NIST Technical Note 2007

NIST Special Database 302

Nail to Nail Fingerprint Challenge

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National Institute of
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U.S. Department of Commerce

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Abstract

In September 2017, the Intelligence Advanced Research Projects Activity (IARPA) held a data collection as part of its *Nail to Nail (N2N) Fingerprint Challenge* [1]. Participating Challengers deployed devices designed to collect an image of the full *nail to nail* surface area of a fingerprint—equivalent to a rolled fingerprint—from an unacclimated user, without assistance from a trained operator. Traditional operator-assisted live-scan rolled fingerprints were also captured, along with assorted other friction ridge live-scan and latent captures. The collection of images collected during the N2N Fingerprint Challenge, entitled *Special Database 302 (SD 302)*, can be freely downloaded from the National Institute of Standards and Technology (NIST) website.

Key words

biometrics; data; devices; fingerprints; images; latent.

Human Subjects Research

The National Institute of Standards and Technology Institutional Review Board reviewed and approved the protocol for this project and all subjects provided informed consent.

Acknowledgments

A data collection of the size and scale presented at the N2N Fingerprint Challenge required the coordination and cooperation of dozens of individuals, without whom the Challenge would not have been possible.

- Thank you to IARPA for sponsoring the N2N Fingerprint Challenge and supporting advancements in fingerprint capture and recognition.
- Thank you to Rebecca Allegar, Nathaniel Short, and the many members of the Booz Allen Hamilton (BAH) team that helped IARPA create, organize, plan, and successfully execute the N2N Fingerprint Challenge.
- Thank you to Ellen Fuller, Christopher Nardone, and the rest of the Johns Hopkins University Applied Physics Laboratory (JHU APL) team for graciously hosting the N2N Fingerprint Challenge and providing the infrastructure by which N2N Challengers submitted imagery.
- Thank you to the many JHU APL, BAH, IARPA, NIST, and Schwarz Forensic Enterprises (SFE) employees who spent countless hours digitizing and isolating latents.
- Thank you to Crossmatch and IDEMIA for providing high-resolution palm scanners for the week of the N2N Fingerprint Challenge in order to help capture exemplar palm data for distribution with the Challenge latent print dataset.
- Thank you to the Biometrics Research Group at Michigan State University for providing a prototype open source single finger capture device for auxiliary data collection.
- Thank you to the staff of the Department of Homeland Security (DHS) Maryland Test Facility for their assistance in prototyping the Challenge data collection.

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1. Introduction

In September 2017, the Intelligence Advanced Research Projects Activity (IARPA) held a fingerprint data collection as part of the *Nail to Nail (N2N) Fingerprint Challenge*, hosted by the Johns Hopkins University Applied Physics Laboratory (JHU APL) [1]. During the event, participating Challengers deployed devices designed to collect an image of the full *nail to nail* surface area of a fingerprint—equivalent to a rolled fingerprint—from an unacclimated user, without assistance from a trained operator. IARPA additionally provided for the capture of baseline operator-assisted rolled and plain fingerprints, palm prints, as well as a robust elicitation and collection of latent fingerprints.

The Challenge test staff, which consisted of employees from organizations involved in the N2N Fingerprint Challenge and other IARPA programs, determined that several hundred live human subjects would need to flow through the data collection in the time frame of a single work week in order to have enough data to be confident in the statistics used to award the Challenge winners. It was critical to collect data from unhabituated users instead of United States Government (USG) volunteers, to ensure that the ergonomics of Challenger's devices and instructions provided by Challenger moderators accounted for people not accustomed to providing their fingerprints. This required human subject recruitment, and thus Institutional Review Board (IRB) oversight. Challenge test staff solicited permission from the IRB and the study participants to create a public dataset from the biometric data that was to be captured. The result is a new Special Database (SD) from the National Institute of Standards and Technology: SD 302.

Challengers	A	IDEMIA	B	Advanced Optical Systems	C	Green Bit	D	Cornell University	E	Jenetric
	F	Touchless Biometric Systems	G	*Undisclosed*	H	Clarkson University	U	Baseline Rolled #1	V	Baseline Rolled #2
Auxiliary	J	Morpho TouchPrint 5300	K	Michigan State University RaspiReader	L	Advanced Optical Systems (Unprocessed)	M	EikonTouch 710		
	N	Green Bit MultiScan 527g	P	Futronic FS88	Q	Crossmatch L SCAN 1000PX	R	Crossmatch L SCAN 1000PX		
	S	Crossmatch Guardian USB	T	Clarkson University (Unprocessed)						

2. Data Collection

The description of the data collection described herein borrow heavily from the previous in-depth documentation from the authors, as published in National Institute of Standards and Technology (NIST) Interagency Report 8210 [2].

2.1 Facility

JHU APL was chosen by IARPA as the host facility for the N2N Fingerprint Challenge. From 18–21 September 2017, N2N Challenge test staff and Challengers transformed much of the Intelligent Systems Center at JHU APL into a secure area for performing a data collection. The facility was a typical airport-style environment, with climate control, high ceilings, and fluorescent lighting. All windows in the facility were obscured by blackout shades. All Challengers were located in the same room, and as such, environmental factors for all Challengers were uniform.

2.2 Study Participant Population

Study participants were recruited by a third-party recruitment company, Matthews Media Group (MMG), on behalf of JHU APL. Study participants were required to have all 10 fingers imaged. Those with any amputated or bandaged fingers when arriving for the data collection were excluded. Study participants were required to be able to speak, read, and understand the English language, and have full mobility in their fingers, arms, and wrists. They also needed the ability to stand for the duration of the data collection, but were encouraged to sit when their interactions with a station were complete. A summary of genders, ages, and occupations of these study participants is shown in Table 1.

Age Range	Percentage
18 to 24	11.8 %
25 to 29	14.2 %
30 to 39	23.0 %
40 to 49	24.2 %
50 to 59	22.3 %
60 to 69	3.6 %
70 to 79	0.6 %
80 to 89	0.3 %

Gender	Percentage
Female	64.7 %
Male	35.0 %
No Answer	0.3 %

Race	Percentage
African American	19.3 %
Asian	7.6 %
Pacific Islander	0.6 %
White	65.0 %
Other	6.0 %
No Answer	1.5 %

Employment Status	Percentage
Disabled	1.2 %
Full-time	54.4 %
Homemaker	8.2 %
Part-time	18.4 %
Retired	3.9 %
Unemployed	4.8 %
Other	7.6 %
No Answer	1.5 %

Employment Type	Percentage
Manual Labor	5.1 %
Office Work	49.2 %
Other	37.5 %
No Answer	8.2 %

Table 1. A summary of genders, ages, races, and occupations of study participants whose biometrics were captured as part of the N2N Fingerprint Challenge dry run data collection.

2.3 Baseline Data

Study participants needed to have their fingerprints captured using traditional operator-assisted techniques in order to quantify the performance of the Challenger devices. IARPA invited members of the Federal Bureau of Investigation (FBI) Biometric Training Team to the data collection to perform this task. Each study

Challengers	A	IDEMIA	B	Advanced Optical Systems	C	Green Bit	D	Cornell University	E	Jenetric
	F	Touchless Biometric Systems	G	*Undisclosed*	H	Clarkson University	U	Baseline Rolled #1	V	Baseline Rolled #2
Auxiliary	J	Morpho TouchPrint 5300	K	Michigan State University RaspiReader	L	Advanced Optical Systems (Unprocessed)	M	EikonTouch 710		
	N	Green Bit MultiScan 527g	P	Futronic FS88	Q	Crossmatch L SCAN 1000PX	R	Crossmatch L SCAN 1000PX		
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participant had N2N fingerprint images captured twice, each by a different FBI expert, resulting in two N2N *baseline* datasets.

To ensure the veracity of recorded N2N finger positions in the baseline datasets, Challenge test staff also captured plain fingerprint impressions in a 4-4-2 *slap* configuration. This capture method refers to simultaneously imaging the index, middle, ring, and little fingers on the right hand (4), then repeating the process on the left hand (4), and finishing with the simultaneous capture of the left and right thumbs (2). This technique is a best practice to ensure finger sequence order, since it is physically challenging for a study participant to change the ordering of fingers when imaging them simultaneously.

Operators at operator-assisted rolled and slap stations were given at most 5 minutes with each study participant, totaling 15 minutes of collection time per study participant dedicated to establishing a baseline dataset.

2.4 Challengers

After an extensive review period, eight Challengers were selected for participation in the N2N Fingerprint Challenge. Each of the Challengers were supplied with a table, chairs, and an electrical power strip. Challenger tables were separated by sound-dampening panels. Challengers brought their fingerprint capture devices and any computer hardware and software necessary to perform fingerprint capture. All software used was written or procured by the Challenger. Each Challenger was given at most 5 minutes with a study participant, totaling 40 minutes of collection time dedicated to Challengers.

For each study participant, Challengers were to submit an individual image for each finger usable with a commercial off-the-shelf (COTS) fingerprint identification system. Challengers could capture more than one finger at a time, but all images submitted had to depict a single finger per image only.

2.5 Latent Fingerprints

NIST partnered with the FBI and Schwarz Forensic Enterprises (SFE) to design activity scenarios in which subjects would likely leave fingerprints on different objects. The activities and associated objects were chosen in order to use a number of latent print development techniques and simulate the types of objects often found in real law enforcement case work.

For brevity, the activities and latent development techniques are not described in this document. Please refer to Section 5 of NIST Interagency Report 8210 [2] for thorough descriptions.

SFE additionally conducted the latent print data collection for the N2N Fingerprint Challenge. Members of SFE instructed study participants to interact naturally with a variety of objects. SFE had 10 minutes to interact with each study participant. Not every study participant performed every activity, but the activities were distributed such that each study participant performed activities with similar characteristics.

2.6 Auxiliary Devices

The facility at JHU APL was large enough to comfortably allow for three latent collection stations, eight Challengers devices, and three baseline devices, while still having plenty of extra room. Since the participants were already consented and paid for their time, additional friction ridge capture devices, referred to as *auxiliary* devices, were deployed and operated by the Challenge test staff. This allowed for additional traditionally-captured data to be made available to the public. Due to logistical issues, not all auxiliary capture devices collected data for all days of the N2N Fingerprint Challenge.

2.7 Flow

Study participants arrived at JHU APL in groups of 17—one more subject than there were stations, to account for the duration of latent collection. In a separate room, a JHU APL IRB representative guided study participants through the informed consent process required before providing their friction ridge data. After all participants in a group were consented, they were escorted into the data collection room. Inside, Challenge test staff would pair with each study participant and accompany them to their specified

Challengers	A	IDEMIA	B	Advanced Optical Systems	C	Green Bit	D	Cornell University	E	Jenetric
	F	Touchless Biometric Systems	G	*Undisclosed*	H	Clarkson University	U	Baseline Rolled #1	V	Baseline Rolled #2
Auxiliary	J	Morpho TouchPrint 5300	K	Michigan State University RaspiReader	L	Advanced Optical Systems (Unprocessed)	M	EikonTouch 710		
	N	Green Bit MultiScan 527g	P	Futronic FS88	Q	Crossmatch L SCAN 1000PX	R	Crossmatch L SCAN 1000PX		
	S	Crossmatch Guardian USB	T	Clarkson University (Unprocessed)						

starting station. An announcement was made to begin, which started a five minute timer. After 5 minutes, study participants had 30 seconds to move to the next station, where the process would repeat. Study participants at the latent collection stations stayed in place for two consecutive rotations. When each 93 minute round of data collection had completed (15 fingerprint stations with 5 minute durations, 1 latent station with a 10 minute duration, and 15 transitions with 30 second durations), subjects were paid for their time and signed out of the facility.

On each day, (3 to 5) groups of 17 study participants would make their rounds in the facility. Each day, Challenge test staff reversed the direction in which a study participant would move to the adjacent station, to reduce the affects of habituation formed by preceding devices. Additionally, half-way through the week, Challengers physically changed location of their stations. Where possible, care was taken to avoid putting devices that operated in a similar manner adjacent to each other. In total, friction ridge data from 331 study participants was usable at the conclusion of the data collection.

Challengers	A	IDEMIA	B	Advanced Optical Systems	C	Green Bit	D	Cornell University	E	Jenetric
	F	Touchless Biometric Systems	G	*Undisclosed*	H	Clarkson University	U	Baseline Rolled #1	V	Baseline Rolled #2
Auxiliary	J	Morpho TouchPrint 5300	K	Michigan State University RaspiReader	L	Advanced Optical Systems (Unprocessed)	M	EikonTouch 710		
	N	Green Bit MultiScan 527g	P	Futronic FS88	Q	Crossmatch L SCAN 1000PX	R	Crossmatch L SCAN 1000PX		
	S	Crossmatch Guardian USB	T	Clarkson University (Unprocessed)						

3. Devices

Code	Challenger	Branding	Technology	Prototype?
A	IDEMIA	MorphoWave Desktop	Touch-free	No
B	Advanced Optical Systems (AOS)	ANDI N2N	Touch-free	Yes
C	Green Bit	DactyScan40i	Optical	No
D	Cornell University	*n/a*	Touch-free	Yes
E	Jenetric	LIVETOUCH QUATTRO	Solid-state	No
F	Touchless Biometrics Systems	S120	Touch-free	No
G	*Undisclosed*	*Undisclosed*	Solid-state	Yes
H	Clarkson University	*n/a*	Touch-free	Yes

Table 2. Friction ridge capture technologies deployed by Challengers during the N2N data collection. Not all of these devices are available COTS, as indicated by the *Prototype?* column. Sample captures for each of these devices can be seen in Fig. 1.

Code	Operator	Branding	Technology	Data
R	Challenge Test Staff	Crossmatch L SCAN 1000PX	Optical	4-4-2 slap
S	Challenge Test Staff	Crossmatch Guardian USB	Optical	4-4-2 slap
U	FBI	Crossmatch L SCAN 1000PX	Optical	Rolled
V	FBI	Crossmatch L SCAN 1000PX	Optical	Rolled

Table 3. Baseline capture devices deployed during the N2N data collection. Baseline devices were necessary for quantifying the performance of Challengers. A sample capture for U/V can be seen in Fig. 1.

Code	Operator	Branding/Description	Technology	Data
J	Challenge Test Staff	Morpho TouchPrint 5300	Optical	Palm
K	Challenge Test Staff	Michigan State University RaspiReader	Optical	Plain
L	AOS	Unprocessed Captures from B	Touch-free	Plain
M	Challenge Test Staff	Crossmatch EikonTouch 710	Solid-state	Plain
N	Challenge Test Staff	Green Bit MultiScan 527g	Optical	Palm
P	Challenge Test Staff	Futronic FS88	Optical	Plain
Q	Challenge Test Staff	Crossmatch L SCAN 1000PX	Optical	Palm
T	Clarkson University	Unprocessed Captures from H	Touch-free	Photographs

Table 4. Auxiliary capture devices deployed during the N2N data collection. These devices were not in use during all sessions of the data collection.

Tables [2–4] shows the friction ridge capture technologies used during the N2N Fingerprint Challenge data collection. Plain, rolled, and touch-free impression fingerprints were captured from a multitude of devices, as well as a several sets of plain palm impressions.

Baseline and Challenger devices in Tables 2 and 3 were available to capture data from all study participants in the Challenge. The remainder of the devices were deployed for as many sessions as was possible, given Challenge test staff availability.

3.1 Auxiliary Devices

Images from L and T were provided by their respective Challengers in an effort to provide more research data to the community. For L, the enrollment process for the corresponding Challenger device (B) required stitching together multiple captures of images taken by the sensor. The images in L represent the best plain-equivalent capture acquired by B prior to stitching with other captures. The images in T are photographic

Challengers	A	IDEMIA	B	Advanced Optical Systems	C	Green Bit	D	Cornell University	E	Jenetric	
	F	Touchless Biometric Systems	G	*Undisclosed*	H	Clarkson University	U	Baseline Rolled #1	V	Baseline Rolled #2	
Auxiliary	J	Morpho TouchPrint 5300	K	Michigan State University RaspiReader	L	Advanced Optical Systems (Unprocessed)			M	EikonTouch 710	
	N	Green Bit MultiScan 527g	P	Futronic FS88	Q	Crossmatch L SCAN 1000PX			R	Crossmatch L SCAN 1000PX	
	S	Crossmatch Guardian USB	T	Clarkson University (Unprocessed)							

representations of images acquired by the camera sensor in H before being transformed into individual grayscale rolled-equivalent fingerprint impressions. These photographs are believed to be of interest to the forensic and image processing communities.

A 4-4-2 slap capture was required to ensure the veracity of the friction ridge generalized positions (FRGPs) recorded for baseline rolled images (Section 2.3). Auxiliary device R was originally deployed for this purpose. After a few sessions of data collection, it was determined that the 39.4 pixels per millimeter (ppmm) (1 000 pixels per inch, or ppi) device would be better served by capturing palm impressions. The device was renamed Q and reassigned to capture upper, lower, and writer's palms at 39.4 ppmm. Device S was deployed to capture 4-4-2 slaps for the remainder of study participants. Since R and S were deployed for the sole purpose of confirming finger sequence positions for U and V (Section 4.4), it was not significant to the results of the N2N Fingerprint Challenge that the capture resolution was different between the two devices.

3.2 Financial Considerations

By providing images captured at the data collection to the public via this dataset, Challengers were awarded $8 000 by IARPA via the N2N Fingerprint Challenge's *Print Provider Prize*. Additional imagery labeled as device L and T were provided by the Challengers to IARPA without cost, reservation, special consideration, or additional compensation.

Auxiliary devices J and Q were temporarily loaned to IARPA without cost for auxiliary data collection, in support of IARPA's goal of providing exemplar images for palm friction ridge data that was collected during the latent fingerprint collection.

Auxiliary device K was provided to IARPA in support of promoting open-source hardware development. The specifications for building the device that captured the images along with a link to the controller software used in K can be found in [3].

Baseline devices and all other auxiliary devices were purchased independently by the Challenge test staff's employers at market price.

Challengers	A	IDEMIA	B	Advanced Optical Systems	C	Green Bit	D	Cornell University	E	Jenetric
	F	Touchless Biometric Systems	G	*Undisclosed*	H	Clarkson University	U	Baseline Rolled #1	V	Baseline Rolled #2
Auxiliary	J	Morpho TouchPrint 5300	K	Michigan State University RaspiReader	L	Advanced Optical Systems (Unprocessed)	M	EikonTouch 710		
	N	Green Bit MultiScan 527g	P	Futronic FS88	Q	Crossmatch L SCAN 1000PX	R	Crossmatch L SCAN 1000PX		
	S	Crossmatch Guardian USB	T	Clarkson University (Unprocessed)						

4. Data

4.1 Operators

Devices U and V were operated by skilled device operators from the FBI. These operators were individuals who routinely interact with the public to facilitate biometric capture. Devices A, B, C, D, E, F, G, H, L, and T were operated by individuals from the device's respective Challenger organizations. All other devices were operated by Challenge test staff. Although these individuals are knowledgeable in the field of biometrics, efficient capture techniques, enrollment quality control, and public interaction are not necessarily a part of their professional responsibilities.

4.2 Acquisition Rate

It was required that baseline devices achieve an acquisition rate of 100 %, in order to verify the recorded FRGPs and study participant identifiers for other devices. There were no such requirements for Challenger devices. Not all devices were able to achieve 100 % acquisition rate, nor were all auxiliary devices deployed for the entire duration of the data collection. To be eligible for most prizes, Challengers were required to acquire all fingers from at least 90 % of all study participants. Details about Challenger acquisition rates can be found in Section 9 of NIST Interagency Report 8210 [2].

4.3 Device Description

Descriptions of Challenger devices shown in Table 2 are thoroughly detailed in Section 6 of NIST Interagency Report 8210 [2]. Sample captures from each of the devices is shown in Fig. 1. Only one encounter was captured for each device.

Although the underlying capture technology varies, interaction with nearly all Challenge test staff-operated auxiliary devices from Table 4 was identical. The study participant approached the device and physically touched 1 to 4 fingers or a section of their palm to a platen.

All auxiliary devices operated at 19.7 ppmm (500 ppi), except for J, Q, and R, which operated at 39.4 ppmm (1 000 ppi). Versions of images from these devices, as well as the baseline rolled (U and V) and slap (R) have been properly downsampled [4] to 19.7 ppmm (500 ppi) and included as part of SD 302 to maximize compatibility with algorithms designed around that resolution.

4.4 Ground Truth

Software used by device operators was required to record the FRGP of captured fingerprints. To ensure the veracity of the recorded FRGPs of individual fingerprint captures, commercial feature extraction and matching algorithms were used. One-to-one matching of the baseline segmented plain captures (FRGPs 13 to 15 from R and S) was performed against all other fingerprint captures of the same study participant. High-scoring non-mated pairs and low-scoring mated pairs in common between the majority of the algorithms were visually inspected to check for finger sequencing errors.

For the release of SD 302, this technique was applied to all devices. It is important to note that this technique was *not* applied prior to performing the data analysis depicted in NIST Interagency Report 8210 [2]. N2N Fingerprint Challenge rules specified that Challengers were fully responsible for sequence checking their own captures. Challenger device sequence errors have only been corrected in SD 302 as a service to the research community.

The ground truth technique employed was a *best-effort* process. In some cases, FRGPs from low-scoring mated pairs could not be confirmed, including by visual inspection, due to poor image quality. Under these circumstances, the original FRGPs recorded by the device operator's software were retained.

4.5 Image Quality

A cursory overview of the observed fingerprint quality from baseline devices (R, S, U, and V) are provided in Figs. [2–4] and Table 5. Fig. 2 shows a stacked bar graph of values of the original NIST Fingerprint Image

Challengers	A	IDEMIA	B	Advanced Optical Systems	C	Green Bit	D	Cornell University	E	Jenetric
	F	Touchless Biometric Systems	G	*Undisclosed*	H	Clarkson University	U	Baseline Rolled #1	V	Baseline Rolled #2
Auxiliary	J	Morpho TouchPrint 5300	K	Michigan State University RaspiReader	L	Advanced Optical Systems (Unprocessed)	M	EikonTouch 710		
	N	Green Bit MultiScan 527g	P	Futronic FS88	Q	Crossmatch L SCAN 1000PX	R	Crossmatch L SCAN 1000PX		
	S	Crossmatch Guardian USB	T	Clarkson University (Unprocessed)						

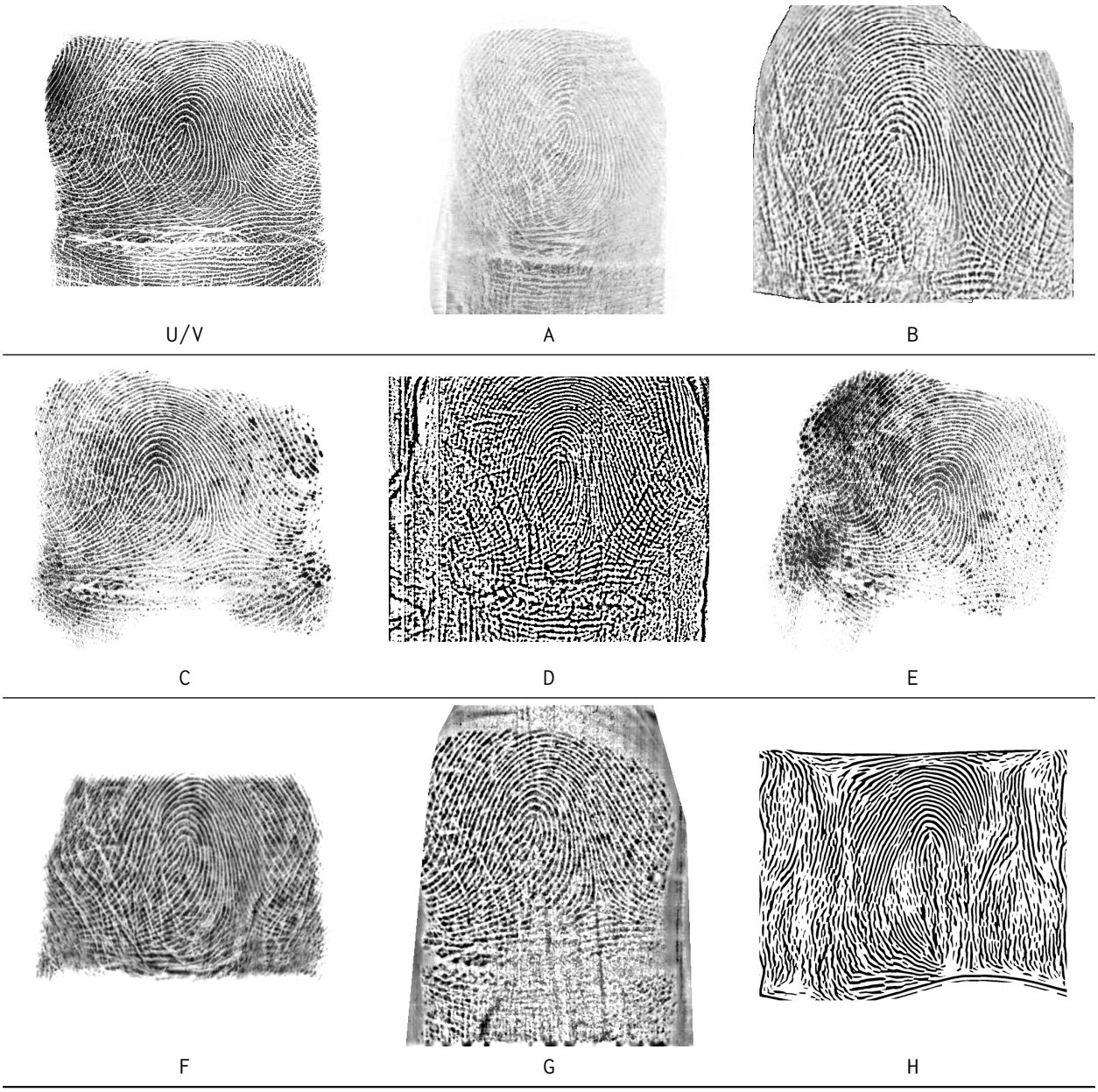

Fig. 1. Example captures from each Challenger. Each capture shows the same left middle finger from the same study participant, identified as `00002446` in SD 302.

Challengers	A	IDEMIA	B	Advanced Optical Systems	C	Green Bit	D	Cornell University	E	Jenetric
	F	Touchless Biometric Systems	G	*Undisclosed*	H	Clarkson University	U	Baseline Rolled #1	V	Baseline Rolled #2
Auxiliary	J	Morpho TouchPrint 5300	K	Michigan State University RaspiReader	L	Advanced Optical Systems (Unprocessed)	M	EikonTouch 710		
	N	Green Bit MultiScan 527g	P	Futronic FS88	Q	Crossmatch L SCAN 1000PX	R	Crossmatch L SCAN 1000PX		
	S	Crossmatch Guardian USB	T	Clarkson University (Unprocessed)						

Fig. 2. Stacked bar plots of NFIQ values for baseline devices, separated by device and FRGP, with equivalent left and right FRGPs adjacent to each other. For `R` and `S`, devices that captured multiple fingers simultaneously, the fingerprint images were segmented and visually inspected before running NFIQ. Additionally, images captured at 39.4 ppmm were downsampled to 19.7 ppmm before computing NFIQ.

Quality (NFIQ) algorithm [5], separated by device and FRGP. A series of violin plots of NFIQ 2.0 [6] values separated by device and FRGP are presented Fig. 3. A tabular version of this data with aggregate FRGPs can be seen in Table 5.

Of the 155 total quality features tested during development of the NFIQ 2.0 algorithm, minutiae counts were selected as one of the final 14 features incorporated into the overall quality score. The count of high-quality minutiae found for images in this dataset, as discovered by *FingerJet FX OSE* via NFIQ 2.0, are presented in Fig. 4. These values were derived by multiplying the `FingerJetFX_MinutiaeCount` NFIQ 2.0 feature value by the `FJFXPos_OCL_MinutiaeQuality_80` NFIQ 2.0 feature value.

In each plot, left and right FRGPs are adjacent to facilitate an easier visual comparison between left and right hands. It should be noted that both NFIQ algorithms are trained on and designed for particular kinds of fingerprint images. Not all baseline devices used in the data collection captured data that met this criteria, and so values depicted here for such unsupported devices should be considered unofficial.

Most baseline devices captured data at 39.4 ppmm. These images were downsampled to 19.7 ppmm before running any image quality algorithms. Additionally, for all images depicting simultaneous finger captures (FRGPs 13 to 15), the `nfseg` fingerprint segmenter, distributed with NIST Biometric Image Software (NBIS) [7], was used to create rectangular polygons around the 1 to 4 individual fingers present in the image. Each set of segmentation position coordinates was visually inspected for accuracy and adjusted if necessary. These coordinates were used by another tool to segment the simultaneous captures into individual images. The coordinates are provided as part of SD 302.

Challengers	A	IDEMIA	B	Advanced Optical Systems	C	Green Bit	D	Cornell University	E	Jenetric
	F	Touchless Biometric Systems	G	*Undisclosed*	H	Clarkson University	U	Baseline Rolled #1	V	Baseline Rolled #2
Auxiliary	J	Morpho TouchPrint 5300	K	Michigan State University RaspiReader	L	Advanced Optical Systems (Unprocessed)	M	EikonTouch 710		
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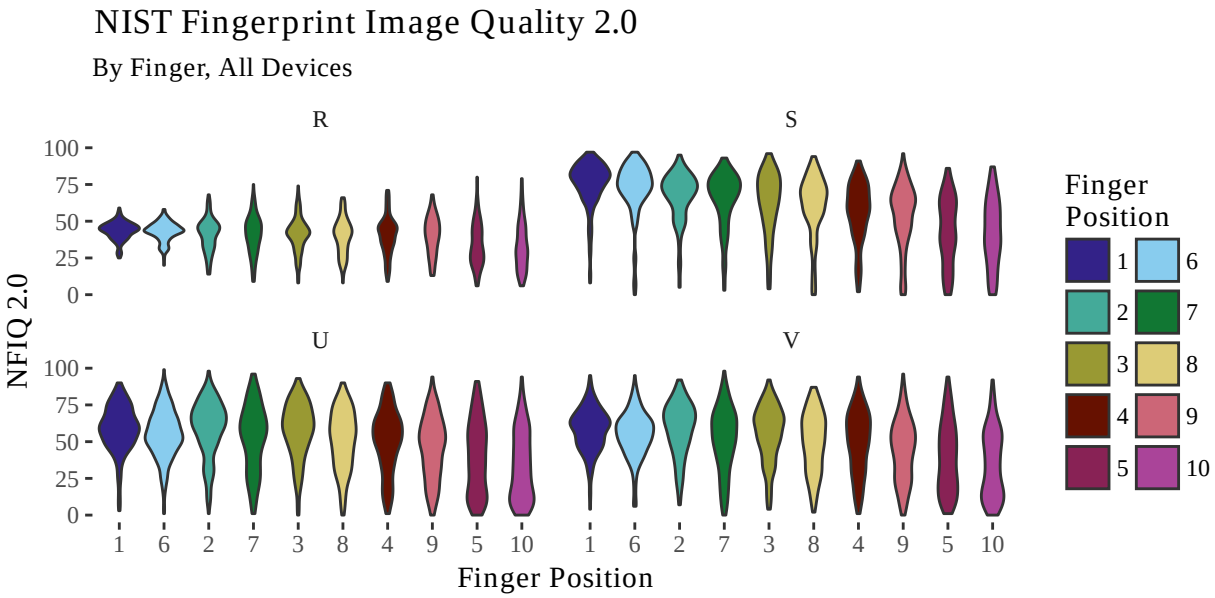

Fig. 3. Violin plots of NFIQ 2.0 values for baseline devices, separated by capture device and FRGP, with equivalent left and right FRGPs adjacent to each other. For devices that captured multiple fingers simultaneously, the fingerprint images were segmented and visually inspected before running NFIQ 2.0. Additionally, images captured at 39.4 ppmm were downsampled to 19.7 ppmm prior to computing NFIQ 2.0. Note that NFIQ 2.0 is an algorithm that has not been trained on rolled data. Values depicted here for rolled impressions should be considered unofficial.

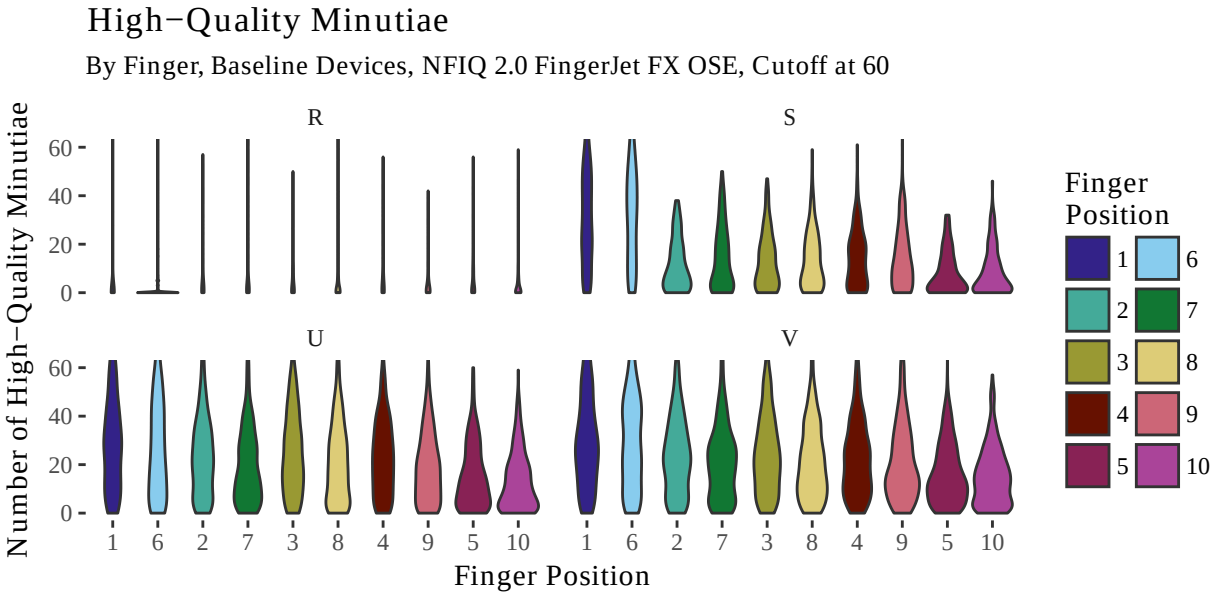

Fig. 4. Violin plots of high-quality minutiae extracted by *FingerJet FX OSE* as part of NFIQ 2.0 for baseline devices, separated by capture device and FRGP, with equivalent left and right FRGPs adjacent to each other. The charts show a maximum of 60 minutiae. For devices that captured multiple fingers simultaneously, the fingerprint images were segmented and visually inspected before running NFIQ 2.0. Additionally, images captured at 39.4 ppmm were downsampled to 19.7 ppmm prior to computing NFIQ 2.0. Note that NFIQ 2.0 is an algorithm that has not been trained on rolled data. Values depicted here for rolled impressions should be considered unofficial.

Challengers	A	IDEMIA	B	Advanced Optical Systems	C	Green Bit	D	Cornell University	E	Jenetric
	F	Touchless Biometric Systems	G	*Undisclosed*	H	Clarkson University	U	Baseline Rolled #1	V	Baseline Rolled #2
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	S	Crossmatch Guardian USB	T	Clarkson University (Unprocessed)						

NFIQ 2.0	R	S	U	V
0 to 9	16	82	194	176
10 to 19	103	75	214	235
20 to 29	215	75	254	279
30 to 39	323	133	328	337
40 to 49	571	170	451	494
50 to 59	153	229	665	631
60 to 69	60	364	586	624
70 to 79	9	414	399	370
80 to 89	0	259	189	148
90 to 100	0	49	20	16

Table 5. Bins of NFIQ 2.0 values for baseline devices, separated by capture device. For devices that captured multiple fingers simultaneously, the fingerprint images were segmented and visually inspected before running NFIQ 2.0. Additionally, images captured at 39.4 ppmm were downsampled to 19.7 ppmm prior to computing NFIQ 2.0. Note that NFIQ 2.0 is an algorithm that has not been trained on rolled data. Values depicted here for rolled impressions should be considered unofficial.

Challengers	A	IDEMIA	B	Advanced Optical Systems	C	Green Bit	D	Cornell University	E	Jenetric
	F	Touchless Biometric Systems	G	*Undisclosed*	H	Clarkson University	U	Baseline Rolled #1	V	Baseline Rolled #2
Auxiliary	J	Morpho TouchPrint 5300	K	Michigan State University RaspiReader	L	Advanced Optical Systems (Unprocessed)	M	EikonTouch 710		
	N	Green Bit MultiScan 527g	P	Futronic FS88	Q	Crossmatch L SCAN 1000PX	R	Crossmatch L SCAN 1000PX		
	S	Crossmatch Guardian USB	T	Clarkson University (Unprocessed)						

5. Obtaining and Using Special Database 302

The dataset can be downloaded from the Internet for free by visiting our website, https://www.nist.gov/itl/iad/image-group/special-database-302. Before downloading, researchers must agree to the terms and conditions of SD 302 that are listed on the webpage. A subset of study participant imagery has been held back for future NIST activities.

Note that SD 302 is a series of distributions, each containing a logical subset of the N2N Fingerprint Challenge data collection images. For instance, SD 302a contains only friction ridge imagery in Portable Network Graphics (PNG) encoding as generated by the Challengers. A description of subsets is available on the SD 302 website.

The directory structure of SD 302 after expanding the downloaded archive can be found in Fig. 5. This directory structure was chosen to allow for NIST to easily deliver future versions of the same images in different file formats alongside the series of partial distributions that make up the entirety of SD 302. The topmost directory contains a directory for each collection type (`auxiliary`, `baseline`, `challenger`, and `latent`). The contents of these directories are explained in Sections 5.1 and 5.2.

5.1 Live Capture

Images collected by devices with live study participant interaction are included in the `auxiliary`, `baseline`, and `challenger` directories. Contained within each collection type directory is a directory for each capture device, underneath which is a directory for different image file formats. Each file format directory contains a directory for applicable capture types, namely `palm`, `plain`, `roll`, `slap`, and `segmented` captures. For baseline and auxiliary devices that captured friction ridge detail at a resolution higher than 19.7 ppmm, images resampled at 19.7 ppmm are available. Images from Challengers are released as returned from the device and are not resampled.

For file size considerations, `auxiliary` devices are separated at the root once more by the type of impression supported by the device (`palm`, `photograph`, and `plain`). Each of these impression types is released as a separate distribution under SD 302.

Images files are contained in the deepest directory and are named in the form **`SUBJECT_DEVICE_RESOLUTION_CAPTURE_FRGP.EXT`**, where:

`SUBJECT` Unique identifier for this study participant.

`DEVICE` The short code used to refer to the device (Section 3).

`RESOLUTION` The resolution of the image in pixels per inch. Images from Challenger devices omit this information—the capture resolution for each axis is encoded into the PNG header.

`CAPTURE` The capture type characterized by the image. In the case of segmented images, the capture type characterized by the source image.

`FRGP` The ANSI/NIST-ITL 1-2011 Update:2015 [8] friction ridge generalized position code (Table 6).

`EXT` File format extension.

For devices that images more than one finger in a simultaneous capture, a comma-separated value (CSV) file, `segmentation_DEVICE_PPI.csv`, is included, which contains the rectangular coordinates and rotation angle (in degrees) used to create the provided `segmented` images from the original simultaneous capture image.

5.2 Latent

Due to the quantity of images, latent fingerprints are separated by directory for each study participant identifier. Image names are in the form **`SUBJECT_ACTIVITY_HAND_ENCOUNTER_TECHNIQUE_DIGITIZER_RESOLUTION_DEPTH_CHANNELS`**_LP**`NUMBER_SOURCE.EXT`**, where:

`SUBJECT` Unique identifier for this study participant.

Challengers	A	IDEMIA	B	Advanced Optical Systems	C	Green Bit	D	Cornell University	E	Jenetric
	F	Touchless Biometric Systems	G	*Undisclosed*	H	Clarkson University	U	Baseline Rolled #1	V	Baseline Rolled #2
Auxiliary	J	Morpho TouchPrint 5300	K	Michigan State University RaspiReader	L	Advanced Optical Systems (Unprocessed)	M	EikonTouch 710		
	N	Green Bit MultiScan 527g	P	Futronic FS88	Q	Crossmatch L SCAN 1000PX	R	Crossmatch L SCAN 1000PX		
	S	Crossmatch Guardian USB	T	Clarkson University (Unprocessed)						

FRGP	Description
1	Right Thumb
2	Right Index
3	Right Middle
4	Right Ring
5	Right Little
6	Left Thumb
7	Left Index
8	Left Middle
9	Left Ring
10	Left Little

FRGP	Description
11	Plain Right Thumb
12	Plain Left Thumb
13	Plain Left Four Fingers
14	Plain Right Four Fingers
15	Left and Right Thumbs

FRGP	Description
22	Right Writer's Palm
24	Left Writer's Palm
25	Right Lower Palm
26	Right Upper Palm
27	Left Lower Palm
28	Left Upper Palm

Table 6. Friction ridge generalized position values, reproduced from ANSI/NIST-ITL 1-2011 Update:2015, Table 9 [8].

ACTIVITY Activity performed to leave this latent impression. For a complete list of activities and their descriptions, refer to NIST Interagency Report 8210, Section 5.1 [2].

HAND **L** for left hand, **R** for right hand, or **X** if unknown.

ENCOUNTER A unique number to represent a particular encounter that was developed from this study participant and `ACTIVITY`.

TECHNIQUE The technique used to expose the print in this image. For a complete list of techniques and their descriptions, refer to NIST Interagency Report 8210, Section 5.2 [2]. This field is abbreviated, with **BP** meaning *black powder*, **IN** meaning *1,2-Indanedione*, **WT** and **BT** meaning *adhesive-side powder* (**w**hite and **b**lack, respectively), and **CA** meaning *cyanoacrylate*.

DIGITIZER The device used to digitize this image. For a complete list of devices and their descriptions, refer to NIST Interagency Report 8210, Section 5.3 [2]. Multiple flatbed scanners were used, indicated by **S#**. Only one piece of hardware was used for other digitization methods.

RESOLUTION The capture resolution of the image, in pixels per inch.

DEPTH The number of bits in a single color channel.

CHANNELS The number of color channels represented in a single pixel. **1** indicates grayscale and **3** represents color in a red, green, and blue arrangement.

NUMBER An identifier to represent an individual latent print of value from this `ENCOUNTER`.

SOURCE The likely source of the latent print, with **1** for distal phalanx, **2** for other phalanx, **3** for palm, and **4** for unknown.

5.3 Validity

A CSV file, `checksum_`**`DEVICE_EXT`**`.csv`, accompanies every directory of images. Contained in this file are the Secure Hash Algorithm (SHA) 256 checksums of the files contained within the named directory.

Challengers	A	IDEMIA	B	Advanced Optical Systems	C	Green Bit	D	Cornell University	E	Jenetric
	F	Touchless Biometric Systems	G	*Undisclosed*	H	Clarkson University	U	Baseline Rolled #1	V	Baseline Rolled #2
Auxiliary	J	Morpho TouchPrint 5300	K	Michigan State University RaspiReader	L	Advanced Optical Systems (Unprocessed)	M	EikonTouch 710		
	N	Green Bit MultiScan 527g	P	Futronic FS88	Q	Crossmatch L SCAN 1000PX	R	Crossmatch L SCAN 1000PX		
	S	Crossmatch Guardian USB	T	Clarkson University (Unprocessed)						

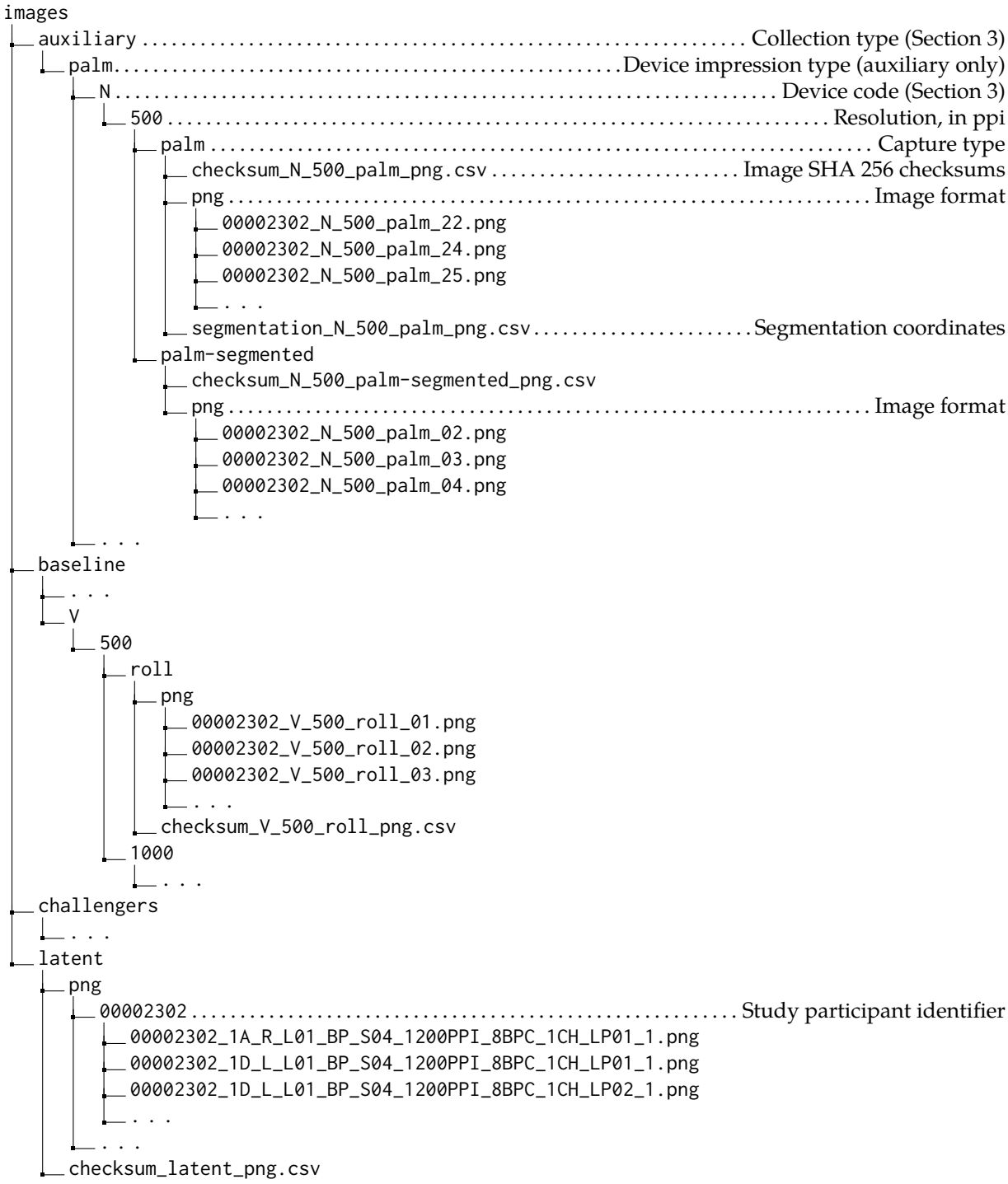

Fig. 5. Example directory listing of friction ridge images in SD 302. For an explanation of filenames, refer to Section 5.

Challengers	A	IDEMIA	B	Advanced Optical Systems	C	Green Bit	D	Cornell University	E	Jenetric
	F	Touchless Biometric Systems	G	*Undisclosed*	H	Clarkson University	U	Baseline Rolled #1	V	Baseline Rolled #2
Auxiliary	J	Morpho TouchPrint 5300	K	Michigan State University RaspiReader	L	Advanced Optical Systems (Unprocessed)	M	EikonTouch 710		
	N	Green Bit MultiScan 527g	P	Futronic FS88	Q	Crossmatch L SCAN 1000PX	R	Crossmatch L SCAN 1000PX		
	S	Crossmatch Guardian USB	T	Clarkson University (Unprocessed)						

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Challengers	A	IDEMIA	B	Advanced Optical Systems	C	Green Bit	D	Cornell University	E	Jenetric
	F	Touchless Biometric Systems	G	*Undisclosed*	H	Clarkson University	U	Baseline Rolled #1	V	Baseline Rolled #2
Auxiliary	J	Morpho TouchPrint 5300	K	Michigan State University RaspiReader	L	Advanced Optical Systems (Unprocessed)	M	EikonTouch 710		
	N	Green Bit MultiScan 527g	P	Futronic FS88	Q	Crossmatch L SCAN 1000PX	R	Crossmatch L SCAN 1000PX		
	S	Crossmatch Guardian USB	T	Clarkson University (Unprocessed)						