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Persistence Of Fingerprint in Adverse Environmental Conditions Such as Temperature, Moisture, Change of Surface

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ABSTRACT

The review article "Persistence of fingerprint in adverse environmental conditions like temperature, humidity, change of surface" presents different types of fingerprints and its persistence under different environmental conditions. Fingerprint is an individual characteristic and are among the earliest and most common forensic evidence to be employed for individual identification. According to the report of the Central Bureau of Investigation, 'fingerprint identification is the most promising method of identification on an individual basis which is founded on the exclusive and repetitive pattern of the ridge details found on the fingertip the most common prints found at the crime scene are the latent prints.". They are not visible prints retained on a substrate due to various bodily secretions."

Fingerprints can be deposited on a variety of substrates, which are typically categorized as porous, non-porous, and semi-porous surfaces. Non-porous surfaces typically are non-absorbent, and therefore the quickly deposited fingerprint residue would be more likely to be eliminated. Prints were deposited on the surfaces as mentioned. Natural prints were impressed on the substrates without pre-hand-washing or post eccrine (wearing gloves) or sebaceous (rubbing fingers on the nose) print grooming. Normal fingerprint is a distinct pattern unlike any other. Fingerprints are the oldest biometric identification method for human beings and have been utilized in China to verify legal documents for three thousand years. Non-porous smooth surfaces consist of glass, metal, and plastic.

INTRODUCTION

Dactyloscopy is the forensic science analysis of the identification of a person based on the study of patterns of resistance edges on the tips of the fingers. The strength and wear-off of impressions are influenced by factors such as the gender and BMI of the person and how long and under what conditions they have reinforced. which also can be change due to temperature. There is an abundance of literature on the role of time played in the perception of fingerprints comprising sebum and sweat, yet little is known regarding the preservation of bloody fingerprints because of the reason that pattern of blood gets created in highly poor cases or are mostly non-existent. The experiment sought to see how sex, dry and fresh conditions of the blood constituting the print, external conditions, then while affected the size of friction ridge prints in fingerprints. Fingerprints from renewed blood survived the longest while those of the female and those exposed to exterior conditions deteriorated the quickest. Because there are many types of gases in the air and temperature is always changing, the print is readily deformed, ambient temperature also played an important role in the width of friction ridge impressions and degradation. The persistence is used to both friction ridge skin and impressions made from these friction ridges. Permanence and ace of skin were measured from direct finger photographs taken two months apart and from finger photographs separated by a time interval of at least 8 years. Because fingerprints never change Perpetuity and persistence were also measured from impressions taken 4 months apart, as well as those separated by 8–53 years. Capture technique inconsistency was tested by using four image capture methods for four months: direct finger photography, ink impressions, holographic images, and live scan. All changes discovered over time and any limitations of capture techniques were reviewed by trained latent fingerprint examiners. Where multiple techniques are used like powder technique, tap technique and optical techniques.

Latent prints are usually negligently deposited at crime scenes in the process of criminal investigations. Whether in whatever state, these prints can be lifted from a myriad of surfaces, and even ephemeral prints which are usually made up of skin oils can be treated so that traceable ones can be produced. These prints are extremely valuable when it comes to implicating a suspect in a crime even though they are incomplete, smudged, or imperfect. One of the most important

pieces of evidence that the enforcement of law can use to confirm or rule out suspects is a fingerprint. There is no comprehensive survey presently available which examines the numerous studies conducted on fingerprint identification and classification. The continuous usability and development of fingerprint analysis signify its critical role in forensic science and daily security use, a guaranteed way of ensuring security and recognizing people in different situations. In an attempt to fully acquire and examine the existing fingerprint research, additional research is required. (Win et al., 2020).

From Locard's exchange principle, in which trace materials are swapped when two surfaces meet each other, fingerprints become an important part of forensic science. When the fingers meet a surface, papillary ridge material is left behind and forms a fingerprint. These prints, especially latent ones, consist largely of sebaceous gland sebum and body sweat gland, eccrine and apocrine gland, secretions. They are not typically visible to the naked eye. Fingerprints can have any form of contamination, such as food particles, cosmetics, or skin cells present on the skin during contact, as well as normal body fluids. Fingerprints have been the gold standard of individual identification in criminal cases for decades. Latent prints aren't typically visible, however, and need to be made apparent by enhancing techniques. The conventional methods such as optical, physical, and chemical methods are rooted in the composition of the fingerprint residue and their interaction with various substances. Traditional methods can be restricted despite their effectiveness because of factors such as complex surfaces, health hazards, and damaging nature to improve latent print identification, new techniques have been invented as a counter to them, some of which include electrochemical techniques, mass spectrometry imaging, spectroscopy, immunogenic and nucleic acid probes, and nanoparticles Fingerprints can potentially contain valuable additional information beyond mere photographs, as per recent research.

Detection of endogenous and exogenous contaminants like explosives and drugs in the latent print allows investigators to link a suspect even more to a crime. This is a deeper understanding of the evidence. These advances still raise the overall capacity of fingerprint analysis to aid criminal investigations as well as open doors to even more sensitive and accurate forensic analyses (Khare & Singla, 2022).

Optical fingerprint sensors have, in the past, suffered with image quality issues caused by factors such as humidity, dirt, and skin or sensor surface topography. Such limitations could constrain the performance of fingerprint identification in real applications. As much as this has been the case, optical fingerprint systems have remained common largely due to the advancements in affordable high-resolution digital image sensors. Surprisingly enough, recent studies challenged the existing belief that water influences optical fingerprint imaging, especially the frustrated total internal reflection (FTIR) method. High levels of wetness on the surface of the fingerprint have the ability to improve image quality by becoming more apparent on the fingerprint patterns, according to research findings. This is an important milestone in understanding how moisture interacts with optical sensors. But the qualitative nature of the research restricts the validity of this conclusion. Generalizability and scientific validity of the claim are restricted because the results were not supported by quantitative information or systematic studies. To ascertain whether moisture always improves image quality and under what conditions this is the case, further research with precise quantitative measurements is needed. The outcome is an encouraging but unfounded result until then (M Shin, S Lee 2025).

LITERATURE REVIEW

Wone et al. (2021) has been discussed that the objective of biometrics testing is to determine the extent to which a biometric system performs in a way that will assurance safety, operator knowledge levels. Constructing biometric hope organizations critical to many manufacturers. The comparison corresponding notches among genuine, fake taster assumed record is normally applied to measure performance. Presentation a biometric scheme remains changed by multiple biases, particularly those due to environmental factors. In work, consider influence gaining circumstances pattern organizations while also seeing precision and quality. We developed our own database to control gaining circumstances, and observe how three dissimilar matchers respond with this biometric information.

Nandar et al. (2020) has discussed that the Fingerprints are essential to criminal investigations and community security, including forensic investigations, law enforcement, customs clearance, and public security agencies. People may also live

more secure and pleasurable lives as a result of this. Numerous neural network and machine learning techniques have been put forth for the collection, identification, categorization, and analysis of fingerprints. We provide a current literature review fingerprint organization procedures impression applications illegal examination in survey.

Jang & Yang et al. (2022) has discussed that the Since humans have been exposed to bisphenol A (BPA) and bisphenol S (BPS) from a variety of products on a regular basis, the consumption of BPS/BPA by humans has been thoroughly investigated. Detecting BPS/BPA in human body organization using traditional biological matrices like urine, blood, or dissected skin is frequently invasive, necessitates a longer exposure period, and rarely identifies contaminant basis of accrued BPS/BPA.

Khare & Singla (2022) has discussed that the Fingerprint analysis is still the most popular method for obtaining significant forensic evidence, despite notable advancements in DNA analysis and recognition. Pattern contrast used for eternities to identify people, but loses effectiveness when pattern hazy, incomplete, or not present in the database. Thus, the evidence will be supplemented by new information derived from the last ten years of improvements in analytical techniques.

Gülekçi (2021) has discussed that each individual has fingerprints that are distinct, and they play a critical role in crime scene work. More effective methods of identifying fingerprints that are either faded or do not have sufficient detail are continually under research. Four individuals, two females and two males, old among 24 and 50 eternities ancient, provided their consent for fingerprints to be sampled for this investigation. To create the fingerprints in a controlled laboratory setting, the research utilized porous and nonporous materials. Cyanoacrylate vapor and staining techniques were applied to treat nonporous materials such as glass, metal, and plastic. Iodin ether, ninhydrin, silver nitrate remained applied to absorbent materials like raw wood and paper. Quality photos were captured in an attempt to enhance the image of every sample and enhance visibility of the fingerprints.

METHODOLOGY

This review is prepared with peer reviewed research articles collected from authentic databases which Google Scholar, JSTOR, Scopus, Elsevier and the Keywords used for this data collection are Fingerprint, classification, Fingerprint identification, Detection, Development etc. This review follows secondary data analysis about the topic of “Persistence of fingerprint in adverse environmental conditions such as temperature, moisture, change of surface etc”. Forensic analysis relies to a great extent on fingerprints' resilience to adverse environmental conditions because it influences the possibility classifying accused connecting them crime scenes. Volunteers' patterns were obtained and transferred to both non-porous surfaces such as glass, metal, and plastic and porous resources a paper, raw timber in a recent study. The results showed that the longevity and visibility of fingerprints are greatly affected by surface type, temperature, and humidity.

Table 1: Inclusion and Exclusion Criteria

Inclusion Criteria	**Exclusion Criteria**
Peer-reviewed journal articles	Non-peer-reviewed sources
Published between 2020 and 2025	Publications before 2020
Written in English	Written in different languages
Focused on Persistence of fingerprint in adverse environmental conditions such as temperature, moisture, change of surface etc.	Not focussed on Persistence of fingerprint in adverse environmental conditions such as temperature, moisture, change of surface etc.

5 most evident research articles are selected for reviewing on the specific topic of Persistence of fingerprint in adverse environmental conditions temperature, moisture, change of surface etc.

Table 2: Presentation of Collected Secondary Data

Author Name	**Year**	**Title of the Research Article**	**Found from the Database**	**Relevance with the topic**
Jang, et al.	2022	sensitive environmental forensic method that determines bisphenol S and A exposure within receipt-handling through fingerprint analysis.	Google scholar	An environmental forensic technique that uses fingerprint analysis to identify exposure to bisphenol S, A during receiving management.
Khare, el al.	2022	A review on the advancements in chemical examination of composition of latent fingerprint residues.	Google scholar	An overview of the developments chemical analysis of latent fingerprint residue composition.
Shin, et al.	2024	A Quantitative Analysis Study on the Effects of Moisture and Light Source on FTIR Fingerprint Image Quality.	Google scholar	A study using quantitative analysis to examine how dampness, light source affect the quality FTIR fingerprint images.
Gülekçi	2021	Effects of Environmental Factors on Fingerprint Development.	Google scholar	environmental influences the formation of fingerprints.

Wone, et al.	2021	Impact of environmental conditions on fingerprint systems performance	Google scholar	Environmental factors' effects on the functionality of fingerprint systems

RESULTS AND DISCUSSION

The most important evidence identification of an individual in a case of forensic science is a fingerprint, which has been left the thing at crime scene. Since fingerprints, even twins', are unique and relatively stable during lifetime of an individual, they can be identified with accuracy. Crimes always deliberately eliminate or erase apparent fingerprints at crime scenes, but they are incapable of eliminating latent fingerprints that apparent, worry for front-line detectives. Everyone knows first level information and second level information in fingerprints are alike in being vital to fingerprint identification and used to trace down suspects who left prints. LFPs visualization materials have been prepared and of high interest. Among the most critical types of evidence used in forensic analysis identification of individuals crime scene fingerprints. Fingerprints are certain form of identification as they are exclusive to every and each individual, twin siblings or brothers, and not experience any alteration in their whole lifetime (Riaz et al., 2024).

Fingerprints have also some thermal resistances. Fingerprint oily content survival capacity of up to 300°C, especially metal and glass. Elevated heat with elevated humidity, however, leads to water and volatile component evaporation with print degradation. Fingerprints tend more useful for identification at ambient temperatures (i.e., ca. 50°C) rather extremes.

It is not crucial for new fingerprints to be humidified, when prints get older, moisture plays a vital role successful development. Excess moisture or extended soaking in water accelerates its deterioration, especially on porous surfaces. More pressure during fingerprint deposition causes distortion of ridge detail, and extended contact has no impact quality or quantity of material that is moved.

Physiological variation among persons and finger hygienic factor can affect amount and character of ridge detail printed. Fingerprints last longer glass and metal than on wood and paper, as these are porous. In areas where air conditions are involved, fingerprints remain identifiable for a period of up to 12 months on a nonporous surface physical disturbance does not occur. Under moist environments, porous surfaces paper deteriorates quickly while nonporous surfaces enable the classification of fingerprints for 30–90 days whether the water is sea water or freshwater. Fingerprint permanence is also influenced by temperature; nonporous surfaces, prints will last exposure to 300°C but their visibility is reduced. 4°C cold storage refrigeration can cause cadaver fingerprints to be preserved for 24 hours, as opposed to 18 hours in the warm environment. The quality fingerprints depends on levels of humidity also—80% humidity is ideal for the development of ridge detail and 100% humidity smoothers out prints over time. Excessive pressure (>400g) applied during deposition can compromise ridge detail, whereas natural, light contact retains the integrity of fingerprints. Long-term stability under environmental conditions of temperature and humidity deteriorates through evaporation and abrasion. New techniques like the employment of iodine-silver plate enable detection on cadavers within 18–24 hours but not on alive skin beyond 15 minutes. More recent trends using nanomaterials, fluorescent markers, and metal-organic frameworks are improving sensitivity for detection, especially in degraded or unsuitable circumstances.

Surface type and condition have strong effects on fingerprint persistence. Glass and metal are surfaces that are free of pores on which fingerprints can remain for extended periods, as studies indicate up to 12 months' longevity in air and 30–90 days' longevity in water. Sorbing mediums such as raw wood and paper enable prints to degrade more rapidly by swelling and absorbing, often restricting recovery to 1–4 weeks of water but conceivably more with air-borne prints unless mishandled. Manmade surfaces such as plastic and nylon may be altered by heat (200–300°C), deforming the surface and obliterating fingerprints. Temperature is also of utmost concern; whereas prints can withstand up to 300°C with decreasing

quality, intense heat (500–700°C) may result in thermal self-formation of latent prints, but this is too surface-reliant and never of any forensic utility. Low temperatures prevent fingerprint formation due to decreased chemical activity and alteration in residue viscosity. Detection is also influenced by humidity—80% humidity conditions best print development, and 100% humidity fills out the details of the ridges and smoothers out the pattern.

Three main categories of fingerprints that found at crime scene: latent prints, most commonly sought after fingerprints in criminal investigations are not visible to naked eye, visible prints, impression prints, or relief prints. Knowledge of the kind of surface where the fingerprints are located and the environment, they exist in is paramount to successfully detecting fingerprints. Classification of surfaces into porous (like paper or cloth) and non-porous types is very vital in determining the best method of detection. With the exception of friction ridge skin, all of the surface characteristics, such as absorbency, surface texture (smooth or rough), and existence of fluids such as blood or oil, can influence the quality and visual presence of a fingerprint. Environmental conditions such as temperature and humidity and the duration for which the print has been present on the surface influence detectability. To select the most appropriate method of fingerprint recovery, forensic examiners must thus take each of these factors into deliberation.

On surfaces, non-porous prints last up to 90 days in fresh water and about 30 days in sea water while porous surfaces deteriorate in weeks. Physiological characteristics of gender, age, and hand hygiene affect the print quality, with women and older individuals, and clean-handed people, leaving identifiable prints as a result of reduced sebum and sweating. Fingerprints persist more than 2.5 years non-porous surfaces combined with impurities such as linseed oil or foodstuffs, especially under indoor stable conditions. Exposure to UV sunlight outdoors, rain, and temperature fluctuations, however, enhances degradation, particularly on porous surfaces. Successful recovery methods vary with surface type: dust brushing and cyanoacrylate fuming most successful on non-porous exteriors, and chemical reagents such as ninhydrin on porous surfaces but deteriorate with age. Notably, the quality of a fingerprint cannot be trusted to determine age after exposure to heat, and therefore contextual evidence must be used in forensic examination.

Forensic Consistency Fingerprint persistence depends on friction ridge pattern permanence that permits prolonged consistency of impression indication in documentation despite the environment rendering latent print quality poor. Adverse Conditions Although fingerprints may survive on some surfaces and under certain environmental conditions, they are degraded in quality and discoverability by conditions like high humidity, extreme temperatures, and long-term immersion in water particularly on porous surfaces. Non-porous surfaces should be a priority for latent print recovery in hostile environments, and environmental history may be taken into consideration while interpreting fingerprint evidence.

CONCLUSION

The longevity and stability of fingerprints in poor environmental conditions is not just question of the biological stability of ridge patterns but also of extrinsic environmental conditions that influence the recoverability and visibility of latent prints. Fingerprints are biologically persistent—stable and individual-specific over life unless physically modified—but detectability is extremely sensitive to environmental stressors. For instance, temperature matters: although fingerprints remain identifiable on nonporous surfaces such as metal and glass despite exposure to very high temperatures (300°C), they deteriorate with worsening quality due to high temperatures since high temperatures cause faster evaporation of organic substances and water from the residue. Fingerprints also greatly rely on moisture and humidity to be clear. extremely high humidity (near 100%), latent prints are obliterated when water saturates ridge detail, and conditions that are too dry cause drying out reduction in development potential. The best humidity of around 80% has been found to maintain clarity without oversaturation. Water immersion, especially saltwater, speeds up destruction, but nonporous surfaces will preserve recognizable prints for 30–90 days based on salinity.

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