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Quantifying the Effect of Seasonal Variations on the Latent Fingerprint Residues Through Photoluminescence Spectroscopy

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Abstract

Perspiration fluctuates with the season. Body mass, humidity, temperature, and other factors affect perspiration. Due to higher temperatures, warmer seasons produce more perspiration in the individuals which is the opposite with colder seasons. Seasonal perspiration regulates body temperature in different climates. Due to seasonal and environmental factors, fingerprint residues are subject to variations. Photoluminescence and UV-VIS spectroscopy were used to evaluate fingerprint residues and their response with respect to seasonal variations. To test the hypothesis, 1600 latent fingerprint residues were collected under various conditions spanning the summer and winter seasons cycle for a year. The collected samples were subjected to ultraviolet (UV) light from 200nm to 1600nm to examine their absorption spectra. Further, their fluorescence intensities were measured using photoluminescence spectroscopy. The research's positive outcomes demonstrate that photoluminescence spectroscopy may accurately detect seasonal resonances on latent fingerprint residues, which can be termed seasonal markers.

Keywords: Photoluminescence spectrometry; Spectrofluorimetry; latent fingerprints; seasonal changes; dactylography

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Introduction

The friction ridge epidermis of the digits creates distinct and permanent patterns of ridges and valleys that constitute fingerprints. Due to their uniqueness and constancy over an individual's lifetime, these patterns, which include minutiae points and ridge characteristics, are utilized in forensic science, law enforcement, and diverse security applications for the purpose of identification. Individual fingerprints consist of intricate, distinctive designs that are discernible on the extremities, palms, and soles of the hands and feet. These patterns are present on the friction ridge epidermis, which is formed during fetal development and is subject to genetic and environmental influences. The development of fingerprint patterns in the neonate commences during the tenth week of gestation. The asymmetrical development of dermal papillae, which are situated in the dermal layer of the epidermis, produces ridges and valleys. Once established, these patterns exhibit minimal variation over the course of an individual's lifetime. The elevated epidermis constitutes the ridges, whereas the valleys comprise the spaces in between the ridges. Along the ridges are sweat pores, which secrete perspiration and oil, and these pores can produce discernible ridge patterns.

A comprehensive understanding of the complex intricacies and distinctiveness of fingerprints is imperative for their utilization across diverse domains, including criminal justice and biometric security. In tribunals, fingerprints are generally acknowledged as a dependable means of verifying identity. This study provides further insights into the correlation between seasonal variations in perspiration and the efficacy of developmental techniques pertaining to perspiration. As conventional development techniques are predicated on perspiration rate, this research aids forensic and fingerprint specialists in the application of more precise techniques. This particular objective is the focus of the study, as there is a dearth of literature that explicitly investigates this research problem (seasonal and climatic variations in perspiration).

Studying the seasonal fluctuations in latent fingerprint residues guarantees more uniformity and dependability of proof. Precision in fingerprint analysis is of utmost importance in forensic investigations since it may significantly influence the result of a case. The conditions

of latent fingerprints may be influenced by seasonal variations, resulting in a broad range of crime scene surroundings. Through the process of quantification, forensic analysts can enhance their interpretation and analysis of fingerprints discovered at crime scenes, resulting in more precise reconstructions of events.

Background

Utilizing photoluminescence spectroscopy to investigate the impact of seasonal fluctuations on fingerprint remnants is an innovative and unique method. This methodology offers a non-invasive and very sensitive approach to examining chemical alterations in fingerprints, representing a significant improvement compared to conventional approaches. This study introduces a novel aspect by taking into account environmental conditions, which earlier studies may have overlooked when analyzing fingerprint remains. This comprehensive method offers a more profound understanding of how fingerprints deteriorate or alter over time in various circumstances.

This research is the *first* to accurately measure the impact of seasonal changes on fingerprint remains using photoluminescence spectroscopy. This establishes a standard for future investigations, promoting more study into the overlap between environmental science and forensic analysis. This study establishes a connection between the fields of forensic science, environmental science, and sophisticated spectroscopic methods. The combination of several disciplines might result in the development of creative solutions and novel approaches in the field of forensic investigations. The discoveries may result in the development of novel forensic instruments and substances that are specifically designed to identify fingerprints under different environmental circumstances. Crime scene investigation techniques need to be enhanced to include factors related to seasonal fluctuations, hence enhancing the caliber and uniformity of fingerprint evidence gathering and examination.

Methods and Methodology

(a) Sample Collection:

The stratified samples collection method was employed to collect the samples, with an even interval of 8 days between each collection.

This process was conducted from December 2021 to December 2022. The undeveloped latent fingerprints were collected from both male and female individuals between the ages of 20 and 25 on glass transparencies that were cleansed with ethanol prior to collection.

Under the subsequent categories, a total of 1600 samples were collected:

i. 40 female samples were collected from 10 subjects during the designated sample collection period under the Uncontrolled condition (UF)

ii. 40 male samples were collected from 10 subjects during the designated sample collection period under the Uncontrolled condition (UM)

iii. 40 female samples were collected from 10 subjects during the designated sample collection period under the controlled condition (CF)

iv. 40 male samples were collected from 10 subjects during the designated sample collection period under the controlled condition: (CM)

(b) Sample Conditions:

Two conditions were used to obtain samples from both sexes: (i) Controlled Samples: samples that were preserved from environmental contaminations and maintained at a consistent temperature of 37^{o}C. The samples were preserved by sealing them in hermetic containers immediately following their collection. (ii) Uncontrolled Samples: samples that were subjected to environmental conditions. For example, a wet laboratory with exposed windows and no temperature control is used to simulate an indoor crime scene scenario. The samples were stored at Gandhinagar, Gujarat, and hence, the environmental conditions of Gandhinagar

(c) Sample Preparation:

The neutral pH solvent (distilled water) was used to cleanse the samples collected on the glass slides, which included both male and female samples as well as controlled and uncontrolled samples. The

glass slides were rinsed with 3 ml of distilled water using a syringe to apply pressure to remove the perspiration composition from the desiccated condition. The cleanse was employed for the analysis. The wash was initially studied under the UV-VIS Spectrometer with the range of 200nm to 1400 nm to investigate the absorption wavelength of the extant fingerprint residues. All of the samples exhibited a robust absorption at 297 nm. Following this, the samples (wash) were transferred onto the photoluminescence spectrometer, and the emission rate at the 297nm wavelength was examined.

The controlled condition samples are free of contaminations; therefore, they also function as control samples for the purpose of evaluating the impact of contamination on the uncontrolled samples. The contamination present in the uncontrolled samples has minimal to no impact on the age estimation of the latent fingerprints, as both the controlled and uncontrolled samples exhibit the maximum absorption at 297nm.

Instrumentation used for the Study

(a) UV-VIS-NIR Spectrophotometer (Make: Varian; Model: 5000):

This method is widely used in the disciplines of chemistry and biology. Its application entails the examination of the manner in which chemical substances absorb ultraviolet and visible light. The instrument is comprised of a light source, which is typically a deuterium lamp for the ultraviolet spectrum and a tungsten lamp for the visible spectrum. Furthermore, the apparatus includes a detector, which may be a photomultiplier tube or a photodiode array, a monochromator for precise wavelength selection, and a sample receptacle. Electronic transitions, which involve the transfer of electrons from orbitals with lower energy to orbitals with higher energy, occur when a molecule absorbs ultraviolet (UV) or visible light. The energy discrepancy between the excited and ground states of the molecule is equivalent to the absorption energy. The transmitted light is perceived through the detectors, which produce the spectrograph, which shows the wavelength at which the absorption is achieved and maximum.

(b) Spectrofluorometer (Make: Jobin Yvon; Model: Fluorolog - FL3-11):

This research employed the Spectrofluorimetry technique to study the variation in the fluorescence emission spectrum of the latent fingerprints that were collected during different climatic conditions for a period of one year, in its undeveloped state. Spectrofluorimetry is a scientific instrument that utilizes a light source to transmit light through a specific sample, allowing the detectors to evaluate the material's response to the excitation generated by the light source.

The study was conducted on the samples that were collected under two sets of conditions: conditional and unconditional samples; the former was prevented from having any such environmental contaminations and maintained at a controlled temperature, respectively (i.e., 37^{o}C), whereas the latter was exposed to the environment and had no control over the temperature and contaminations to depict the indoor crime scene scenario. This study also addressed a common challenge faced by fingerprint analysts, demonstrating the efficacy of sophisticated scientific apparatus methodologies in the context of criminal investigations.

Results and Discussions

The samples were collected over the span of one year, from December 2021 to December 2022, in accordance with the winter-summer-winter cycle (UF (Uncontrolled Female Samples), UM (Uncontrolled Male Samples), CF (Controlled Female Samples), and CM (Controlled Male Samples). Utilizing sterile glass slides, the acquisition procedure established a standard protocol. Time-dependent photoluminescence distinguishing potential that could be applied to the latent fingerprints was assessed by examining the samples for the presence of such potential with the help of the instrumentation Photoluminescence Spectroscopy.

The ability of the samples to absorb and emanate light, as stipulated by the principle, is a prerequisite for the observation of luminescence. For this purpose, UV-Vis Spectroscopy was utilized to analyze the absorbance of the 160 samples. At wavelengths of 297nm and 356nm, all of the samples demonstrated absorption, with absorption at

297nm being the most pronounced. Furthermore, photoluminescence spectroscopy was employed to evaluate the emission capabilities of each sample.

The mean emission intensity data obtained through PL Spectroscopy analysis per week is presented in the table below (Table 1).

Sample Collection Week No.	Uncontrolled-Female Samples	Uncontrolled-Male Samples	Controlled-Female Samples	Controlled-Male Samples
1	67890	61234	93646	50671
2	75281	67017	100320	57527
3	73062	72860	84641	74617
4	54289	72034	59298	63595
5	56999	96373	142990	57441
6	52441	100056	132861	77017
7	65975	90942	85041	74757
8	72065	90279	81910	68866
9	74419	88014	77910	71956
10	74451	68045	82391	91961
11	898434	477904	162456	262196
12	1204994	225576	186974	291260
13	179078	206143	146037	242337
14	223260	188524	169752	445197
15	197133	229973	155444	66048
16	310734	239094	154134	2298830
17	225424	273890	464394	289633
18	408990	215138	998652	182189
19	235924	194338	758599	217742
20	259921	261966	1926736	175259
21	1365844	59462	137653	116527
22	94662	77662	810972	113624
23	575792	88665	141799	117018
24	171515	65834	146562	122755
25	135809	183558	128327	124056
26	142635	141633	132643	32573
27	148822	129239	129313	132721
28	128827	134256	133345	128064
29	136782	132954	142057	134423
30	131999	129676	137635	126428
31	154648	134822	219004	133828

Sample Collection Week No.	Uncontrolled-Female Samples	Uncontrolled-Male Samples	Controlled-Female Samples	Controlled-Male Samples
32	143162	137575	137096	128561
33	144776	144249	125629	145981
34	98279	143691	128954	144569
35	440153	160242	129543	132349
36	45244	107029	119748	140402
37	69282	145583	127742	131332
38	134378	139291	128024	131826
39	132890	147335	80711	128568
40	1008171	144236	96076	130801

(Table 1: Mean emission intensity of the samples- UF, UM, CF, and CM collected for 40 weeks; Unit: CPS; count per second)

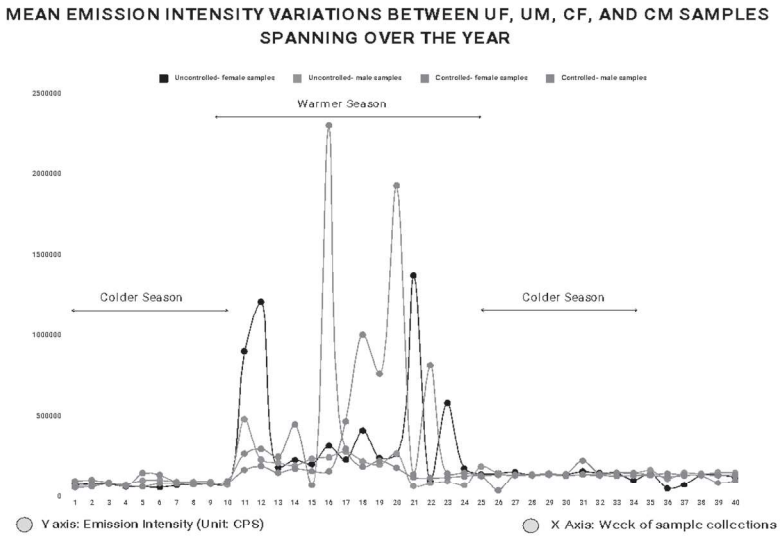
The table demonstrates a comprehensive understanding of the emission fluctuation among the categories UF, UM, CF, and CM. Firstly, the samples exhibited greater variability in the summer and lower variability in the winter, which can be attributed to the significantly higher amount of sweat produced during the summer and the contrary pattern during the winter. Upon comparing the variations in the mean values of emission intensity within the samples, the mean emission intensity rates over time were found to be higher in the controlled female and controlled male samples than in the uncontrolled female and uncontrolled male samples that were exposed to environmental conditions. This is majorly due to the factor of swear residue in the fingerprint sample's slow degradation according to the law of progressive change, which states that with the passage of time, there are changes and damages to the original properties of the evidence.

In this study, the controlled samples were utilized as the reference samples, while the uncontrolled samples served as the comparative samples. The uncontrolled samples exhibited emission variation comparable to the controlled samples when analyzed using PL spectroscopy, with the main distinction being the intensity of the emission.

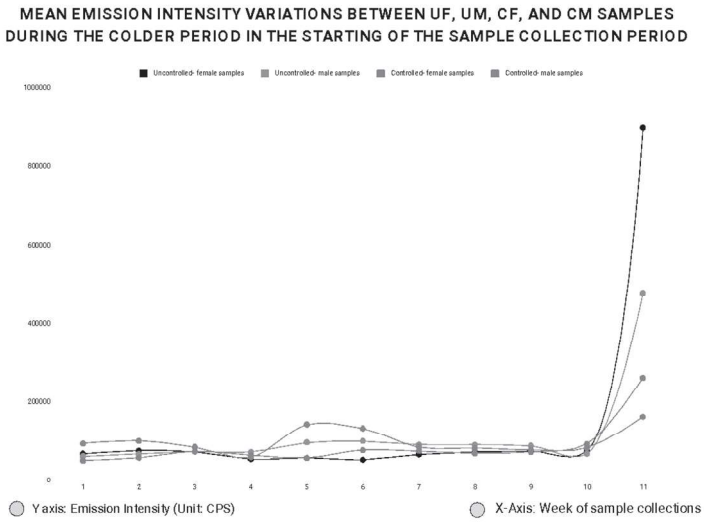
The difference in the means of the variation in emission intensities with regard to seasonal changes is shown in the graph below (Graph

1). The intensity variation is found to be higher with the controlled samples, which are free from environmental contaminations in comparison to that of the uncontrolled samples. On observing the samples, in the controlled conditions, the male samples exhibit a higher emission intensity, whereas the female samples show lesser intensity.

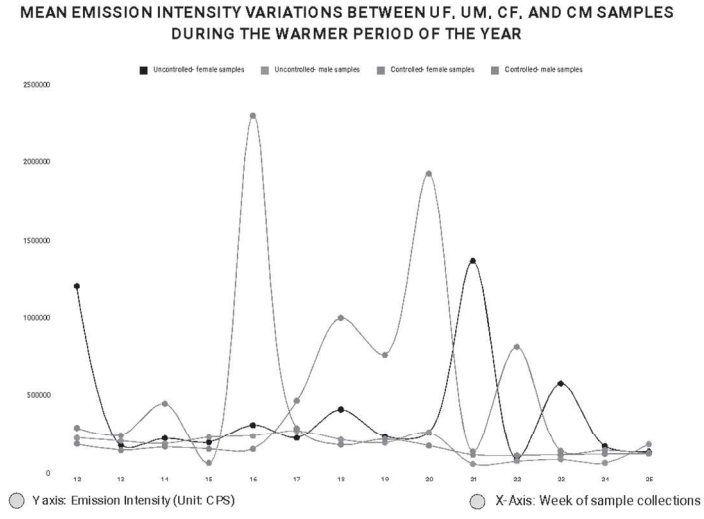
Contrastingly, on observing the uncontrolled samples, it was found that male samples showed lesser intensity in the summer than female samples, which explains three conditions: (a) the male fingerprint residues exhaust faster than female samples, (b) the degradation is faster than the female fingerprint residues in the warmer months, and (c) the male samples are more affected by the environmental conditions and contaminations than that of the female samples.



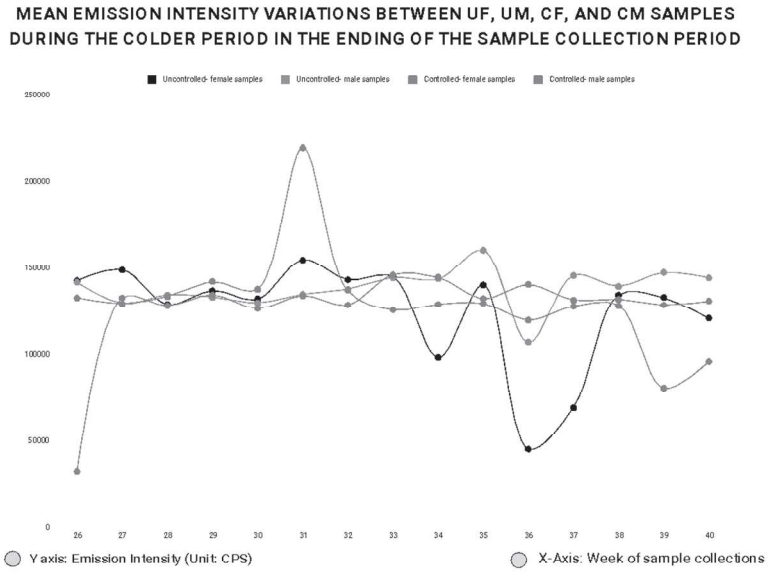
(Graph 1: Graphs indicating the variation in the mean emission intensities with respect to the seasonal change between the samples- UF, UM, CF, and CM))



Graph 2: Mean emission intensity variations between UF, UM, CF, and CM samples (during the colder season at the start of the sample collection period)



Graph 3: Mean emission intensity variations between UF, UM, CF, and CM samples (during the warmer season of the year)



Graph 4: Mean emission intensity variations between UF, UM, CF, and CM samples (during the colder season in the end of the sample collection period)

To prove the above hypothesis, a statistical examination such as the z-test, t-test, and F-test was performed among the samples between the samples collected during the summer and winter months, and their P-values are mentioned below in table no.2.

Z-test:			t-test:	F-Test Two-Sample for Variances
Category	**P-Value (one-tail)**	**P-Value (two-tail)**	**P-Value**	**P-Value**
UF(s): UF(w)	0.012	0.042	0.0073	0.0413
UM(s):UM(w)	0.004	0.011	0.0391	0.0383
CF(s):CF(w)	0.0319	0.046	0.0198	0.0213
CM(s):CM(w)	0.051	0.012	0.0149	0.009

(Table 2: Significance analysis on the samples of the mentioned categories) (*s=summer, and *w=winter)

The above table implies that there are significant results in the fingerprint residues and their emission intensities with respect to their seasonal changes. All the above significance are $P<0.05$.

Descriptive Statistics for the Samples:

Category:	*Overall*	*UF*	*UM*	*CF*	*CM*
Mean	20.50	255360.81	171659.71	234925.37	191387.53
Standard Error	1.85	50201.53	27042.28	54015.79	55470.76
Median	20.50	139708.65	138433.05	133102.75	128564.45
Mode	-	-	-	-	-
SD	11.69	317502.36	171030.40	341625.84	350827.88
Kurtosis	-1.20	5.17	23.87	15.92	35.71
Skewness	0.00	2.40	4.52	3.78	5.84
Range	39.00	1320600.00	1047566.60	1867437.80	2266257.20
Minimum	1.00	45244.40	59462.30	59297.70	32573.20
Maximum	40.00	1365844.40	1107028.90	1926735.50	2298830.40
Sum	820.00	10214432.50	6866388.30	9397014.80	7655501.10
Count	40.00	40.00	40.00	40.00	40.00
Confidence (95.0%)	3.74	101542.18	54698.18	109257.25	112200.20

(Table 3: Descriptive statistics for the samples: UF, UM, CF, CM, and Overall)

The table below shows that the controlled female samples exhibit a maximum mean emission intensity of around 1926735.50 CPS (counts per second). In comparison, the controlled male samples show a maximum mean emission intensity of roughly 2298830.40 CPS during the summer. The uncontrolled female samples exhibit a maximum mean emission intensity of approximately 1365844.40 CPS (counts per second). In comparison, the uncontrolled male samples show a maximum mean emission intensity of roughly 1107028.90 CPS during the summer.

Contrastingly, the controlled female samples exhibit a maximum mean emission intensity of around 59297.70 CPS (counts per second), while the controlled male samples show a maximum mean emission intensity of roughly 32573.20 CPS during the winter months. The uncontrolled female samples exhibit a maximum mean emission intensity of approximately 45244.40 CPS (counts per second). In comparison, the uncontrolled male samples show a maximum mean emission intensity of roughly 59462.30 CPS during the winter months.

ANOVA test was also performed with Type 1 error, and the following table (Table 4) shows the significant results of the tested hypothesis.

ANOVA ANALYSIS:						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1634109344383.06	4.00	408527336095.76	5.52	0.00	2.42
Within Groups	14424055174671.10	195.00	73969513716.26			
Total	16058164519054.20	199.00				

(Table 4: ANOVA for the samples: UF, UM, CF, and CM)

A correlation analysis was conducted on the samples to assess the statistical significance of the study further. The results indicated that the mean emission intensity data of all the fingerprint residues exhibited a consistent positive correlation with time, indicating that as the residue settlements are newer, the intensity of the emission is also higher. (Table 5) Moreover, to strongly support the hypothesis, the regression model was performed between categories UF, UM, CF, and CM between summer and winter samples, and the Variance-inducing Factor (VIF) was studied. Table 6 shows the VIF values were derived from the regression model's R square value using the following formula:

VIF value = 1 / (1-R sq value)

CORRELATION TEST				
	UF	*UM*	*CF*	*CM*
UF	1			
UM	0.057238671	1		
CF	0.031052069	0.096905193	1	
CM	0.10371341	0.127280008	0.014096389	1

VARIANCE INFLUENCING FACTOR ANALYSIS		
CATEGORY	**R SQ VALUE**	**VIF VALUE**
UF(s):UF(w)	0.00620158	1.006240284
UM(s):UM(w)	0.0509424	1.053676847
CF(s):CF(w)	0.0000311	1.000031092
CM(s):CM(w)	0.0015678	1.001570267

(Table 5: Descriptive statistical data of the samples: UF, UM, CF, and CM, and Table 6: Variance Influencing factor analysis for the samples: UF, UM, CF, and CM) (*s-summer, and *w-winter)

The variance-inducing factor above 0 indicates that there is a variance between the winter and summer samples, and regardless of the sexes, the fingerprint residues are influenced by the seasonal changes, and these results aid in understanding latent fingerprint residue deposition with the help of UV-Vis spectrometry and Photoluminescence Spectroscopy.

Conclusion

Sweat is not just water; it also contains electrolytes like sodium, potassium, and chloride. The composition of sweat may vary slightly among individuals, but its purpose is to help maintain the body's electrolyte balance. Perspiration, or sweating, can vary with the seasons in humans. The amount and nature of sweating are influenced by several factors, including temperature, humidity, physical activity, and individual differences. In warmer seasons, such as summer, people tend to sweat more due to higher temperatures. Sweating is the body's natural mechanism to cool down and regulate body temperature. Humidity also plays a role. In humid conditions, the air is already saturated with moisture, making it harder for sweat to evaporate. In contrast, it is the opposite when it comes to the cold climatic conditions. People vary in their sweat rates and responses to temperature. Some individuals may be more prone to sweating profusely, while others may sweat less in similar conditions. Overall, the variation in perspiration with the seasons is a normal part of the body's response to environmental conditions, and it helps humans maintain a stable internal temperature in different climates. Considering this important fact, it is very unlikely that fingerprints are less affected by seasonal changes, which also come with different climatic conditions. This study spotlights on how seasonal changes bring changes in the fingerprint residues using UV-VIS spectrometry and Photoluminescence Spectrometry techniques.

Photoluminescence spectroscopy may be used to determine the most favorable circumstances for identifying latent fingerprints in various environmental settings. By using this technique, the sensitivity and specificity of fingerprint detection may be improved, enabling the recovery of fingerprints that may otherwise go undetected. Analyzing the impact of environmental conditions on fingerprint residues

to enhance evidence preservation protocols. Forensic teams may implement measures to mitigate the influence of seasonal fluctuations on gathered evidence, guaranteeing its long-term integrity.

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Conflict of Interest: There are conflicts of interest among the authors with respect to this study.

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