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NOVEL APPROACHES FOR THE DETECTION OF LATENT FINGERPRINTS: A COMPREHENSIVE REVIEW

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Abstract
Latent fingerprints are considered as one of the most important evidence generated by crime scenes. In such circumstances lifting of fingerprints involve poor quality or less advanced techniques often related to noise or poor background. Following with an introduction to the importance of fingerprints as unique identifiers and the challenges associated with latent fingerprints (LFPs); current review focuses on the principles of fingerprint detection, various methods used to develop LFPs, and the factors affecting LFP detection. The main focus of the review is on the technological advancements that have revolutionized the field including the use of nanoparticles, infrared laser ablation technology, Advanced Fingerprint Identification Technology (AFIT), colour changing fluorescent film, Automated Fingerprint Identification, spectroscopy, micro–X Ray Fluorescent Elemental Imagining, chemical imaging technology, synchrotron-based technology, and detection on unfired cartridges by depositing Palladium. The article concludes with a comparative analysis of these novel approaches highlighting their strengths and limitations

INTRODUCTION

In forensic science, detection of traces of evidences on the crime scenes represents continuous challenges for scientists working on the advancements or developments of new identification techniques. Fingerprints have been used extensively in the field of forensic science to catch the perpetrators and for the exoneration of the innocents. They are one of the most powerful and effective source of evidence for individual's identification due to their uniqueness throughout one's life [1]. On the contrary, the false identification of latent fingerprints could lead to the release of criminal person and the worst side of this is the apprehension of an innocent person.

Although, most of the fingerprints found at the crime scenes are invisible to naked eye termed as latent fingerprints (LFPs), and therefore several additional efforts are required for the development of these fingerprints for their easy visualization. However, certain types of fingerprints are visible if they are contaminated with blood or paint. Over the past few years several physical and chemical methodologies have been developed to enable the visualization of LFPs which includes ninhydrin spraying, powder dusting method, tetraphenylethene

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base dyed fluorescence probe, cyanoacrylate fuming respectively [2-4]. Powder dusting method is mostly used among these methods as an extremely simple and efficient method for the development of fingerprints over a number of surfaces, using luminescent, magnetic and metallic materials [5, 6]. Owing to the simple usage and easy availability of these methods, such traditional methods are only effective under normal circumstances hence forming several challenges to visualize LFPs such as poor selectivity, insufficient sensitivity and inappropriate information.

Previously, extraordinary efforts have been made toward the improvement of sensitivity of identification. Apart from the advancements in the detection techniques of LFP, scientists have paid much attention towards the detection of fingerprint residues because they provide more valuable information about a person's identity than the use of identification of LFPs solely [7]. This comprehensive review focuses on the various technological advancements that aids in the detection of latent fingerprints in this modern era of technology.

1. Principle of Fingerprint detection

Every individual has unique set of fingerprint patterns which makes them identifiable amongst the 7 billion population globally. However, Galton's evolution states that most of the humans have same fingerprint patterns [8]. Detection of the perpetrators and exoneration of the innocent is also achievable through Latent fingerprints (LFP). Identification procedure via LFP detection involves the matching the detailed pattern of ridges and the comparison between the fingerprints found on the crime scene with the control fingerprint on the database. The finger ridges mainly depend upon the shape and the coating type. Mostly human fingerprint ridges have loops along with few of them having the arches and whorls respectively. The ridge patterns comprised of three levels i.e. level-1 (arch, loop, whorl), level-2 (minutiae) and level-3 (sweat pores) [9].

In forensics, three types of fingerprint detection have been studied yet; involving latent, regarded and plastic fingerprint detection. Amongst these, LFPs provides the two-dimensional images of the ridges of the finger on substrate with oil, sweat and other contaminants. LFP detection accounts for easy identification and referred to as patent prints. The wide approach of developing and identification of the fingerprints involves the visibility of finger ridges via applying the fingerprint onto the objects or contrasting surfaces [10]. However, fingerprint images can be obtained using the popular techniques such as black printer ink, some chemical methods with digital fingerprints and inkless detections connected to computer systems to scan the finger [11].

2. Development of LFPs

The main purpose of developing the latent fingerprints at the crime scene is to make them visible by naked eye. Several methods are available for developing the LFPs. Although, the selection of the appropriate method primarily depends upon the nature of surfaces from where the fingerprints need to be developed [12]. Normally, surfaces from which LFP can be developed are of two types termed as porous and non-porous. Different sweats glands (eccrine and apocrine) and oil gland (sebaceous) secretions from palm, nose and head are useful in LFP detection. A high concentration of sweat is observed in the presence of organic compounds and minerals. Eccrine gland's secretion contains creatinine, choline, sugars, urea, amino acids, uric acids and lactic acids while oil gland's secretion contains wax, glycerides, sterol esters, squalene, fatty acids, and esters.

Sebaceous sweat mainly depends upon several factors including age, food plan, intercourse and medications that mainly effects on the detection of fingerprints. On the contaminated surfaces, LFP detection and the images are not very visible. Although, the detection of LFP depends upon several factors such as time, warmth, air, moisture, light, and substances applied to it [13]. Various techniques have been applied to improve the detection of latent finger prints; including powdering, vacuum metal deposition and small particle reagents have been used in identification of LFP [2, 14, 15]. Similarly, various physical and chemical approaches involving the materials like iodine, cyanoacrylate and multi-metallic deposition are also used in enhancement and detection of LFP [16, 17].

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3. Technological advancements and approaches in identification of Latent Fingerprints

In this digitalized world, use of modern technology to catch the perpetrators aided in the field of forensic science particularly in finger print identification. The necessary technology is now being used in interpreting the essential chemical and biological information like DNA fingerprinting; thus helping the analysts to identify the real victim and the perpetrator [18].

3.1. Nanoparticles for the detection of Latent finger prints

Nanoparticles have very striking properties which includes larger surface area, optical properties, low size and easily surface alterations through various coating agents. Such kinds of characteristics are favourable and easily engaged with porous and non-porous substances including fingerprint residues. Moreover, owing to its hydrophilic nature, nanomaterials also aid in better production of fingerprint images and sharper ridge patterns with lesser background interruptions [19]. One of the major advantages of nanomaterials is the detection of both fresh and aged fingerprints make it more useful in the field of forensics.

3.1.1. Silver nanoparticles for the detection of LFPs

Due to the electrostatic bonding between the finger residues of fatty acids, amino acids, and silver steel fragments; LFP detection images are captured via physical approach. Interestingly, organic compounds are more attracted to the colloidal silver debris, thus the LFP pictures on the porous substances are formed smoothly [20]. Lipids and fatty acids which are not dissolved in water and the organic amino derivatives of the finger sweat are persistent over a longer period of time on the porous surfaces at the crime scene [21]. The advancements in imaging tools for LFP detection makes it easy to uplift the latent finger prints whom photographs were previously been produced under dark conditions and were black in colour [22] [23]. However, silver nanomaterials are still very useful in detection of the fingerprints and these also have led to various novel enhancements in the quality of the images as well. Presently, metal nanoparticles powders are more commonly used in LFP detection on porous and non-porous substances commonly. Although these powders have low cost and high adhesive characteristics, which give good results of the latent fingerprint detection. The powder comprised of silver nanoparticles has the adsorption property on the sweat along with oily substrates in fingerprint ridges as a fine powder [24]. Silver nanoparticles show promising results in identification of LFP due to their higher affinity for organic chemicals seen on fingerprint remnants. For instance, in 1970, latent fingerprints on porous surfaces were physically developed using silver nanoparticle powder [25]. In order to detect fingerprints, the silver was converted into silver nanoparticles with the help of iron salt as an oxidant, which clearly indicated the clear images of LFP on the porous materials. However, the positive charge on sweat and negative charge on silver nanoparticle played a crucial role in the creation of LFP. Albeit, the silver nanoparticle solution didn't produce low visibility and poor quality fingerprints.

3.1.3 Detection of LFP via Gold nanoparticles

Apart from silver nanoparticles, gold nanoparticles (AuNPs) have played an important part in detection of LFPs due to their improved selectivity and specificity followed by inert nature along with other qualities that enable them to develop and store fingerprints over a longer period of time. Considering these properties, AuNPs were also used to enhance the reflectivity of LFPs via multi-metal deposition (MMD); a two-step gel based technique. The fingerprints adhered to the surface is submersed in the solution of AuNPs monitored by the physical developer of silver (Ag-PD) solution [26]. The AuNPs binds to the fingerprint residues and forms the precipitation of the silver ions to metallic silver [27] [28]. Therefore a silver image of the LFP is obtainable because of electrostatic interactions among the negatively charged AuNPs and positively charged residues of fingerprints.

Although, usage of multi metal deposition methodology is confined as it involves the surface or object containing the finger-marks of the suspect or the perpetrator to be submerged in a solution of gold nanoparticles. Therefore, the defined methodology is not appropriate for the detection and development of latent fingerprints on various surfaces which

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includes the entities that are too big to be soaked in a water bath, the floors or the walls at the crime scene.[29].

3.2. Infrared Laser Ablation Technology

Whenever the crime is reported at any place, the crime scene investigators after securing the crime scene; they take the photographs of the fingerprints in order to store them on their databases along with the swabs of fingerprints which lately submitted to the laboratory for chemical evidence. Whereas, introduction of this new technology (ILAT) aided the CSIs in identifying the chemical compounds in latent fingerprints at the crime scene [30]. Mechanism of this technology involves the scanning of the latent fingerprints using laser beams on the suspected surface. These are then heated enough to obtain higher energy in a minute location. However, after the required heat, the chemical bonds starts stretching and finally burst ending up lifting the latent prints with the process known as laser ablation. These bonds are stuck to a filter components and are further analysed using techniques like spectrometry [31]. Likewise, this technology also helps in analysing various components including lipids, fingerprints, genetic materials, explosives and proteins that can be analysed. The impact of this technology alongside to latent fingerprint identification and lifting is helpful in identifying the traces of fingerprints on explosives as well.

3.3 Advanced Fingerprint Identification Technology (AFIT)

The use of AFIT technology by Federal Bureau of Investigation (FBI) is equipped with collection, development and identification of the fingerprint evidence more quickly and effectively. The accuracy of this technology is determined as it obtains the fingerprints which are wiped away or been tried of wept. This technology is linked with the database which identifies the fingerprint at the crime scene and at the same time match it with the existing database [32]. Several FBI reports indicated the accuracy of AFIT technology with the implementation of first fingerprint matching algorithm from 92% to more than 99.6% simultaneously [33]. As per the reports of FBI, during the initial time period of AFIT more than 900 fingerprints were matched in a lesser time as compared to old fingerprint identification system. AFIT technology use has a high impact in declining the number of manual fingerprint reviews by 90% [34].

3.4 Colour Changing fluorescent film

Previously, researchers around the globe have been trying to develop the ways to enhance the fingerprint identification system. The induction of fluorescent technology which involves the addition of fluorophore molecules to the film having fingerprints that are sensitive to light and UV rays has enhanced the efficacy of detecting the LFPs [35]. The fluorescent film provide researchers with extra contrasting tools in the latent fingerprints in the form of fluorescent and extra chromic. Comparative to this, another technology “Micro-X-Ray Fluorescence (MXRF)” also assisted investigators in establishing the fingerprints. The ability of this technology to detect the concentration of various compounds like potassium, chlorine and sodium elements along with other elements present in the fingerprints are easily detectable as the finger touches the surface causing these compounds to land and reside on the surface and making it easy to identify the finger print patterns. These ridges in forensic sciences is known as friction ridges [18]. This technology has a lot of advantages as compared to old methods of fingerprint identification systems. Also the MXRF technology is a non-invasive method of identification means that the analysis of fingerprints using this method left pristine in order to find other evidences like DNA extraction etc. [36].

3.5 Automated Fingerprint Identification

In today’s modern world, biometrics has gained extreme importance and acceptance worldwide for identifying and authenticating an individual with high accuracy. Biometric refers to some biological extents including both behavioural and physiological characteristics such as fingerprints, facial images, voices, signature, keystroke dynamics[37].

There have been enormous advancements recoded over the past few years in biometric technologies resulting ease and safety in everyday life operations, numerous applications, transactions etc. Areas where

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this technology is use and getting installed on priority basis includes airports, borders security, attendance systems in organisations; forensics and law and enforcement, commercial sectors and many more. Since the evolution and advancements in technology, automated Fingerprint Identification System (AFIS) has been developed referring to the computer systems to aid in the processes of matching, maintaining and searching of fingerprints. Therefore, the AFIS identification system is deployed over a large scale in order to enhance and improve the process of identification [38]. A comparison of identification before and after the development of AFIS is described in table-1.

Table 1: Aspects of fingerprint detection before and after the development of AFIS

Aspect	Before AFIS	Before AFIS
Detection Process	Their analysis is mainly based on the visual comparison of fingerprints by experts, hence labour-intensive and highly manual.	Fully automated and computer aided and high power algorithms matching fingerprints against a database very fast. [39]
Speed	This can take days or weeks sometimes to find a match.	Significantly faster; the search time would be in a few minutes or seconds, rather than very long and tiresome time to find matches. [40]
Accuracy	Prone to human error due to the possibility of visual fatigue and subjective judgment.	It provides high accuracy along with minimum error according to the precise algorithms and pattern recognition techniques. [41]
Record Maintenance	Difficult to maintain and update, with a very high risk of losing or misplacing data.	Maintenance of electronic records with efficient updating, retrieving, and keeping them safe. [42]
Criminal Identification Rate	Lower identification rates because processing is slow and prone to human errors.	Higher identification rates with more efficient and accurate fingerprint matching. [43]

The identification of latent fingerprints through AFIS directly involves the human interference for feature making and verification purposes. The process of AFIS is sub categorised into four successive processes namely segmentation, quality valuation and augmentation, feature abstraction and matching as mentioned in figure 1[44].

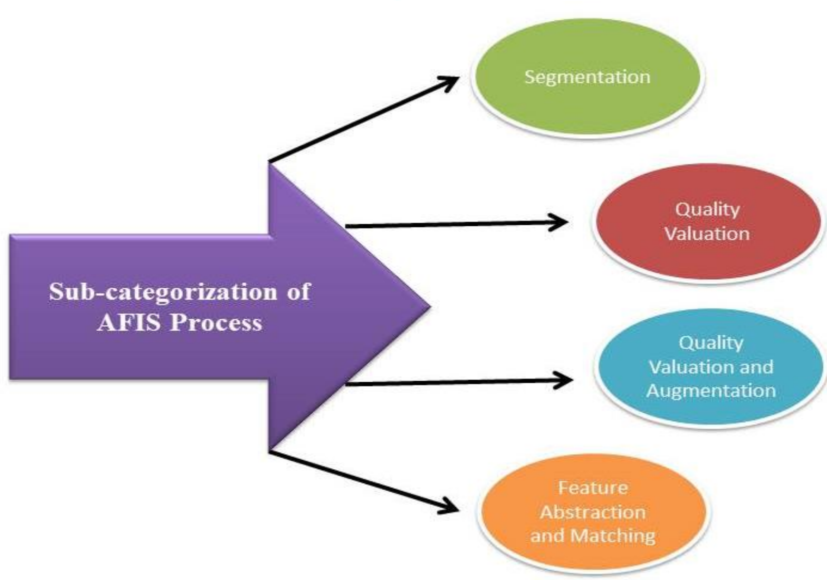

Figure 1: Subcategorization of AFIS Process

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3.6 Spectroscopy

Spectroscopy is a matter-light interaction that studies how different wavelengths of light are absorbed, emitted, or scattered by a sample in order to determine the composition and structure of it [45]. Spectroscopy aids the fingerprint analysis process by allowing a non-destructive method that can chemically identify and differentiate between various substances within the fingerprint so that trace components are visualized and analysed better for forensic investigation purposes [46]. The characteristics of the surface holding the fingerprint, however, determine which spectroscopic technique is employed precisely. Moreover, Fourier Transform Infrared spectroscopy, both through and without the Attenuated Total Reflectance (ATR) mode, is one of the key methods in this domain. Without using ATR, FTIR spectroscopy has been utilized to identify the variations in fingerprints between children and adults as well as their deterioration through time[47]. The sebum and perspiration were discovered to be mostly composed of lipids and organic and inorganic salts, respectively, whilst the skin cells were found to be primarily composed of proteins. The concentrations of the lipids discovered in children's and adults' fingerprints were found to differ noticeably. Children's fingerprint lipid disintegration is slower than that of adult fingerprint lipids due to this variation, which leads in a difference in volatility[48]. Raman spectroscopy is another well-liked spectroscopic technique. The detection of fingerprints has also benefited from the use of line-scanning Raman spectroscopy. Utilizing -carotene and fish oil, it was especially utilized to identify fingerprints[49].

3.7 Synchrotron Based Technology

The discovery of synchrotron-based technology has indeed revolutionized the forensic study of fingerprints, which could now be examined at the chemical and structural level. In this regard, the forensic study of fingerprints provides high-resolution insight into composition and patterns of chemical makeup, so that each identification of fingerprint turns out to be very accurate [50]. Chemical markers and profiles of latent human fingerprints have been studied using synchrotron-based x-ray fluorescence and infrared (IR) micro spectroscopy[51]. In order to create basic data and analyse and visualize latent human fingerprints, synchrotron radiation x-ray fluorescence microprobe and infrared spectro-microscopy have been used. The aim is to create a sophisticated forensic method to recognize complex partial latent prints[52].

3.8 Detection on unfired cartridges by depositing Palladium

Analysis of fingerprints on unfired brass cartridges using a unique palladium deposition technique is favoured by Electron probe microscopy (EPMA), Scanning electron microscopy (SEM) along with Auger electron spectroscopy (AES) respectively. Palladium was discovered to deposit onto both ridges and valleys, despite the produced photos' stark colour contrast between the two, which implies that the palladium was applied only to the valleys. Organic material clumps were typically seen beside to the ridges. The work offers a prototype for how the metals were deposited on brass cartridges that had sebaceous fingerprint impressions on them[53].

This novel technique depends on the chemical affinity between the palladium and organic compounds found in fingerprint residues on a cartridge, rendering even faint impressions visible on the surface. Applicaton of palladium increases the sensitivity to detect prints as clear and well-defined to help identify partial or degraded prints. Furthermore, the images generated by SEM and AES will be high resolution to aid in a more profound observation of not only the physical structure of fingerprints but also that of their elemental composition. This would subsequently lead to a more refined forensic method applied to cases of firearms.

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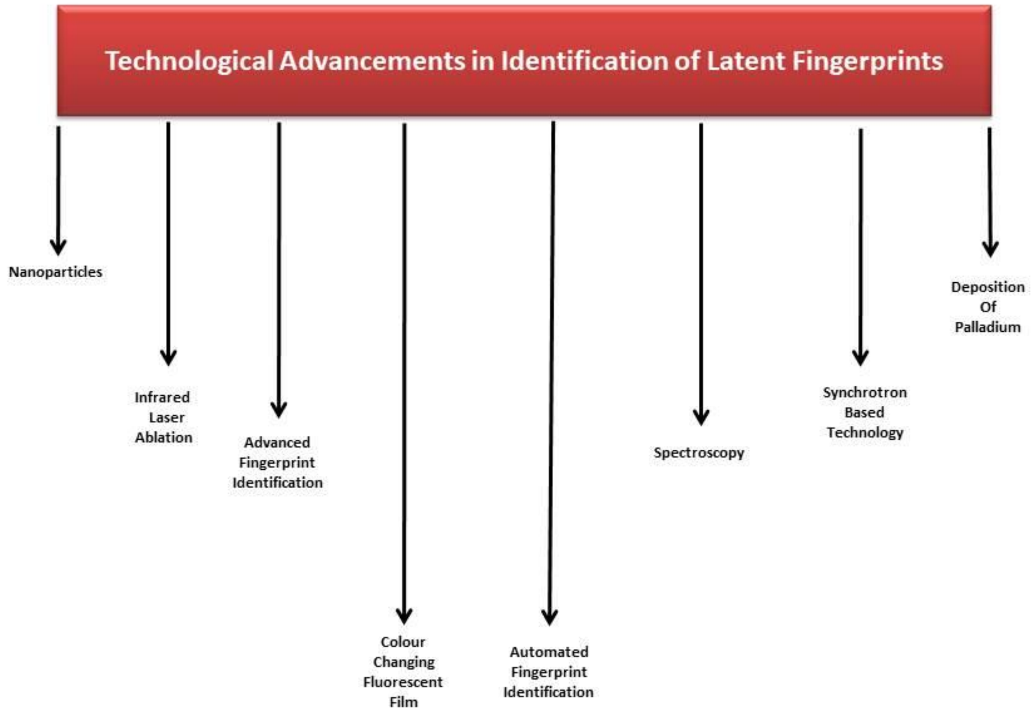

Figure 2: Technological Advancements in Identification of Latent Fingerprints

5.0. Comparative Analysis of Novel Approaches

Latent fingerprinting techniques play a crucial role in forensic investigations by identifying and matching fingerprints left at crime scenes. With the passage of time, several practices have been established in order to enhance the visualization and extraction of latent fingerprints. Nanoparticle-based techniques offer high sensitivity but require specialized equipment and complex sample preparation. Whereas, technological approaches are rapid and provide high-quality results but often necessitate sophisticated equipment and expertise. Biological methods are highly specific but may be limited by antibody availability and potential contamination. Digital imaging techniques are non-destructive and offer efficient storage and retrieval but rely on the quality of the imaging equipment. Spectroscopy-based techniques offer non-destructive analysis and molecular information but may have limitations in depth sensitivity and data interpretation complexity. Chemical-based techniques are versatile, cost-effective, and easy to implement but can be destructive and may lack specificity

Each latent fingerprint technique has its own merits and limitations, whereas selection of method adopted is determined by nature of the evidence, available resources, and the expertise of the examiner. Often, a combination of techniques is used to maximize the chances of successful latent fingerprint recovery and identification.

Conclusions

Techniques in latent fingerprint detection have advanced significantly to improve the sensitivity and accuracy of forensic analysis. Despite this, the most widely used include dusting with powder and cyanoacrylate fuming which are unfortunately not effective on all surfaces. Such a limitation is easily enough to understand why more innovative methods must be found to keep the field moving. Nanoparticles, such as silver and gold have seriously revolutionized the latent fingerprint imaging process because results tend to be sharper on both porous and non-porous surfaces. These techniques detect via spectroscopy, infrared laser ablation, and the AFIS, which are all non-invasive yet highly precise

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techniques. Detection has been achieved by the combination of multiple techniques despite these constant environmental factors and substrate types. Further advances in technology will take this much further into the future, and fingerprint detection outcome promises much accuracy and reliability with continued relevance in forensic science and criminal justice.

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