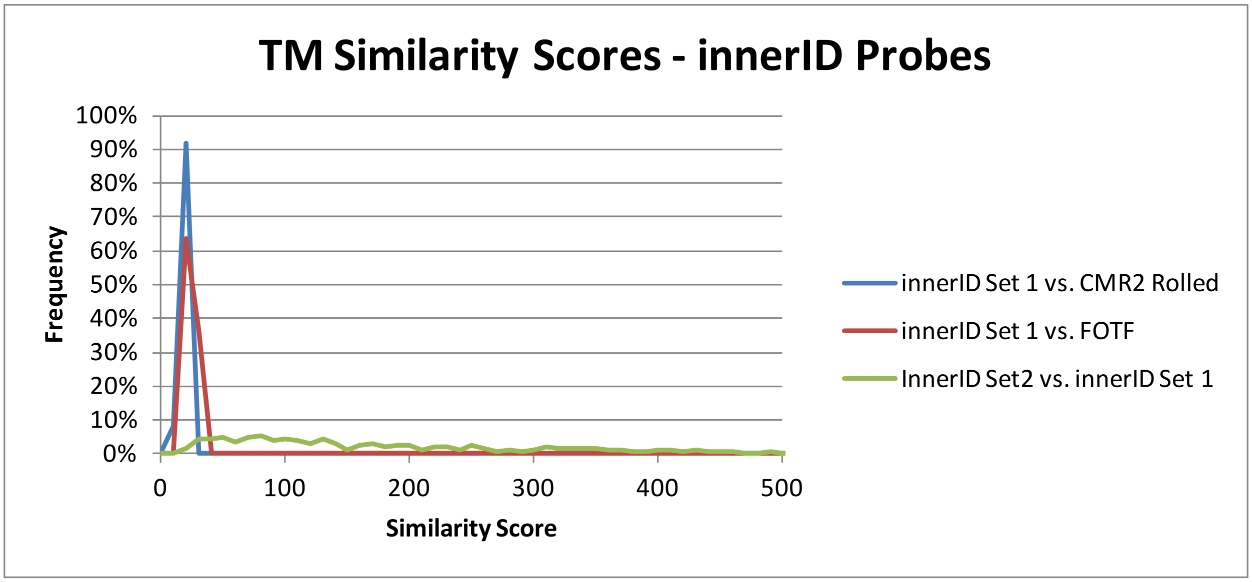


Figure 14: Similarity Score Distributions – innerID

6.0 CONCLUSIONS

In general, several key observations/conclusions were identified as a result of this analysis effort:

- This effort is the second quantitative demonstration by a third party that fingerprints collected under ideal conditions from LFP and CFP devices can be matched against each other in a statistically meaningful way.
  - **Conclusion:** The experimental methodology employed (data collection and analysis) can be used to determine a comparative match performance among LFP and CFP using 2D projections.

- The CFPv2 dataset possesses sufficient breadth and depth for investigating the performance and interoperability of CFP and LFP devices. Few biometric dataset resources exist that cover as many devices capturing the same subject pool.
  - **Conclusion:** The CFPv2 dataset is a unique and useful resource for biometric researchers that can further the understanding, performance, and adoption of CFP systems, as well as inter-device matching.

- The FOTF and OTG performed well against a LFP (see Section 5.4.1 Fixed System Results). Using single finger matching, the FOTF demonstrated TMR > 90% and Very Good quality images; the OTG produced TMR > 83% and Very Good – Excellent quality images.
  - **Conclusion:** The FOTF is a mature system and a possible candidate for operational environments.
  - **Conclusion:** The OTG is near production ready and with minor improvements in capture and image processing will be ready for operational consideration.

- The contact mobile devices performed well (both plain and rolled printed). The results were comparable to fixed livescan systems (see Section 5.4.2 Mobile Device Results).
  - **Conclusion:** The SEEK and BioSled are suitable for field enrollments, and are more than adequate for field queries.
  - **Conclusion:** The MID is well suited for field queries.

- The matching accuracy of a probe set was highest when matched against its same type (see Sections 5.4 LFP Gallery Results and 5.5 CFP Gallery). The OTG Grayscale images performed better against the CFP than they did against the LFP (TMR = 79.5% vs. 76.0%) and the SEEK Plain images performed worse against CFP than LFP (TMR = 87.2% vs. 95%).
  - **Conclusion:** The feature extraction process for MM (and possibly other matchers) may be different for CFP images than LFP images due to image characteristics and common image defects.

- The OTG Binary images led to a higher match accuracy than OTG Grayscale images (see Section 5.4.1 Fixed System Results). OTG Binary probes matched against the LFP resulted in a TMR = 83.6%, as compared to TMR = 76.0% for Grayscale images.
  - **Conclusion:** The use of a vendor-optimized binarization processing step after image capture could increase matching accuracy prior to submission to an agnostic third party AFIS matcher, even if that matcher includes a standard binarization stage.

- The NFIQ score distributions of some CFP datasets were not fully consistent with the resulting match accuracy (see Section 5.4 LFP Gallery Results). The OTG Grayscale probe set had a high mean image quality ($NFIQ_{avg}$ = 1.9), but the lowest TMR of the datasets. The innerID probe set had an Average overall image quality ($NFIQ_{avg}$ = 2.7), but extremely low TMR.
  - **Conclusion:** The NFIQ algorithm may not be optimized for predicting match performance for certain kinds of CFP images.

- The innerID produced very low matching accuracy submitted against LFP or CFP galleries, but significantly higher matching when submitted against a second innerID gallery (see Section 5.6 innerID Comparison). Against a second device gallery, TMR = ~2% but against innerID Set 2 TMR = 66.4%.
  - **Conclusion:** Some CFP capture devices that perform poorly against third party databases may have a role in low security verification applications.
  - **Conclusion:** Test parameters need to mirror operational end-use rather than relying solely on simplified generic test procedures.

6.1 Future RDT&E Directions

Included here are follow-on RDT&E topics that build upon this work, explore topics discussed here in more detail, or pursue complimentary experiments. Resource limitations have precluded the SSBT CoE team from pursuing these, but given the availability of the WVU collection datasets, it would be easy to continue the work.

- **Expand the experiments to utilize the entire CFPv2 dataset so as to improve analysis results and reduce statistical variations.** The SSBT CoE utilized half of the data collected to conduct experiments and carry out analysis. There are a total of 450 subjects in the full dataset. In addition, the matching runs were performed utilizing only the 538 subject/fingers common to all datasets. Analyses involving LFP devices could take advantage of significantly more data since the OTG limited the datasets to only four fingers.

- **Investigate the intra-device match performance using the two collection sessions to determine repeatability and behavior of various devices in verification applications.** The innerID verification matching provided interest results when compared to its low identification performance. Further experiments are needed to determine if this performance variation is unique to innerID, CFP devices, or common to all devices involved.

- **Investigate the use of multi-finger fusion for improved CFP matching performance.** As previously emphasized, no fusion techniques have been incorporated into the matching runs or analysis. In operational deployments, some systems may utilize multi-finger fusion methods as a standard part of the identification process when communicating with an AFIS database (local or remote) to improve match performance. The CFPv2 dataset allows for researching and developing these methods and comparing their efficacy for CFP and LFP datasets.

- **Expand experiments to incorporate additional matching algorithms.** Matching results are strongly dependent on the type of matching algorithm utilized and any optimization performed in configuring the matcher for a specific application. Neurotechnology MM is an average matcher, but other matchers have been shown to provide more accurate results.[4] Other matchers, particularly those with known processing and feature extraction processes, would allow researchers to correlate performance with image characteristics and therefore optimize matchers for CFP data.

- **Utilize demographic information to determine subject dependent match performances among CFP and LFP datasets.** The CFPv2 collection report (see APPENDIX A: WVU COLLECTION REPORT) includes anecdotal reports from operators that the CFP systems showed some difficulties in capturing fingerprints from dark-skinned subjects. The dataset could be leveraged to investigate any differences across ethnicities and devices.

- **Explore image pre-processing techniques to improve CFP match performance.** Results involving grayscale and binarized images in this work suggest improvements in match accuracy can be achieved when vendors incorporate device-optimized processing steps prior to submission to a gallery. Other on-board or pre-submission processing could enhance matching beyond relying on matching algorithms.

- **Investigate NFIQ and NFIQ-II in more detail when applied to CFP datasets to improve its predictive correlation to matching accuracy.** Some of the matching runs possessed match rates and NFIQ score distributions with discrepancies. The NFIQ score is determined using a multi-dimensional image feature vector (11 different image features).[8] Applying these metrics to CFP and LFP datasets could provide insight into how best to optimize predictive accuracy.

APPENDIX A: WVU COLLECTION REPORT

Non-Contact Multi-Sensor Fingerprint Collection – Phase II
11/2014 - 4/2015

FINAL REPORT

<u>For:</u>
ManTech International Corp.

Jeremy M. Dawson, Ph.D. - PRINCIPLE INVESTIGATOR
Christopher Robison – Collection Staff Lead

Contents

1. Project Overview

The purpose of this data collection was to obtain data to enable the evaluation of non-contact fingerprint devices. In addition, human factors information was collected from operators performing the data collection to assess the operability of the prototype devices and how the general public interacted with these devices. The target number of participants for this collection was 400. An initial cohort of data was provided after ~200 participants were collected, followed by a second cohort of the remaining data. Data collection took place between 12/1/2014 and 4/2/2015, with 450 participants providing data.

The following is a description of the data collection effort, a summary of data collected and participant demographics, and operator feedback from WVU staff members.

2. Data Collection

Data collection was performed on the WVU Evansdale Campus. The collection utilized livescan and non-contact fingerprint devices provided by ManTech. An indoor laboratory space (164 ESB Addition) was used as the collection area, with all sensors and rolled ink impressions collected in the same space. Data was collected from each device and assembled in a common data repository on a regular basis.

2.1 Fingerprint Devices

Data collection was performed using seven different fingerprint devices (both livescan and non-contact systems), as well as rolled ink impressions on a standard 10-print card. Table 1 lists the devices used in this data collection, along with the data collected from each device. *Note: The Single-finger non-contact system from FlashScan 3D was slated to be included in this data collection. However, it developed an operational issue prior to the start of collection. It was sent to FlashScan for repair, but was not returned.*

Table 1: Fingerprint device details.

Vendor	Sensor	Collection Type	Data Collected
1. CrossMatch	Guardian R2	Livescan, contact	Left & right hands, slaps & rolls
2. L1/Morpho	TouchPrint 5300	Livescan, contact	Left & right hands, slaps & rolls
3. CrossMatch	SEEK Avenger	Mobile, contact	Livescan equivalent to 10-print card
4. Northrup Grumman	BioSled	Mobile, contact	Livescan equivalent to 10-print card
5. MorphoTrak	MorphoIDent	Mobile, Contact	Left & right hands, slaps only
6. Advanced Optical Systems (AOS)	ANDI On-The-Go	Portal, contactless	4 fingers on right hands only
7. MorphoTrak	Finger-on-the-Fly	Livescan, contactless	Left & right hands, 4 fingers only
8. IDair	InnerID (on iPhone)	Mobile, contactless	Left & right hands, finger photos

Images of these devices are shown in Fig. 1.

Figure 1: Fingerprint devices (from top left): CrossMatch Guardian R2, L1/Morpho TouchPrint 5300, CrossMatch SEEK Avenger, Northrup Grumman BioSled, MorphoTrak MorphoIDent, Advanced Optical Systems (AOS) ANDI On-The-Go, MorphoTrak Finger-on-the-Fly. The IDair InnerID (on iPhone) system was not available for photograph.

2.2 Collection Site

The laboratory space housing the various collection equipment was approximately 24x24ft, with the collection area encompassing ~12x24ft of this space. Three standard lab benches were used to acquire data from the 8 different sensors used in this collection. The first bench housed the MorphoIDent, BioSled, and InnerID devices, along with a laptop for data transfer from these devices. The second bench housed the SEEK Avenger and Finger-On-The-Fly (FOTF) devices, and the control laptop for the FOTF system. The third bench housed the Guardian and TouchPrint devices and their control laptop, as well as the control laptop for the ANDI On-The-Go (OTG) system. The OTG system was located adjacent to the collection area to allow the participant to gain a walking start before interacting with the system. A plywood riser with ink plate and card bracket for inked fingerprint impression collection was placed on a nearby counter surface. A sink was available in the room for cleanup, as well as standard ink remover pads. The restrooms were located nearby for additional hand-washing if needed. Fig. 2 illustrates the arrangement of the equipment in the laboratory used for the data collection.

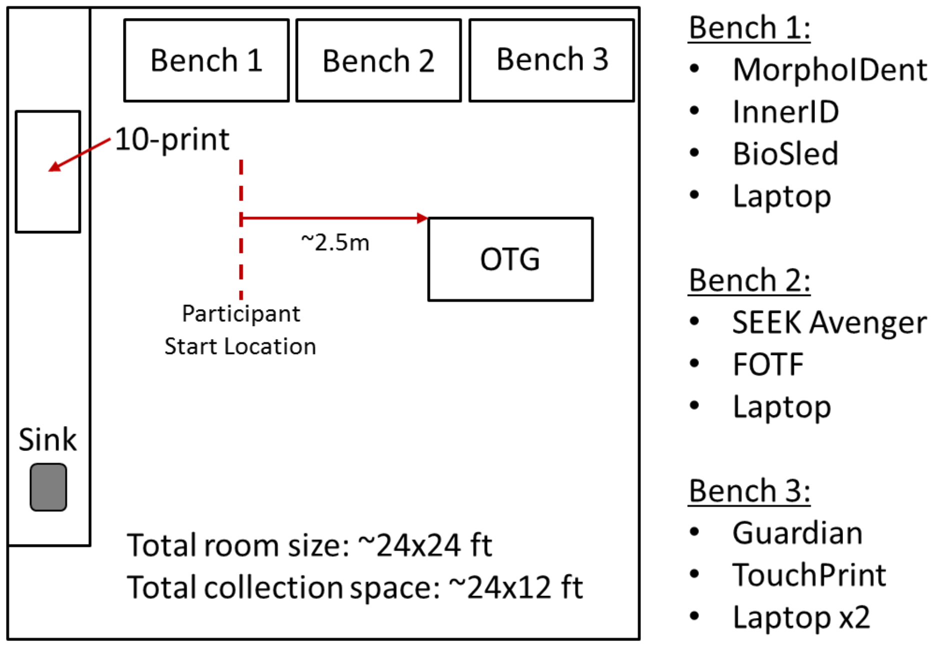


Figure 2: Collection laboratory and station arrangement.

2.3 Data Types & Organization

Each participant in the data collection provided two sequential sessions of fingerprints for each sensor. Inked prints were collected once and scanned at 500 and 1000ppi. The file structure of the data is as follows:

- 10 print cards
  - Subject ID_Date_WVU Collection ID
    - 500
      - .eft file x1, .bmp images x14
    - 1000
      - .eft file x1, .bmp images x14
- Andi OTG
  - Subject ID_Date_WVU Collection ID
    - Session 1 & 2 folders
      - Binary .bmp images x4
      - Grayscale .bmp images x4
- BioSled
  - Subject ID_Date_WVU Collection ID
    - Session 1 & 2 folders
      - BioSled system files x16
      - .bmp images x16
- Crossmatch SEEK avenger
  - Subject ID_Date_WVU Collection ID
    - Session 1 & 2 folders
      - .eft file x1
      - .bmp images x14

- FPII Guardian
  - Subject ID_Date_WVU Collection ID
    - Session 1 & 2 folders
      - Sensor date folder
        - .bmp images x13
- innerID
  - Subject ID_Date_WVU Collection ID
    - Session 1 & 2 folders
      - .bmp images x10
- L1 TouchPrint
  - Subject ID_Date_WVU Collection ID
    - Session 1 & 2 folders
      - .bmp images x13
- Morpho FOTF
  - Subject ID_Date_WVU Collection ID
    - Session 1 & 2 folders
      - Unsegmented .bmp images x4
      - Segmented .bmp images x16
- MorphoMobile
  - Subject ID_Date_WVU Collection ID
    - Session 1 & 2 folders
      - .bmp images x10

The syntax of each fingerprint image filename is as follows:

SubjectRID_CollectionDate_CollectionNumber_SensorName_Slap/RollIdentifier_SessionNumber_Finger/SlapIdentifier.EXT

The numerical values in the 'Slap/RollIdentifier' and 'Finger/SlapIdentifier' fields are determined based on the NIST standard(s) for fingerprint capture and archiving (Publicly Available). To keep file path lengths at a minimum, each sensor has been abbreviated with a 3 letter code in the 'SensorName' field. Table 2 defines each abbreviation.

Table 2: Sensor codes used in file naming convention.

Code	Definition
10P	Ten Print Card (Scanned at 1000 & 500 dpi)
IID	InnerID (iPhone App)
MFF*	Safran Morpho Finger on the Fly
CSA	CrossMatch SEEK Avenger
BIO	Northrup Grumman BioSled
OTG	ANDI On the Go (OTG)
L-1	L-1 scanner
CG2	CrossMatch Guardian 2
SMM	Safran Morpho Mobile MorphoIDent
**Note:* The session IDs for this device will appear as <X-Y> where X denotes which session data was being collected and Y denotes the individual passes of the subject's hand through the device per session.	

Due to operator error and sensor malfunction, some data may be missing or corrupted. A list of missing data was included with the dataset upon delivery to ManTech. In instances where a particular sensor was malfunctioning or away for repair, collection was continued and this data will be missing from the subject's data record.

2.4 Collection Procedure

The following is a description of the collection procedure the participant experiences from consent to remuneration. It is written as an instructional document describing to staff members the standard operating procedure of each data collection station. Total time through the collection was 45 minutes to 1 hour.

2.4.1 Consent

Greet the participant and provide the consent form. Explain each section of the consent form, including all locations on the form that need to be initialed, dated, or signed. Ensure that your explanation includes the following:

- The purpose of the study is to collect data for biometrics research funded by ManTech International and the National institute of Justice.
- Data collection consists of fingerprints captured by multiple electronic fingerprint devices and on paper with ink.
- Participation is strictly voluntary; they may opt out of the process at any time.
- Inform the participant that they will be receiving gift cards upon completion of data collection and that if they choose to not complete the study they will not receive the gift cards.

Once the participant has read and completed the consent form, ask if they have any further questions and direct them to the Enrollment workstation.

2.4.2 Enrollment

Once the participant has arrived at the Enrollment Workstation, ask them for a photo ID to verify their identity. Participants may already be in the Enrollment database from another study, so ask if they have participated before. If they have participated before they will already have an RID number, if not they will need a new RID generated in the system. Using the Enrollment interface, search the database to see if the basic information (name, date of birth, etc.) exists in the database. Searching the database can be completed by using the participant's first or last name, date of birth, or all three. Typically it is most efficient to search by last name and identify the correct person based on the date of birth that appears after searching. If the participant already has an RID in the system, make a note of the RID for use while completing the enrollment process. If the participant is not in the system proceed to enter new data for the participant. Once you have completed the enrollment form, print the barcode and save the information. Instruct the participant to proceed to the fingerprint collection laboratory.

2.4.3 Sensor Workflow

The prototype devices were typically initialized at the beginning of each collection day, and operated continuously until all appointments scheduled for that day were completed. Each participant provided data in two sessions per visit. Data was collected from all sensors in one session, then repeated in the same sequence for the second session. For sensors with built in quality assessment, if fingerprint capture failed three times in a row with no visible quality issues, the last image was accepted and collection was continued. Inked fingerprints were collected after all livescan images were captured to ensure that the participants' fingers were clean for livescan collection. The following is a description of the standard operating procedures for each sensor used in the data collection.

2.4.3a – Northrup Grumman BioSled

1. Unplug any USB cables from the system
2. Tap BioSled software icon
3. Select CAR tenprint format for fingerprinting
4. Select Demographics menu and enter subject RID in the name field and select the save icon
5. Select the fingerprint menu
6. The device will prompt for two finger slaps starting with the left little and ring fingers (Fig. 3).

Figure 3: BioSled in operation.

7. Once all 6 slap captures are completed, the device will prompt for finger rolls starting with the right thumb.
8. Place the subject's right thumb on the Sherlock sensor and make sure that their finger is touching both the sensor and the bezel surrounding the sensor pad. When placed correctly, a red line will appear indicating the device has started to capture.
9. Roll the subjects thumb toward their body until the roll is complete. The line will turn green when a satisfactory print has been captured. The device will then prompt for the next finger.
10. Repeat steps 8 & 9 for each finger on the subject's right and left hands
11. When finger capture is completed, select the save button for the fingerprint images and then again to save the whole session.
12. Repeat steps 4 – 11 for the second capture session.
13. Once both sessions have been captured, plug a mini USB cable into the device and connect the cable to a windows PC.
14. Mount the device as a media device and access the phone's root directory.
15. Navigate to the BioMob folder and (need folder name) select the two most recent session folders. If there were more than two participants stored on the device, check with the transaction review list in the BioMob software.

2.4.3b – MorphoIDent

1. Begin fingerprint capture by pressing the green ‘check’ button the device’s fingerprint scanner with light up red indicating it is ready to capture (Fig 4).

Figure 4: MorphoIDent ready to capture.

2. Have the subject place their right index finger on the platen until the device vibrates. *NOTE:* If the print is of poor quality, the device will prompt the operator to attempt a recapture or to accept the low quality print. If the subject’s prints do not show up well on the scanner, a striped pattern will flash across the fingerprint image. When this happens, have the subject replace their finger on the platen.
3. Have the subject place their left index finger on the platen until the device vibrates.
4. Repeat steps 1-3 for the remaining fingers starting with Right finger followed by left.
5. After 5 captures, the device will be in a state where it is ready to download its images to a computer running the MorphoMobile 2.0 software.
6. Connect the device to the computer and the software will automatically download the images and convert them to .nst files.
7. Open the %Temp/MorphoMobile/Bodega/Repository/ folder and copy the five folders to C:\ManTechFingerprints\Morphomobile\SubjectRID\Session\. If the subject ID folder or session folders do not exist, create them and then paste the fingerprint files into their respective location.
8. Open a text file and list which CAP#### file corresponds to which pair of fingers. Also note which hand was captured first by writing R > L or L < R.
9. Repeat 1-8 for the second session

2.4.3c – Morpho Finger-On-The-Fly

1. Start the FOTF software with the default settings (Fig. 5).
2. Begin capture by clicking the enroll button followed by the green start button.

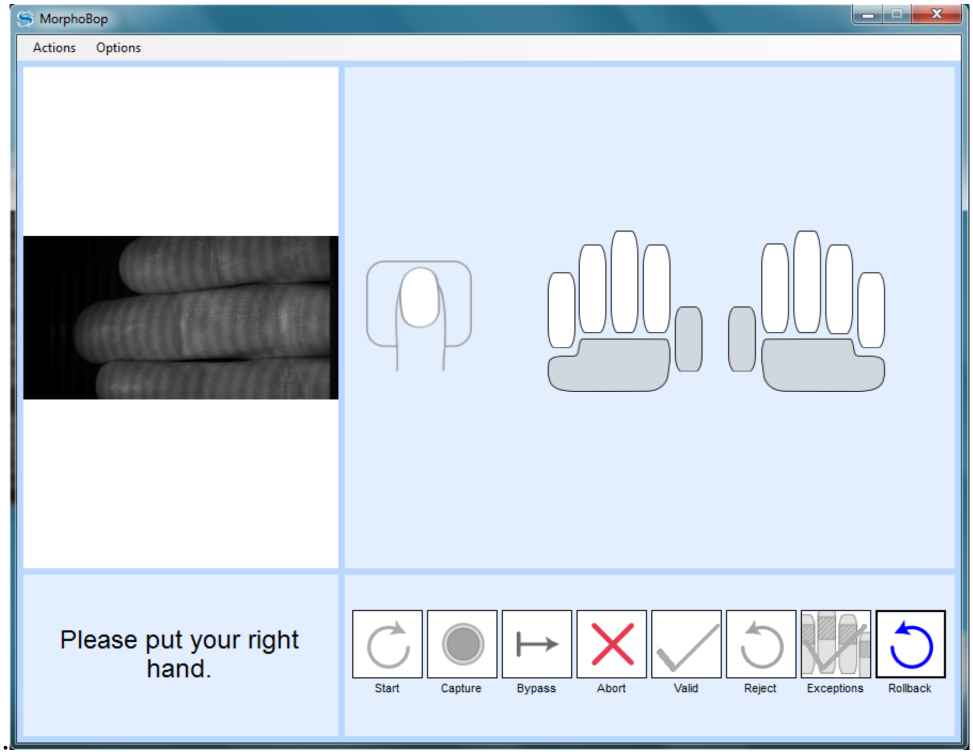


Figure 5: FOTF user interface.

3. Have the subject swipe their right hand through the device in the direction indicated above the platen (Fig. 6).

Figure 6: FOTF in operation.

4. Repeat step 3.
5. Repeat 3-4 for the left hand.
6. After capture is completed, a review screen will appear, allowing the fingerprints to be evaluated (Fig. 7). When finished, close the review window and a box will prompt to save the session. Click yes and proceed to scan the subject's RID number and click submit. The files will be moved to a session folder within the subject's ID folder.

Figure 7: FOTF evaluation screen.

7. Repeat steps 1-6 for the second session.

2.4.3d – IDair InnerID

1. Start the InnerID app
2. Have the participant hold their right index finger steady, line up the oval shape over the fingerprint and touch the screen to capture.
3. Check the image to see if there is any noise or blur causing artifacts to the processed image, if so, recapture.
4. Repeat 1-3 for the remaining fingers moving from index to little followed by thumb and repeat the same for the left hand.
5. Connect the device to a computer using the lightning cable provided and give the computer permission to access files.
6. Copy the image files over to C:\MantechFingerprint\InnerID\subjectID\Session\
7. Repeat 1-6 for the next session.

2.4.3e – ANDI OTG

1. Start up the ANDI OTG monitoring software. The system dialog box on the computer desktop will give a message of ‘got heartbeat,’ indicating it is ready for operation.
2. Instruct the subject to pass their 4 right fingers through the green box as they walk past the device (Fig. 8).

Figure 8: ANDI OTG in operation.

3. After the subject passes their fingers through the capture region, the fingerprint images that were captured will show up in preview windows on the desktop (Fig. 9).

Figure 9: ANDI OTG image preview.

4. Once capture has completed, copy the images in the OTG folder to: C:\mantechFingerprints\ANDI OTG\subject ID\session
5. Repeat steps 2-4 with the subject's right 4 fingers for the second session.

2.4.3f – CrossMatch SEEK Avenger

1. On the SEEK Avenger mobile computer desktop, select 'MOBS'
2. From within the 'MOBS' program, select Enrollment.
3. Select the 'CAR' folder.
4. Select 'Personal Information'
5. Select 'Arrest'
6. Select 'Arrest Segment' Tab
7. Scan subject's ID and select save twice
8. Select 'Enrollment.'
9. Select 'Fingerprints.'
10. Select 'Capture,' as shown in Fig. 10.

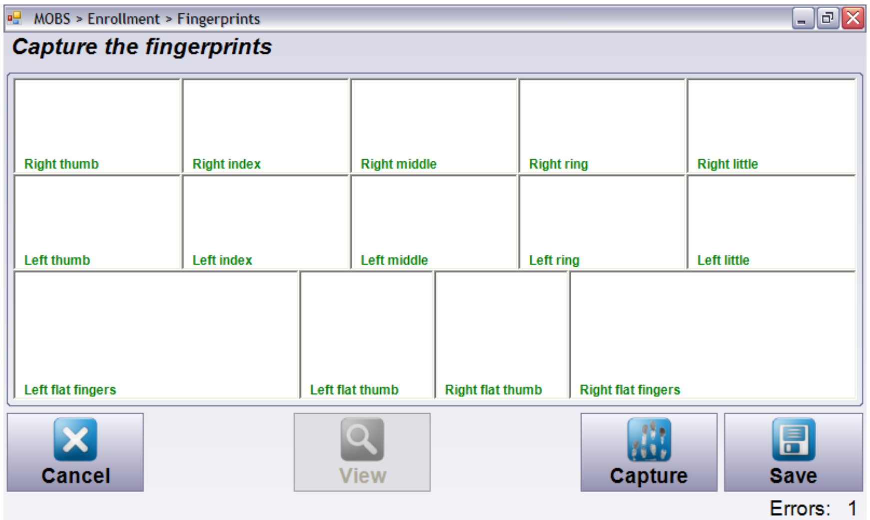


Figure 10: MOBS fingerprint capture interface.

11. The participant will place right index and right middle fingers on the platen to capture the slaps.
12. The participant will then place right ring and right little fingers on the platen to capture the slaps.
13. The participant will then place right and left thumb on the screen to capture the slaps.
14. The participant will then place the right thumb flat on the platen. The staff member will roll the thumb from nail to nail to capture the rolled fingerprint image.
15. Repeat step 10 for all four fingers on the right hand.
16. Repeat steps 7-11 for the left hand.
17. If, at any time, partial or low quality prints are captured, you may go back and recollect a new image. If print quality has been assured, select 'Save' as shown in Fig. 11.

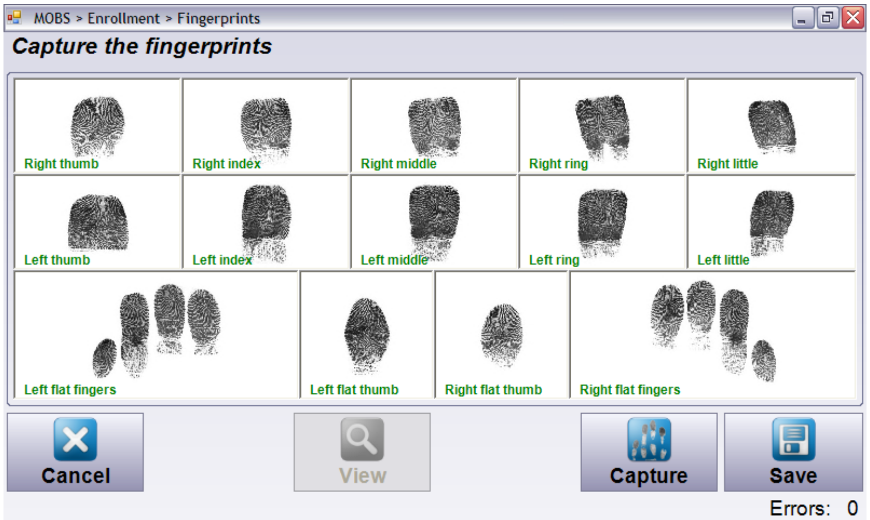


Figure 11: Completed MOBS fingerprint capture. The 'Save' option is located in the lower right.

18. Select 'Save' again on the next screen.
19. From there, a new notification will pop up. Select 'Later.'
20. Navigate back to the SEEK II Desktop.
21. Select 'Computer.'
22. Select 'My Computer.'
23. Select 'C Drive.'
24. Select 'Documents and Settings.'
25. Select 'All Users.'
26. Select 'Application Data.'
27. Select 'Cross Match Technologies.'
28. Select 'MOBS.'
29. Select 'Pendings.'
30. Rename the most recent file with the format 'RID_DATE_SESSIONNUMBER.eft.' Since the random ID is manually entered, double check the number to ensure no errors are made in file naming.
31. Repeat steps 2-26 for session number 2. Collection with this device is now completed. If necessary, clean the platen of the device using lift tape.

2.4.3g – CrossMatch Guardian R2

1. Select the 'ManTechData' folder on the Desktop.
2. Create a folder labeled 'CrossmatchR2' inside the participant's RID folder. Use the barcode scanner to scan the RID number when naming the folder.
3. Inside the 'CrossmatchR2' folder, create two separate folders labeled '1' and '2.'
4. Start the CrossMatch software by clicking on the CrossMatch L-SCAN Essentials icon on the computer desktop.
5. Select the 'Save Images' radio button shown on the left side of Fig. 12.

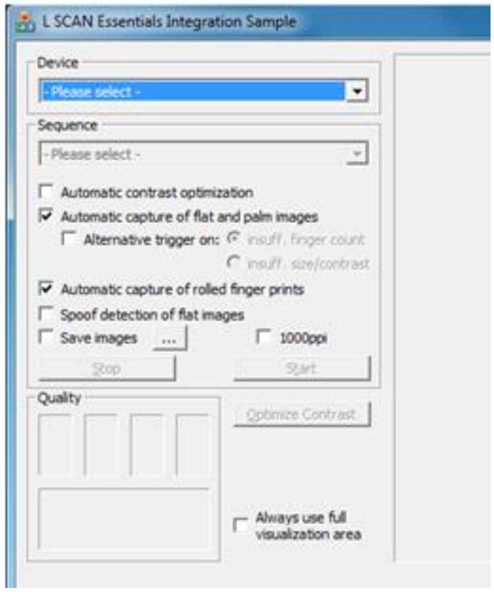


Figure 12: Guardian fingerprint collection interface.

6. Select the Save images radio button, and then select the '…' box, shown in Fig. 12.
7. Select the folder '1' that you created in step 4.
8. Select the 'Always use full visualization area' radio button, shown at the bottom of Fig. 12.
9. The participant places both thumbs on the platen to capture the thumb slap (Fig 13(a)).
10. The participant places the right four fingers on the platen to capture the right slap (Fig 13(b)).
11. The participant then places the left four fingers on the platen to capture the left slap (Fig 13(c)).
12. Place the participant's right thumb on the platen and roll the thumb, nail to nail, to capture the rolled fingerprint. A general demonstration of this is shown in Fig 13(d).
13. Repeat step 11 for all fingers on the right hand, beginning with index and ending with little.
14. Repeat step 11 for all fingers on the left hand, starting with the thumb and ending with little.
15. Once the rolled left little capture is completed, repeat step 6 to change the folder to '2' created in step 4.
16. Repeat steps 7-15 for collection session 2. Collection with this device is now completed. If necessary, clean the platen of the device using lift tape.

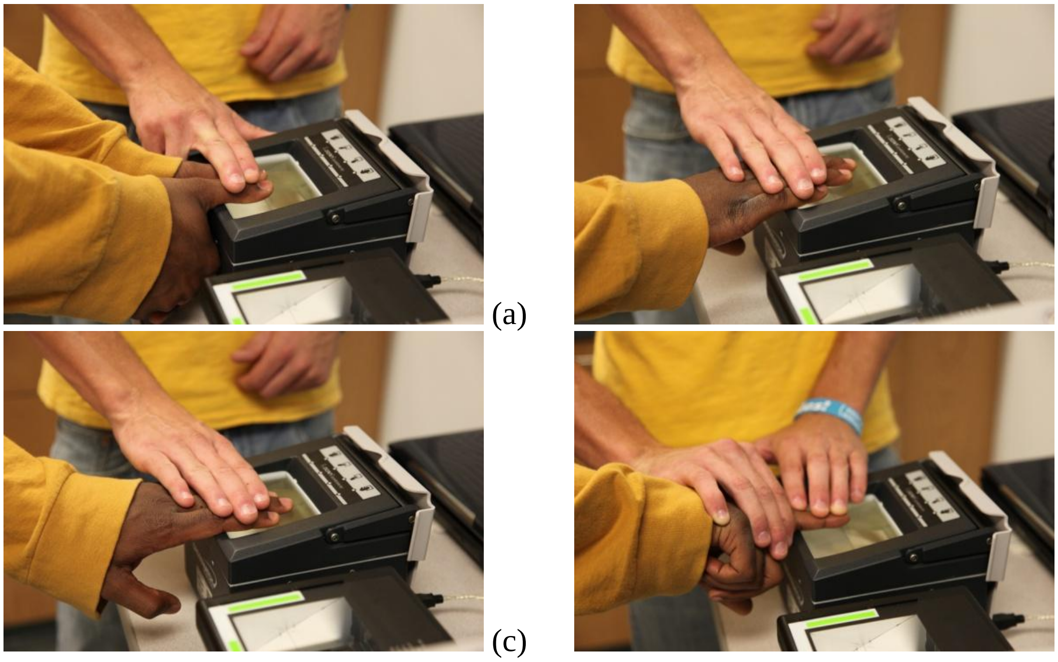


Figure 13: Fingerprint collection using Crossmatch Guardian R2: (a) thumb slap, (b) right slap, (c) left slap, and (d) rolled prints.

2.4.3h – L1 Touchprint

1. Click on ‘Fingerprint Capture’ on the Desktop.
2. Select the “L-1 TouchPrint 5300” radio button in the user interface, shown in Fig. 14.

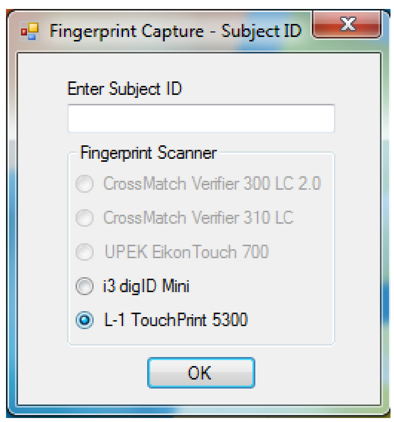


Figure 14: TouchPrint capture interface initiation.

3. Place the cursor in the field labeled “Enter Subject ID” and scan the RID using the barcode scanner.
4. Click ‘OK’ to initialize the capture interface.
5. Place the participant’s right thumb in the middle of the platen, similar to the Crossmatch Guardian sample shown in Figure 10. Roll the thumb from nail to nail to complete fingerprint capture.
6. Proceed to the right index finger, and roll as described in step 5 for the remaining fingers on the right hand

7. Repeat steps 5 & 6 for the left hand
8. Once each individual fingerprint is captured, the participant places both thumbs on the machine to capture the thumb slap.
9. The participant then places the right four fingers on the machine to capture the right slap.
10. The participant repeats step 9 with the left four fingers to capture the left slap.
11. Once all fingerprints are captured, the operator performs any necessary re-captures and clicks 'Save.'
1. The process is repeated for the second session of fingerprints. Collection with this device is now completed. If necessary, clean the platen of the device using spray cleaner and a lint-free cloth.

2.4.4 Collection Completion

After the participant has provided fingerprints at all of the stations, provide directions to the bathroom (or lab sink) in case they wish to wash their hand more thoroughly, and instruct them to proceed to the remuneration office to receive their gift cards.

2.4.5 Post Processing

The data collected was stored on each station's laptop computer, where it was then compiled onto the storage server in weekly backup operations. With all the data compiled, a script was written to rename and re-order the data according to the hierarchy listed in section 2.3. Preparing the MorphoIDent data required more effort than expected to extract .bmp files from the device. First, an Apache based AFIS server was connected to the MorphoMobile2.0 software in order to decrypt the data stored on the device as it is transferred to the computer. Once transferred, the fingerprint images were stored in .nst files which can be opened with NISTPack's TransactionEdit software. To extract these image files, the data was split among 4 workstations and each file was manually exported from the .nst files into .bmp format. Once all the files had been exported, a Matlab script was used to reorganize and rename the files according to the format listed in section 2.3.

Data was delivered to ManTech in two releases. One took place after the collection of data from ~200 participants, and the second after the final total of 450 was achieved. Prior to each of these data releases, the data was evaluated and a list of quality issues or missing data was compiled and supplied along with the release.

The ten-print cards could not be delivered due to IRB restrictions on data transfer. Because of this, ManTech supplied the WVU team with an FBI-certified flat-bed scanner (Epson Perfection V700) and Aware AccuScan card scanning software to create electronic records of the ten-print cards. Cards were scanned at both 500 and 100ppi, and an .eft record and individual .bmp images were created for each participant at both resolutions. Card scanning was performed on a daily basis using a computer located in guest office on the same floor as the collection lab. The card scanning procedure is as follows:

1. Open 'CSScanDemoEFT.exe' located on the computer's Desktop.
2. Once the GUI is loaded, the designated scanner should be changed to 'Epson Perfection V700' in the drop down selection list.

3. The layout file then needs to be chosen by following the following steps in the Windows 7 OS:
    a. Browse
    b. select C drive
    c. Choose ‘program files(x86’
    d. Choose ‘Aware’
    e. Choose ‘AccuScan’
    f. Choose ‘Samples’
    g. Choose ‘Samples’
    h. Choose ‘acuscan_fbi_criminal_alt2.xml’
4. Place ten print card in scanner.
5. Click ‘Scan’ in the scanning software interface (Fig.15). Note that the default resolution is 500ppi.

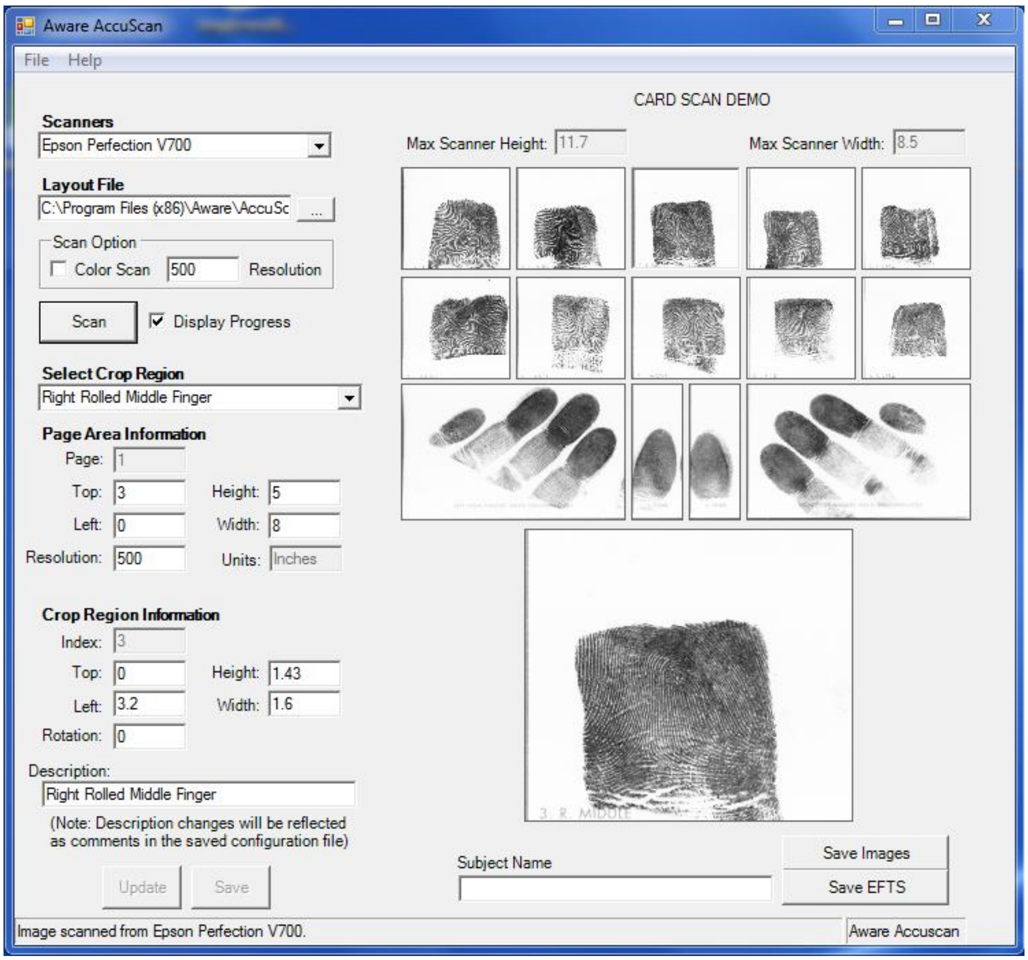


Figure 15: AccuScan scanning interface.

6. Click ‘Save Images.’
7. Save in ‘ManTech Ten Print Data’ in a folder named according to participant’s RID number located in the date collected. Use the barcode scanner to scan the barcode in the envelope along with the ten print card to avoid number entry errors.

8. Save files using the naming convention 'RID_DATE_500.bmp.' Again, the barcode scanner can be used to retrieve the RID and date.
9. In the same naming convention from step 8, put the file name in the Subject name area, click 'Save EFTs,' and save the data in the same folder as above.
10. Change the scanner resolution to 1000ppi in the 'Scan Option' field.
11. Under 'Page Area Information,' change the resolution to 1000.
12. Click 'Update' near the bottom of the window.
13. Repeat steps 5-8.
14. Save files the naming convention 'RID_DATE_1000.bmp.' Again, the barcode scanner can be used to retrieve the RID and date.
15. Repeat step 9 using the naming convention from step 14.

3. Collection Demographics

Figs. 16-20 provide information on cumulative participation in the data collection and a breakdown of ethnicity, age and gender. Fig. 16 indicates that participation peaked in February 2015. Collection activities were suspended for two periods in December 2014 and March 2015 due to closure of the university for winter and spring breaks. Low participation in January was due to inclement weather for most of that month, one instance of which caused a 2-day closure of the university. Fig. 17 shows steady growth in participation throughout the project period, despite university closures. Fig. 18 indicates that Caucasians make up over half of the participants at 51.6%, followed by Asian Indians (11.4%) and Hispanics (8.9%). This ethnicity distribution shows higher than normal Hispanic participation, most likely due to higher participation from the community rather than student population. Fig. 19 indicates that the majority of participants were in the 20-29 age range, making up 77.9% of the total, with the next highest groups in the 30-39 (11.0%) and 18-19 (5.9%) age ranges. Fig. 20 shows that male & female participation was almost equal for Hispanic and Caucasian participants, with male participation being higher for all other ethnicities.

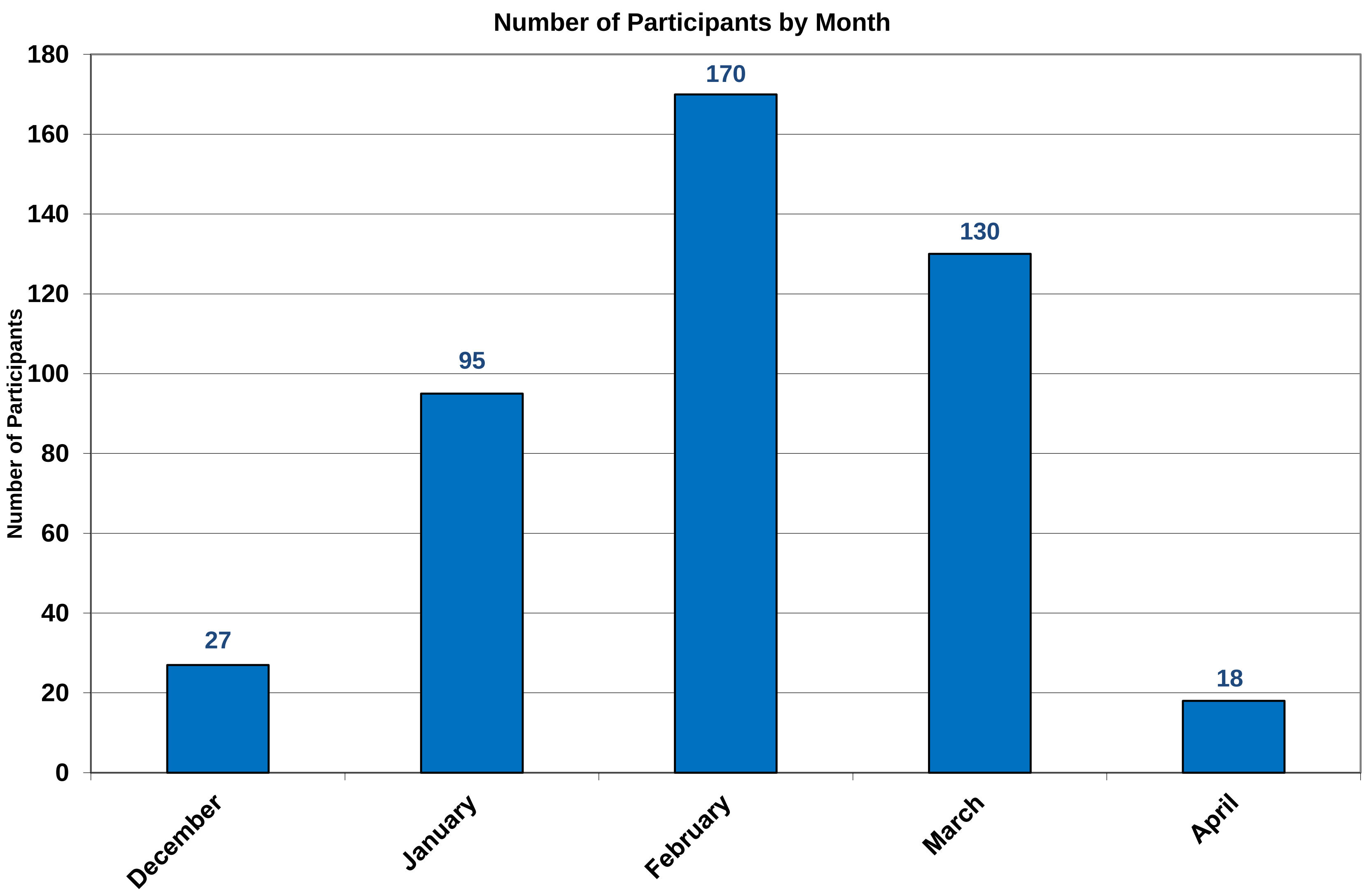


Figure 16: Number of participants by month.

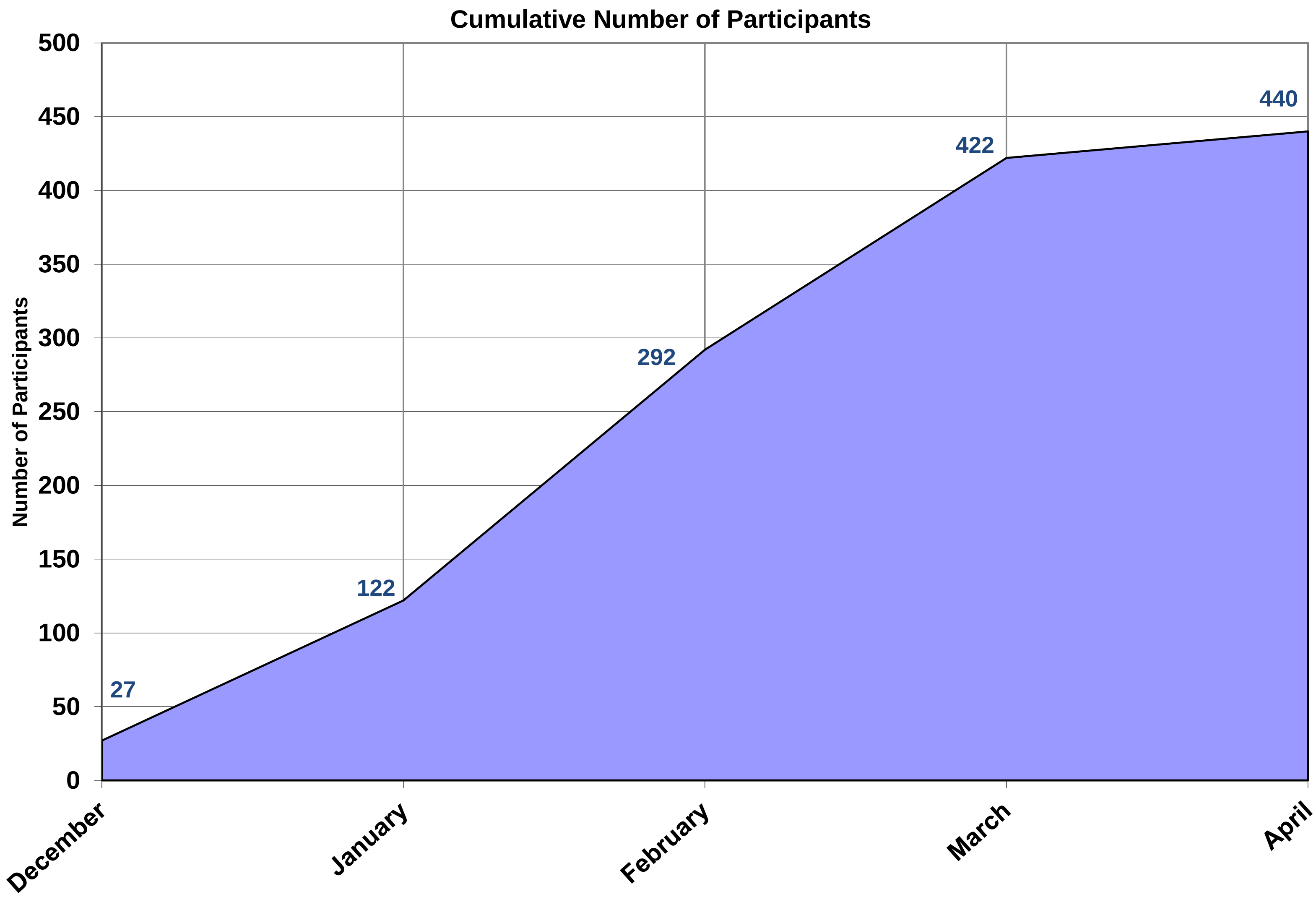


Figure17: Cumulative participation.

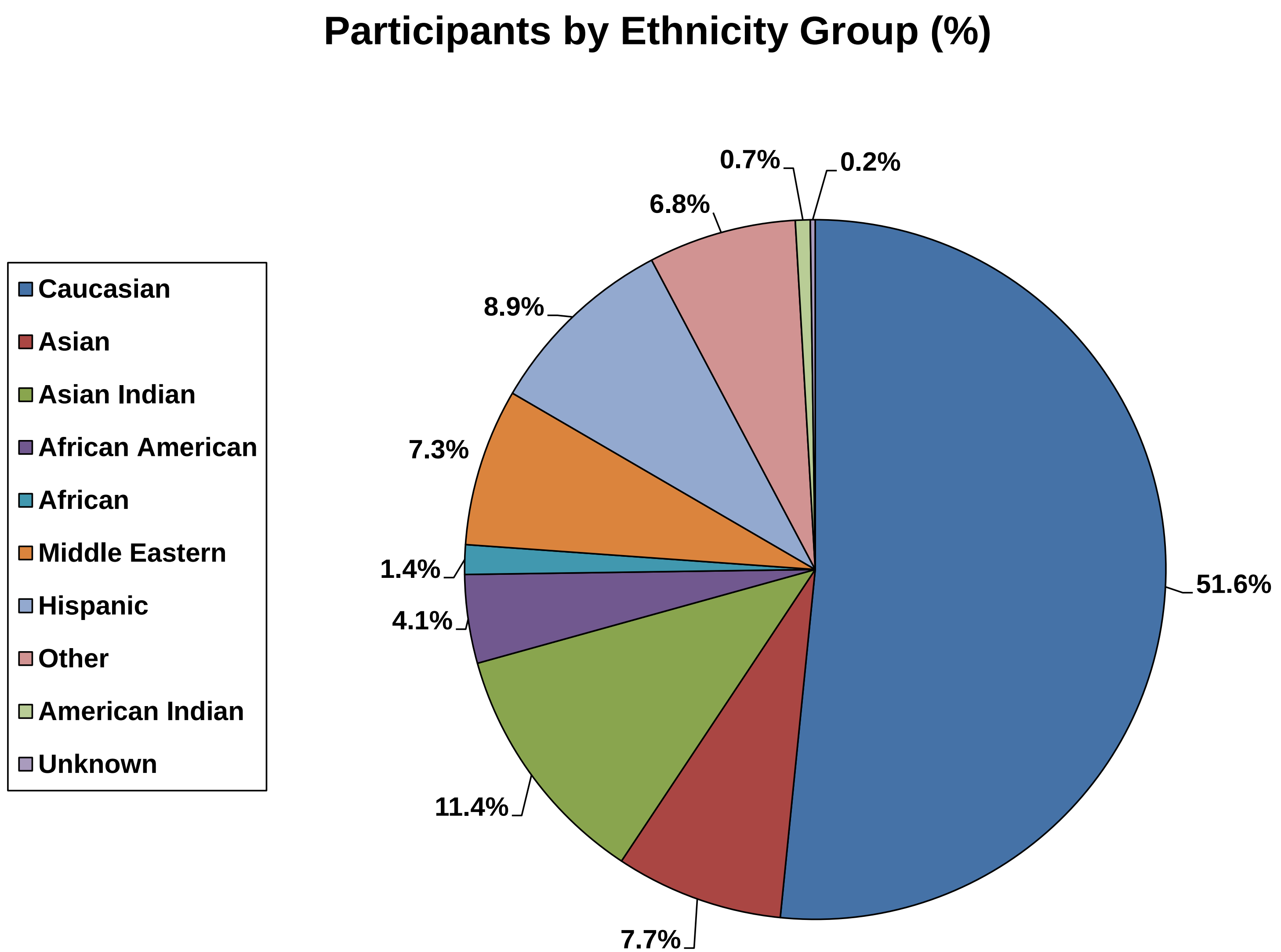


Figure 18: Participant ethnicity.

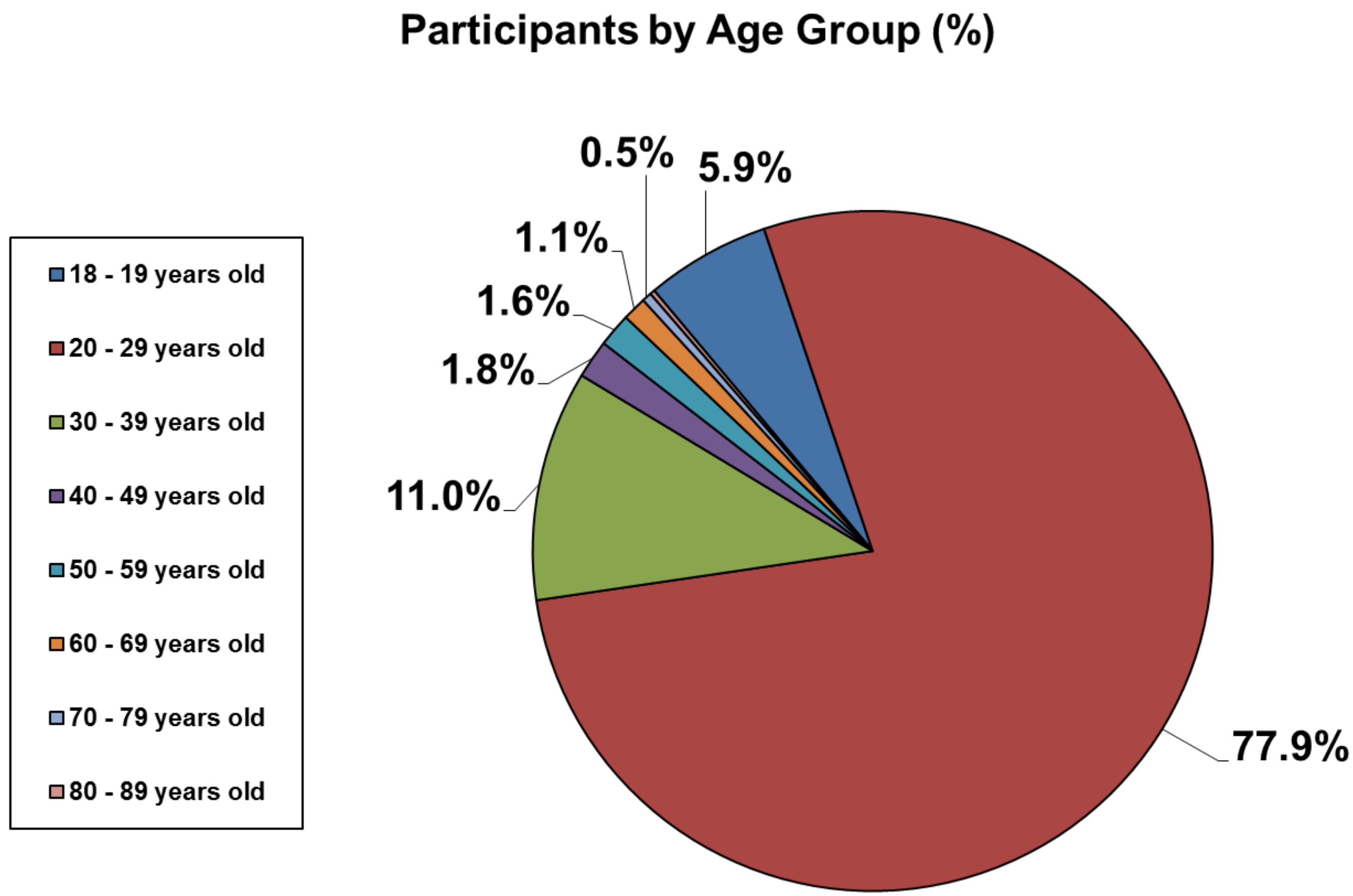


Figure 19: Participant age.

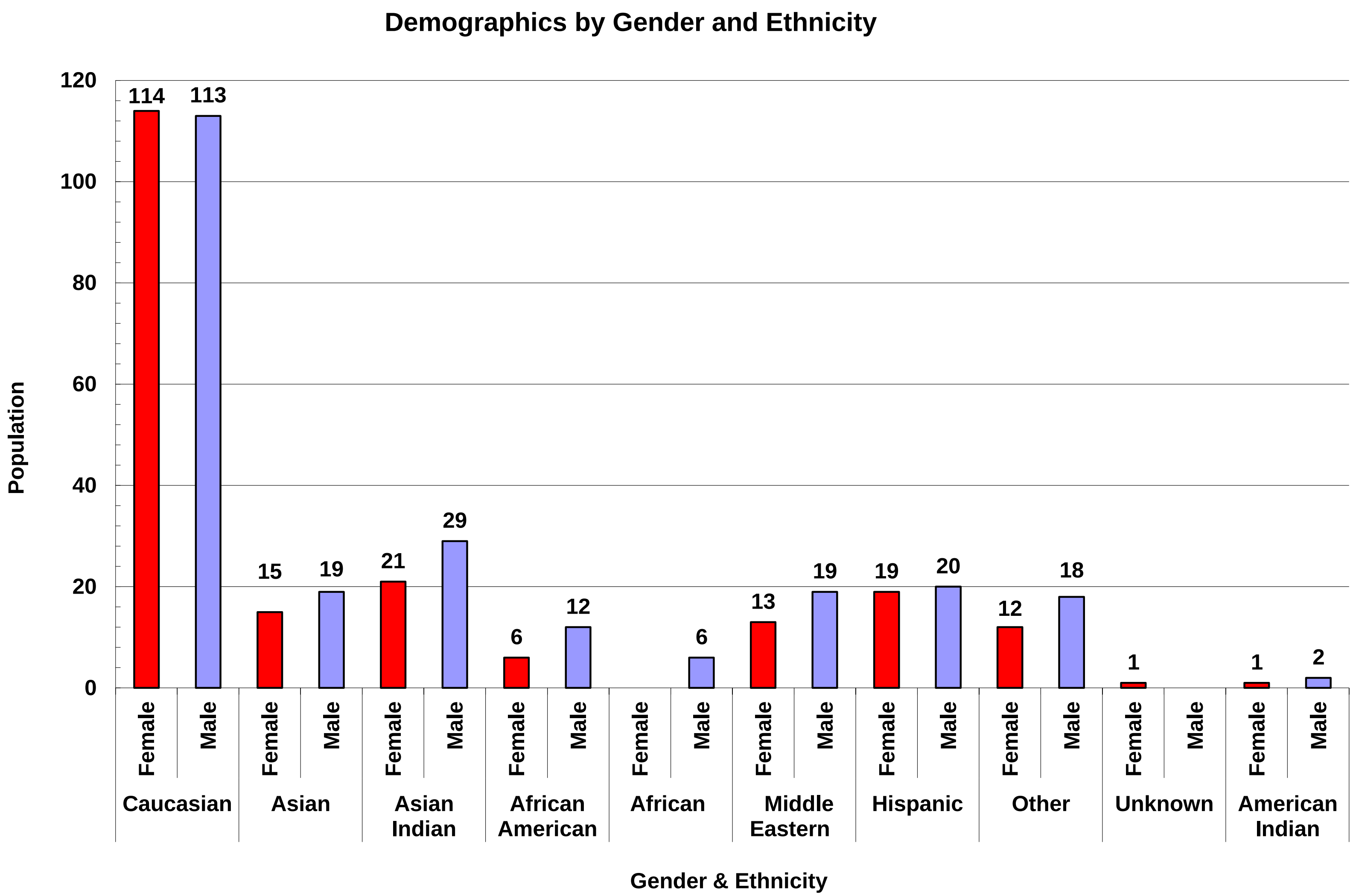


Figure 20: Breakdown of gender & ethnicity.

4. Device Issues and Operator Feedback

4.1 Device Issues

This section provides a list of issues encountered with the fingerprint devices used in this data collection effort, and, if possible, steps taken to overcome them.

BioSled: Individuals who had smaller than average fingers (Usually petite women) found it difficult for the device to register their print well enough to begin capture. The device's battery may only last about 5-7 hours if left unplugged during collection hours. The device would not initialize the Sherlock sensor if the USB charging cable was plugged into the device. This is most likely related to the Android OS rather than the NG software, although it became an inconvenience towards the end of a collection day due to the very limited battery life. The software would sometimes crash without warning and lose a participant's session if not saved. Likewise, if a session is left open and the device goes into rest mode, the session is also lost. Finally, the Sherlock sensor would sometimes not recognize a fingerprint unless the subject or operator "shorted" the conductor bar to the sensor by sliding their finger along the device's edge where the sensor meets the bezel.

MorphoIDent: The IDent device has a very hard time capturing the fingerprints of individuals with very dry and/or cracked fingertips. From a lack of clarity in documentation, the MorphoIDent device would only store the fingerprint images in an encrypted file format. With help from the Morpho California office, the problem identified was that the local AFIS server software provided by Morpho was not communicating properly with the device software. Due to this communication issue, over 80% of the fingerprint images captured needed to be reloaded into the MorphoMobile software and decoded by the AFIS server. This was a labor-intensive manual operation, for this data collection. However, the issue is likely due to the device being used in a stand-alone setting and not integrated with an operational AFIS.

Morpho Finger-On-The-Fly: Subjects with darker skin tones were much more difficult to capture. For some, multiple re-captures were attempted, and were never of high enough quality to be captured by the device. The sample enrollment software would sometimes crash when several subjects were captured consecutively. The circumstances of the errors were sporadic and the cause was not determined. Subjects with long fingernails would cause distortions to the final image.

CrossMatch SEEK Avenger: The 'MOBS' software would sometimes crash unexpectedly when capturing a subject's prints. Upon restarting the system, MOBS would crash on startup, and an error prompt would appear stating that a file was missing or corrupt (Fig. 21). After moving/renaming the file in question, MOBS would then run without issue. This error was very uncommon but happened enough times to warrant mentioning.

Figure 21: CrossMatch SEEK Avenger error message.

ANDI OTG: The ANDI system would not capture a participants fingerprints at what seemed to be random intervals. The problem would be more likely to happen if the system had been sitting idle for an extended period of time (3+days). Upon restarting the system, the system would sometimes return to normal operation. However, as the problem persisted, the system would more frequently remain non-responsive. As with the Morpho Finger-On-The-Fly, subjects with long fingernails would cause distortions to the final image.

InnerID: The app would sometimes crash, causing a loss of the most recent image captured. Also, the system did not have any form of customized file/subject naming scheme, so the capture pattern for each subject needed to be consistent. In low light settings, it was too difficult for the operator and participant to hold the device and fingers steady enough to capture, resulting in a noisy or poor quality binarized image. This device developed an uncorrectable issue midway through the collection. It was sent back to IDair for repair, but was not returned.

4.2 Operator Feedback

The operators who performed the bulk of the data collection over the project performance period were asked to provide feedback on their experience using the non-contact devices alongside other commercial fingerprint acquisition devices. They were to also comment on how the general public adapted to using the varying types of sensors included in the collection. They provided a written description of their interaction with the various devices during the data collection process. Anonymized, unedited responses from these operators are provided below.

Operator 1

> The BioSled software on the Samsung galaxy S4 was one of the more contrary devices. There were instances where the BioSled would randomly not save data. Many times while a participant was rolling their prints, the device timed out, causing us to have to restart the application and losing their data. This sensor would also take bad images if the participant's hands were sweaty.

The Seek Avenger and BioSled were very similar in the how they retrieved the data, since they have the same sensor. However, due to the software differences, the Seek Avenger was one of the most difficult sensors, giving us errors regularly. The four major errors that we received were; “Finger Shifted”, Poor Quality”, “Print Not Wide Enough”, and “Segmentation Error”. This sensor was tricky at times, since it would act as if it were recording the print and as soon as the participant lifted their finger off of the scanner the print would disappear, causing the participant to have to rescan. A nice thing about this device is that it would recognize whether the correct fingers were on the scanner or not. Since this device has the same scanner as the BioSled, this device also didn’t work well with sweaty hands.

The MorphoIDent proved to be very reliable and through the duration of this collection, we didn’t have any issues.

The Finger on the Fly device was one of the operator and participant favorites. It rarely gave problems, except when the participant was of very dark skin color, in this occurrence, the scanner sometimes would not capture their prints.

The Guardian R2 was one of the least user-forgiving devices that we had as it could be very contrary. On occasion this device would take partial rolling print images, each would have to be retaken, causing the operator to manually go into the file and replace the image. To get the replacement image, the operator had to start a whole new session.

The L1 was very user-forgiving and extremely easy to clean. This was also one of the most participant friendly devices, as it made it very easy to retake prints.

The ANDI was very simple and quick to use, we never had any major issues with it. The ANDI did show to have some hardware issues, but those were not due to participant/sensor interaction.

Due to the malfunction of the iPhone 5C we were using with the InnerID software application, we didn’t get to collect quite as much data with it. From the little that we did get to use it, it showed to be a very touchy device. My own experience with the device was rather difficult since I do not have the steadiest of hands, this made it very hard to get a good picture. I had to keep retaking until I received a clear image.

Operator 2

In the course of three months and after using both prototypes and newly released products I believe there are advantages and disadvantages with each type of product. Starting with the released products [MorphoIDent, Seek Avenger, Guardian R2, and L-1], some products were more user friendly than others and had seemingly less problems. Released products that were user friendly include: MorphoIDent, Guardian R2 and L-1. These products were easy to operate and volunteer subjects were able to navigate quickly and efficiently through these products. The only issues with Guardian R2 was if a mistake in capturing a fingerprint had occurred, the product would sometimes restart from the beginning as opposed to allowing a single fingerprint to be recaptured. Following up with user friendly released products, a released product that was not user friendly was Seek Avenger. One of the major issues with Seek Avenger was the product rejecting fingerprints of good quality along with its inability to capture fingerprints even with pressure on both the finger bar and fingerprint pad.

The prototype products [InnerID, BioSled, Finger on the Fly, and ANDI], like the released products, had both its advantages and disadvantages. Easy to operate and user friendly prototype products includes InnerID and ANDI along with the previously stated Finger on the Fly. The ANDI system, aside from Finger on the Fly and MorphoIDent, was probably the easiest product to use along with the most user friendly. The only prototype product that had its disadvantages was BioSled. BioSled would constantly stop its function and would have to be restarted and after performing this task it would still have a tendency to not restart function. Another issue was its inability to capture fingerprints on occasion which required the operator to move ahead to next finger(s) and refer back to the previous, uncaptured finger(s). Unlike Seek Avenger, this was easier to capture fingerprints when function was in working order and allowed the operator to review fingerprints and recapture if necessary. As expected when working with both the released and prototype products, there were advantages and disadvantages which would be expected but overall these products, once corrections could be made, would be beneficial in both the public and private sector.

Operator 3

ANDI: The ANDI was easy for both the operator and participants to use. At times it would not capture all the prints as participants would separate their fingers too much or not have enough separation for the software to differentiate the fingers. Every once in a while ANDI would stop capturing images or the flash would stop firing.

GUARDIAN: The Guardian was easy to for the participants to use. It was more difficult to recapture a print if the software thought it was acceptable, as you had to create a temp folder and do another session to get the print needed.

L1: The L1 was easy for both the operator and participant to use. Compared to the guardian it is was a lot easier to recapture a print if needed.

Finger on the Fly: Finger on the Fly had difficulty capturing prints from people with dark skin. Also, if they swiped their hand in a diagonal motion or changed the speed they moved their hand over the sensor while capturing. At times I noticed that it saved the left hand prints in the right hand format.

Seek Avenger: The Seek Avenger was easy for the operator to use as it checked for errors in the participants prints as they rolled their fingers. The participants had difficulty with the sensor as they would lift their finger up mid roll or didn't have a large enough surface area to start the capture.

BioSled: The BioSled was difficult for both the operator and participant. Farley, often the sensor would not detect the participant's fingers on the sensor and we had to rub the bar with our finger to get it to capture. Also, it would still capture the participants' prints even if they were incomplete due to them lifting their finger off the bar mid roll.

MorphoIDent: The MorphoIDent was easy for both the operator and participant to use.

InnerID: The participants had difficulty keeping their hand steady to capture a clear print. It was also hard to keep the phone steady to get a clear print. It appeared at times that the camera went out of focus right before it captured the participant's prints.

Operator 4

While I did not participate in the ManTech fingerprint project to a great extent, I still had the opportunity to operate most of the machines, including ANDI, MorphoIDent, Seek Avenger, BioSled, Finger on the Fly, and Guardian R2. I found most of these sensors easy to learn, however, I feel that certain improvements can be made on them.

Some of the sensors were very sensitive to movement. For example, the Seek Avenger often gave a "sequence error" or sensed that the finger was shifted while being rolled. This was beneficial to an extent, however, these errors would sometimes show up when the fingerprint seemed to be completely fine. In addition to this, the sensor would occasionally not register a participant's fingerprint, but this could be easily fixed by moving a finger along the bottom of the sensor, as well as ensuring that the participant's finger was always in contact with the bottom of the sensor. Aside from this, I felt that the Seek Avenger was easy to operate and produced high quality fingerprints.

On several of the sensors, saving the data or retaking a fingerprint seemed to be inefficient. Some of the sensors did not have an option to retake a fingerprint, so after the set of fingerprints was finished, a temporary folder had to be created so that the image could be retaken, placed in this folder, and copied into the original folder. The original fingerprint that had to be retaken was then deleted from the folder, and the temporary folder was deleted. Having an option to retake a fingerprint either right after it is taken or after all of the fingerprints have been completed would make for a quicker process.

One other small problem that I believe could be improved upon is allowing the MorphoIDent to charge while being used. In addition, the ANDI prototype would occasionally have completely black images show up rather than the participant's fingerprints. I think that improvements such as those listed above would produce a quicker, more efficient fingerprint collection.

Operator 5

Working with the prototypes and the released instruments, I noticed that some were much easier to use than others. To begin with, the released products: MorphoIDent, Seek Avenger, Finger on the Fly, Guardian R2, and the L-1 were all relatively easy to work with aside from the Seek Avenger. The Seek Avenger had difficulty taking prints even when they were of excellent quality. I also experienced multiple times where the instrument would shut down, the screen would turn upside down, or it would say "poor quality" when the print was excellent. The Finger on the Fly only had problems when the participants skin color was "too dark" otherwise there were no other major problems with the Finger on the Fly. It was very user friendly. The Guardian R2 also worked wonderfully 99% of the time and was very user friendly. The only problems I experienced was when the cable connecting the instrument to the laptop was touched the program would shut down and have to be restarted. I experienced no technical problems with the MorphoIDent or the L-1 thereby making them the best-released product strictly going off of technical problems and user friendliness.

The prototypes: InnerID, BioSled, and ANDI also varied for user friendliness. The innerID was easy to use, if you had steady hands. If your hands were not steady than you had to retake photos multiple times and then go back into the photo album to delete the bad photos. The BioSled had the most technical problems out of all of the instruments. The BioSled took any print whether it was good or bad which was helpful because some participants had wrinkly hands or scars and the other instruments would deny the print multiple times. It was also bad because participants with sweaty hands or those who rushed the roll had to redo the print multiple times and it would not recognize that the prints were bad. The ANDI was the easiest of the prototypes to use because participants could just walk through it. The only problem I encountered was if a participant did not hold their pinky up high enough or did not separate their fingers it would miss some of their fingers.

The qualities of the prints were good on the ANDI, L-1, MorphoIDent, Guardian R2, Finger on the Fly, and InnerID consistently. The Finger on the Fly had problems catching the edges of the print but with some work I believe that the Finger on the Fly can have the quality and quantity that the ten prints have. On the other hand, the BioSled and the Seek Avenger need work on the sensor. They do not adequately capture participants with sweaty hands and depending on where the sensor is to be used that may need to be addressed.

Operator 6

The commercial devices used in this study, including the MorphoIDent, Seek Avenger, L-1, Guardian R2, and Finger on the Fly, all worked very well, except for the Seek Avenger. The seek avenger would repeatedly crash in the middle of a collection. Occasionally restarting the program would fix it, but other times we were forced to skip over it while it was being repaired. Not only did it shut down regularly, but the scanner would often times reject full rolled prints that seemed to be of good or excellent quality and there would be no explanation as to why. Also, the Avenger would say there was a "Sequence Error" even when the correct fingers were placed on the scanner. Finger on the Fly was a great piece of equipment and hardly ever had any problems. It was very user friendly and was by far the fastest off all collection devices we studied. One of the only problems I experienced was that participants with darker skin tones would have a difficult time with the Finger on the Fly. The device would reject those fingers and force us to repeat the collection several times. MorphoIDent was by far the most user friendly of the devices. In my experiences with it, the device never had any technical difficulties and was very easy to handle. The Guardian R2 was also very user friendly, although there were several times when the device would shut down in the middle of a collection due to certain error codes. Usually, once I restarted the program, it continued to work just fine. The L-1 was a personal favorite and took very high quality prints. The program is very user friendly and never crashed while I was using it. The only problem I noticed with the device was that if the participant's hands were very sweaty, the prints would be very light in color and more difficult to examine.

The prototypes, including the InnerID, BioSled, and ANDI, were also very user friendly. The ANDI was extremely impressive and requires little effort from either the participant or operator. I would estimate about 90% of the time the ANDI captured all four finger of the participant on the first trial. The majority of trials where the ANDI did not capture a finger was due to the participant bumping into the cutout or holding their fingers too close together. Even though InnerID only worked for about half of the collection, I thought it was a very user friendly and simple device. It certainly requires a steady hand and proper lighting, but it was very quick and being able to see the picture I took before moving on was very beneficial. The BioSled was not as user friendly as the other prototypes. The BioSled would crash occasionally and required a hard restart of the device before continuing. Also, when attempting to recapture prints of poor quality, the screen would sometimes not show the newly captured fingerprint and would instead still show the poor quality print.

Overall I think all of these products have the potential to be very useful in the private and public sectors. All of the devices have the ability to capture very high quality prints when operated by well-trained personnel.

APPENDIX B: COLLECTION DEVICE SUMMARIES – CFPV2

DISCLAIMER: The product information contained in this appendix has been provided by vendors. Commercial products included herein do not constitute an endorsement by NIJ, DOJ, NLECTC or ManTech. NIJ, DOJ, NLECTC and ManTech assume no liability for any use of this content. Product information is included for educational and reference purposes only. None of the claims contained in product summaries herein have been verified or validated. Any questions regarding a device should be directed to the vendor. All material has been published with the permission of the vendor.

Advanced Optical Systems, Inc. (AOS) of Huntsville, AL has developed the Automated, Non-contact, Distance, Identity (ANDI) On The Go (OTG) system. The ANDI OTG takes fingerprints at human walking speed with a publically demonstrated through-put rate of 3,000 people per hour. The OTG produces output fingerprints meeting the FBI's image quality certification requirements. AOS is working closely with the FBI to gain certification for the second generation of the ANDI OTG.

Figure 1. Prototype ANDI OTG tested by NIJ

The first generation prototype device provided to the NIJ for testing included a number of known limitations that are improved upon in the second generation ANDI OTG system currently in production.

All of our zero-contact ANDI OTG devices require no operator or user to touch the system in operation. Refinements to the original OTG system architecture have significantly increased the reliability of the second generation system.

ANDI OTG is a passive fingerprint sensor that uses visible light and high speed imagers to generate exemplar fingerprints. Once an image is collected, AOS proprietary fingerprint algorithms rapidly convert the image into segmented fingerprint files. The prototype under test by NIJ provides no guaranteed finger order, provides no management of fingernails, and is not optimized to meet the FBI's illumination uniformity requirements. As a result, some regions within the field of view of the device (such as the pinky) can return less than optimal fingerprint images. All of these issues have been corrected in our production unit.

Using the ANDI OTG at walking speed helps eliminate travel bottlenecks and long lines. ANDI OTG is ideal for enrollment, verification, and access control. ANDI OTG is designed for high security, high throughput applications like border control, embassy entrances, federal facility entrances, airport identity verification, refugee camp population management, ticketless event access, medical identity management, and checkpoint authorization. It is also well suited to service high volume time and attendance.

The ANDI OTG can be located in historic facilities or even over terrazzo or stone flooring without degradation of the walls or floors. The ANDI OTG works with existing networks and includes proprietary Zero Contact fingerprinting software. A variety of high-speed on-board fingerprint matchers are available.

Figure 2. Production ANDI OTG currently undergoing FBI image quality testing.

ANDI OTG meets international electric current standards. The ANDI OTG comes with a North American standard NEMA -15B plug and uses a standard CAT5 network connection. The ANDI OTG complies with 2010 ADA Standards for Accessible Design as published by the Department of Justice and also works well in tests with wheel chair bound fingerprinting subjects.

The new ANDI OTG II was developed on a new product architecture delivering a more reliable and commercialized product. The new ANDI OTG II has been available since November 2014.

CROSSMATCH™

Guardian® R2

Ruggedized, Appendix F Certified Ten-print Livescan

FEATURES

- Ruggedized ten-print scanner for harsh environment and outdoor use
- Ergonomically friendly design, tailored for field use
- Easy to understand pictograms and fully automatic image capture
- Instant quality check feedback to the user
- The illumination technique allows the capture of high-quality images regardless of skin color and age
- Auto Capture both hands and thumbs, in under 15 seconds
- Ultra lightweight and portable for use in Jump Kits and portable travel cases
- Convenient, adjustable handle for positioning Guardian R2 to accommodate special needs
- FBI-certified for both civil ID flats and full criminal ten-print rolls and flats

PRODUCT DESCRIPTION

Identity management solutions often require deployment under a wide variety of environmental conditions with demanding operational requirements. The Crossmatch™ Guardian R2 ruggedized ten-print livescan is designed to meet these operational challenges while delivering unsurpassed image quality capture performance in the most diverse and often harshest of environments.

Capable of rapidly capturing ID flats and full criminal ten-print flats and rolls, the Guardian R2 meets Appendix F requirements and is well suited for high-volume processing applications. The device has been independently certified to conform to MIL-STD-810F standards for equipment durability in various harsh environmental conditions. In addition, the Guardian R2 is factory calibrated and sealed, and meets IEC IP 65 standards for dust and water intrusion and functions in humidity ranging from 10% to 90%. The device can operate as a battery powered system, is lightweight and easily integrated into jump kits – making it an ideal choice for the most remote and rugged operational missions

ABOUT CROSSMATCH

Crossmatch helps organizations solve their identity management challenges through biometrics. We empower governments, law enforcement agencies, banks, retailers and other enterprises to mitigate risk, drive productivity and improve service levels. Our solutions are built on consultative expertise, refined best practices and the application of advanced biometrics technologies. Crossmatch understands the forces of change in the markets we serve and we develop solutions that anticipate customer requirements. Our network of consultative and technical service experts collaborate with customers in more than 80 countries worldwide.

Learn more at www.crossmatch.com.

Guardian® R2

Ruggedized, Appendix F Certified Ten-print Livescan

CROSSMATCH™

SPECIFICATIONS

Operating System	Windows® XP, Windows Vista®, Windows 7
Resolution	500 ppi
Power	External power supply and by USB 2.0 interface
Heated Platen	Eliminates condensation and halo effect (usable by external power only)
Auto Capture	Feedback through four LED lights indicating image quality
Image Quality	FBI specification EBTS Appendix F
Capture Area	3.2” x 3.0” (81 mm x 76 mm), single prism, uniform capture area
Operating temperature	32 °F to 122 °F (0 °C to 50 °C)
Humidity Range	10-90 % non-condensing; sealed protection against low pressure jets of water from all directions
Dimensions	6.0” x 6.4” x 5.2” (153 mm x 163 mm x 133 mm)
Weight	4.85 lbs (2.20 kg) device with cover 7.38 lbs (3.35 kg) device with included packing
Battery	Standard USB 2.0 interface, high speed 480 Mbits/s, IP 65 connector
Housing	Sealed, metal case meets IEC IP 65 standard for protection from dust and water intrusion
Durability	Designed and tested to meet MIL-STD-810F durability specifica-tions
Certifications	FBI, Appendix F,UL,CE, RoHS

SOFTWARE FEATURES

Auto Capture	Patented capability for flat and roll fingerprints without opera-tor intervention
Perfect Image	Filters and rejects residual ghost fingerprint images
Perfect Roll	For rolled fingerprint acquisition, either direction
Software Update	Firmware and base level software can be updated through the USB 2.0 port
Base Level Software	L Scan Essentials 5.4 and higher

Data subject to change without notice

OPTIONAL COMPONENTS

- Optional ambient light shield for use in direct sunlight
- Available in Jump Kit for field deployable ID Management Solutions

Corporate Headquarters:

Crossmatch
3950 RCA Boulevard, Suite 5001
Palm Beach Gardens, FL 33410 USA

www.crossmatch.com

20141119

CROSSMATCH™

SEEK® Avenger

Rugged Multimodal Handheld

ADVANTAGES

SEEK Avenger incorporates all the lessons learned in the development of SEEK II. The difference is our years of experience in integrating the multimodal biometrics technology in a user-friendly, ergonomic form that has been proven in theater, on the streets and at the borders – some of the harshest and most demanding environments.

PRODUCT DESCRIPTION

Ideally suited for in-field operations, the compact SEEK Avenger is the only fully certified biometric enrollment and credential reading solution purpose built to perform in the harsh and challenging environments of the military, border security, and law enforcement. Combining forensic-quality fingerprint, stand-off dual iris capture, high resolution facial and evidence imaging, and multiple format credential reading, the SEEK Avenger delivers a lighter, smarter, and faster solution than what is available in the market today.

As the first mobile device of its kind capable of fingerprint and dual stand-off iris capture in direct sunlight, the SEEK Avenger provides mission flexibility by limiting operating constraints. Optional 3G/4G wireless connectivity and an onboard watchlist of up to 250,000 records, eliminates the need to transport unknown subjects in uncertain conditions for enrollment or identification; further reducing operational risk. With the addition of the optional MRZ and RFID readers, the functionality of the Avenger expands to include the reading and verification of ePassports and other noncontact credentials. These capabilities prove extremely valuable in highly remote locations, conditions where connectivity has been compromised, or when virtually instantaneous confirmation is required.

The SEEK Avenger delivers superior multi biometric enrollment and identity management capabilities in an age where risks are not always obvious and can carry extreme consequences. Being able to rely on a high degree of mobility, interoperability, and rapid accuracy can provide the decisive difference.

To learn more, visit www.crossmatch.com

ABOUT CROSSMATCH

Crossmatch helps organizations solve their identity management challenges through biometrics. We empower governments, law enforcement agencies, banks, retailers and other enterprises to mitigate risk, drive productivity and improve service levels. Our solutions are built on consultative expertise, refined best practices and the application of advanced biometrics technologies. Crossmatch understands the forces of change in the markets we serve and we develop solutions that anticipate customer requirements. Our network of consultative and technical service experts collaborate with customers in more than 80 countries worldwide.

Learn more at www.crossmatch.com

SEEK® Avenger

Rugged Multimodal Handheld

CROSSMATCH™

SPECIFICATIONS

Main Processor	Intel® Atom N2600 Dual Core – 1.6 GHz
Operating System	Windows® 7 Ultimate
Hard Drive	32 GB removable SATA solid state drive (64 GB optional)
Memory (optional)	2 GB DRAM (4 GB optional)
External Interfaces	2 USB 2.0, 1 ethernet, headphone and microphone jack
Cellular Data Connectivity (optional)	3G/4G (UMTS / DC HSPA+ & LTE) DC HSPA+ (850 / 1900 / 2100 MHz), LTE (700 MHz and AWS)
Other Wireless Communications	802.11 b/g/n, Bluetooth® 4.0 LE / 3.0 HS / 2.1 EDR and GPS
Ruggedized Standards	Designed to MIL-STD 810G and IP65
Display	5.0 Inch, 800 x 480 resolution resistive touchscreen
Keypad	Large backlit QWERTY keypad with optical mouse
Dimensions	9.5” x 6.2” x 1.8” (24.13 cm x 15.75 cm x 4.57 cm)
Weight	3.2 lbs (1.45 kg)
Battery	Dual hot-swappable, 2.9 Ahr, Li Ion
Battery Life	Up to 8 hours (use case dependent)
Operating Temperature	35°F to 120°F (2°C to 50°C)

Large QWERTY keyboard and display

FAP 45 fingerprint sensor

BIOMETRIC / CREDENTIAL CAPTURE

Fingerprint Capture	500 ppi; FBI Appendix F (FAP 45)
Iris Capture	Stand-off, SAP 40 simultaneous dual eye, Autofocus range 6”-10” (15.24 cm - 25.4 cm)
Camera	5 MP autofocus, autoflash
Contact Card	ISO / IEC 7816 (CAC, PIV)
Bar Code Reading	Using Facial Camera - 1D / 2D (PDF 417, Code 39)

Stand-off dual iris and facial capture

APPLICATIONS

Enrollment, Matching, and Transmission	MOBS, IDTrak, and Transmission Manager
SDK	SEEK Integrator SDK (finger, iris, face, credentials)

ADDITIONAL OPTIONS

MRZ Reader	ICAO 9303 and ISO/IEC 7501-1 (passports, visas)
RFID Reader	ISO/IEC 14443 documents (ePassports, PIV)

Data subject to change without notice

MRZ and RFID Reader

Corporate Headquarters:

Crossmatch
3950 RCA Boulevard, Suite 5001
Palm Beach Gardens, FL 33410 USA

www.crossmatch.com

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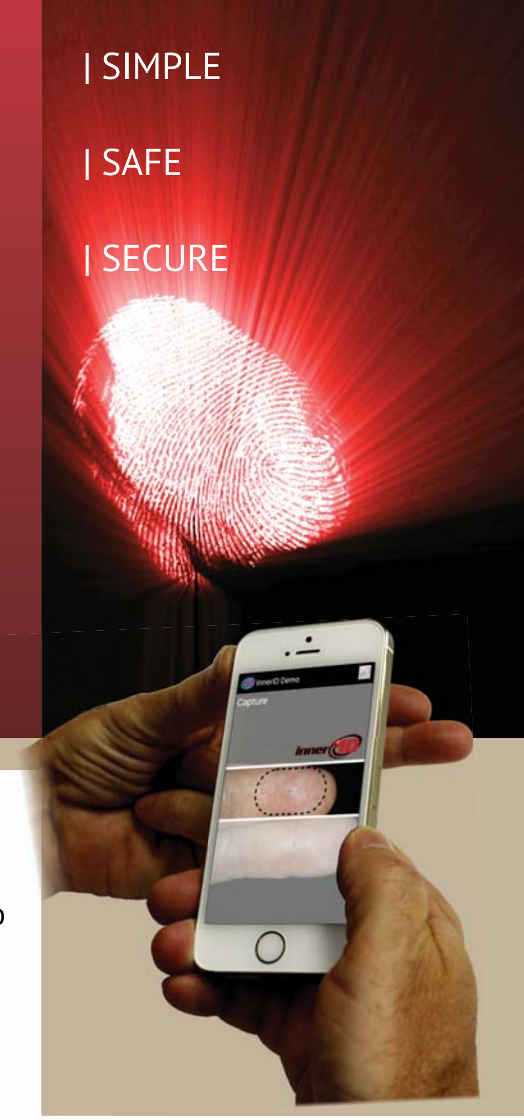
innerID



Fingerprint Authentication on Mobile Devices

innerID® brings fingerprint biometrics to smartphone apps. It eliminates the need for additional hardware by using the phone’s native camera.

Imagine securely accessing the world with your fingertips, today.

PATENT PENDING

Mobile Biometric Fingerprints

innerID is a fingerprint software module for mobile device apps. It requires no additional hardware. innerID captures finger images and converts them to fingerprint templates for user authorization.

Matching your fingerprint is fast and easy. Avoid the hassle and time wasted; replace your passwords! You can be free of passwords to memorize or to have stolen. Give your passwords the finger! Experience security and convenience with innerID. ***YOU are the password.***

Uses Native Device Hardware

innerID uses the rear-facing camera and light of the device as the fingerprint reader. There is no need for hardware plug-ins, no special cases, and no external dongles. Simply hold your finger in front of the camera and use the intuititve interface. Done!

Use Your Identity Securely

innerID is an app module for Android and iOS that collects, processes and matches fingerprints. Developers easily integrate the module into apps using the innerID SDK. App users enroll their prints with no hassle. Fingerprint collection and matching only takes a few seconds, with intuitive action. When prompted within an app, place your finger in the enrolled position, and touch the screen. That’s it!

Easy Operation

Faster than a password, always with you. Point. Tap. Go on with your life.

That’s innerID.

- Physical access control
- Logical access control
- Mobile Device Management
- Bring Your Own Device
- User authentication/ID
- Multi-factor authentication
- Biometric data collection

IDair

www.idairco.com

Touchless Fingerprint Biometrics on Today's Mobile Devices

Diverse Applications

innerID® adds a convenient biometric option for user login or multi-factor authentication scenarios. Using innerID, an app maker determines biometrically whether the person holding the phone is known. Authorized users could then unlock the phone, access a folder or app, unlock a door via NFC/Bluetooth, safely make a purchase at a store, pay a bill or view secure records over the web -- actually, any application imaginable.

Device Compatability

innerID works with the native hardware on **today's** smart mobile devices. No upgrades to a new model or additional hardware are needed - just the rear camera and flash of your Android or iOS mobile device. In general, any device that is less than two years old is a good candidate for using innerID.

User Benefits

Lose the hassles of PINs and passwords:

Fast Access - No passwords or PINS means no typing
Ease of Use - Simple interaction - Point the camera at your finger. Tap. Go.
Privacy - No 'shoulder surfing' or unknown use of your PIN
Safety - No fingerprints stored, only templates
Security- No way to "guess" a fingerprint

Rapid Integration

innerID is easy to integrate with your apps. Our API delivers fingerprint reading, image processing, quality scoring, template creation, enrollment, and matching -- everything needed for fingerprint biometrics on today's mobile devices, without new hardware! A full SDK is available including concise documentation and example source code, in multiple languages. Contact us to discuss a trial license.

For sales and additional information about innerID, please contact:

info@idairco.com
+1.800.973.3901
www.idairco.com/products

IDair, LLC
601 Genome Way
Suite 3003
Huntsville, AL 35806
United States of America

www.idairco.com

Finger On the Fly®

Introduction

Finger On the Fly® is a 10 fingerprint acquisition device based on a state-of-the-art contactless technology. It captures up to 4 fingerprints simultaneously in one wave of the hand, significantly decreasing capture time to less than 1 second. While much research is underway to continually improve upon this technology, large corporations and international government organizations are actively fielding Finger On the Fly® products to better streamline their existing fingerprint capture processes. Additionally, the efficiency, ease of use, alleviation of cultural or religious objections to touching or being touched, and sanitary benefits of contactless capture are permitting new stakeholders to finally implement identification technologies via Finger On the Fly® where legacy capture solutions limited the ability to successfully support their customer requirements. The feedback from current consumers of contactless fingerprint live-scan is that the demand for devices such as Finger On the Fly® is high. Morpho is proud to have advanced the first proven contactless fingerprint live-scan solution with multiple operational deployments, and we appreciate the opportunity to further improve upon Finger On the Fly® capabilities by participating in ManTech's 2015 Fingerprint Sensor Evaluation. We are eager to collaborate and receive feedback from you about this revolutionary technology.

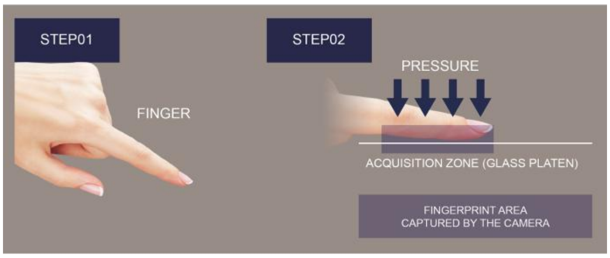
Technology Overview

From its inception in the Morpho R&D labs, the Finger On the Fly® technology has been designed with speed, accuracy and interoperability as primary targets. Since 'fingerprint' biometrics is a mature technology with widespread deployments, customers have legacy databases which need to be compatible with any new solutions brought to market. As such, it has been paramount in the development of Finger On the Fly® that it seamlessly integrates with existing systems and provides at least the same level of accuracy as existing live-scan solutions, while bringing the added benefits of speed and contactless acquisition.

The leading concept behind Finger On the Fly® product development and research is to minimize the effects of human behavior on the capture process. This principle not only improves the user experience but it also helps speed up the capture process with better accuracy in challenging environmental conditions such as at a land border or in an airport. In addition to swift identification of individuals, the solution also alleviates many cultural concerns inherent to the touch-sensor technology, in particular hygiene.

There are a number of major differences between contact and contactless acquisition devices:

ACQUISITION ON A CONTACT DEVICE:



ACQUISITION ON A CONTACTLESS DEVICE:

	Contact Devices	Finger On-The-Fly
Motion of the finger	Fingers are **static** on the acquisition surface and required not to move until the end of the acquisition.	**Dynamic** acquisition: Fingers are waved over the device.
Lighting technique	Total Internal Reflection (for most optical devices covered by IQS)	Direct view
Field of acquisition	**2D area,** usually inferior to the size of the acquisition glass platen	**3D volume,** the entire space between the top and the protection glass.

The consequences of the differences in acquisition method can be summed up as:

A. **Convenience**. Finger On-The-Fly® requires only one step (place the finger over the top of the device) where contact devices require a contact, pressure and a hold position. This explains the improvement of the speed and ease of use.

B. **Area**. Finger On-The-Fly® acquires a wider surface, since the whole finger is captured as it is swiped over the capture area. For contact devices, only the part of the finger in contact with the glass platen can generate any signal or information.

C. **Fidelity**. Since the finger doesn't suffer from any physical constraint (the pressure on the glass platen for instance) when acquired on Finger On-The-Fly®, the image acquired is a closer representation of the real finger and more consistent when acquired at different times in different conditions.

D. **Grayscale**. One thing specific to contact acquisition is the ability to enhance the difference between ridges of fingers in contact with the glass platen from the valleys (which are not in contact with the glass platen). This results in images with very high apparent contrast for contact images, where Finger On-The-Fly ® images are using the whole range of greyscale.

E. **Dry & Wet fingers**. For contact devices, the downside of enhancing differences between contact and non-contact parts of the skin" (as mentioned in previous point D) is that it relies on optical properties. In case of wet or dry fingers, even of perfect quality, these optical properties (mainly the refractive index) are not consistent, decreasing the image quality to different levels dependent on how much the finger under acquisition is wet or dry. Based on a different optic principle, Finger On-The-Fly® simply solves the issue of wet or dry fingers.

F. **"No smear, smudge, no latent"**. This is an obvious benefit of the contactless acquisition, as nothing is left behind after an acquisition.

G. **Accuracy**. All benefits of modern AFIS accuracy for searching contactless as well as searching legacy contact databases has been proven via large-scale benchmarking when capturing as little as 4 fingers.

MorphoIDent™

Introduction

MorphoIDent™ is a handheld mobile identification device based on fingerprint recognition technology. MorphoIDent™ is approximately the size of a smartphone that fits in a shirt pocket. Compact, easy to use and accurate, it communicates via USB, Bluetooth, or WiFi with a laptop, a tablet or a smartphone. Morpho provides client software available for each of these platforms to provide a connection to one or more central AFIS. The MorphoIDent also provides on-device matching vs. local watch lists. MorphoIDent has been in full production for over three years with full customer validation in the field. (An excellent example of an agency field deployment of MorphoIDent exists in the National Capital Region through NOVARIS, a regional organization of police agencies headquartered at the Fairfax County Police in Virgnia.)

Technology Overview

The MorphoIDent employs the MorphoSmart Compact Biometric Module (CBM-E2).The CBM-E2 is Morpho's second generation of compact biometric module complying with the FBI PIV IQS standard, the worldwide reference in terms of single fingerprint image quality.

MorphoIDent also employs the Morpho Embedded Platform (MEP), a standard design platform for implementation of processors with scalable capability.

The CBM-E2 is able to detect counterfeit fingerprints using Software Fake Finger Detection based on statistical comparison between fake fingers and true fingers.

MorphoIDent comes with a complete range of solutions for identification in the field, including:

- On device matching, 1:N with up to 5000 fingerprints
- Host applications for Windows XP/7/8.1/Phone 8.1, Android, and iOS platforms.
- HTTP/HTTPs, SMTP/SMTPs interface with server

MorphoIDent Specifications:

- Dimensions (LxWxH): 133 x 66 x 18 mm (5.2 x 2.6 x 0.7 inches)
- Weight:<150 grams (5.3 oz)
- Optical sensor: FBI PIV IQS certified, 500 dpi,
- 256 gray levels, 14x22 mm sensing area
- Display: 2.4" QVGA color LCD
- Battery: Li-ion, 1230 mAh
- Drop test: 1.4m (4 ft)
- Ingress Protection: IP32
- Operating conditions:
- Temperature: -10° to 50°C (14° to 122° F)
- Humidity: 95% non-condensing
- Storage conditions: -20° to 70°C (-4° to 158° F)

MorphoTrust USA

TOUCHPRINT™ 5300/5600

Law enforcement legislation and sex offender registration policies require the capture of all types of images with a live scan device, including tenprints, palms, rolls, and writers' edges. The TouchPrint™ 5300 live scan appliance and TouchPrint™ 5600 cabinet booking station are capable of all types of high quality images using an innovative, single platen. The detailed print images are scanned at either 500 ppi or 1000 ppi using advanced imaging power and antismearing and anti-smudging technologies, with our fingerprinting solutions exceeding FBI standard requirements.

SUPERIOR PRINT CAPTURE AND IMAGE QUALITY

Image quality is critical for live scan systems. Poor quality prints cannot be used to correctly identify or verify a subject on the first AFIS submission, resulting in higher rejection rates and lengthy processing times.

Our patented optics ignore moisture, dirt and latent prints left behind on the platen, making it easier to capture high quality images – consistently – regardless of the challenges faced, such as dry or sweaty fingers or an unclean platen. "Best in class" in image capture quality, rather than "good enough" is the choice to make in deciding which live scan to use in accurately identifying people.

The TouchPrint™ 5300 and TouchPrint™ 5600 are provided with the image clarity needed to prevent artifacts and capture important friction ridge detail. Both models boast high dynamic range sensor results in maximum contrast and gray scales, bringing out the minutiae and pore detail in the fingerprint and hand print images with virtually no distortion, which makes the image ideal for latent print comparison.

ADVANCED CABINET DESIGNS

This scanner is available in three models, a small desktop unit or a laptop model (5000) and a full cabinet booking station (5500).

All models are designed with a platen encased in a durable, rugged housing environment. A sealed unit permits for deployment in demanding environmental conditions that may be dusty, wet, hot or humid.

The cabinet design has an ergonomic structure with a small foot print design, that allows for ease of use in space-constrained environments. The adjustable, 17" LCD flat panel monitor allows for optimal, high-resolution fingerprint image display. In addition, optional accessory trays are available for extra workspace.

ADVANCED TECHNOLOGY ON A SINGLE PLATEN

- High resolution, realtime preview of palm (approximately 10 frames/ second) for optimal precapture positioning
- Palm capture in less than 1.5 seconds
- Scan resolutions available in 500 ppi or at more than 1000 ppi (exceeding the FBI certified requirement)
- MegaView camera system provides 70% more pixels compared to conventional scanners
- Our patented Moisture Discriminating Optics™ ensures details in pores and no obscured ridge contours
- Designed to eliminate variability that directly impacts image quality: no moving parts, no pads or coatings

SUPERIOR FINGERPRINT IMAGES FROM A FAST AND INTUITIVE DEVICE

Telephone 978-215-2400
www.MorphoTrust.com

SAFRAN
MorphoTrust USA

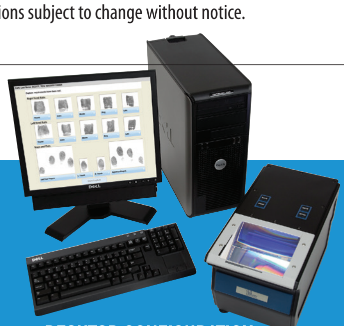
TouchPrint™ 5300/5600 Product Features Impacting Image Quality

FEATURES	BENEFIT
MegaView Camera System	Greater image detail – over 70% more pixels than conventional 1000 ppi scanners.
Grayscale	Linear, 256 levels with no lost detail from grayscale compression. Full ridge detail maintained for optimal latent comparisons.
Clean Image View™	70% better than the FBI specification for signal-to-noise ratio for greater ability to read features and ridge detail in fine ridge structures.
Balanced Image Distribution™	200% less geometric distortion equals enhanced accuracy of minutiae and ridge detail location.
AntiSmear™ Technology	Prevents smudging and smearing during finger rolls. High quality prints with less-skilled operators.
Clear Trace Imaging™	Prevents false minutiae by ignoring dirt or latents left on the platen. Provides greater uniformity across platen region. Less platen cleaning equals faster throughput.
Moisture Discriminating Optics™	Our patented optic technology ignores moisture and sweat to prevent loss of fine feature detail essential for realizing the benefits of 1000 ppi scanning.
Auto Light Balancing	Maintains consistent image quality over time. Best prints all the time.

TouchPrint™ 5300/5600 Technical Specifications*

TECHNICAL	
Model Number	TouchPrint™ 5300 and TouchPrint™ 5600
Scanning and Image Capture Resolution	Scan Resolution: 1062 ppi (v) x 1638 ppi (h) Scan Depth: 8 bits/pixel (256 gray levels) Capture Resolution: 1000 ppi (v) x 1000 ppi (h) Capture Depth: 8 bits/pixel
Active Image Dimensions	Multi-Finger Plain: 3.2 (h) x 2.0 (v) (nominal) inches Palm: 5.0 (h) x 5.1 (v) inches 10 Print Rolled: 1.6 (h) x 1.5 (v) inches ID Slap: 3.2 (h) x 3.0 (v) inches
Image Quality	Geometric Distortion: Exceeds FBI IQS specification without calibration Linearity, signal to Noise, CTF, Scanned gray levels: Meets or exceeds FBI IQS specifications
Illumination	White LED light panel for low operator eye fatigue and no color memory
Scanner Data Interface	USB 2.0
Size (appliance) **Size (cabinet)**	15 in (38 cm) (l) x 8.5 in (21.5 cm) (w) x 9 in (23 cm) (h) Width: 24.0in (60.96 cm); Height: 65.0in (165.1cm); Depth: 28 in (71.12 cm)
Weight (appliance)	Approximately 20 lbs (9 kg)
Power Requirements	110-120/220-240 VAC, 50/60HZ/-less 15 watts, Includes separate DC power module
Operating Environment (appliance)	Ambient temperature: 40º-104º F (5º-40º C) Relative humidity: 20-90% non-condensing Altitude: 0-7500 ft (2460 m) AMSL
Logical Scanner/Host Interface	• Software Development Kit (SDK) includes application program interface and device drivers for Windows XP, Windows Vista, and Windows 7 • (Available for licensed developers)

* Specifications subject to change without notice.



DESKTOP CONFIGURATION

TRANSPORTABLE CONFIGURATION

Telephone 978-215-2400
www.MorphoTrust.com

SAFRAN
MorphoTrust USA

C.8 Northrop Grumman BioSled

Northrop Grumman did not provide any reference material or product datasheet for the BioSled. BioSled is a mobile handheld biometrics device developed by Northrop Grumman that is currently in pre-production. It uses a contact-based sensor to capture rolled and plain fingerprints. Further details regarding technical specifications will be released shortly by the vendor.

APPENDIX C: COLLECTION DEVICE SUMMARIES – CFPV1

Device summaries from *Evaluation of Contact versus Contactless Fingerprint Data*.[2]

Figure 15: Cross Match SEEK II

SEEK II (by Cross Match) – Medium-large mobile handheld biometric device for queries and enrollment from the field. FBI FAP Level 45 certification; 500 dpi capture resolution. The device has been replaced by the SEEK Avenger.

Figure 16: TBS 3D Enroll

3D Enroll (by TBS) – Commercially available compact desktop single-finger contactless scanner for civilian and criminal access control and enrollment applications. The device utilizes three fixed cameras with diffuse illumination to detect and capture an image of an inserted finger. Captured images are nail-to-nail in capture area, but do not include 3D topological ridge details. Not FBI-certified; Output includes three 2D converted grayscale rolled-equivalent images (HT1, HT2, HT6) for each individual finger generated using unspecified pre and post processing methods at 500 dpi resolution. The TBS vendor recommends HT1 or HT2 as probes against legacy databases.
http://www.tbs-biometrics.com/fileadmin/tbs-media/products/3D-Enroll/en_productsheet_3d-enroll.pdfhttp://www.tbs-biometrics.com/fileadmin/documents/products/productsheets_en/en_productsheet_3d-enroll.pdf

APPENDIX D: ACRONYMS, ABBREVIATIONS, AND REFERENCES

D.1 Acronyms and Abbreviations

ACRONYM	DESCRIPTION
2D	Two Dimensional
3D	Three Dimensional
AFIS	Automated Fingerprint Identification System
AOS	Advanced Optical Systems
ASD(R&E)	Assistant Secretary of Defense for Research and Engineering
AT&L	Acquisition, Technology, and Logistics
CFP	Contactless Fingerprint
CFPv1	Contactless Fingerprint Collection, Round 1
CFPv2	Contactless Fingerprint Collection, Round 2
CMR2	Cross Match Guardian R2
CoE	Center of Excellence
DOD	Department of Defense
DOJ	Department of Justice
FAP	Fingerprint Application Profile
FAR	False Accept Rate
FM	False Match
FMR	False Match Rate at Rank 1
FOTF	Finger-On-The-Fly
ID	Identification
IRB	Institutional Review Board
LFP	Legacy Fingerprint
MID	MorphoIDent
MM	Neurotechnology MegaMatcher
NFIQ	NIST Fingerprint Image Quality
NIJ	National Institute of Justice
NIST	National Institute of Standards and Technology
NLECTC	National Law Enforcement and Corrections Technology Center
OSD	Office of the Secretary of Defense
OTG	On-The-Go
RDT&E	Research, Development, Test, and Evaluation
SDK	Software Development Kit

ACRONYM	DESCRIPTION
SEEK	Cross Match SEEK Avenger
SSBT	Sensor, Surveillance, and Biometric Technologies
TAR	True Accept Rate
TB	Terabyte
TBS	Touchless Biometric Systems
TM	True Match
TMR	True Match Rate a1 Rank 1
WVU	West Virginia University

D.2 References

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[1] WVU, *Non-Contact Multi-Sensor Fingerprint Collection – Phase II* (April 2015).
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