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# Evaluation of the Use of a Non-Contact, 3D Scanner for Collecting Postmortem Fingerprints

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***Final Summary Overview***

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## I. Project Purpose and Background

### Statement of the Problem

Recording postmortem (PM) fingerprint impressions from decedents is a manual and often labor-intensive process requiring a trained technician. The attempt to improve the quality of an acquired PM fingerprint record is a continuous process. Various advanced methods for fingerprinting the deceased have significantly advanced and are continuously progressing due to ongoing research, publications, and information sharing [1-64]. However, many of these techniques require a significant amount of time, training, effort, personnel, supplies, and hazards (ie. sharp instrument use, biohazard contamination, etc.). Recovered unidentified human remains (UHR) may exhibit significant PM changes resulting in damaged friction ridge skin that may be due to fauna (animals and insects), water (maceration), fire (charring), and weather (cold, heat, humidity). The deteriorated condition of the remains, which can alter and even destroy the fragile friction ridge detail. Additionally, desiccated human remains exhibit depressions within the friction ridge skin, causing contouring and distortion of the surface (**Figures 1-5** in *Appendix*). This causes significant difficulties to accurately capture forensic-quality friction ridge information. Each case of PM fingerprint processing may require a unique combination of basic and advanced techniques due to the unique set of circumstances and the environment surrounding an individual's death. As such, the condition of the friction ridge skin on each finger will dictate which method must be used to successfully enhance and record any valuable friction ridge information; multiple techniques may be used on each finger and the time, resources, and cost to employ them can vary considerably. In order to maximize the quality of a PM fingerprint record and capture as much information as possible, continuous research must be pursued in an attempt to develop more efficient and detail-enhancing techniques for severely decomposed remains, particularly in regards to the fingerprint recovery of desiccated or mummified fingers, as rehydration techniques are the most labor-intensive, time-consuming, and potentially destructive. Furthermore, streamlined and more efficient PM fingerprint recovery techniques would be especially helpful for large agencies exhibiting a high caseload and during mass fatality incidents (MFIs), when rapid victim identification is under significant time constraints and trained personnel and resources may be significantly limited. [1]

Rapid advancements in biometric technologies are causing significant improvements in mobility, speed, efficiency, accuracy, reliability, and affordability. As such, some Medical Examiner/Coroner (ME/C) Offices and Law Enforcement Agencies (LEAs) have started to use digital livescan and cardscan devices to capture fingerprints from the deceased. However, using current digital fingerprint capture devices with the deceased has shown to be quite cumbersome, as current contact livescan devices were specifically designed for use on the living and were simply adopted for use with UHR. Digital fingerprint capture from the living and the deceased are significantly different. During digital antemortem (AM) fingerprint acquisition, the living person is usually manipulated against the immobile recording platen. Conversely, during digital PM fingerprint acquisition, the recording platen is usually manipulated against the immobile decedent, which often exhibits rigor mortis. Many digital capture devices are large, bulky, and tethered to another device, such as a laptop. In addition, current digital capture devices record friction ridge information using contact scanners, which can prove to be quite cumbersome, awkward, and the device must be decontaminated continuously due to deposition of the decedent's biological fluids on the device. Furthermore, manipulating the fingers and placing pressure on the already delicate and compromised PM friction ridge skin can further damage or collapse the friction ridge detail. [1, 65, 66]

Contactless scanners are in development, which create a three-dimensional (3D) impression and use specific flattening algorithms to convert the data into a two-dimensional (2D) impression for searching in current biometric repositories that contain 2D fingerprint records [67, 68]. However, current digital fingerprint capture devices were designed to record fingerprints from living subjects and are difficult to manipulate against decedents exhibiting rigor mortis and/or advanced PM changes [66]. Further research and development is required to produce devices that are specifically geared toward enhancing the PM fingerprint capture process, such as ruggedized, mobile, wireless, contactless scanners. These "deadscan" devices would make the digital PM fingerprinting process less cumbersome and awkward. In addition, contactless scanners will be able to capture friction ridge information that is located within the depressions of desiccated and mummified fingers or remains exhibiting advanced PM changes (**Figures 1-5** in *Appendix*), as current contact scanners are unable to capture this information. [1]

Furthermore, the development of mobile, wireless, contactless digital fingerprint capture devices could be used during MFIs for the accelerated acquisition of fingerprint identification data with the potential for rapid identification. It would reduce the amount of time, supplies, personnel, and hazards it takes to recover forensic-quality PM fingerprint records. The availability of handheld, mobile, contactless digital fingerprint capture devices would allow for the collection of large numbers of PM fingerprint records for remote transmission, analysis, and storage. It would also completely eliminate the need to use a flatbed scanner for converting manually acquired fingerprint records into digital fingerprint records. Additionally, contactless scanners would reduce the amount of biohazardous contaminants deposited on supplies and equipment. This will be especially useful when human remains are contaminated by chemical, biological or radiological agents; under such circumstances, traditional manual PM fingerprint recovery techniques are not possible. Fingerprint records could be sent electronically and remotely, which would prevent the removal and spread of contaminated materials. [1, 66, 69]

As contactless 3D digital fingerprint capture technology continues to advance, further research and development is required for current flattening algorithms that convert 3D PM fingerprint impressions to 2D PM fingerprint impressions due to the wide variety of shapes and depressions that a deceased fingerprint can exhibit from multiple PM changes (**Figures 1-5** in *Appendix*). Moreover, ten-print and latent-print matching algorithms are needed to account for dimensional variations in 3D PM fingerprint impressions that are converted to 2D PM fingerprint impressions. Additionally, further research is warranted for contactless scanning of fingerprint castings, and the resulting 3D-to-2D flattening algorithms.

### Purpose

3D scanners have been identified as a potentially important tool for forensic scientists to help address the challenges of PM fingerprint recovery due to their contactless scanning capabilities, as well as their ability to scan complex surfaces and capture scale. However, in-depth research is necessary to demonstrate the potential for 3D data to facilitate the collection, analysis, and comparison of PM fingerprint impressions. Additionally, it is necessary to explore how 3D data should be incorporated into the workflow of current PM fingerprint recovery techniques and what additional tools are required to fully take advantage of this new technology. Prior to this project, minimal work had been done to evaluate the required specifications, accuracy as compared to existing techniques, and algorithms converting the acquired 3D PM image into a 2D PM image compatible with existing fingerprint matching algorithms and databases. [1, 5] For a more comprehensive literature review, please see the *Appendix*.

The purpose of this project was to evaluate the potential for using a contactless, 3D fingerprint scanner for the capture of examination-quality PM fingerprints to facilitate rapid identification of the deceased. It was hypothesized that due to its contactless nature, the 3D scanner would be able to acquire higher quality fingerprints from PM friction ridge detail, as compared to traditional recovery techniques. Additionally, it was hypothesized that capturing PM impressions using a 3D scanner would decrease the amount of time, resources, funding, and hazards it would take to recover an examination-quality digital PM fingerprint record. With direction from subject matter experts, a 3D scanner prototype and a series of tools were modified and used to incorporate 3D scanning into the PM fingerprint recovery workflow. A series of experiments were performed on donated cadavers exhibiting various stages of PM changes at the Boston University School of Medicine to test contactless 3D scanning techniques and benchmark them against traditional PM fingerprint recovery techniques. The scanner's potential was also evaluated for use in daily casework and during MFIs.

## II. Design and Methods

**Experimental Design**

This project had the following goals:

1. Develop a prototype scanner capable of digitally acquiring PM fingerprints.
2. Produce fingerprints that are consistent and compatible with existing fingerprint matching algorithms and databases.
3. Conduct a series of experiments to test non-contact collection techniques in a series of fingerprint collections designed to mimic the types of cases that would be encountered in a ME/C office or crime laboratory; test the use of a non-contact scanner for the conversion of fingerprint castings to digital fingerprints.
4. Benchmark non-contact PM fingerprint acquisitions against existing collection techniques in terms of quality of fingerprints, time necessary to process and acquire the fingerprints, training requirements, and ease of use.
5. Increase the understanding of 3D scanning and its application to the recovery and analysis of PM fingerprints to guide future discussions about policies, best practices, and standards, as well as to influence future device and software tool development; disseminate project findings to the broader scientific community; provide recommendations to NIJ and the forensic science community for future work and additional research.

*Project Goal 1*

The project team assembled two scanning prototypes that were designed to scan directly from cadavers (**Figures 6-9** in *Appendix*). Both designs attempted to correct for a number of issues that were encountered during preliminary testing. The primary issues were motion and object positioning due to the difficulties of maneuvering a finger exhibiting rigor mortis into the scanner's capture volume. The team attempted to minimize the effects of motion both in the scanner's hardware and software. In its hardware, faster cameras were incorporated to shorten the acquisition time. In the scanner's software, the software pipeline was accelerated, which resulted in faster acquisition times and the ability to check scan quality more rapidly and rescan if necessary. Additionally, improvements were made in motion correction algorithms throughout the project. Furthermore, the team attempted to address the issue of finger placement by designing a smaller, handheld scanner that could be easily positioned to scan the cadaver's fingers. Nevertheless, preliminary testing results revealed that 3D scanning of castings recorded from cadaver friction ridge detail yielded the best results for "Phase I" of this project (please see *Scholarly Products Produced/In Process* section for more information regarding phases). Originally, the project's final testing plan was to 3D scan friction ridge detail directly from the cadavers. However, due to the promising results of preliminary testing with castings and the scanner's limitations during Phase I (please see *Project Findings and Implications for Criminal Justice Policy and Practice* section for more information regarding limitations), the project team unanimously decided to slightly change the research design and scan the castings in order to evaluate the 3D scanner. This modification did not significantly change the project goals. After this decision, the team assembled a third scanner prototype (**Figure 10** in *Appendix*). This desktop scanner was optimized for scanning the castings collected during the final testing phase. The problem of motion and finger positioning were effectively eliminated using the third scanner coupled with castings.

*Project Goal 2*

**Task 1 (Modify flattening algorithms to account for variability of PM fingerprints):** FlashScan3D's existing flattening algorithms produce fingerprints that are compatible with existing matching algorithms and fingerprint databases. However, the team's current flattening algorithm is based on the fundamental assumption that the finger is tubular in shape. Due to the variety of forms a PM fingerprint can have, this assumption is not valid and the algorithm was modified to smooth any wrinkles or depressions and then flatten the fingerprint to a 2D form compatible with existing matching algorithms and databases. After testing a number of algorithms, the "springs" algorithm suggested in the project proposal was not used due to speed constraints. The final algorithm used a smoothed surface of the finger, unwrapped that surface from a wavy form to a flat surface, and then used the extracted ridge information from the original scan data to generate the flattened 2D output fingerprint. University of Texas San Antonio (UTSA) project team members developed a non-invasive method to perform 3D deformed/PM finger modeling, which produces a 2D rolled equivalent fingerprint for automated verification. The algorithm included the following series of procedures: (i) masking and filtering, (ii) a non-parametric unrolling process preserving the Euclidean distance between points in the 3D model. The robustness and feasibility of the method was tested by applying the algorithm on 3D finger models of varying deformations. The results revealed that the 2D equivalent unrolled deformed fingerprints were visually similar to the 2D equivalent unrolled normal fingerprint. However, significant spatial distortions were observed in models with very high deformations, which could lead to higher false rejection rates. The National Institute of Standards and Technology (NIST) Fingerprint Image Quality (NFIQ) 2.0 program (please see *Materials and Methods* section for more information) was used to evaluate the quality of the unrolled fingerprint images, and these results helped classify the unrolled outputs. Using computer simulations in

MATLAB software, UTSA was able to show that the 2D equivalent unrolled deformed fingerprints were visually similar to the 2D equivalent unrolled normal fingerprint. The project team evaluated the quality of unrolled fingerprint images using measures of enhancement EME, AME and SDME, and estimated the feasibility by detecting minutiae using NFIQ 2.0. The project team observed that significant spatial distortions in 3D finger images with very high deformations could lead to higher false rejection rates.

**Task 2 (Develop image enhancement and reconstruction algorithms):** A number of image enhancement and reconstruction algorithms were developed during the project. A summary of each is included below:

*Missing Data Reconstruction Using Gaussian Mixture Models for Fingerprint Images:* Since PM fingerprints can be missing data, a dependable reconstruction algorithm would be helpful, however is challenging due to the complexity and ill-posed nature of the problem. The developed algorithm was tailored using a Gaussian Mixture Model (GMM) for reconstruction of the missing data in fingerprints for both binary and gray-level images. A new similarity score was introduced to evaluate the performance of the developed algorithm for binary images. The new steps designed in the algorithm included the use of a diamond kernel to estimate the gradients and median filters were used for edge enhancement. The computer simulation results displayed that the presented algorithm generally had higher accuracy than the previously published algorithms.

*A Comparative Study of Image Feature Detection and Matching Algorithms for Touchless Fingerprint Systems:* UTSA produced a visual and statistical comparative study of the existing feature detectors, namely, Difference-of-Gaussian, Hessian, Hessian Laplace, Harris Laplace, Multiscale Hessian, Multiscale Harris and Open SURF on a database that contained multiple images of a finger. The process involved (i) feature detection, (ii) feature matching and validation, and (iii) image stitching. Detection of feature points in fingerprint images would help solve the dilemma of increasing the effective area of the fingerprint. The UTSA team performed feature detection using different detectors and then matched the extracted features to obtain the final mosaicked image. The merits and demerits of the various detectors were realized. The team also evaluated the performance by visually examining the mosaicked images as well as the number of matches. After performing computer simulations in MATLAB, the UTAS team found that the Multiscale Hessian detector extracts the best features for the multiple finger images and provides the best mosaicked image.

*Alpha Trimmed Correlation for Touchless Finger Image Mosaicking:* Since occlusions from the deformed nature of a PM fingerprint are an operational reality, UTSA developed a method to obtain a reliable combined/stitched finger image from multiple views of a finger, with no visible artifacts. They developed a new correlation algorithm to mosaic finger images, namely, Alpha-trimmed correlation, which accurately estimates the best seam-line. The results obtained illustrated that the algorithm presented much better results in terms of the quality of the mosaicked image (no visible artifacts like misalignment and visible seam line) when compared to existing correlation mosaicking algorithms, such as, Pearson's correlation, Kendall's correlation, Spearman's correlation. The quality of the mosaicked image was determined by comparing it to the reference image. Additionally, a quantitative evaluation was performed that illustrated the advantages of the proposed algorithm.

*Comparison Study of Gaussian Mixture Models for Fingerprint Image Duplication:* To benchmark the reconstruction algorithms, UTSA performed a comparison study of GMM for fingerprints image duplication and analysis. The team also developed a new probabilistic Parametric GMM. The system is built around the likelihood ratio test for verification, using simple but effective GMMs for likelihood functions and a form of Bayesian adaptation to derive the models. The best fit statistical model for the fingerprint model images was obtained, which had the minimum pixel distances as compared to the original image. The performance of the new algorithm was evaluated by SSIM Index, Entropy and Mean Square Error.

**Task 3 (Develop scaling algorithms):** Scaling algorithms were created to address any issues with a finger that may be enlarged or reduced in size from PM conditions. This algorithm was implemented in the 3D data and can scale the captured finger data before it goes through the unrolling and ridge extraction process. Inherent in the technique and the benefits of using a 3D scanner is that scale is inherent in the image, allowing for accurate re-scaling of data.

*<u>Project Goal 3</u>*

To test this project's hypotheses, the project team utilized 34 cadavers donated to the Boston University School of Medicine (BUSM) for testing (12 for final testing) and was designed to mimic the types of cases that would be encountered in a ME/C office or crime laboratory. This particular location was chosen so preliminary research could be conducted in a controlled laboratory setting without concurrent casework occurring. As such, the experiments were not conducted with the time constraints that exist in ME/C offices, where ongoing fingerprint casework requires a rapid turnaround time. This particular sample size was chosen to gather enough data for an accurate evaluation and analysis of 3D PM scanning techniques, 2D PM scanning techniques, and manual PM recovery techniques. Additionally, the sample size allowed for cadavers that exhibited various conditions (decomposed, waterlogged, mummified, etc.) in order to encounter a variety of PM friction ridge conditions for testing and evaluation. Please see the *Materials and Methods* and *Procedures* sections for more detailed information.

*<u>Project Goal 4</u>*

The aforementioned experimental design in Project Goal 3 allowed the research team to encounter a variety of resulting friction ridge conditions for testing and evaluation, similar to cases encountered at ME/C offices. The collected data was analyzed and used by FlashScan3D and UTSA to refine current computer algorithms. Moreover, this data was analyzed and used to compare and evaluate the effectiveness, time involved, personnel involved, supplies involved, and costs involved for the current manual fingerprint recovery techniques, as well as the current digital 2D PM fingerprint recording techniques using a contact scanner.

*Project Goal 5*

The purpose of this evaluation was to test a modified 3D scanner prototype to determine whether it is effective for the forensic science application of recovering examination-quality PM fingerprints from PM friction ridge detail. Prior to this project and despite research on manual fingerprint recovery techniques and 2D PM fingerprint capture, there had been no systematic study performed to date on evaluating the 3D digital capture of PM fingerprint impressions, no direct comparison of flattened PM images acquired by a contactless digital 3D fingerprint scanner against traditional PM fingerprint recovery recording methods, no direct comparison of PM images acquired by a contact digital 2D fingerprint scanner against traditional manual PM fingerprint recovery recording methods, and no comprehensive analysis or experimentation with different algorithms that would assist the examiner in the flattening of 3D PM fingerprint record images collected by the scanners.

**Materials and Methods**

34 cadavers (12 for final testing) were used for the recovery of PM fingerprint records using traditional manual and digital PM fingerprint recovery techniques, as well as non-contact PM fingerprint recovery techniques. Additionally, two living subject volunteers (1 used for final testing) took part in this research study because control samples[1] from living subjects were needed in order to have a baseline of maximum forensic-quality fingerprint records. The fingerprint techniques were applied from the least invasive to most invasive in order to prevent any deterioration from the friction ridge skin affecting the results. *Uhle's Deceased Processing Methodology* (**Figure 11** in *Appendix*) was used for all manual PM fingerprint recovery and reconditioning techniques; techniques that were utilized are delineated in Mulawka *et al.*'s *Postmortem Fingerprint Processing Workflow* (**Figure 12** in *Appendix*). For digital PM fingerprinting, two devices were utilized to collect fingerprint data from the cadavers: 1. A 3D non-contact scanner prototype assembled by FlashScan3D. The FlashScan3D Prototype is a single-operator system with a 1000-ppi resolution, requiring a power supply and a USB connection with a laptop or PC running FlashScan3D software with Microsoft Windows. 2. A 2D contact scanner—Crossmatch Verifier 320 contact-based dual-fingerprint capture device (**Figures 13 and 14** in *Appendix*). The Crossmatch Verifier 320 is an optical USB 2.0 fingerprint scanner that allows for the capture of two flat fingerprints simultaneously or one rolled fingerprint. It is a single-operator system with a 500-ppi resolution, weighs 1.4 pounds (620 grams), and requires a power supply with a laptop or PC running Crossmatch software with Microsoft Windows. For manual PM fingerprint processing, basic and advanced PM fingerprint recovery supplies for approximately 50 cases were purchased (**Figures 15 and 16** in *Appendix*) using supply lists from Mulawka's book *Postmortem Fingerprinting and Unidentified Human Remains* [1]. Manual fingerprint cards were scanned using an Epson Perfection V550 flatbed scanner. Photographs of castings were taken using a Nikon D3200 digital single-lens reflex (DSLR) camera with a 18-55mm 1:3.5-5.6 DX VR lens. All data was recorded on an NIJ Research Case Processing Form, entered into an internal NIJ Research Project Google Forms Database, and analyzed by the research team. The contactless 3D scanner was benchmarked against traditional PM fingerprint collection techniques among the categories of quality, time, personnel, costs, and effectiveness. The assessment and analysis techniques used for each category are described in more detail below.

*Quality:* For the purpose of this project, *examination-quality* was defined as exhibiting enough friction ridge detail that is deemed suitable for fingerprint searching and comparison. According to the Scientific Working Group on Friction Ridge Analysis, Study and Technology (SWGFAST), *suitability* is the "determination that there is adequate quality and quantity of friction ridge features in an impression [to allow for further processing]" [70]. During this project, each technique produced a resulting fingerprint impression that was analyzed using an objective measure of fingerprint quality - the National Institute of Standards and Technology (NIST) Fingerprint Image Quality (NFIQ) 2.0 program, which was recently updated and released on April 28, 2016.

The NFIQ program uses an algorithm that is a fingerprint quality measurement tool, producing a quality value from certain features in a fingerprint image that is directly predictive of expected recognition performance. These features include segmentation of the fingerprint, frequency domain analysis, local clarity, ridge orientation and flow analysis, ridge valley uniformity, minutiae count, and minutiae quality. NFIQ produces a value between 0-100 from a fingerprint image that is directly predictive of expected matching performance, with 100 as the best quality score, and 0 as the worst quality score [71]. The quantitative NFIQ scores of the 3D scanner technique were compared to the NFIQ scores of traditional collection techniques.

*Time*: The total time to collect the final PM fingerprint record was recorded. Some decedents were missing digits or friction ridge detail and thus, the comparison among techniques was performed with the average processing time for a case with 10 digits. This was calculated as follows:

$$Ta = \frac{Tt}{N} * 10$$

Where $Ta$ is the average time per case for the given collection technique, $Tt$ is the total time for collection of all digits from the subject, and N is the number of collectable digits for the given subject. The average time of the 3D contactless scanner technique was compared to the average time of traditional PM fingerprint recovery techniques.

*Personnel*: The number of personnel needed to collect the full set of fingerprints was recorded for each technique. If additional personnel were present as scribes for data collection, they were not included in the personnel count. Only personnel needed for PM fingerprint recovery were recorded. The quantity of personnel needed to operate the 3D scanner were compared to the quantity of personnel required for traditional PM recovery techniques.

*Cost*: Material costs for each PM fingerprint recovery technique were analyzed based on a collection of a full set of 10 fingerprints for each technique using the supply lists for each individual technique delineated in Mulawka's book *Postmortem Fingerprinting and Unidentified Human Remains* [1]. Costs were delineated for processing approximately 50 decedents for each technique, then the total was divided by 50 to yield estimated costs for each technique per case (10 fingers). Supplies and equipment were designated as consumable or non-consumable. Personnel,

[1] *A control sample is a material of known composition that is analyzed along with test samples in order to evaluate the accuracy of the analytical procedure(s).*

taxes, and equipment costs were not included in the calculations. Equipment for all techniques was not consumable and a singular purchase that can be used on >50 cases.

*Effectiveness*: The goal of the study was to evaluate the potential for using a contactless, 3D scanner for the capture of PM fingerprints to facilitate rapid identification of the deceased. This section analyzed the outcomes of the above categories in aggregate and discussed the performance of the 3D scanner against traditional techniques.

*Statistics:* **Table 1** (*Appendix*) displays the statistics, abbreviations, and descriptions used for data analysis.

**Procedures**

*Postmortem Fingerprint Processing and Data Collection*

The following procedures were used for each research case:

1. Assign a unique NIJ case number for each research case in the following format: NIJ-001, NIJ-002, NIJ-003, etc.
2. Document each research case on an NIJ Grant 2014 Case Processing Form and at a later time, enter all data into a corresponding NIJ Grant 2014 Case Processing Google Form database.
3. Record physical descriptors of human remains:
    a. Record notes and limited demographics such as gender, etc.
    b. Record the condition of the hands and each individual digit.

*RECONDITIONING (IF NECESSARY)*

4. Follow *Uhle's Deceased Processing Methodology* (**Figure 11** in *Appendix*)—recondition the friction ridge detail (if necessary) and record PM fingerprint impressions using manual techniques as delineated in Mulawka *et al.*'s Postmortem Fingerprint Processing Workflow (**Figure 12** in *Appendix*) and individual Standard Operating Procedures (SOPs).

*RECORDING*

5. Photograph friction ridge detail on all viable digits using a digital single lens reflex (DSLR) camera with scale.
    a. Record camera settings.
    b. Record the time and amount of personnel required to photograph all digits.
    c. Record if resulting photographs are of examination-quality (yes/low/no/not printable).
6. Scan the friction ridge detail on all viable digits using a non-contact 3D digital fingerprint scanner following individual SOPs:
    a. Record the non-contact 3D scanner settings.
    b. Record the time and amount of personnel required to scan all viable digits.
    c. Record if resulting fingerprint impressions are of examination-quality (yes/low/no/not printable).
7. Scan the friction ridge detail on all viable digits using a contact 2D digital fingerprint scanner following individual SOPs:
    a. Record the contact 2D scanner settings.
    b. Record the time and amount of personnel required to scan all viable digits.
    c. Record if resulting fingerprint impressions are of examination-quality (yes/low/no/not printable).
8. Record the friction ridge detail on all viable digits using manual fingerprint recovery techniques following individual SOPs:
    a. Fingerprint Powder/Acetate Card/Lifter Technique.
        i. Record the time and amount of personnel required to record all viable digits.
        ii. Record if resulting fingerprint impressions are of examination-quality (yes/low/no/not printable).
        iii. Scan the acetate fingerprint card into digital form using a flatbed scanner with scanning settings of at least 500 dpi.
    b. Fingerprint Powder/Casting Technique.
        i. Record the time and amount of personnel required to record all viable digits.
        ii. Record if resulting fingerprint impressions are of examination-quality (yes/low/no/not printable).
    c. Fingerprint Ink/Stock Card Technique.
        i. Record the time and amount of personnel required to record all viable digits.
        ii. Record if resulting fingerprint impressions are of examination-quality (yes/low/no/not printable).
        iii. Scan the acetate fingerprint card into digital form using a flatbed scanner with scanning settings of at least 500 dpi.
9. Photograph castings acquired during Step 9b using a digital single lens reflex (DSLR) camera with scale.
    a. Record camera settings.
    b. Record the time and amount of personnel required to photograph all castings.
    c. Record if resulting photographs are of examination-quality (yes/low/no/not printable).
10. Scan castings acquired during Step 9b using non-contact 3D digital fingerprint scanner:
    a. Record the non-contact 3D scanner settings.
    b. Record the time and amount of personnel required to scan all castings.
    c. Record if resulting fingerprint impressions are of examination-quality (yes/low/no/not printable).
11. Scan castings acquired during Step 9b using contact 2D digital fingerprint scanner following individual SOPs:

   a. Record the contact 2D scanner settings.
   b. Record the time and amount of personnel required to scan all castings.
   c. Record if resulting fingerprint impressions are of examination-quality (yes/low/no/not printable).

12. Record two sample sets using the techniques from Steps 5-11 from two volunteer living subjects (IRB approved) that will serve as controls for the study; assign each control case a unique NIJ case number: NIJ-CA, NIJ-CB, etc.

*Post-Processing of 3D Data*

The following procedures were used to process the collected 3D data into 2D fingerprint records:

1. Run the FlashScan3D post processing software.
2. Locate the folder which contains the 3D scanned fingerprint data for a case.
3. Click "Process" to process the 3D data to 2D data.
4. Record the time to process all fingers.

*Image Analysis with NFIQ 2.0*

The following procedures were used to analyze the digital fingerprints with NFIQ 2.0:

1. Run the NFIQ executable in a command window.
2. Type the folder path in the command window that contains all 2D fingerprint images.
   a. All images were .bmp files with 500 dpi resolution
3. Set the flag to output the file names and scores to a .csv file.

**III. Data Results and Analysis**

Final testing was done on approximately 130 digits (12 deceased subjects, 1 living subject). For images of all of collected PM fingerprint records used for final testing, please see the *Appendix*. Each manual or digital technique used for final testing was assigned a label and the description of each technique label can be found in **Table 2** (*Appendix*). Before data analysis began, the data was cleaned[2]. To clean the data, any samples that were not able to be acquired due to unforeseen circumstances out of the team's control for a given technique were removed from the data set. "Out of the team's control" refers to fingers or epidermal/dermal skin that was removed from the cadavers by anatomy students working in the laboratory or cadavers being unavailable during testing periods. Therefore, only fingers with data collected for each technique A, B, C, D, E, and F remained in the set before the following statistical analyses were conducted.

Prior to beginning fingerprint processing, physical descriptors of each cadaver were recorded, including the condition of the body/hands and classification of ridge detail. The condition of the body/hands was listed as *fresh, decomposed, mummified, macerated*, or *other*. Just over half (53%) of the cadavers tested during final testing exhibited minimal PM changes—designated as *fresh* remains—and 47% exhibited issues such as *decomposition* (20%), *mummification* (7%), *greasiness* (7%), *flakey skin* (7%), and *maceration* (6%) (**Figure 17** in *Appendix*). The classification of ridge detail was separated into the following categories: *excellent, good, poor, very poor*, and *not printable* (**Table 3** in *Appendix*). According to **Figure 18** (*Appendix*), the majority (69%) of the cadavers included in final testing exhibited ridge detail that was in *good* condition. 8% displayed *excellent* ridge detail, 15% displayed *poor* ridge detail, and 8% displayed *very poor* ridge detail.

**Quality**

NFIQ 2.0 was used as an objective measure of the quality on the collected fingerprint impressions across the techniques used. It should be noted that Technique E (photographs of the castings) was not analyzed with the NFIQ algorithm. Reason being, the ridge information would have to be extracted from the casting images before being analyzed by the NFIQ algorithm, which was not anticipated or completed during this study. Therefore, Technique E was omitted from the data analysis for quality. As such, only fingers with data collected for each technique A, B, C, D, F remained in the set before the following statistical analyses were conducted. The final remaining sample count was 96 digits exhibiting friction ridge detail after cleaning the data sets. **Figure 19** displays the average NFIQ score per technique for each individual case used for final testing. **Table 4** displays the condition of remains and ridge detail classification for each case as compared to average NFIQ score per technique. Originally, it was thought that the poorer the condition of the remains and/or classification of ridge detail, the lower the resulting NFIQ scores would result for each technique. However, the resulting data in from **Table 4** and **Figure 19** displays no visible trend and could be due to low sample number.

*Average NFIQ:* The average and standard deviation for each collection technique was computed across the dataset and is displayed in **Figure 20** (*Appendix*). The results show that on average, the non-contact 3D scanner technique (F) yielded higher scores than all other techniques tested. Although Technique F yielded the highest standard deviation, the range of scores within the standard deviation still remained higher than the average score for any other technique. For comparison, scores from NFIQ 2.0 were computed on fingerprints collected from a living subject using each of the individual collection techniques to serve as control samples in order to understand the baseline. These control values allowed the research team to understand if the cadaver fingerprints fell near an NFIQ 2.0 score value expected from a living subject. The largest discrepancies existed with technique C being the 2D contact based scanner as well as with F being the 3D non-contact scanner. Technique C displayed far worse performance on cadavers as compared to a living control subject, with the average score difference being 26 points. Technique F displayed poorer results than the average control by 11 points.

[2] *Data cleaning refers to detecting and removing errors and inconsistencies from data in order to improve the quality of data [72].*

_Average Delta NFIQ:_ The average distance from each technique, when compared to the non-contact 3D scanner technique (F), was computed using the formula below and the results are displayed in **Figure 21** (*Appendix*).

$$\Delta NFIQ(T) = Average(F) - Average(T)$$

T denotes the technique and F denotes Technique F. Average(T) returns the average of the scores for the given technique, T. The results show that on average, for any given finger, Technique F resulted in an NFIQ score greater than 25-point increase in score, with similar standard deviations across the techniques.

_Max NFIQ Score Count:_ The final quality data analysis looked at how many times each technique resulted in the maximum NFIQ score across the whole dataset for each finger and are displayed in **Figure 22** (*Appendix*). The results display that 87 out of the total 96 cadaver samples collected resulted in the highest NFIQ score when utilizing Technique F. NFIQ 2.0 was developed to address known weaknesses with the first version, NFIQ 1.0. Although the team that developed NFIQ 2.0 has not published the correlation between an increased score with matching results, this is the fundamental premise of developing a NFIQ score. The project team recommends that future research should be conducted to to test the correlation of an increased NFIQ 2.0 score with matching results for PM fingerprint collection. Specifically, a single point score increase may have a different weight or impact on matching within a given technique.

**Time**

The average time and standard deviation for processing PM fingerprints using each of the individual collection techniques was computed across the dataset and is displayed in **Table 5** and **Figure 23** (*Appendix*). For comparison, time for processing fingerprints from a living subject using each of the individual collection techniques was recorded to serve as control samples in order to understand the baseline. These control values allowed the research team to understand if the cadaver fingerprints fell near a time value expected from a living subject. The results show that on average, the contact-based 2D scanner technique (C) yielded a faster time for processing PM fingerprints than the other techniques. Even though Technique C yielded the fastest processing time, it yielded the lowest-quality NFIQ score average than any other technique. Out of the manual techniques, the ink/stock fingerprint card technique (A) yielded a faster processing time and higher average NFIQ score than the powder/acetate/lifter technique (B). The average times to record PM fingerprint castings were included in the time calculations for techniques D, E, and F. The photography of castings technique (E) yielded the slowest processing time, as the photographs were also manually enhanced (brightness, contrast, etc.). Out of the digital techniques, the non-contact 3D scanner (F) yielded both a faster processing time[3] and highest average NFIQ score than the other techniques.

**Personnel**

The average amount of personnel required for processing PM fingerprints using each of the individual collection techniques was computed across the dataset and the results are displayed in **Table 6** and **Figure 24** (*Appendix*). For comparison, amount of personnel for processing fingerprints from a living subject using each of the individual collection techniques was recorded to serve as control samples in order to understand the baseline. The results show that on average, both manual techniques required 3 personnel for processing. The contact-based 2D scanner technique (C) required an average of 2 personnel. All techniques that were coupled with castings required an average of 2 personnel for recording castings and 1 personnel for the digital processing of castings.

**Costs**

The average cost for processing PM fingerprints using each of the individual collection techniques was computed across the dataset and the results are displayed in **Tables 7-12** and **Figures 25** and **26** (*Appendix*). The results show that on average, the contact-based 2D scanner technique (C) yielded the lowest cost for processing PM fingerprints as compared to the other techniques. However, Technique C yielded the lowest-quality NFIQ score average than any other technique. Out of the manual techniques, the ink/stock fingerprint card technique (A) yielded a lower cost and higher average NFIQ score than the powder/acetate/lifter technique (B). The average cost to record PM fingerprint castings were included in the cost calculations for techniques D, E, and F. Out of the digital techniques, the non-contact 3D scanner (F) yielded both a lower cost[4] and highest average NFIQ score than the other techniques.

**Effectiveness**

Lastly, Techniques A, B, C, D, and F were analyzed in aggregate for effectiveness when taking all categories of quality, time, personnel, and costs into consideration. Technique E was not included since it could not be analyzed for quality using NFIQ 2.0. Out of the manual techniques used for final testing, the ink/stock fingerprint card technique (A) was the most effective, as it yielded a higher average NFIQ score, lower cost, and faster time to process than the powder/acetate/lifter technique (B). Out of all the techniques used for final testing, the 2D contact scanner technique (C) yielded the fastest processing time and lowest cost; however, it yielded the lowest-quality NFIQ score average than any other technique and required an average of two personnel for processing. The non-contact 3D scanner (F) was the most effective out of the digital techniques that were coupled with castings, as it yielded the highest average NFIQ score, fastest time to process, lowest cost, and required an average of one person for processing.

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[3] *If the average casting time was removed from the calculations for Technique F, the average time to process would lower from 1948 seconds (32 m, 28 s) to 377 seconds (6 m, 17 s).*

[4] *If the estimated casting cost was removed from the calculations for Technique F, the average cost to process would lower from $5.51 – 7.44/case ($275.64 – 371.89/~50 cases) to $0.52 – 0.62/case ($26.24 – 31.24/~50 cases).*

**IV. Scholarly Products Produced/In Process**

The primary product of this research project is this Final Summary Overview Report of the research team's results and progress. Preliminary results were presented at the American Academy of Forensic Sciences (AAFS) meeting in Las Vegas, NV in February 2016 as a poster titled "*A Comprehensive Comparison of Various Postmortem Fingerprint Recovery Techniques"* by Ms. Mulawka and Mr. Reinecke. In August 2016, Ms. Mulawka presented the results of final testing at the International Association for Identification Forensic Educational Conference in Cincinnati, OH as a poster titled "*Utilizing a Contactless 3D Digital Fingerprint Scanner Coupled with Castings for Postmortem Fingerprint Recovery."* The UTSA team has presented posters and papers at two conferences and has published on various aspects of this project in academic journals. For a consolidated list of all accepted products and those in process, please see the *Appendix*. Furthermore, Ms. Mulawka will share this research and resulting publications with members of the new formed AAFS Standards Board (ASB) Consensus Bodies (Friction Ridge, Medicolegal Death Investigation, Disaster Victim Identification), as she is also a member. The research team has also collaborated with three forensic agencies (two ME/C offices and one crime laboratory) to apply for Phase II of this research under the FY 2016 Research and Development in Forensic Science for Criminal Justice Purposes grant solicitation (project titled "*Evaluation of The Use of A Contactless, Three-Dimensional Scanner for Collecting Postmortem Fingerprints from Unidentified Human Remains,*" award number 2016-DN-BX-0180)[5] in order to gather data concurrent with actual casework and where unidentified PM fingerprint records can be searched against a database of known AM fingerprint records. If a match is found, an identification may be effected and the team will also have the qualified opinions of experienced latent fingerprint examiners as to the quality-index of the fingerprint records. This will allow for the acquisition and analysis of qualitative and quantitative data since the resulting PM fingerprint records will be search against a database of AM fingerprint records. Lastly, discussions from this research resulted in two tangent projects: 1. The recently awarded (July 2016) National Science Foundation Small Business Innovation Research Grant project titled "*Evaluation of the Use of a Contactless, Three-Dimensional Scanner for the Collection of Various Fingerprint Impressions*" (Award ID 1621938)[6]. 2. John Jay College of Criminal Justice Graduate Program in Forensic Science Thesis Project titled "*Comparing the Forensic-Quality of Plastic Fingerprint Impressions Created Using Various Combinations of Casting Colors Coupled with Various Fingerprint Powders*."[7]

**V. Project Findings and Implications for Criminal Justice Policy and Practice**

The results of this project found that when compared to traditional PM fingerprint recovery techniques, the non-contact 3D scanner technique has significant promise to yield the highest-quality PM fingerprints. However, more research must be conducted in order to perform a more accurate assessment of the non-contact 3D scanner technique. The project team encountered a multitude of unforeseen variables that prevented a more accurate assessment from being performed including, but not limited to:

1. Cadaver condition—the condition of the bodies was much more difficult than expected.
    a. Most of the donated cadavers were elderly and thus, had poor ridge detail.
    b. Some cadavers appeared to be diabetics and thus, had dried finger tips.
    c. Rigor was a major issue and at times and unbreakable due to the cadavers being over-embalmed (filled with too much fluid)—attempting to keep the fingers open introduced significant motion issues.
    d. The remains continued to be very greasy and slippery from the continual spraying of glycerin solution on the cadavers, which made it very difficult for manual processing and it was difficult to recover fingerprint impressions from the greasy residue present on the friction ridge detail. Alcohol wipes were not as successful as initially thought to remove or wipe away the glycerin solution.
2. Motion—a significant amount of motion was occurring due to multiple variables:
    a. Resistance of the decedent's fingers when opening the hands to gain access to friction ridge detail.
    b. Motion caused by personnel holding the decedent's hand open.
    c. Motion caused by personnel holding the decedent's arm steady.
    d. Motion caused by the scanner operator, which was increased when the scanner was not mounted on a tripod.
3. Logistics—the testing facilities presented unforeseen and unexpected logistical issues.
    a. Cadavers were constantly moved in and out of testing rooms by anatomy students.
    b. Anatomy students removed or severed friction ridge detail on some cadavers.
    c. Cadavers were prematurely cremated before testing with all techniques could be completed on some cases.
    d. The project team was unable to perform advanced reconditioning techniques on some cases to enhance the friction ridge detail due to friction ridge detail damaged by anatomy students, time constraints, and/or cadavers being prematurely cremated.
    e. The project team was not permitted to manually fingerprint using ink/powder outside of the 34 testing cases.
4. Equipment—the digital scanners exhibited unforeseen limitations.
    a. The 2D scanner had a delay in capturing fingerprints, the software was not optimized to record PM fingerprints, and the "ridge-enhancing" silicone pad covering had to be removed because of smudged images causing "phantom fingerprints."
    b. The 3D scanner prototype for this project had unforeseen limitations (projector, depth of field, lack of adequate motion correction algorithms for all of the aforementioned motion variables, etc.).

Due to the aforementioned variables and limitations of the scanner prototype for Phase I, the project team made the unanimous decision to slightly change the final testing plan and evaluate the contactless 3D scanner for PM fingerprint recovery by 3D scanning grey castings recorded from the cadavers as opposed to scanning the cadavers' friction ridge detail. This change eliminated the major issue of motion. As a result, the team was able to meet the project goals and evaluate the potential for using the non-contact, 3D fingerprint scanner for the capture of examination-quality PM fingerprints and benchmark the scanner against traditional PM fingerprint collection techniques. Based off of the NFIQ

[5] *Please see https://external.ojp.usdoj.gov/selector/awardDetail?awardNumber=2016-DN-BX-0180&fiscalYear=2016&applicationNumber=2016-90345-TX-IJ&programOffice=NIJ&po=NIJ for more information.*
[6] *Please see http://www.nsf.gov/awardsearch/showAward?AWD_ID=1621938 for more information.*
[7] *Draft title that is subject to change. M. Mulawka (Project PI) is the thesis advisor for the graduate student.*

2.0 quality scores, when coupled with castings, the 3D scanner was able to acquire higher quality fingerprints from PM friction ridge detail, as compared to traditional recovery techniques. Nevertheless, the resulting data had its limitations, since preliminary testing did not take place in a ME/C office or crime laboratory on actual casework. During actual casework, unidentified PM fingerprint records are searched against a database of known AM fingerprint records and if a match is found, an identification is effected. For this particular research study, designated as "Phase I" (please see *Scholarly Products Produced/In Process* section for more information regarding phases) the research team did not have potential identification data since the PM fingerprint records resulting from the aforementioned experimental setup were not searched against a database of AM fingerprint records. Quantitative data was yielded through the NFIQ 2.0 analyses of the acquired fingerprint impressions to determine their fingerprint image quality score. The project team recommends that future research should be conducted to gather data concurrent with actual casework and where unidentified PM fingerprint records can be searched against a database of known AM fingerprint records. Additionally, research should first be conducted on fresh decedents exhibiting robust friction ridge detail in order to minimize the introduction of too many variables. Furthermore, qualified latent fingerprint examiners should be included as subject matter experts, which will allow for the acquisition and analysis of qualitative and quantitative data. Lastly, it is recommended that future research should be conducted to test the correlation of an increased NFIQ 2.0 score with matching results for PM fingerprint collection. Specifically, a single point score increase may have a different weight or impact on matching within a given technique.

## **Appendix**

### **Literature Review**

*Postmortem Fingerprint Recovery*

One of the most rapid, efficient, and cost-effective methods of forensic identification of unidentified human remains (UHR) is fingerprint identification through the comparison postmortem (PM) fingerprint records against antemortem (AM) fingerprint records. Moreover, fingerprint analysis is very effective during mass fatality incidents (MFIs) because decomposed or damaged human remains can be identified in a short amount of time. However, due to the rapid advancement and popularity of DNA analysis, fingerprint identification has been overlooked as the faster, cheaper, and relatively easier identification modality. Additionally, although various fingerprinting techniques have been published and are currently used in many medical examiners and coroner (ME/C) offices, many agencies continue to be unaware of the newly developed techniques, devices, and the avenues that can be pursued to facilitate searching against many available AM fingerprint records. As such, significant shortfalls in understanding the complexity of PM fingerprint processing and identification contribute to major national issues regarding the identification of UHR in the United States. If the law enforcement and forensic communities better understand the strengths and limitations of current fingerprint technology, training, and resources available, PM fingerprint identification has the possibility increase on a nationwide scale. [1, 2, 73-80]

According to the National Research Council's (NRC) 2009 Report *Strengthening Forensic Science in the United States: A Path Forward*, "It is clear that death investigations in the United States rely on a patchwork of coroners and medical examiners and that these vary greatly in the budgets, staff, equipment, and training available to them, and in the quality of services they provide" [81]. The report also concludes that all ME/Cs share the following deficiencies to some degree: inadequate training of personnel in the forensic science disciplines, inadequate facilities and equipment, inadequate technical infrastructure (laboratory support), and lack of translational research and associations with university research. The quality of forensic work is further limited and diminished due to deficiencies in trained staff, heavy caseloads, absence of equipment, lack of availability of required day-to-day and consultative services, and the presence of contradictory policies and practices. [81]

Since preserving, processing, and recording PM fingerprint records can present a multitude of challenges, forensic examiners should be properly educated and trained in the various basic and advanced PM fingerprint recovery techniques. Specific staff should be trained as fingerprint technicians, receiving adequate training in basic and advanced PM fingerprint recovery techniques. As PM fingerprint recovery can be very complex and fingerprint identification is designated as a scientific identification modality, all fingerprint technicians should possess a scientific background and adequate training, which is significantly extensive and will require time, supplies, and funding. It is also beneficial for fingerprint technicians to receive training in ten- and latent-fingerprint fundamentals, as grasping these concepts will aid in obtaining higher examination-quality fingerprint records. Additionally, adequate skill, experience, patience, physical dexterity, mental composure, and determination are also necessary traits required for PM fingerprint processing due to the various levels of difficulty that each unique case may present. [1]

Although their technical aspects may appear similar, fingerprint recovery methods for recovering PM fingerprint records from the deceased can be significantly more challenging than acquiring AM fingerprint records from the living. When acquiring AM fingerprint records, the living subject's friction ridge information is usually manipulated against the immobile recording medium (ie. fingerprint card, fingerprint lifters, digital capture scanner platen). On the other hand, when recovering PM fingerprint records, the opposite action is required—the recording medium usually must be manipulated against the immobile decedent. Additionally, if a living individual has an injury (ie. laceration) on the friction ridge skin, the AM fingerprint record can be recorded once the wound heals. On the contrary, the condition of PM friction ridge skin may be significantly compromised by various destructive influences due to the circumstances of death and/or severity of PM changes, such as rigor mortis, dehydration, decomposition, and deterioration. As such, special reconditioning techniques may need to be utilized prior to recording the PM fingerprint impressions. Once a person is deceased, damaged friction ridge skin will never heal and its fragility must be evaluated during the forensic examiner's initial assessment. The skin may be so fragile that the examiner may have only one chance to capture a forensic-quality fingerprint record before a significant portion of the scientific information is unsalvageable. As such, since preserving, processing, and recording PM fingerprint records can present a multitude of challenges, forensic examiners should be properly educated and trained in the various basic and advanced PM fingerprint recovery techniques. [1, 5]

Basic PM fingerprint recovery techniques are used on remains that exhibit undamaged and visible friction ridge skin; they do not require extensive training, significant time, or alteration of tissue. Advanced PM fingerprint recovery techniques are used on remains that exhibit damaged and poorly visible friction ridge skin; they require moderate to extensive training, a substantial amount of fingerprint supplies, a significant amount of time, as well as manipulation, alteration, or removal of tissue [1]. Nevertheless, various advanced techniques for PM fingerprint recovery are continuously progressing due to ongoing research, publications, and information sharing [1-64]. However, even with the advancement of techniques, the recovery of PM fingerprint impressions continues to be an arduous, time-consuming, and costly process, especially when dealing with remains exhibiting significant PM changes.

*Dermal Postmortem Fingerprint Impressions*

The recorded dermal fingerprint impressions will appear differently than epidermal fingerprint impressions because the dermal impression will exhibit a double fine line created by the dermal papillae. When compared to the epidermal impression, each double row of dermal papillae represents a single epidermal ridge. There are also instances when the epidermis is only partially sloughing off and parts of the dermis are exposed. The dermal ridge appears as a double fine line wherever it meets the single fine line of the epidermal ridge. The difference in these ridges can significantly affect the accuracy of fingerprint matching algorithms in Automated Fingerprint Identification Systems (AFIS). [1]

*Postmortem Fingerprint Castings*

The casting technique is an advanced PM recording technique used as an alternative transfer medium to the adhesive lifters used during the powder, acetate, and lifter technique. The casting technique is very useful when working with a decedent exhibiting desiccation and mummification, where the friction ridge skin is hard, significantly dry, and is not pliable. The casting technique can also be used after a method known as the rehydration technique. In addition, it can be used during a MFI when fingerprints need to be recovered rapidly and the rehydration method is not an option. During PM changes, excessive drying of the skin leads to multiple depressions within the friction ridge skin that cannot be flattened. Application of adhesive lifters will not capture the friction ridge information within the depressions. Since the casting material is very pliable at the time of application, it will capture friction ridge information that is available on a flat surface, as well as within any depressions. This process creates a manual 3D fingerprint impression that can be manually "flattened" into a 2D fingerprint impression, scanned or photographed, and then searched similar to fingerprint impressions created using the ink transfer technique or the powder, acetate, and lifter techniques. Furthermore, contact livescan devices and contactless devices have the ability to electronically capture the fingerprint impression generated after using the casting technique. 2D and 3D scanners are designed to scan friction ridge detail from a finger (the "positive impression") to create a "negative impression" similar to that of an inked fingerprint on a stock fingerprint card. A casting of friction ridge detail from a finger is also "negative impression". The resulting PM fingerprint impressions in castings display ridges as furrows and furrows as ridges. As such, when the "negative impression" casting is scanned, the resulting image is a mirror image, and displays furrows as the black portion and ridges scanned as the white portion. Thus, the image must be inverted to accurately represent the correct "negative impression" orientation of the fingerprint in order to be searched against fingerprint databases containing AM fingerprint records of "negative impressions." Currently, without manually "flipping" the resulting digital images of castings using commercial digital photography enhancement programs, there is no way of searching casting impressions since they are captured in a different orientation than a regular electronic fingerprint impression. The casting technique has proved to be very useful for capturing PM fingerprint records from friction ridge skin exhibiting multiple depressions, however, the lengthy, labor intensive, and complex, manual post-processing of the captured digital images is a significantly limiting factor and should be streamlined in order fully maximize the potential of the technique. [1]

*Digital Fingerprint Capture*

Some larger jurisdiction ME/C Offices and LEAs have started to use digital livescan and cardscan devices to capture fingerprints from the deceased. The benefits of PM digital fingerprint capture include immediate feedback on the quality of the fingerprint being obtained, as well as rapid response with results through regional, national, and international fingerprint databases. The development of mobile, handheld, and wireless biometric units could be used with single or multiple fatalities for the accelerated acquisition of fingerprint identification data with the potential for rapid identification. Studies reported that a full set of examination-quality fingerprints can be acquired in 45 to 90 seconds (unit-dependent) [65, 66]. However, fingers or hands often must be removed, flexor tendons must be severed, or rigor mortis broken in order to appropriately position the fingers [3]. Furthermore, fingerprints can be obtained from decedents where friction ridge detail is visible to the naked eye using contact scanners, but they could not acquire fingerprints from bodies affected by fire or showing advanced changes of decomposition. Also, the capture devices must be routinely decontaminated and free of biological fluids. [1, 65, 66]

Digital fingerprint capture devices could be used instead of manual fingerprinting during Mass Fatality Incidents (MFIs), when bodies are contaminated by chemical, biological or radiological agents and where, under such circumstances, traditional manual fingerprint recording techniques are not possible or appropriate. Fingerprint records can be sent electronically and remotely under such circumstances, which would stop the removal and spread of contaminated materials. The availability of handheld, mobile, non-contact digital fingerprint capture device would allow for the collection of large numbers of PM fingerprint records for remote transmission, analysis, and storage. [1, 65, 66]

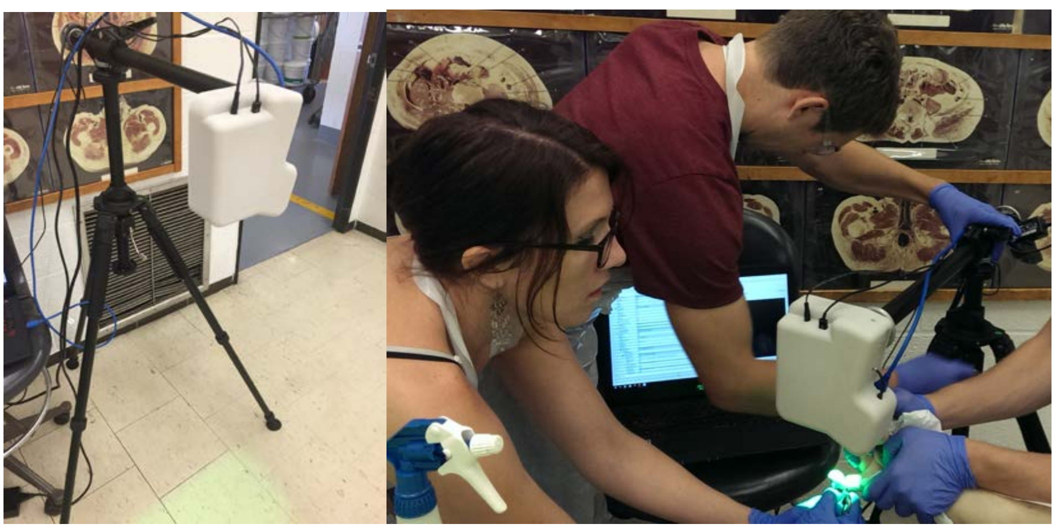
*Structured Light Illumination*

The structured light illumination imaging technique (SLI) is one of the most accurate non-contact surface scanning methods [82]. It is a commonly used method in scientific and industrial applications because of its high degree of accuracy, speed and scalability to different object sizes. The concept is to project a structured pattern of light onto the target surface and extract the depth by the amount of deviation that the reflected light pattern undergoes. The state-of-the-art techniques can be used in the presence of ambient light, yield non-ambiguous depth, and when processed result in a high density of accurate 3D point measurements. A simple example would be a pattern of stripes projected onto a sphere. When viewed obliquely, the light stripes on the sphere appear curved as shown in **Figure 27** below. For a given arrangement of the projector and camera, the variation in a pattern can be characterized extremely accurately, such that a precise model of the surface can be reconstructed.

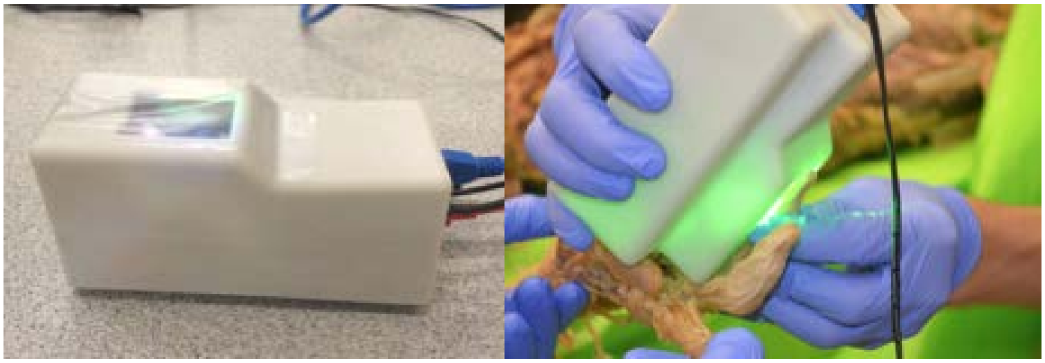
Mathematically, the SLI measurement process is based on triangulation [83]. Accurate results can be produced only when there is a well-defined relationship between a single point on the projection plane and the corresponding point on the captured image, as indicated in **Figure 28** below. It is to establish this relationship that projection patterns are utilized. A projection pattern is designed such that each pixel (or row or column, depending on the specific implementation) of the projection image is uniquely characterized, either by some characteristic intensity value sequence or by some other identifiable property such as a local pattern of shapes or colors. When projected onto an object, the captured image (or series of images) can be analyzed to locate these identifiable projection pattern points. Given a fixed placement of camera and projector, the location of any given pattern point on the subject creates a unique triangle with dimensions defined by the depth of the subject surface.

**Figures**

**Figures 1-5**: *Friction ridge detail from desiccated human remains exhibiting depressions, causing contouring and distortion of the surface (Photographs courtesy of G. Reinecke).*



**Figures 6 and 7**: *First preliminary prototype used during first initial testing visit (Photographs courtesy of M. Mulawka).*



**Figures 8 and 9**: *Second preliminary prototype used during second testing visit (Photographs courtesy of G. Reinecke).*

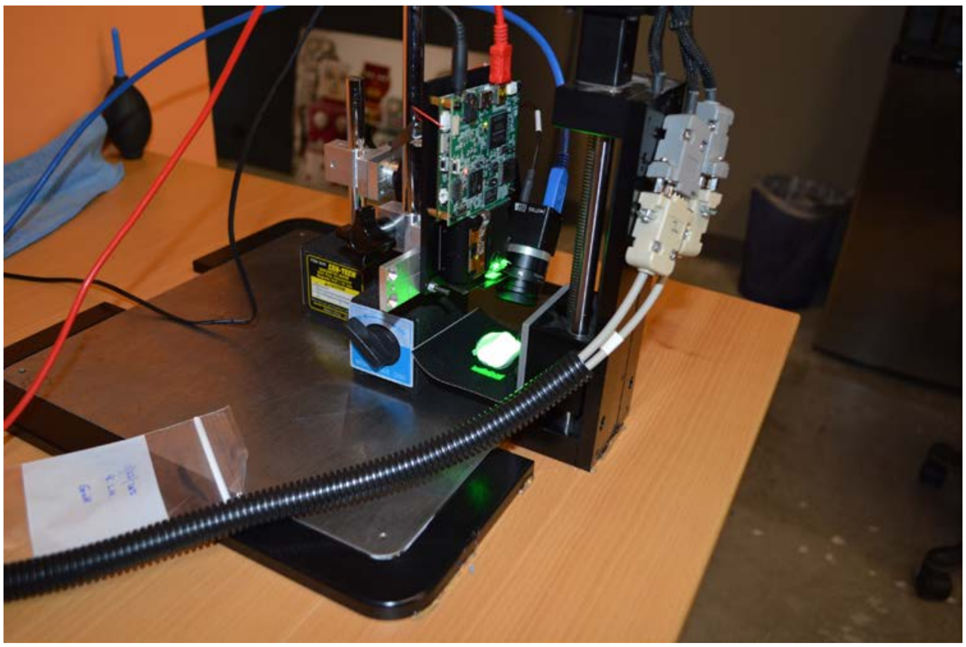


**Figure 10**: *Third prototype used during final testing (Photograph courtesy of FlashScan3D).*

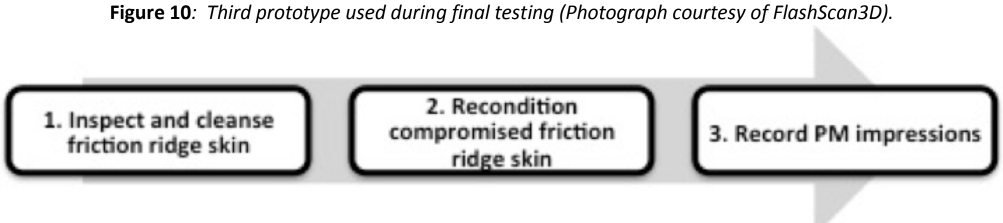



**Figure 11**: *Uhle's Deceased Processing Methodology. Reprinted from "Postmortem Fingerprinting and Unidentified Human Remains" by M. Mulawka, 2013 [1].*

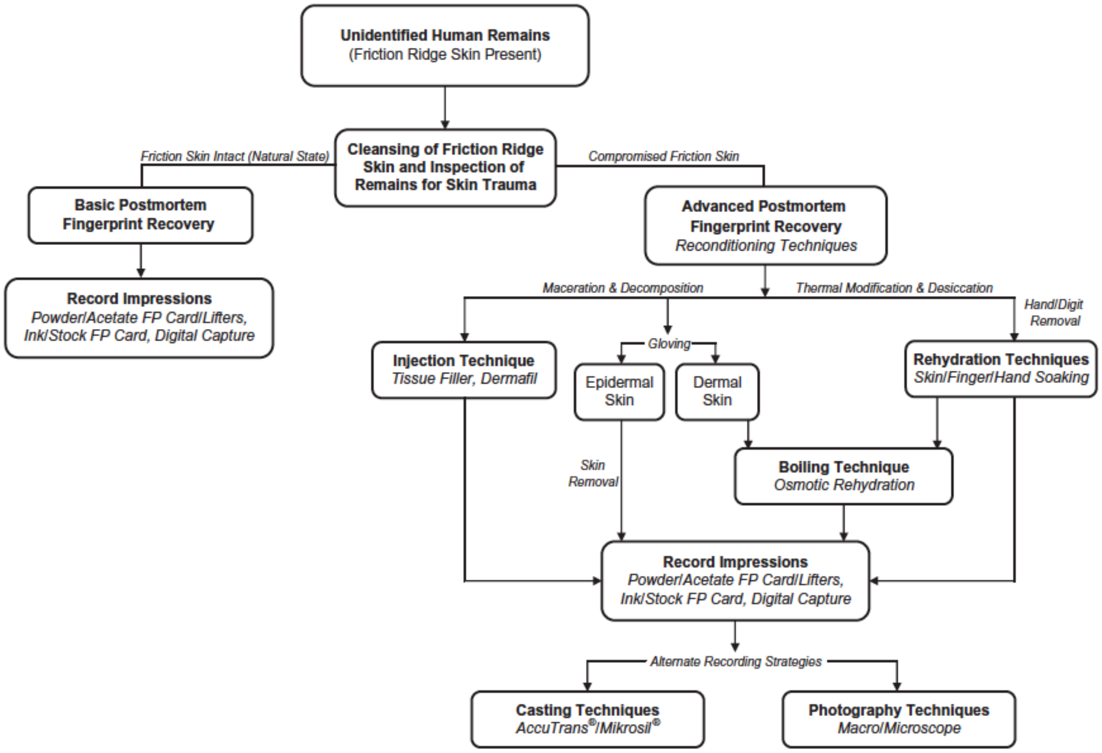
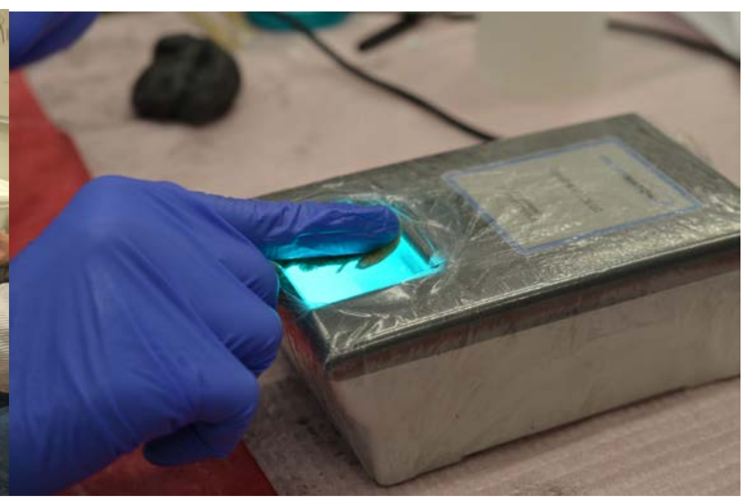



**Figure 12***: Postmortem processing workflow (Mulawka, Mosco, Uhle & Mokleby, 2013). Reprinted from "Postmortem Fingerprinting and Unidentified Human Remains" by M. Mulawka, 2013 [1].*

**Figures 13 and 14***: Contact-based 2D Crossmatch Verifier 320 fingerprint scanner used during preliminary and final testing (Photographs courtesy of M. Mulawka and G. Reinecke).*

**Figures 15 and 16***: Manual PM fingerprint recovery supplies (Photographs courtesy of M. Mulawka).*

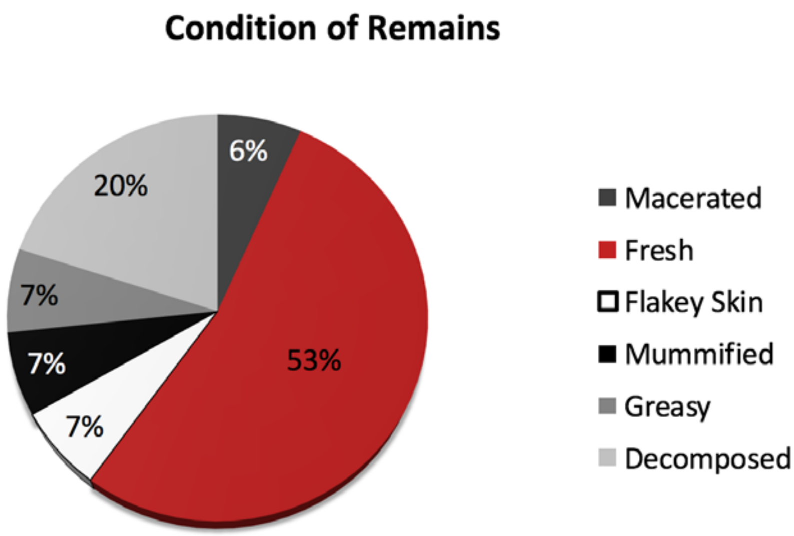



**Figure 17**: *Conditions of remains in cadavers tested during final testing.*

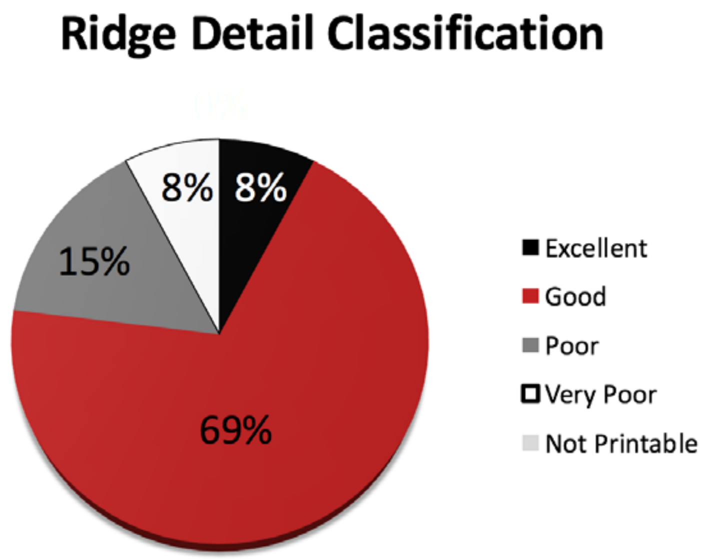



**Figure 18**: *Classification of ridge detail in cadavers tested during final testing.*

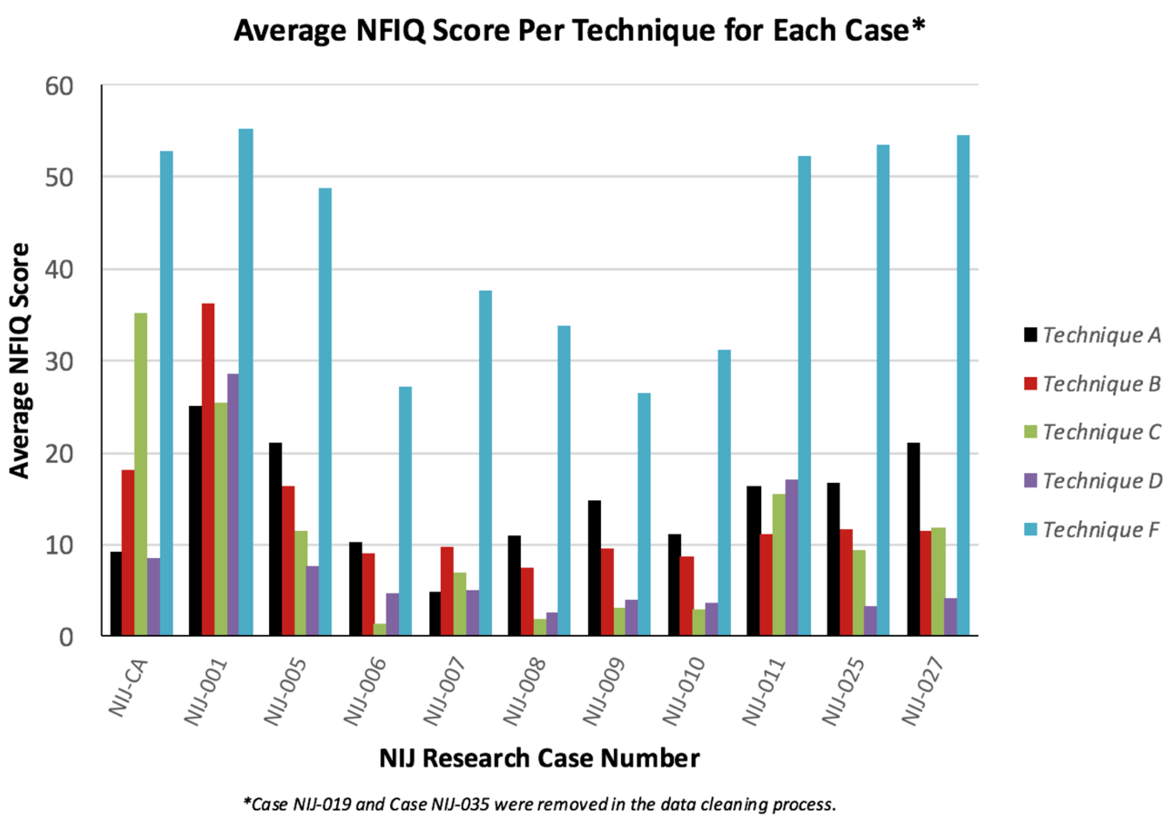



**Figure 19**: *Average NFIQ score per technique for each case.*

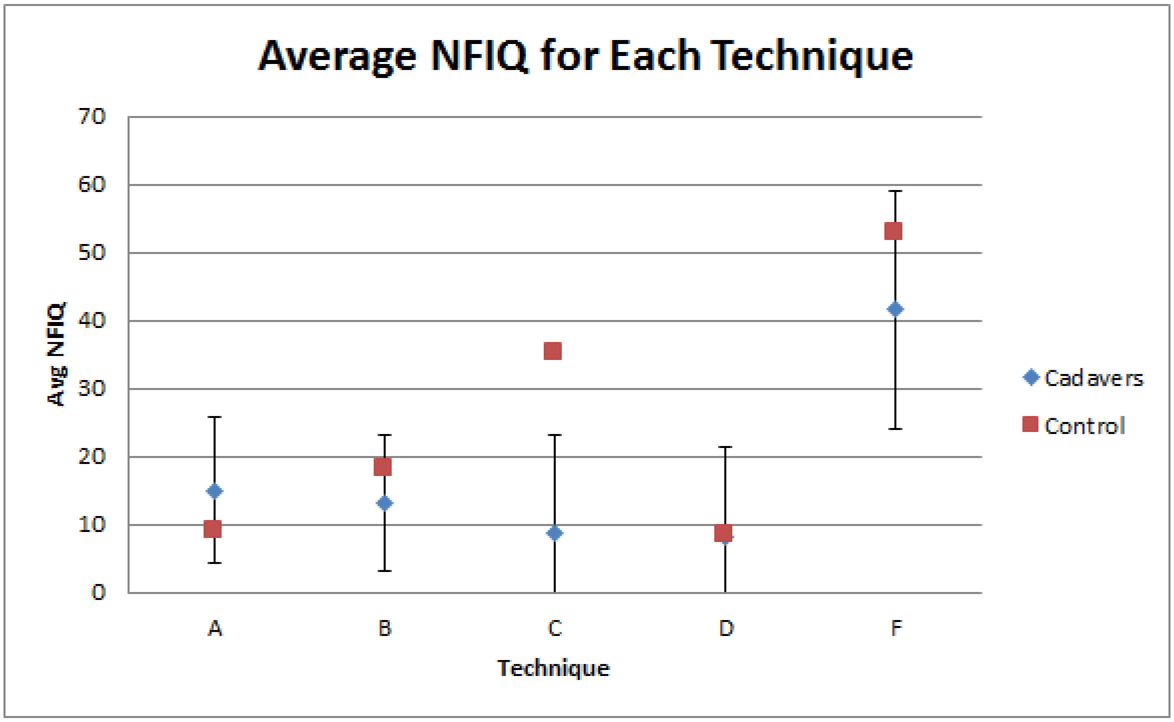



**Figure 20**: *Average NFIQ distance from each technique NFIQ, when compared to the non-contact 3D scanner technique (F).*

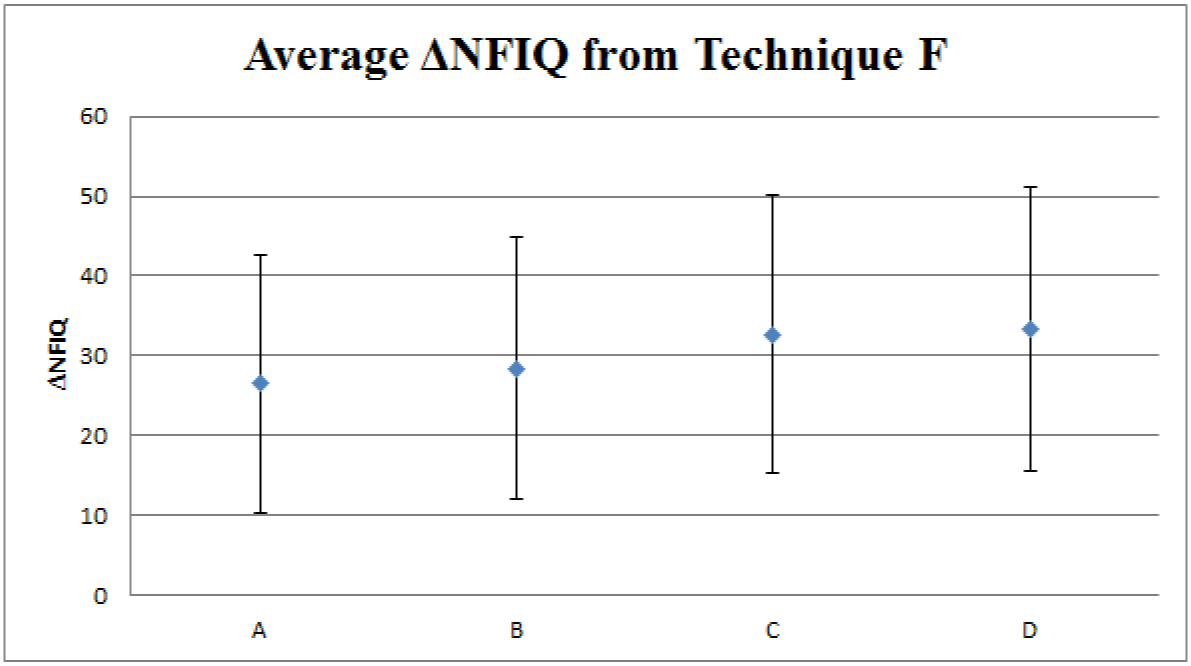



**Figure 21**: *Average NFIQ distance from each technique NFIQ, when compared to the non-contact 3D scanner technique (F).*

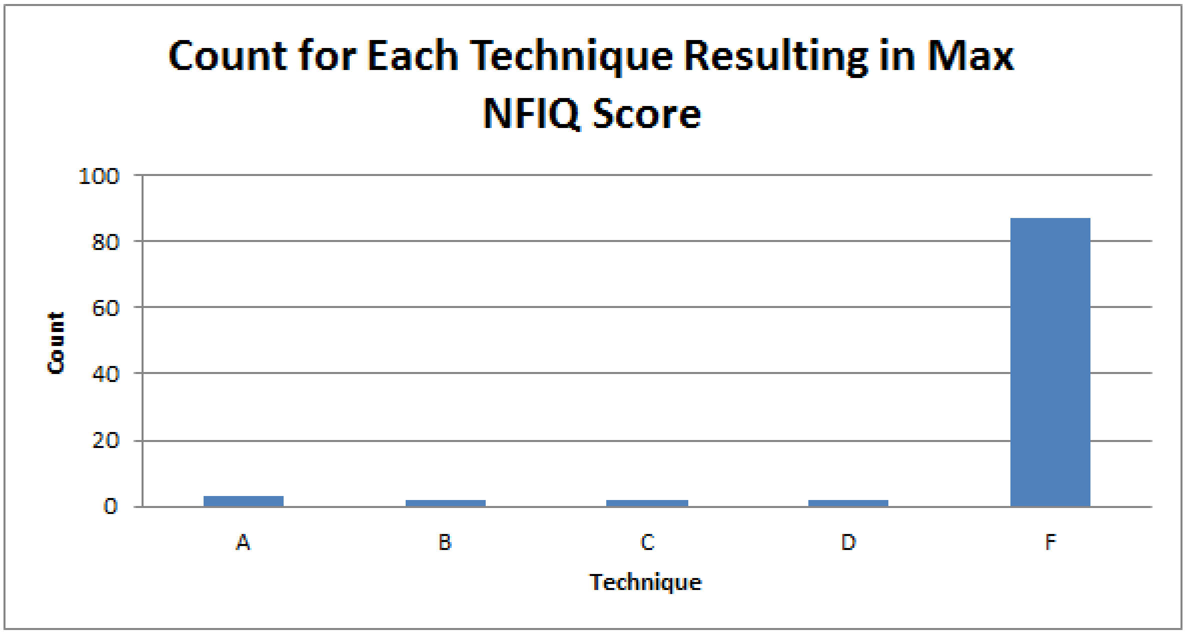



**Figure 22**: *Count for how many times each technique resulted in the maximum NFIQ score across the whole dataset for each finger.*

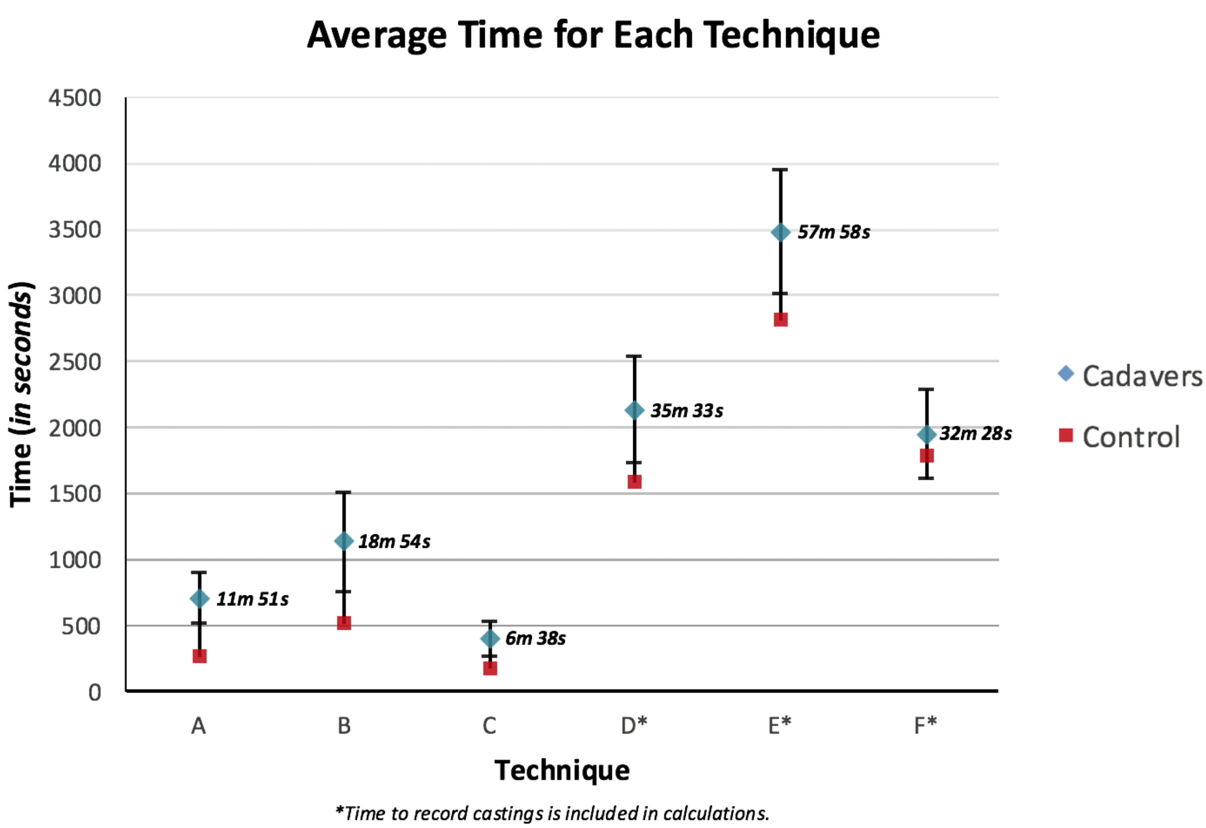



**Figure 23**: *Average amount of time required for processing using each technique.*

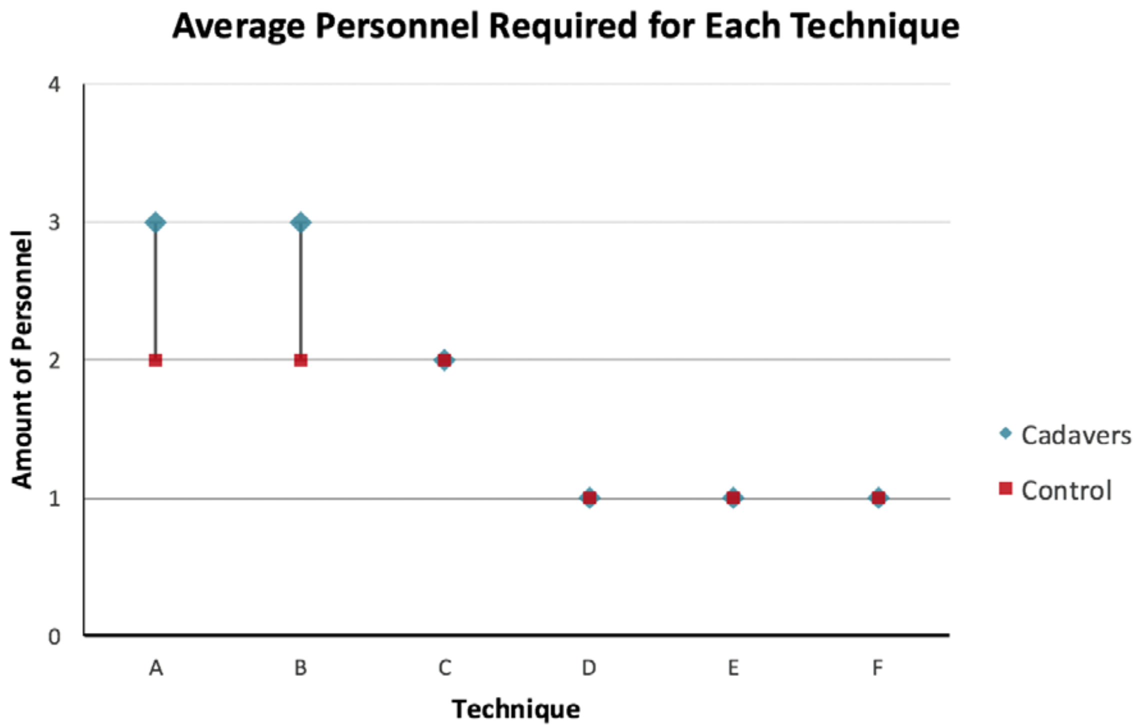



**Figure 24**: *Average amount of personnel required for each technique.*

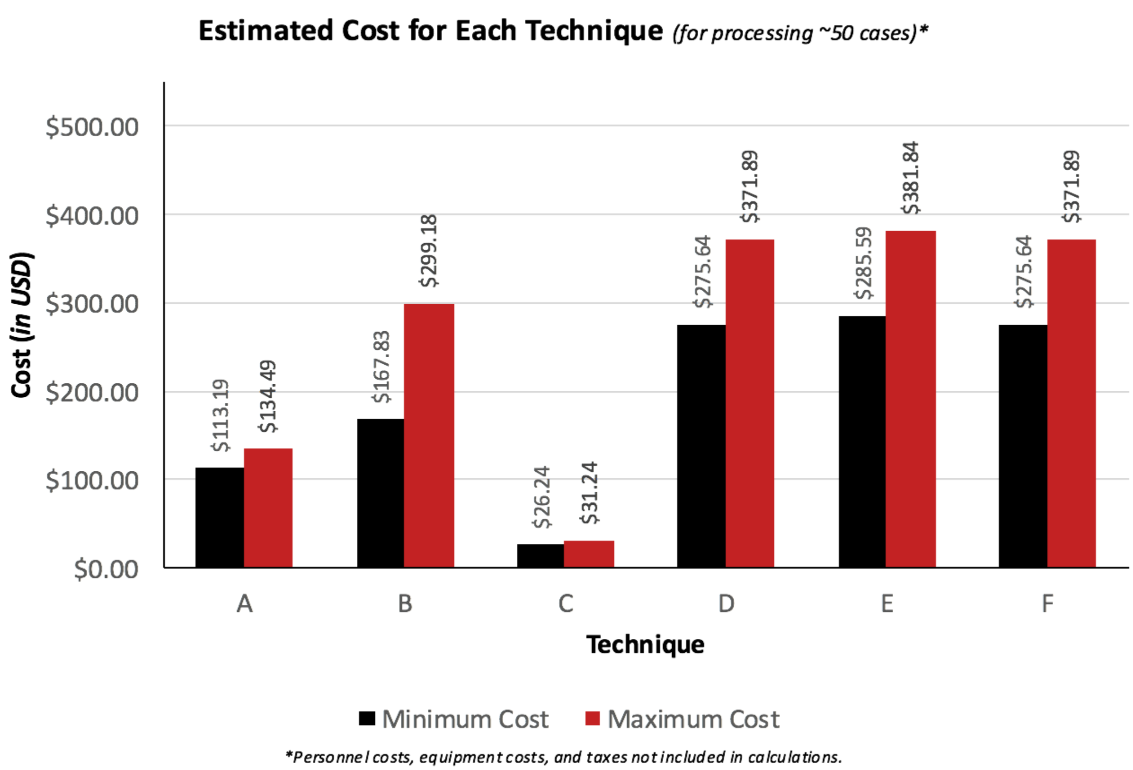



**Figure 25**: *Estimated cost of supplies required per technique for processing approximately 50 cases.*

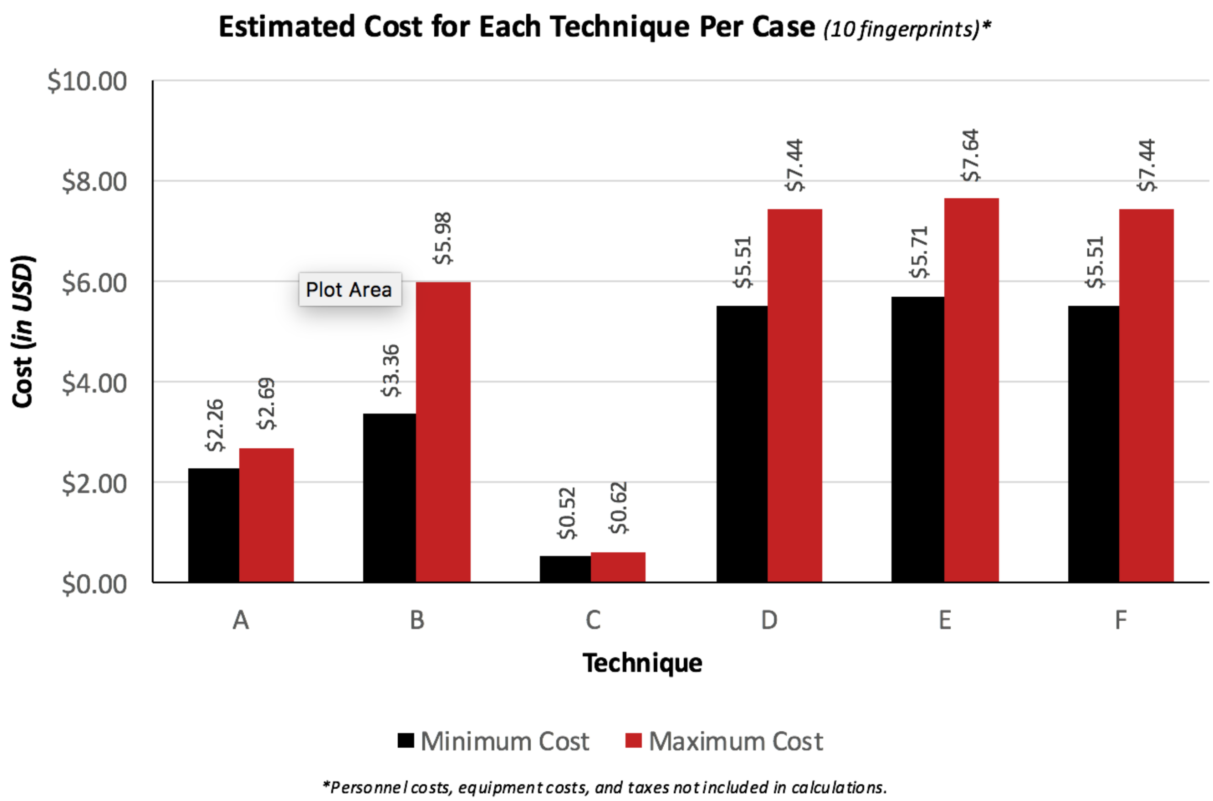
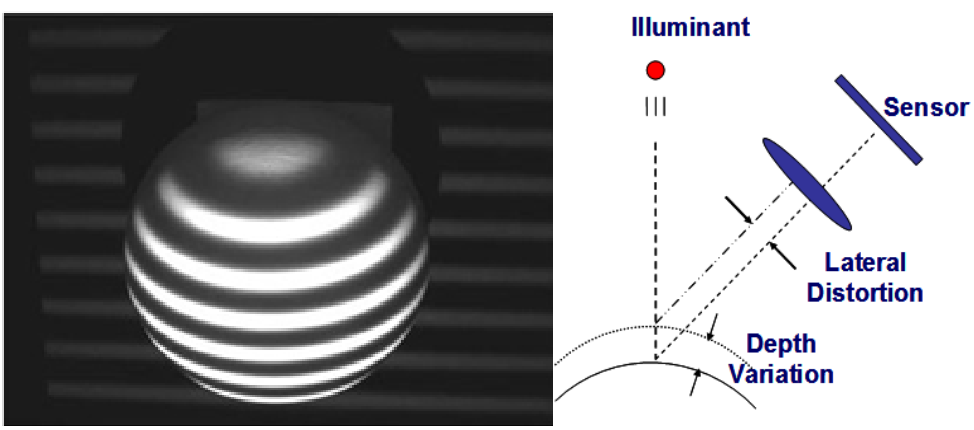



**Figure 26**: *Estimated cost of supplies required per technique for processing one case.*




**Figures 27 and 28**: *(left) example stripe pattern on sphere highlighting deformations in the light pattern on 3D object and (right) SLI geometry (Photographs courtesy of University of Kentucky Center for Visualization & Virtual Environments).*

**Tables**

**Table 1**: *Statistics, abbreviations, and descriptions used for data analysis.*

| Statistic | Abbreviations | Description |
|---|---|---|
| Sample Size | *N* | The number of observations in a statistical sample. |
| Mean (Average) | *M* | The average value of the data set. |
| Median | *Mdn* | The middle value of the data set. |
| Mode | Mode | The value that occurs most often in the data set. |
| Standard Deviation | *SD* | The measure that is used to quantify the amount of variation or dispersion in the data set. |
| Minimum Standard Deviation | Min *SD* | The minimum standard deviation from the mean in the data set. |
| Maximum Standard Deviation | Max *SD* | The maximum standard deviation from the mean in the data set. |
| Square Root of Sample Size | $\sqrt{N}$ | The square root of the sample size. |
| Margin of Error | MOE | The range of values below and above the sample statistic in a confidence interval. |
| Standard Error of the Mean | *SEM* | The standard deviation of sample means over all possible samples (of a given size) drawn from the population. |
| Sample Variance | $s^2$ | Average of the squared differences from the mean of the data set. |
| Minimum | Min | Minimum value in the data set. |
| Maximum | Max | Maximum value in the data set. |
| Range | R | The difference between the largest and smallest values in the data set. |
| Confidence Interval | CI | The amount of uncertainty associated with a sample estimate of a population parameter. |

**Table 2**: *Label and description of each manual or digital fingerprint recovery technique used for final testing and analysis.*

| Label | Fingerprint Technique Description |
|---|---|
| A | Ink and Stock Fingerprint Card |
| B | Powder, Acetate Fingerprint Card, Lifter |
| C | 2D Contact Scan of Finger |
| D | 2D Contact Scan of Casting |
| E | 2D Photographs of Casting |
| F | 3D Non-Contact Scan of Casting |

**Table 3**: *Ridge detail classification categories and descriptions.*

| Category | Description |
|---|---|
| Excellent | Complete ridge detail, no need for reconditioning, easily obtainable. |
| Good | Complete ridge detail, some reconditioning required, minor effort. |
| Poor | Partial ridge detail, ridge detail is smooth, requiring extensive reconditioning, major effort, time consuming. |
| Very Poor | Missing most ridge detail, requiring extensive reconditioning, major effort, extremely time consuming. |
| Not Printable | No results after multiple attempts, little available detail, extensively time consuming. |

**Table 4**: *Condition of remains and ridge detail classification as compared to average NFIQ score per technique.*

| Condition of Remains and Ridge Detail Classification Compared to Average NFIQ Score Per Technique | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Case #** | **Condition of Remains** | **Ridge Detail Classification** | **Average NFIQ Score Per Technique** | | | | |
| | | | **A** | **B** | **C** | **D** | **F** |
| NIJ-CA[1] | Fresh | Excellent | 9.20 | 18.10 | 35.10 | 8.50 | 52.80 |
| NIJ-001 | Decomposed/macerated | Good | 25.00 | 36.30 | 25.50 | 28.60 | 55.30 |
| NIJ-005 | Fresh, flakey skin | Excellent | 21.10 | 16.40 | 11.50 | 7.70 | 48.70 |
| NIJ-006 | Fresh | Poor | 10.30 | 9.10 | 1.30 | 4.70 | 27.10 |
| NIJ-007 | Fresh | Good | 4.80 | 9.70 | 7.00 | 5.10 | 37.70 |
| NIJ-008 | Fresh | Good | 10.90 | 7.40 | 1.80 | 2.60 | 33.70 |
| NIJ-009 | Fresh | Good | 14.80 | 9.50 | 3.10 | 4.00 | 26.50 |
| NIJ-010 | Fresh | Good | 11.20 | 8.70 | 2.90 | 3.70 | 31.20 |
| NIJ-011 | Fresh | Good | 16.40 | 11.10 | 15.50 | 17.10 | 52.20 |
| NIJ-019 | Decomposed/mummified | Poor/Very Poor | N/A[1] | N/A[1] | N/A[1] | N/A[1] | N/A[1] |
| NIJ-025 | Greasy | Good | 16.67 | 11.56 | 9.44 | 3.33 | 53.44 |
| NIJ-027 | Decomposed | Good | 21.00 | 11.43 | 11.86 | 4.14 | 54.57 |
| NIJ-035 | Fresh | Good | N/A[1] | N/A[1] | N/A[1] | N/A[1] | N/A[1] |

[1] *Case NIJ-019 and Case NIJ-035 were removed in the data cleaning process.*

**Table 5**: *Amount of time required for each technique per case and resulting statistical calculations.*

| Amount of Time Required for Each Technique (*In Seconds*) | | | | | | |
|---|---|---|---|---|---|---|
| **Case #** | **A[2]** | **B[2]** | **C** | **D[3]** | **E[3]** | **F[3]** |
| NIJ-CA[1] | 265 | 516 | 183 | 1594 | 2821 | 1786 |
| NIJ-001 | 749 | 1294 | 587 | 2732 | 4364 | 2663 |
| NIJ-005 | 693 | 1130 | 392 | 2108 | 4053 | 2165 |
| NIJ-006 | 664 | 931 | 254 | 1933 | 3256 | 1896 |
| NIJ-007 | 651 | 938 | 366 | 2301 | 3576 | 1961 |
| NIJ-008 | 541 | 764 | 304 | 1723 | 2904 | 1486 |
| NIJ-009 | 608 | 797 | 349 | 1668 | 3065 | 1635 |
| NIJ-010 | 655 | 921 | 186 | 1994 | 3244 | 1616 |
| NIJ-011 | 572 | 860 | 305 | 2284 | 3333 | 1986 |
| NIJ-019 | 903 | 1523 | 605 | N/A[3] | 3888 | 2293 |
| NIJ-025 | 595 | 1340 | 457 | 1656 | 2894 | 1603 |
| NIJ-027 | 1186 | 1976 | 515 | 2213 | 3823 | 2054 |
| NIJ-035 | N/A[4] | N/A[4] | 454 | 2850 | 3341 | 2021 |
| ***Time Statistics*** | | | | | | |
| **Statistic** | **A** | **B** | **C** | **D** | **E** | **F** |
| *N* | 11 | 11 | 12 | 11 | 12 | 12 |
| M | 711 | 1134 | 398 | 2133 | 3478 | 1948 |
| Mdn | 655 | 938 | 379 | 2108 | 3337 | 1974 |
| Mode | None | None | None | None | None | None |
| SD | 185.8726837 | 371.3321963 | 129.8606479 | 400.2642763 | 466.8348858 | 335.5974659 |
| Min *SD* | 524.7636799 | 762.6678037 | 267.9726854 | 1732.644815 | 3011.581781 | 1612.652534 |
| Max *SD* | 896.5090473 | 1505.332196 | 527.6939813 | 2533.173367 | 3945.251552 | 2283.847466 |
| √*N* | 3.31662479 | 3.31662479 | 3.464101615 | 3.31662479 | 3.464101615 | 3.464101615 |
| MOE | 30.15% | 30.15% | 28.87% | 30.15% | 28.87% | 28.87% |
| SEM | 56.04272278 | 111.9608698 | 37.48754002 | 120.6842201 | 134.7636235 | 96.87864363 |
| $s^2$ | 34548.65455 | 137887.6 | 16863.78788 | 160211.4909 | 217934.8106 | 112625.6591 |
| Min | 541 | 764 | 186 | 1656 | 2894 | 1486 |
| Max | 1186 | 1976 | 605 | 2850 | 4364 | 2663 |
| R | 645 | 1212 | 419 | 1194 | 1470 | 1177 |

[1] *Control sample from living subject.*
[2] *Calculated with time to convert physical fingerprint card into digital form using flatbed scanner.*
[3] *Calculated with non-powdered casting recovery time.*

[4] *Technique could not be performed due to unforeseen circumstances out of the team's control described in Data Results and Analysis section.*

**Table 6**: *Amount of personnel for each technique per case and resulting statistical calculations.*

| **Amount of Personnel Required for Each Technique** | | | | | | |
|---|---|---|---|---|---|---|
| **Case #** | **A** | **B** | **C** | **D** | **E** | **F** |
| NIJ-CA[1] | 2 | 2 | 2 | 1 | 1 | 1 |
| NIJ-001 | 2 | 2 | 2 | 1 | 1 | 1 |
| NIJ-005 | 3 | 3 | 2 | 1 | 1 | 1 |
| NIJ-006 | 3 | 3 | 2 | 1 | 1 | 1 |
| NIJ-007 | 3 | 3 | 2 | 1 | 1 | 1 |
| NIJ-008 | 3 | 3 | 2 | 1 | 1 | 1 |
| NIJ-009 | 3 | 3 | 2 | 1 | 1 | 1 |
| NIJ-010 | 3 | 3 | 2 | 1 | 1 | 1 |
| NIJ-011 | 3 | 3 | 2 | 1 | 1 | 1 |
| NIJ-019 | 2 | 2 | 2 | 1 | 1 | 1 |
| NIJ-025 | 2 | 3 | 2 | 1 | 1 | 1 |
| NIJ-027 | 1 | 1 | 3 | 1 | 1 | 1 |
| NIJ-035 | N/A[2] | N/A[2] | 2 | 1 | 1 | 1 |
| ***Personnel Statistics*** | | | | | | |
| **Statistic** | **A** | **B** | **C** | **D** | **E** | **F** |
| *N* | 11 | 11 | 12 | 12 | 12 | 12 |
| M | 3 | 3 | 2 | 1 | 1 | 1 |
| Mdn | 3 | 3 | 2 | 1 | 1 | 1 |
| Mode | 3 | 3 | 2 | 1 | 1 | 1 |
| SD | 1 | 1 | 0 | 0 | 0 | 0 |
| Min *SD* | 2 | 2 | 2 | 1 | 1 | 1 |
| Max *SD* | 3 | 3 | 2 | 1 | 1 | 1 |
| $\sqrt{N}$ | 3.31662479 | 3.31662479 | 3.464101615 | 3.464101615 | 3.464101615 | 3.464101615 |
| MOE | 30.15% | 30.15% | 28.87% | 28.87% | 28.87% | 28.87% |
| SEM | 0.207304623 | 0.203278907 | 0.083333333 | 0 | 0 | 0 |
| $s^2$ | 0.472727273 | 0.454545455 | 0.083333333 | 0 | 0 | 0 |
| Min | 1 | 1 | 2 | 1 | 1 | 1 |
| Max | 3 | 3 | 3 | 1 | 1 | 1 |
| R | 2 | 2 | 1 | 0 | 0 | 0 |

[1] *Control sample from living subject.*

[2] *Technique could not be performed due to unforeseen circumstances out of the team's control described in Data Results and Analysis section.*

**Table 7**: *Approximate supply costs for the Ink and Stock Fingerprint Card Postmortem Fingerprint Recovery Technique (A).*

| **Ink and Stock Fingerprint Card Technique Supply Costs** *(for processing ~ 50 cases)*[1,2] | | |
|---|---|---|
| *Item* | *Consumable?* | *Approximate Price Range*[3] |
| Alcohol wipes (100/box) | Yes | $13.25 |
| Tech wipes or lint-free paper towels (140/box) | Yes | $7.99 |
| White stock paper fingerprint cards (100/box) or fingerprint card strips (100/box left hand, 100/box right hand) | Yes | $19.95 – 22.00 |
| Fingerprint ink (ink pad, or ink/roller/spatula) | Yes | $21.75 – 31.00 |
| Postmortem fingerprinting spoon | No | $14.75 |
| Fingerprint printover tabs (500/roll) | Yes | $21.50 |
| Black permanent marker | Yes | $4.00 |
| *Shipping costs* | N/A | $10.00 – 20.00 |
| **Ink and Stock Fingerprint Card Technique Equipment**[4] | | |
| FBI-certified flatbed scanner (>500-1,000 dpi)[5] | No | $199.00 – 1,000.00 |
| **Amount of Consumable Supplies** | **7 out of 8** | |
| **Approximate Total Cost for Processing ~ 50 Cases**<br>**Approximate Total Cost for Processing 1 Case** | **$113.19 – 134.49**<br>**$2.26 – 2.69** | |

[1] *Personnel costs, equipment costs, and taxes not included in calculations.*
[2] *Supply list (or portion) reprinted from "Postmortem Fingerprinting and Unidentified Human Remains"* by M. Mulawka, 2013 [1].
[3] *All item price estimates were obtained using www.sirchie.com, http://www.crime-scene.com, www.staples.com, and www.amazon.com.*
[4] *Equipment costs were not included in calculations. Equipment is a singular purchase, not consumable, and can be used on >50 cases.*
[5] *Information obtained from https://www.fbibiospecs.cjis.gov/Certifications.*

**Table 8**: *Approximate supply costs for the Powder/Acetate/Lifter Postmortem Fingerprint Recovery Technique (B).*

| **Powder/Acetate Fingerprint Card/Lifter Technique Supply Costs** *(for processing ~ 50 cases)*[1,2] | | |
|---|---|---|
| *Item* | *Consumable?* | *Approximate Price Range*[3] |
| Alcohol wipes (100/box) | Yes | $13.25 |
| Tech wipes or lint-free paper towels (140/box) | Yes | $7.99 |
| Acetate fingerprint cards (100/box) | Yes | $29.99 – 45.00 |
| Black fingerprint powder (8-16oz.) | Yes | $18.95 – 32.00 |
| Small weigh boat | Yes | $.15 |
| Fingerprint brush (camel hair or squirrel hair) | Yes | $13.50 – 53.85 |
| Fingerprint lifters (500/box) | Yes | $70.00 – 123.00 |
| Black permanent marker | Yes | $4.00 |
| *Shipping costs* | N/A | $10.00 – 20.00 |
| **Powder/Acetate Fingerprint Card/Lifter Technique Equipment**[4] | | |
| FBI-certified flatbed scanner (>500-1,000 dpi)[5] | No | $199.00 – 1,000.00+ |
| **Amount of Consumable Supplies** | **8 out of 9** | |
| **Approximate Total Cost for Processing ~ 50 Cases**<br>**Approximate Total Cost for Processing 1 Case** | **$167.83 – 299.18**[1]<br>**$3.36 – 5.98**[1] | |

[1] *Personnel costs, equipment costs, and taxes not included in calculations.*
[2] *Supply list (or portion) reprinted from "Postmortem Fingerprinting and Unidentified Human Remains"* by M. Mulawka, 2013 [1].
[3] *All item price estimates were obtained using www.sirchie.com, http://www.crime-scene.com, www.staples.com, and www.amazon.com.*
[4] *Equipment costs were not included in calculations. Equipment is a singular purchase, not consumable, and can be used on >50 cases.*
[5] *Information obtained from https://www.fbibiospecs.cjis.gov/Certifications.*

**Table 9**: *Approximate supply costs for the 2D Contact Scanning Postmortem Fingerprint Recovery Technique (C).*

| **2D Contact Scanning Technique Supply Costs** *(for processing ~ 50 cases)*[1,2] | | |
|---|---|---|
| *Item* | *Consumable?* | *Approximate Price Range*[3] |
| Alcohol wipes (100/box) | Yes | $13.25 |
| Tech wipes or lint-free paper towels (140/box) | Yes | $7.99 |
| *Shipping costs* | N/A | $5.00 – 10.00 |
| **2D Contact Scan of Casting Technique Equipment**[4] | | |
| 2D contact fingerprint scanner and software | No | $400.00 – 1,000.00+ |
| **Amount of Consumable Supplies** | **2 out of 2** | |
| **Approximate Total Cost for Processing ~ 50 Cases**<br>**Approximate Total Cost for Processing 1 Case** | **$26.24 – 31.24**[1]<br>**$0.52 – 0.62**[1] | |

[1] *Personnel costs, equipment costs, and taxes not included in calculations.*
[2] *Supply list (or portion) reprinted from "Postmortem Fingerprinting and Unidentified Human Remains"* by M. Mulawka, 2013 [1].
[3] *All item price estimates were obtained using www.sirchie.com, http://www.crime-scene.com, www.staples.com, and www.amazon.com.*
[4] *Equipment costs were not included in calculations. Equipment is a singular purchase, not consumable, and can be used on >50 cases.*
[5] *Information obtained from http://www.biometricsupply.com/prices.html.*

**Table 10**: *Approximate supply costs for the 2D Contact Scan of Casting Postmortem Fingerprint Recovery Technique (D).*

| **2D Contact Scan of Casting (Non-Powdered) Technique Supply Costs** *(for processing ~ 50 cases)*[1,2] | | |
|---|---|---|
| *Item* | *Consumable?* | *Approximate Price Range*[3] |
| Alcohol wipes (100/box) | Yes | $13.25 |
| Tech wipes or lint-free paper towels (140/box) | Yes | $7.99 |
| Casting Material (Mikrosil®) | Yes | $201.25 – 287.50 |
| Small resealable plastic bags for individual castings (1000/box) | Yes | $39.00 |
| Small weigh boat | Yes | $.15 |
| Black permanent marker | Yes | $4.00 |
| *Shipping costs* | N/A | $10.00 – 20.00 |
| **2D Contact Scan of Casting Technique Equipment**[4] | | |
| 2D contact fingerprint scanner and software | No | $400.00 – 1,000.00+ |
| **Amount of Consumable Items in Supply List** | **6 out of 6** | |
| **Approximate Total Cost for Processing ~ 50 Cases**<br>**Approximate Total Cost for Processing 1 Case** | **$275.64 – 371.89**[1]<br>**$5.51 – 7.44**[1] | |

[1] *Personnel costs, equipment costs, and taxes not included in calculations.*
[2] *Supply list (or portion) reprinted from "Postmortem Fingerprinting and Unidentified Human Remains"* by M. Mulawka, 2013 [1].
[3] *All item price estimates were obtained using www.sirchie.com, http://www.crime-scene.com, www.staples.com, and www.amazon.com.*
[4] *Equipment costs were not included in calculations. Equipment is a singular purchase, not consumable, and can be used on >50 cases.*
[5] *Information obtained from http://www.biometricsupply.com/prices.html.*

**Table 11**: *Approximate supply costs for the Photography of Casting Postmortem Fingerprint Recovery Technique (E).*

| **Photography of Casting (Non-Powdered) Technique Supply Costs** *(for processing ~ 50 cases)*[1,2] | | |
|---|---|---|
| *Item* | *Consumable?* | *Approximate Price Range*[3] |
| Alcohol wipes (100/box) | Yes | $13.25 |
| Tech wipes or lint-free paper towels (140/box) | Yes | $7.99 |
| Casting Material (Mikrosil®) | Yes | $201.25 – 287.50 |
| Small resealable plastic bags for individual castings (1000/box) | Yes | $39.00 |
| Small weigh boat | Yes | $.15 |
| Black permanent marker | Yes | $4.00 |
| Photography scales (10/pack) | No | $9.95 |
| *Shipping costs* | N/A | $10.00 – 20.00 |
| **Photography of Casting Technique Equipment**[4,5] | | |
| Digital single lens reflex (DSLR) camera with macro lens | No | $300.00 – 3,000.00 |
| Copystand | No | $200.00 – 1,000.00 |
| **Amount of Consumable Items in Supply List** | **6 out of 7** | |
| **Approximate Total Cost for Processing ~ 50 Cases**<br>**Approximate Total Cost for Processing 1 Case** | **$285.59 – 381.84**[1]<br>**$5.71 – 7.64**[1] | |

[1] *Personnel costs, equipment costs, and taxes not included in calculations.*
[2] *Supply list (or portion) reprinted from "Postmortem Fingerprinting and Unidentified Human Remains"* by M. Mulawka, 2013 [1].
[3] *All item price estimates were obtained using www.sirchie.com, http://www.crime-scene.com, www.staples.com, and www.amazon.com.*
[4] *Equipment costs were not included in calculations. Equipment is a singular purchase, not consumable, and can be used on >50 cases.*
[5] *Information obtained from www.amazon.com.*

**Table 12**: *Approximate supply costs for the 3D Non-Contact Scan of Casting Postmortem Fingerprint Recovery Technique (F).*

| **3D Non-Contact Scan of Casting (Non-Powdered) Technique Supply Costs** *(for processing ~ 50 cases)*[1,2] | | |
|---|---|---|
| *Item* | *Consumable?* | *Approximate Price Range*[3] |
| Alcohol wipes (100/box) | Yes | $13.25 |
| Tech wipes or lint-free paper towels (140/box) | Yes | $7.99 |
| Casting Material (Mikrosil®) | Yes | $201.25 – 287.50 |
| Small resealable plastic bags for individual castings (1000/box) | Yes | $39.00 |
| Small weigh boat | Yes | $.15 |
| Black permanent marker | Yes | $4.00 |
| *Shipping costs* | N/A | $10.00 – 20.00 |
| **3D Non-Contact Scan of Casting Technique Equipment**[4] | | |
| 3D non-contact fingerprint scanner and software | No | *Unavailable*[5] |
| **Amount of Consumable Items in Supply List** | **6 out of 6** | |
| **Approximate Total Cost for Processing ~ 50 Cases**<br>**Approximate Total Cost for Processing 1 Case** | **$275.64 – 371.89**[1]<br>**$5.51 – 7.44**[1] | |

[1] *Personnel costs, equipment costs, and taxes not included in calculations.*
[2] *Supply list (or portion) reprinted from "Postmortem Fingerprinting and Unidentified Human Remains"* by M. Mulawka, 2013 [1].
[3] *All item price estimates were obtained using www.sirchie.com, http://www.crime-scene.com, www.staples.com, and www.amazon.com.*
[4] *Equipment costs were not included in calculations. Equipment is a singular purchase, not consumable, and can be used on >50 cases.*
[5] *Device is currently a prototype and has not been commercialized.*

**Dissemination of Research Findings**

*Accepted Products*

1. Mulawka, M., Reinecke, G., Troy, M. & Agaian, S. (2016, August). *Utilizing a contactless 3D digital fingerprint scanner coupled with castings for postmortem fingerprint recovery*. Poster session presented at the 101st Annual Meeting of the International Association for Identification Forensic Educational Conference, Cincinnati, OH.
2. Rao, S. P., Rajendran, R., Agaian, S. S. & Mulawka, M. (2016, May). Alpha trimmed correlation for touchless finger image mosaicing. *SPIE Commercial + Scientific Sensing and Imaging* (pp. 98690U-98690U). International Society for Optics and Photonics.
3. Rajeev, S., Kamath K. M. & Agaian, S. S. (2016, May). Method for modeling post-mortem biometric 3D fingerprints. *SPIE Commercial + Scientific Sensing and Imaging* (pp. 98690S-98690S). International Society for Optics and Photonics.
4. Mulawka, M., Reinecke, G., Troy, M. & Agaian, S. (2016, February). *A comprehensive comparison of various postmortem fingerprint recovery techniques*. Poster session presented at the 68th Annual Meeting of the American Academy of Forensic Sciences, Las Vegas, NV.
5. Agaian, S. S., Yeole, R. D., Rao, S. P., Reinecke, G., Mulawka, M., Troy, M. (2016, May). Missing data reconstruction using Gaussian mixture models for fingerprint images. In *SPIE Commercial + Scientific Sensing and Imaging*. International Society for Optics and Photonics.
6. Rajendran, R., Agaian, S. S., Rao, S.P., Kamath K. M., S., Rajeev, S. & Mulawka, M. (2016, February). *A comparative study of image feature detection and matching algorithms for touchless fingerprint systems.* Paper presented as poster session at the 28th Annual IS&T International Symposium on Electronic Imaging in the Image Processing: Algorithms and Systems Conference, San Francisco, CA.
7. Agaian, S. S., Yeole, R. D., Rao, S. P., Reinecke, G., Mulawka, M., Troy, M. (2016, February). *Comparison study of Gaussian mixture models for fingerprint image duplication.* Paper presented as oral presentation at the 28th Annual IS&T International Symposium on Electronic Imaging in the Image Processing: Algorithms and Systems Conference, San Francisco, CA.
8. Patent application submitted in 2015 (patent pending): Agaian, S. S., Rajeev, S., Kamath K. M., S., Rao, S. P. & Rajendran, R. *Methods and system for biometric 3D data capture modeling, processing and matching.*

*Products In Progress*

9. Rajeev, S. & Agaian, S. S. *Unrolling Postmortem Biometric 3-D Fingerprint for Automated Verification*, in preparation for IEEE Transactions on Information Forensics and Security Journal.
10. Kamath K. M., S. & Agaian, S. S., *Non-reference Fingerprint Image Quality Measure*. in preparation for IEEE Transactions on Information Forensics and Security Journal.
11. Agaian, S. S., Kamath K. M., S., Rajeev, S. & Panetta, K., *LQM: Localized Quality Measure for Fingerprint Image Enhancement*. in preparation for IEEE Instrumentation & Measurement Magazine.
12. M. Mulawka, G. Reinecke, Troy, M. & Agaian, S. "*Postmortem Fingerprinting Issues in the United States*," in preparation for Evidence Technology Magazine or Forensic Magazine.
13. Mulawka, M. & Reinecke, G. "*An Updated Comprehensive Postmortem Fingerprint Processing Workflow*" in preparation for the IAI Journal of Forensic Identification or AAFS Journal of Forensic Sciences.
14. Mulawka, M. & Reinecke, G. "*An Illustrated Guide to Postmortem Fingerprint Recovery Using Various Ink and Fingerprint Card Methods,*" technical note in preparation for the IAI Journal of Forensic Identification.
15. Mulawka, M. & Reinecke, G. "*An Illustrated Guide to Postmortem Fingerprint Recovery Using Various Powder, Lifter, and Acetate Fingerprint Card Methods*," technical note in preparation for the IAI Journal of Forensic Identification.
16. Mulawka, M. & Reinecke, G. & Wells, N. "*An Illustrated Guide to Postmortem Fingerprint Recovery Using Various Casting Methods*," technical note in preparation for the IAI Journal of Forensic Identification.

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**Images Used for Final Testing**
For comparison, fingerprints from a living subject were collected as control samples in order to understand the baseline. These control values allowed the research team to understand if the cadaver fingerprints fell near expected values.