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FINAL SUMMARY OVERVIEW

NOVEL QUANTITATIVE MICROSCOPY OF WET-POWDERED LATENT FINGERMARKS OF DIFFERENT AGES

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Abstract

This research project developed and tested a novel wet-powdering method using commercially available 0.5 μm diameter polystyrene (PS) particles suspended in an acidic (pH 4.1) solution, as well as a novel illumination method for imaging the enhanced fingermarks. The novel illumination method, based upon the total internal reflection (TIR) of light, visualizes only the secretions deposited by the friction ridges of the fingermark, eliminating the background in the image. Both natural and sebum-enriched fingermarks from three young adult (two male and one female) subjects were acquired on borosilicate glass microscope slides under well-controlled conditions using a mechanical fingermark press. The fingermarks acquired with this press were quantitatively shown to be more consistent than manually acquired fingermarks.

The quantitative metrics used to assess the fingermarks were the number of matched minutiae N_M to characterize the "identifiability" of the fingermarks; the (average) intensity of the image to estimate the total signal; and the contrast-to-noise ratio *CNR* to quantify the contrast of the enhanced fingermark image. Images of enhanced fingermarks under TIR illumination were compared with those obtained by illuminating the same fingermarks obliquely with white LED light. Finally, images of the fingermarks enhanced with the PS particles were compared with those enhanced with conventional methods, namely dry-powdering with commercial fluorescent fingerprint powder and cyanoacrylate fuming.

Purpose

The research objectives of this project, which ended at the end of calendar year 2020, were to:

I) determine whether evanescent-wave, or TIR, illumination can be used to quantify the characteristics of latent fingermarks, including aged fingermarks;

II) develop a fundamental understanding of how latent fingermarks interact with a variety of treatments used to enhance these fingermarks.

Direct quantitative comparison of how various types of enhancement and illumination affect fingermarks could significantly improve detection and yield of latent fingermarks—and lead to protocols that optimize the detection efficiency of fingermarks, especially aged fingermarks.

Project Methods

Latent Fingermark Acquisition and Enhancement Procedures

In order to ensure consistent fingermark deposits before enhancement, a mechanical fingermark press (Fig. 1) was built in house based upon the press recently developed by Reed *et al.* [1] and the "fingerprint sampler" developed by Fieldhouse [2]. Fingermarks from the right (male subject 1) and left (male subject 2 and female subject 3) index fingers were acquired on borosilicate glass microscope slides at applied forces of 4.1 N and 6.2 N, respectively. Since the characteristics of the enhanced fingermark depend upon the amount of secretions deposited on the slide, the applied force was optimized for each subject.

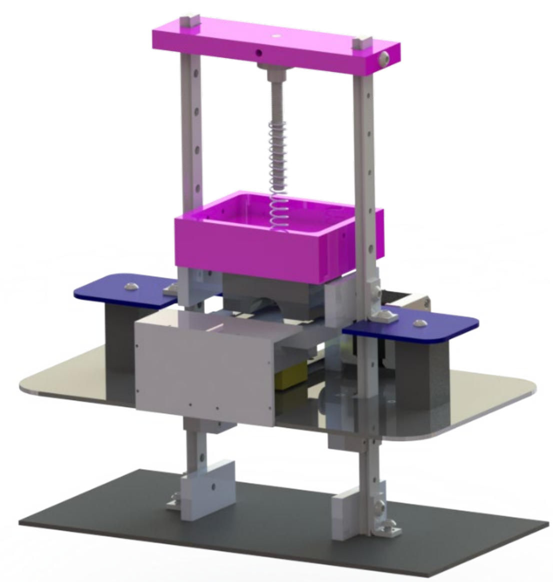

Figure 1 Sketch of fingerprint press.

Natural fingermarks were acquired from subjects 2 and 3 after they rubbed their hands together (with no prior handwashing). No natural fingermarks were acquired from subject 1 because his natural fingermark secretions were negligible. Sebum-enriched fingermarks were acquired from all three subjects after they thoroughly washed their hands with soap and dried them with paper towels, rubbed their fingers on the sides of their nose, then rubbed their hands together to homogenize the sebum-enriched secretions between each fingermark. The fingermarks acquired on glass were stored in sealed containers from 12 h to 435 days at ambient temperatures of 18–22 °C and relative humidities of 52.3–85.1%.

The fingermarks were enhanced with 0.5 μm diameter carboxyl(–COOH)- and sulfate(–SO_4)-terminated polystyrene (PS) particles (Thermo-Fisher C37269) suspended at 5 g/L in a 0.1 mol/L potassium hydrogen phthalate (KHP) buffer solution at pH 4.1; these enhanced fingermarks are referred to as CP and SP, respectively. The slide with the fingermark was submerged in the particle solution for 15 min, then rinsed in KHP buffer (no particles) and deionized water.

CP and SP enhancement were compared with two conventional enhancement methods. Commercial fluorescent powder (Lighting Powder Redwop #1-0050), with absorption wavelengths of 254–550 nm, was applied to the fingermarks on the microscope slides using a forensic brush (Armor Forensics 1003982); these dry-powdered fingermarks are referred to here as FP. Fingermarks were also fumed for 105 min using cyanoacrylate packets (Sirchie Products CNA20001) in a sealed fuming chamber (Sirchie Products FR100); these cyanoacrylate fumed fingermarks are referred to here as CF.

Fingermark Image Acquisition, Processing, and Analysis

The enhanced fingermarks were illuminated using a large area LED-based TIR illumination system constructed in house and imaged from below through the glass slide using a scientific

1392×1024 pixels CCD camera (Pixelfly PCO) with a C-mount lens (focal length 12–36 mm) at *f*/2.8 and an exposure time of 65.5 ms (Fig. 2). The TIR illuminator uses green light (average emission wavelength 525 nm) from a LED strip (SuperBright NFLS-X3-LC2) coupled with an optical gel (SiliconeSolutions SS-988) into a 10 cm diameter borosilicate glass disk (Edmund Optics 43-895). Brightfield white light (WL) images of the same fingermarks were also acquired with the same camera from above by illuminating these fingermarks with light at an angle of about 45° above the horizontal from a desk lamp with a 9 W white LED bulb. In almost all cases, four images were added to increase the signal from the enhanced fingermarks under TIR and WL illumination for an effective exposure time of 262 ms.

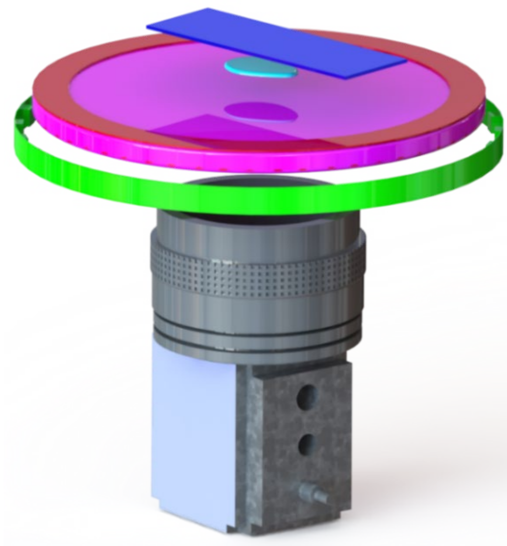

Figure 2 Exploded view of the large-area TIR illumination system illuminating the fingermark on a microscope slide (*dark blue*) imaged from below by a CCD camera.

To estimate the total signal from the fingermark, the intensity averaged over the entire image, called here the "image intensity", was calculated by identifying the outer edge of the region occupied by the fingermark using an active contour model [3], then taking the average grayscale value of the pixels inside this boundary. To calculate *CNR*, the region inside this contour were separated into ridges and grooves using Otsu thresholding [4]. The contrast-to-noise ratio $CNR \equiv (\mu_r - \mu_g)/\sigma_g$, where μ_r and μ_g are the average grayscale value over the pixels within the ridge and groove regions, respectively, and σ_g is the standard deviation in grayscale over all the pixels within the groove regions.

Fingermarks are commonly identified by matching characteristics, or "minutiae," from a "candidate" fingermark that are unique to each fingerprint to minutiae from a known "template" print. The template used here was from the same finger inked with a black gel ink stamp pad acquired on paper with the fingermark press. The number of matched minutiae, N_{M}, was the number of minutiae detected within a given candidate fingermark that matched those detected within the template fingermark of the same finger. Trained expert human fingermark examiners usually detect, or mark, such minutiae and match groups of minutiae to inked or live scan fingermark images from a database. Human detection of fingermark minutiae can, however, have significant variations due to subjective judgement of image features [5].

Since we did not have the services of a trained fingermark examiner, an Automatic Fingerprint Identification Systems (AFIS) was used instead to detect and match minutiae to the template to quantify the “identifiability” of enhanced latent fingermarks. The open-source software package SourceAFIS was used to detect and match groups of minutiae after the template and candidate fingermark images were scaled to the same geometric size. SourceAFIS detects two types of minutiae, bifurcations and ridge endings, and determines the location and ridge flow “direction” [6]. The groups of minutiae detected by SourceAFIS on the template and candidate fingermarks are post-processed with a global one-to-one matching algorithm that aligns, then optimally pairs, the minutiae by minimizing the total distance between the matched pairs of minutiae. N_{M} is then simply the number of these matched pairs.

Findings

To determine if the fingermark press provided fingermarks that were more consistent than manually acquired (*i.e.*, rolled) fingermarks, Table 1 compares the characteristics of press-acquired fingermarks with those for manually acquired fingermarks over sets of 9 natural fingermarks from subject 2 and sebum-enriched fingermarks from subject 1 enhanced with CP under TIR illumination. The enhanced natural and sebum-enriched fingermarks acquired with the press have higher average N_M and image intensity, and lower relative standard deviations in N_M and intensity, than their manually acquired counterparts. These results suggest that press-acquired fingermarks have more consistent characteristics. The remainder of the results shown here are therefore for press-acquired fingermarks.

Table 1. Statistics for N_M and image intensity (average ± standard deviation) for press- and manually acquired sebum-enriched fingermarks and natural CP-enhanced fingermarks.

	Sebum-enriched		**Natural**	
	Press	***Manual***	***Press***	***Manual***
N_M	22.1±4.5	16.7±6.0	15.0±4.42	10.8±3.89
Intensity	3677±394	2792±840	9427±1817	5042±1310

Table 2 compares the characteristics of images of natural (N) and sebum-enriched (SE) (press-acquired) fingermarks from subject 2 enhanced with CP, CF and FP under TIR illumination. The FP fingermarks have the highest N_M, with the SE fingermarks having slightly more matched minutiae than the N fingermarks. Interestingly, this trend is reversed for the CP and CF enhanced fingermarks. In all cases, the N fingermarks have higher *CNR* than their SE counterparts, while the SE fingermark images have higher intensities than their N counterparts.

Table 2. Statistics for N_M, *CNR* and image intensity for images of CP, CF, and FP enhanced natural (N) and sebum-enriched (SE) press-acquired fingermarks under TIR illumination.

	CP		**CF**		**FP**	
	N	**SE**	**N**	**SE**	**N**	**SE**
N_M	15.0±4.4	13.7±4.3	13.3±3.1	10.4±3.2	18.4±3.0	19.4±5.1
CNR	4.5±0.4	3.5±0.2	4.1±0.4	2.8±0.2	4.0±0.2	3.9±0.2
Intensity	9427±1817	11872±1023	13663±3180	15073±2695	6624±643	10021±1090

Table 3 compares instead the characteristics of images of CP, CF and FP enhanced natural (N) fingermarks from subject 2 under TIR and WL illumination. In all cases, images under TIR illumination had higher N_M, higher *CNR*, and much lower intensities than images of the same fingermarks under WL illumination for all types of enhancement. Based on these results, the rest of the quantitative results presented here are for images acquired under TIR illumination.

Table 3. Statistics for N_M, *CNR* and image intensity for images of CP, CF, and FP enhanced natural (N) fingermarks from subject 2 under TIR and WL illumination.

	CP		**CF**		**FP**	
	TIR	**WL**	**TIR**	**WL**	**TIR**	**WL**
N_M	15.0±4.4	13.0±4.1	13.3±3.1	10.1±5.6	18.4±3.0	9.3±4.7
CNR	4.5±0.4	4.1±0.4	4.1±0.4	2.6±1.0	4.0±0.2	3.1±0.4
Intensity	9427±1817	34054±3834	13663±3180	26097±1659	6624±643	22163±6382

Table 4. Similar to Table 2, but for SP, CF and FP enhanced N and SE fingermarks from subject 3 under TIR illumination.

	SP		**CF**		**FP**	
	N	**SE**	**N**	**SE**	**N**	**SE**
N_M	10.6±3.2	4.9±0.73	12.3±5.6	6.4±0.8	11.6±6.1	7.2±1.1
CNR	4.1±0.6	2.9±0.4	2.9±0.4	3.4±0.9	5.3±1.5	3.2±0.4
Intensity	6458±1595	16893±2382	14784±1933	17456±4114	3372±258	9409±759

Table 4 compares instead the characteristics of N and SE fingermarks from subject 3 (*vs.* subject 2 in Table 2) enhanced with SP, CF and FP under TIR illumination. The CF enhanced N fingermarks had the highest N_M, followed by the FP and the SP N fingermarks, although all average values were within a standard deviation. The standard deviations in N_M for both the CF and FP enhanced natural fingermarks were much higher than those for the SP enhancement. This may be due to the relatively few minutiae in the fingermarks from subject 3 (compared with those from subjects 1 and 2), which made it difficult for the AFIS algorithm to reliably match minutiae with those on the template. In all cases, the N fingermarks had significantly higher N_M than their SE counterparts. The *CNR* for the SP and FP enhanced N

Figure 3. Images of CF-enhanced SE fingermarks from subject 3 under TIR illumination. The scale bar denotes 1 cm.

fingermarks is higher than that for the SE fingermarks, but lower for CF enhancement. This may be due to difficulty with the cyanoacrylate ester binding to the SE fingermarks, based on visual inspection (Fig. 3).

Table 5. Quantitative results for SE fingermarks from subject 1 enhanced with CP, SP, CF and FP under TIR illumination.

	CP	**SP**	**CF**	**FP**
N_M	27.6±5.9	26.6±6.6	20.8±6.4	20.9±5.6
CNR	3.4±0.4	3.2±0.2	3.2±0.3	3.5±0.5
Intensity	4560±802	4864±860	4876±696	2831±186

Finally, Table 5 presents the characteristics of CP, SP, CF and FP-enhanced sebum-enriched fingermarks from subject 1 under TIR illumination. The CP fingermarks have the highest N_M, although the CP and SP enhanced fingermarks are essentially identical based on all three metrics. The intensities are comparable for all types of enhancement except FP, which has a significantly lower intensity.

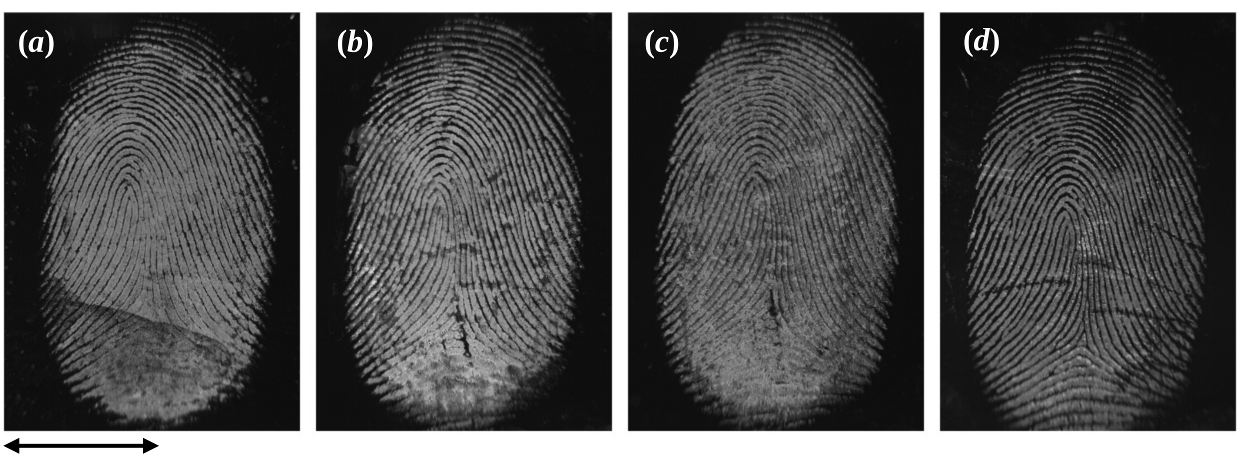

Figure 4. Images of CP-enhanced SE fingermarks from subject 1 under TIR illumination after aging for: (*a*) 3; (*b*) 27; (*c*) 54; and (*d*) 435 days. The scale bar represents 1 cm.

Surprisingly, age appears to have little effect on sebum-enriched fingermarks. Figure 4 shows representative images of SE fingermarks enhanced with CP or SP after aging between 12 h and 435 days, while Figure 5 shows N_M as a function of fingermark age over sets of 5 fingermarks.

The number of matched minutiae over this broad range of fingermark ages N_M = 19.4±4.8; remarkably, SE fingermarks appear to show almost no aging effect, even after aging for 435 days. These results for aged fingermarks are consistent with, and extend those of Alcaraz-Fossoul *et al.* [7], who observed negligible changes in sebum-enriched prints on glass slides enhanced with tin oxide for ages up to 6 months, or 180 days.

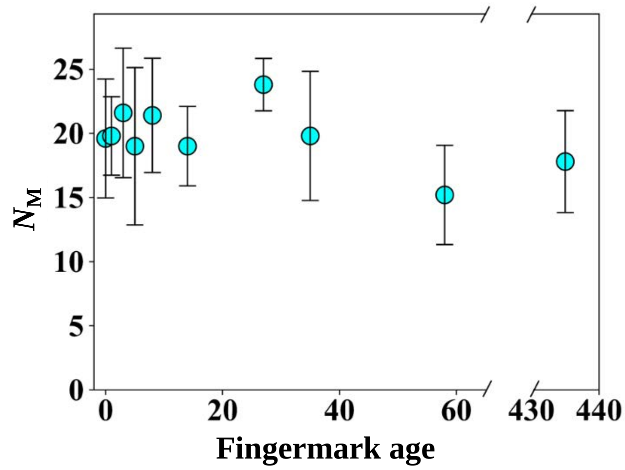

Figure 5. Graph of N_M *vs*. fingermark age for CP-enhanced, and 435 day old SP-enhanced, SE fingermarks. The error bars represent standard deviations. Note the break in the horizontal axis.

Summary

Natural (N) and sebum-enriched (SE) fingermarks from three adult (two male and one female) subjects were acquired with an in-house mechanical fingermark press on glass microscope slides. The fingermarks were enhanced with a novel system based on suspended commercially available polystyrene (PS) microparticles, and compared with conventional enhancement methods, namely fingermarks dry-powdered with fluorescent fingerprint powder and cyanoacrylate fumed fingermarks. The images of the enhanced fingermarks were quantitatively evaluated based on the number of matched minutiae N_M between the enhanced fingermark and an inked template fingermark, the image contrast-to-noise ratio *CNR*, and the (mean) image intensity as measures of fingermark "identifiability," image contrast, and overall image brightness, respectively. For all types of enhancement, the press-acquired fingermarks had much more consistent N_M and intensity

than manually acquired fingermarks for both N fingermarks from subject 2 and SE fingermarks from subject 1.

A novel large-area total internal reflection (TIR) illumination system was built in house and used to illuminate and image the enhanced fingermarks. Images of the same enhanced fingermarks acquired under TIR illumination were compared with those obtained using standard oblique white light (WL) illumination. In all cases, TIR illumination gave higher N_{M} and higher *CNR*, but lower intensities, for all types of enhancement, compared with WL illumination. These results suggest that large-area TIR illumination is a useful alternative to conventional WL illumination for acquiring images of enhanced latent fingermarks.

Overall, enhancement with PS particles gave N_{M} that were comparable to conventional enhancement methods. Specifically, PS enhanced N and SE fingermarks from subject 2 had more matched minutiae than cyanoacrylate fuming but less than dry-powdering. Natural fingermarks from subject 3, who had enhanced with PS particles had N_{M} values slightly less than, but within a standard deviation of, both conventional methods, although the fingermarks from this subject may have too few identifiable minutiae for reliable matching.

Finally, PS enhancement gave the best results for SE fingermarks from subject 1. Interestingly, PS particle enhancement appears to be capable of enhancing very old sebum-enriched fingermarks, with no significant changes in the number of matched minutiae for fingermarks aged as much as 435 days. The results from this work have been documented and submitted to the Elsevier journal *Science and Justice*.

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