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Review Article

Emerging Latent Fingerprint Imaging Technologies (Instrumental Methods)-A Review of Recent Literature

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Abstract

There have been tremendous scientific and technological developments in the 21st century. The field of fingerprints has also not been left untouched from the same. Latent fingerprints are the most frequently encountered evidence at the crime scene and thus demand more advanced research for their examination. Fingerprints left behind on the surface are the secretions of different sweat glands mainly eccrine, sebaceous and apocrine. Sweat is composed of water, and organic and inorganic compounds. The powder methods or the physical enhancement methods of fingerprint development are based on the interaction and/or adhesion of sweat residue to the powder constituents. While the principle behind chemical methods of development is chemical reactions taking place between the fingerprint residues and the chemicals used. Most of the conventional methods are destructive in nature. The ease of examination of developed impressions depends upon the clarity of the print developed. The prints can be analyzed irrespective of the clarity by imaging them chemically. In this review, we have tried to present the recent latent fingerprint imaging technologies which have gained popularity within fingerprint science and thereby have the potential to aid law enforcement agencies in cases where complex or difficult fingerprints are encountered. Many conventional techniques are already in use such as powder development methods, fuming, and chemical methods; however, this paper mainly focuses on instrumental methods that can help in imaging invisible prints that are otherwise difficult to develop and preserve using conventional methods. The present work aims to gather and elucidate various analytical techniques used till date in fingerprint studies. Though several techniques have been developed, detailed information is still lacking and limitations of these techniques needs to be taken into consideration. Therefore, advanced future research is the need of the hour for analysis and imaging of fingerprints found on variety of surfaces and in different circumstances.

Keywords: Fingerprint imaging; Finger marks; Instrumental techniques; Latent fingerprints; Latent mass-spectrometry; Powder development

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Introduction

The latent fingerprint impressions are one of the most important types of evidence which is collected from the crime scene. They need specific development techniques for proper visualization as they are not visible to the naked eye. The palmar surface of the finger deposits greasy colourless substances which get deposited on the surface when touched, thereby leaving a latent fingerprint [1]. For law enforcement agencies, the identification of latent fingerprints plays a crucial role [2]. During the time of the commission of the crime, the criminal tends to sweat more due to physical activity and psychological factors. This sweat mixes with the oil or greasy substances which are present on the finger and the latent fingerprints get transferred to the surface coming in contact. The latent fingerprints need to be looked for with utmost care and precautions. They are searched using oblique light, alternate light sources, and other available techniques [1]. The latent fingerprints which are collected from the crime scene hold high evidentiary value. The ACE-V procedure is followed for the examination of the fingerprint which involves analysis, comparison, evaluation, and verification [2]. All the possible objects that the criminal would have come in contact with, should be examined properly and thoroughly [1].

Various hitches need to be tackled while examination of fingerprint including lowered quality of friction ridge impression, less finger area, and large nonlinear distortion [2]. As the latent impressions are poor in visibility, physical and chemical techniques should be taken into consideration for the development and proper visualisation of latent impressions [1]. The application of fingerprint powder, by brushing, blowing, or tapping is the most common technique used till date in fingerprint science for non-absorbent surfaces, where adherence of powder with sweat residues is the principle. To develop latent fingerprint impressions, the powder development technique is commonly used. The powder color selection should contrast with the surface colour for the perfect observation of developed fingerprints. Before all, the fingerprints should be photographed with appropriate filters. In practice, the powder development method is the one that is mostly used at the crime scene for developing latent impressions which is also been validated by the studies. In some cases, this method has been found to pose a problem in identification [3]. Forensic investigations involve matching latent prints against rolled fingerprint databases to identify criminals [2].

In the last few years, there have been many developments in the area of development of latent fingerprints including improved powder development techniques, fuming method, electrochemical method, dye-based method, nanoparticles method, and highly efficient instrumental methods [4]. This paper is mainly a review of recent instrumental technologies that can be used in latent fingerprint imaging in cases where other methods failed to develop a print clearly and effectively.

Tof-Sims (Time-Of-Flight Secondary Ion Mass Spectroscopy)

It is a surface-sensitive analytical approach that uses a pulsed ion beam to remove molecules from the sample's outermost shell. It has been used in forensic research to visualise, characterise, and analyse fingerprints that have been contaminated by residues of narcotics, cosmetics, and other contaminants on the surface [5].

Lee et.al has considered unusual surfaces offering great details of information for retrieving high-resolution images of finger impressions. The surfaces considered are curved bullet casings which consist of great details. They have developed a rotation stage to allow researchers and forensic practitioners to perform highly sensitive, non-destructive Time-of-Flight Secondary Ion Mass Spectroscopy (ToF-SIMS) measurements. Further, they succeeded in developing high resolution fingerprint images on challenging surfaces such as bullet casings where traditional methods pose difficulties. During analysis of the casings, they were rotated in a way so that the entire casing is covered along the length and this is repeated until the whole casing is covered. The images captured have shown the presence of ridges and also the sweat pore details of these ridges. These results were not observed when the same casings were treated with chemical methods (cyanoacrylate fuming and BY40) [6].

Szynkowska et al. have conducted another study involving ToF-SIMS in the detection of exogenous contaminants of fingerprints. Fingerprint samples taken were contaminated with several substances like arsenic, nickel, gunshot residues, Methamphet Amine (MA), and Methylene Dioxy Methamphet Amine (MDMA/ecstasy) which were deposited on bases like aluminium, stainless steel, and brass. The technique turned out to be effective as it was able to highlight the specific ions at their m/z ratio and thereby form an image of the print. It proved to be a useful tool to identify drugs and other materials which can be eventually linked with the crime scene [7].

Lesi Cai and their team in another study considered the use of Graphene Oxide (GO) enhanced ToF-SIMS for detection and imaging of substances such as poisons, controlled drugs which are with relatively high mass molecules in fingerprints. Using GO as a matrix to boost the molecular ion signals of relatively high mass molecules in fingerprints, the detectable mass range was expanded. The uniform and smooth GO layer preserve the delicate shape of fingerprints while maintaining SIMS imaging's excellent spatial resolution. The SIMS images generated could clearly display particular features of fingerprints such as the number and distribution of pores in a ridge, as well as the size and shape of a pore [8].

While Szynkowska et al. have demonstrated the use of TOF-SIMS in fingerprints deposited on inorganic substrates like steel, brass, and glass similarly, Steven and John have demonstrated fingerprint imaging in fingerprints deposited on substrates like Si Wafer and other difficult organic surfaces like polymeric coatings, paper, and printed card. Surfaces like newspaper yielded poor-quality print images while surfaces like PVdF coating, Si wafer, Polyester coating, carry bags, etc. yielded acceptable to high-quality print images using this technology [9].

DESI-MS (Desorption Electrospray Ionization-Mass Spectrometry)

Desorption Electro Spray Ionisation (DESI) is an ambient ionization technique that may be used in conjunction with Mass Spectrometry (MS) to analyse samples chemically under ambient settings. It extracts analytes from sample surfaces and propels secondary ions into the mass analyser using a fast-moving charged solvent stream at an angle to the sample surface [10]. It has the advantage of in situ analysis of ordinary samples in their native environment without treatment.

Cooks et al. have pioneered the utilization of DESI MS for the chemical imaging of LFPs based on spatial MS detection of different endogenous components, along with small amounts of drugs of abuse such as cocaine and Δ9-tetrahydrocannabinol, and contaminated explosives. A solvent was electro-sprayed onto the surface with a fingermark to generate the secondary scattered droplets, which carried the fingerprint components and were subsequently evaporated, ionized, and analysed. Mass spectra at each place on the surface were captured by rastering the stream of charged droplets over the surface. Eventually, the 2D mapping MS signals of a certain fragment ion can retrieve the spatial distribution of compounds investigated and can be simultaneously used to construct images of fingerprint ridge details [11].

Bailey et al. conducted a comparative study on the detection of cocaine, benzoylecgonine (BZE), and, methylecgonine (EME) in fingerprints using mass spectrometric techniques like DESI, MALDI and SIMS. The sensitivity of SIMS was found to be insufficient however, DESI could detect BZE and EME both. Hence, they could demonstrate that the use of these techniques could be used as a screening test for drugs of interest [12].

The DESI-MS technique was paired with a machine learning model called Gradient Boosting Tree ensemble (GDBT) by another researcher Zhou and Zare. DESI detected a wide array of ions like Fatty Acids (FA), tri(acyl/alkyl) glycerols (TG), or di(acyl/alkyl) glycerols (DG) along with pattern information. Further, with the help of the classification algorithm of GDBT on the lipid profiles, personal information (Sex, age, ethnicity, etc.) was collected with higher accuracies from 194 samples. In this way, they were able to demonstrate how machine learning, combined with MS, was an effective method for determining personal information by a non-invasive process [13].

Coming to the real-time application of DESI-MS, Van Helmond et al. invented a method of analysing fingerprints contaminated with condom lubricants by developing them using cyanoacrylate fuming (CA) and then imaging using DESI-MS. Most common condom lubricants components such as Polyethylene Glycol (PEG), Polydimethylsiloxane (PDMS) were detected in the majority of the samples, while in some others the polyethoxylated phenol non-ionic surfactants octoxynol-9 or nonoxynol-9, serving as spermicides were also detected. This was further followed by distinguishing between 32 different kinds of condom types within 21 different brands. It was done using a statistical approach, PCA (principal component analysis) followed by LDA (linear discriminant analysis). Results of higher accuracies were obtained by the analysis of lubricant spots as well as lubricant containing fingerprints. This can prove to be an effective method in tracing condom lubricants in sexual assault cases [14].

SERS (Surface- Enhanced Raman Spectroscopy)

SERS is a molecular detection and characterization technique that relies on the enhanced Raman scattering of molecules adsorbed on or near SERS-active surfaces like nanostructured gold or silver.

Connatser et al. developed a technique which are based on amino-acid detection using Raman spectroscopy. The analytes are observed in close proximity to roughened metal surfaces or nanoparticle clusters. In valence electrons of the metal, coherent oscillations parallel to the surface are initiated by interaction with laser light. The use of dispersible Raman-enhancing metal nanoparticle systems is essential for imaging latent fingerprints in practice. SERS chemical imaging can be performed when these high-Raman enhancement nanoparticles are dispersed on surfaces without chemical inhibition.

In addition to this, the SERS method can also help to detect prints contaminated with blood, explosives, drugs, etc suggesting that this is a highly feasible technology that can be incorporated for analysis. Based on the extent of Raman Scatter, vibrational signals are displayed using a graph for different wavelengths, and thereby an image is formed which is later visualized on a screen [15].

When a medical point of view is considered, Leordean and Canpean demonstrated the use of SERS in analysis of urea traces in urine, fingerprint, and tear samples by using gold particulate films as SERS substrates. The concentration of urea found in fingerprints is usually about 19.64Mm. The SERS spectrum of the fingerprint applied on the substrate was dominated by a band at 1004 cm which confirmed the presence of urea biomarkers in the print. This method has potential use in detecting trace amounts of urea and diagnosis of other kidney disorders [16].

XRF (X-RAY Fluorescence)

The non-destructive analytical technique XRF (X-ray fluorescence) is used to study the elemental makeup of materials. By detecting the fluorescence (or secondary) X-ray released by a sample when it is excited by the main X-ray source, XRF analyzers can determine the chemistry of a sample.

Zheng et al. experimented on porous and non-porous substrates such as plastic film, glass, paper, etc. using four brands of sunscreen. Three out of the four sunscreens were physical sunscreens that contain a significant number of oxides of Zinc and Titanium. These elements are added to sunscreens to reflect the UV rays away from the skin which in turn reduces skin damage. The fourth sunscreen was a chemical sunscreen containing UV filters and other chemical ingredients which absorb the UV rays and convert them into heat so that they do not affect the skin. Hence Ti/Zn was not detected using XRF in the fourth sunscreen and imaging could not be done for it. This work has studied contaminated fingertips with different brands of sunscreens to analyse and image the inorganic elements of fingerprint residue left behind by touching the surface. Further, the elemental composition and images were obtained by X-ray fluorescence and synchrotron radiation X-ray fluorescence (SRXRF). The results were also compared with the results obtained from inductively coupled plasma optical emission spectroscopy (ICP-OES) and Laser-Induced Breakdown Spectroscopy (LIBS).

The use of different brands of sunscreen may provide a link with the suspect. Since it has been found that, the inorganic element composition of different sunscreen varies from manufacturer to manufacturer. The elemental profile of fingerprint impression left behind at the crime scene may help in reducing the suspect pool. Images and spectra were better obtained by XRF than SRXRF due to limited beam time in SRXRF. Later the Ti/Zn ratios in 3 sunscreen finger marks in different substrates were determined using an EDAX Eagle III XRF spectrometer. Hence it was proven that the XRF method offers great feasibility in analysing and imaging finger marks and could be used in the future [17].

Further, Worley and Wiltshire also conducted research wherein they detected visible and latent fingerprints using the micro-XRF elemental imaging technique. This was based on the elemental composition of the friction ridges. Prints were collected in different ways like plain sebaceous prints, prints post-perspiration, prints taken after application of hand lotion/ saliva/ food residue, etc, and were subjected to the XRF analysis. Thus, it was observed that prints taken in such scenarios could be imaged and the elemental composition could also be examined [18].

MALDI-MS (Matrix-Assisted Laser Desorption Ionization Mass Spectrometry)

MALDI-MS is a technology for detecting high-molecular-weight compounds that is extremely effective. It makes use of a matrix to help with the ionization and desorption of laser desorption imaging, resulting in a higher yield of analyte ions. As a result, improved structural information about the object of interest can be obtained with enhanced ion yield. Analysis of endogenous lipids in the residues of finger-mark is also one of the applications of this method [5].

Scotcher, K., and Bradshaw, R. determined the applicability of MALDI – MS in the analysis of latent fingermarks deposited onto polymer banknotes within the UK.

The most abundant ions (providing the best ridge quality) were derived from each separate fingermark analysis which was then normalised against the Total Ion Current (TIC). The ions were derived from each separate fingermark analysis providing the best ridge quality which was then normalised against the Total Ion Current (TIC).

The samples were also sprayed with MALDI matrix and then analysed. Post-imaging, clear ridge details were observed on the banknotes and the most abundant molecular ions were selected for the reconstruction of fingermark images. Additionally, the detection and confirmation of cocaine residue in the latent fingermark were also obtained using MALDI-MS Profiling. Hence it can be said that this technique can provide both physical and chemical information of a latent fingerprint [19].

Bradshaw et al. also studied the application of MALDI MS in combination with several fingerprint processing techniques in which it was observed that MALDI – MS is an efficient technique and can be used in conjugation with other techniques. Additionally, sequential processing still leaves molecules that can be imaged by MALDI MS imaging. It fills the gaps left after developing fingerprints using conventional methods [20].

Hinners and Lee investigated the use of common development powders as matrices for MALDI-MS. Hence titanium oxide (TiO_2), a latent fingerprint development powder was used as a matrix. TiO_2 was also effective in showing MS images of exogenous and endogenous latent print compounds without the requirement of a high- resolution mass spectrometer [21].

Further, Wulfert and Ferguson investigated the use of MALDI-MS in the direct detection of peptides and proteins from fingermarks along with the determination of sex. They combined this technique with the multivariate modelling of the spectra and could determine the sex of the individual with a higher degree of accuracy [22].

Groeneveld and Bradshaw mapped a large number of illicit drugs and their metabolites in fingermarks using MALDI-MS. They also presented the compatibility of Forensic Enhancement Techniques (FET) like Cyanoacrylate fuming (CA) and Vacuum Metal Deposition (VMD) with MALDI-MS. Although the ridge pattern quality was substantially molecule dependant, VMD treatment proved to be considerably more compatible than CA, indicating gold's capacity to enhance the MALDI signal in general. Also, the use of FET did not prevent the detection of forensically interesting species like illicit drugs and their metabolites [23].

Additionally, the detection of blood using MALDI-MS has also been explored. Bradshaw et al. successfully detected haem and haemoglobin molecules using this technique based on their m/z ratios. They were also able to distinguish between human, equine, and bovine blood because the haemoglobin chains have slightly different amino acid sequences and hence different m/z values [24]. Furthermore, Heaton et al. conducted a study to demonstrate the detection and mapping of haemoglobin variants (Hb var) in bloodstains and blood fingermarks by a combined proteomics-MALDI based approach. HbS, HbC HbD-Punjab/Los Angeles, HbD-Iran, HbE, HbJ-Baltimore were some of the HB variants that were studied. This method has the potential to narrow down the suspect pool during an investigation [25].

LADI – MS (Laser Ablation Direct Analysis In Real-Time Imaging-Mass Spectrometry)

Fowble and Musah demonstrated the use of this novel technique LADI-MS in the analysis of fingerprints. It was observed that LADI-MS had the potential to detect endogenous compounds like cholesterol from the latent fingermark and also detected exogenous compounds like cocaine, RDX, pseudoephedrine, and yangonin which are forensically significant. The mass ranges collected were between m/z 100 and 700. In addition to this, LADI-MS proves to be an efficient and feasible technology since it does not require high vacuum conditions, and the experiments can be conducted in the open air. It also uses a soft ionization source like DART (Direct Analysis in Real-Time) which does not cause extensive fragmentation of the molecules being analysed and hence does not change the composition of the latent fingerprint. LADI-MS requires no sample pre-treatment steps and can be performed on non-conductive surfaces. It also uses the laser ablation technique that permits the preservation of the complete fingermark for subsequent analysis by other conventional methods [26].

Lastly, a brief summary of the techniques and their features has been tabulated in the Table 1 below:

SR. NO.	Technique	Features
1.	TOF-SIMS	Uses pulsed ion beam to remove molecules from the sample's outermost shell. Highly sensitive, non-destructive, in-situ Metal and drug identification Proved efficient on difficult and unusual surfaces
2.	DESI-MS	Uses a fast-moving charged solvent stream to propel secondary ions into mass analyzer. Can be combined with machine learning for determining personal information
3.	SERS	Relies on the enhanced Raman scattering of molecules adsorbed on or near SERS-active surfaces Gives descriptive vibrational spectra of amino acids. Good sensitivity.
4.	XRF	Simple, fast and safe sample preparation Detects the fluorescence (or secondary) X-ray released by a sample when it is excited by the main X-ray source Non-destructive elemental analysis
5.	MALDI-MS	It makes use of a matrix to help with the imaging. Enables chemical data to be rendered in a form that displays the distribution of the ions in 2D space. Less destructive to sample molecules.
6.	LADI-MS:	potential to detect endogenous as well as exogenous compounds. does not require extensive instrument conditions. no sample pre-treatment

Table 1: The techniques and their features.

Conclusion

Conventional powders are generally useful for latent fingerprint development however, they're nonspecific in nature. At times, unusual surfaces also make it difficult to visualise latent prints using powders. No single technique can be considered ideal for the processing of latent prints. Every technique has its pros and cons, advantages, and limitations with respect to the condition of the print, the surface on which print has been deposited, and other environmental conditions. With the advent of highly sophisticated instrumentation, chemical imaging of latent prints is possible. In addition to that, these methods can also help in the detection of other compounds present in the print giving an idea about the lifestyle, dietary habits of a person, and other relevant details. Irrespective of the ability of these techniques to provide results in less time, traditional methods of fingerprint analysis and examination cannot be replaced. Thus, authors have put efforts to highlight the techniques which can be used in cases where the ridge details are not clear and cannot be considered for matching them with the database. In such conditions, these methods can play a role in establishing the link between the suspect, victim and crime scene and thus will be helpful in delivering justice.

This review has made an attempt to furnish an updated review of the instrumental techniques available for qualitative and quantitative analysis of constituents present in fingerprint residues. However, there is a need for extensive research studies, and comparison-based experiments to determine the favorable conditions of using each of these techniques, development time, manpower required, and factors that can affect the imaging of the prints. Research also needs to be done in order to ascertain the extent of implementing these techniques in a practical criminal investigation. Detailed information is still lacking and so, advanced future research is needed in this area.

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