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Review Paper

MAGNETIC FINGERPRINTING, AFIS AND BEYOND IN FORENSIC SCIENCE: A REVIEW

Sajid Hussain
Ph.D. Scholar, Department of Criminology, University of Karachi. Advocate High Courts & Federal Shariat Courts of Pakistan

Azhar Humayun Khan
L.L.M. Civil Judge 1st Class. Punjab judiciary, Lahore High Court Lahore.

Sumbul Asif
School of Interdisciplinary Engineering and Sciences, National University of Sciences and Technology, Islamabad 44000, Pakistan.

Sanobar Zaib
L.L.B. MSC Criminology, University of the Punjab, Advocate High Courts of Pakistan.

Dr. Naima Saeed
Chairperson Department of Criminology, University of Karachi.

**Corresponding author: Sajid Hussain (sajidqureshi.law@gmail.com)*

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Abstract

This review analyzes fingerprint identification technologies from different perspectives with particular attention being paid to both the traditional methods and cutting-edge inventions. The study integrates the findings from a large body of literature, covering both historical developments, technological innovations, experimental research, and the practical applications of forensic science. This includes inkless methods like magnetic resonance fingerprinting and automated fingerprint identification systems (AFIS) along with their modern way of depositing fingerprints using nanomaterials and macromolecules. In addition, this paper discusses the challenges and limitations of fingerprint identification, particularly the technical problems, the legal and ethical considerations and the need of human intervention in AFIS technology. The review, through comparative analysis and the discussion of the findings from various studies, gives insights into the value of fingerprint identification in criminal investigations and shows the emerging trends and future prospects in the field. It also offers insights for the researchers and forensic scientists a roadmap to combine the novel technologies with the existing practices in forensic science which might enhance the reliability as well as the accuracy of fingerprint identification.

Keywords: *Fingerprint identification, Forensic science, Magnetic resonance fingerprinting, Automated fingerprint identification systems (AFIS), Latent fingerprint development.*

Introduction

Fingerprinting is the main component in the whole forensic process, being the only one that is reliable and can be used in criminal investigations and court cases. Classic fingerprints have been used up to now, and they still serve their purposes, which simply are the identification of people using their unique fingerprints. However, these methods also have their own limitations that are occasionally found during smearing, degradation, and the need for manual comparison that, in turn, reduces the system's accuracy and speed (Assis et al., 2023). The magnetic fingerprinting and the Automated Fingerprint Identification System (AFIS) application have revolutionized the field of forensic science with the improvement of precision, speed, and accuracy in fingerprint analysis. Magnetic imprinting that exploits magnetic interactions to view latent fingerprints is a non-destructive but very sensitive technique that has an advantage over a traditional method. However, AFIS is provided with the capability of automating fingerprint identification through its advanced algorithms and database searching capabilities, a real innovation in the way fingerprints is analyzed or matched (Coffey & John, 2018). Thus, in this review, we will critically evaluate the principles, techniques, applications, challenges, and directions of magnetic fingerprinting and AFIS in forensic science, with the intention of giving a comprehensive view of their relative strengths and weaknesses and potential impact on forensic practice. An assessment of the revolutionary technologies will be done first in order to answer the critical questions, which include the effectiveness, reliability, and utility of these technologies in modern forensic practice with a purpose of a good understanding of their role in the current forensic investigations.

2. Materials and Methods:

The methodology used in this critical paper was a systematic one that involved the collection, analysis, and synthesis of the pertinent information on magnetic fingerprinting and AFIS in forensic science. A methodical search strategy has been developed with a view to collect books, proceedings and other articles from scholarly sources that are related to the said topic of study (Creswell, 2014). Libraries such as PubMed as well as Web of Knowledge, IEEE Xplore, and Google Scholar were specifically chosen through the use of appropriate keywords for that particular information. Studies being included to the review was based on the criteria that are its relevance to the principles, methodology, applications, developments and challenges of the magnetic fingerprint and AFIS. The research that elucidates the contrast in technologies that were most significant in terms of their impacts were given the greatest priority (Leedy and Ormrod, 2014). This study was undertaken to identify and read carefully every one of the prior studies, with their main findings, methodologies and conclusions. Each study was recorded, and the data was summarized and grouped into themes on magnetic markers and fingerprints in AFIS (Yin, 2018). Analysis starts with the stage of comparison/contrast of the studies to determine whether there are some similarities, common patterns, or even agreements across the studies. In conclusion, the evidence from these studies was the script for the descriptive text (Neuman, 2013) which was the main goal of the reviewed paper. In the process of writing, the review was written in manner which was objective, unbiased, and based on empirical evidence. The integrated results of the two compilations correspond with the cognition of the whole information from the studies review.

3. Critical Appraisal of the Related Studies:

The articles that were studied together encompass a detailed analysis of magnetic fingerprinting and AFIS (Automated Fingerprint Identification System) in the area of forensic science. The authors discuss magnetic resonance fingerprinting (MRF), unraveling its mechanisms, methodology, and possible role in qualitative tissue evaluation. These studies show that MRF has the potential to be used in forensic

analysis for fingerprint identification and that it is very versatile and can be applied in many medical imaging applications.

Below is the table of selected studies for this review*;*

Table 1: Selected Studies with Critical Appraisal and Data Extraction

Authors, Year & Country of Study	**Study Type & Sample Size**	**Major Findings in Relation to Our Research Purpose/Goal**	**Critical Strengths & Weaknesses of the Studies**
Assis et al., 2023, Portugal	Review	The study explores innovative technologies for latent fingerprint development by concentrating on nanomaterials and macromolecules.	Strengths: Describes advances in the area of latent fingerprint development. Weaknesses: May note practical housekeeping data.
Berry & Stoney, 2001, USA	Review	Offers a historical overview of fingerprinting development.	Strengths: Provides a comprehensive historical view. Weaknesses: This might not be applicable to modern-day issues.
Burgess et al., 2015, Various	Experimental	Investigates the magnetic fingerprint of individual Fe4 molecular magnets under compression by a scanning tunneling microscope.	Strengths: Uniquely captures magnetic fingerprints through the vast experimental array. Weaknesses: Limited applicability to forensic science.
Cardwell & Bavarian, 1997, USA	Review	Discusses trends in AFIS technology, past, present, and future.	Strengths: Shows the development of the technological features of AFIS. Weaknesses:

				Some of the recent discoveries can be missed out.
	Chaisawvong et al., Various	Experimental	Focuses on the development of multipurpose fingerprint powders.	Strengths: Introduce practical applications of forensic science in general. Weaknesses: May lack generalizability beyond specific powder formulations.
	Coffey & John, 2018, USA	Review	Investigates basic skills for scene processing, involving fingerprint evidence.	Strengths: Practical advice on the techniques of fingerprint evidence. Weaknesses: It may lack depth in the technical aspects.
	Cole, 2009, USA	Review	Provides a historical account of fingerprinting and criminal identification.	Strengths: Makes historical context more valuable. Weaknesses: It may not account for the latest developments.
	Coppo et al., 2016, Various	Review	Offers an overview of magnetic resonance fingerprinting.	Strengths: Reveals the nature of a very clever fingerprinting technique. Weaknesses: Maybe the problem is the lack of practical details.
	Daluz, 2018, Various	Review	Focuses on the fundamentals of fingerprint analysis.	Strengths: Delivers the basic understanding of the analysis of fingerprints. Weaknesses: The downside is that it might not cover

				advanced techniques.
	Dass, 2013, Various	Review	Examines fingerprint-based recognition methods.	Strengths: It provides information on the recognition algorithms. Weaknesses: They can lack practical application data.
	Ghosh & Pahari, 2021, Various	Review	Explores the unique tool of fingerprinting in forensic science.	Strengths: Reveals the significance of fingerprinting. Weaknesses: It may lack technological aspects.
	Girod-Frais & Bécue, 2021, Various	Review	Discusses the past, present, and future of the forensic use of fingermarks.	Strengths: Represents the evolution of fingermark technology. Weaknesses: Lacks explanation of the latest technologies.
	Huang & Zhang, 2018, China	Experimental	Synthesizes Fe3O4@GSH-Pt NCs for latent fingerprint detection.	Strengths: It provides experimental data on a new detection method. Weaknesses: Restriction of the use beyond concrete nanoparticles is also needed.
	Jakupi, 2019, Various	Review	Explores methods and techniques for revealing latent fingerprints.	Strengths: Practical description of latent print detection. Weaknesses: Possible blind spots in the coverage of these

				emerging technologies.
	Ma et al., 2013, Various	Experimental	Introduces magnetic resonance fingerprinting technology.	Strengths: Plays an important role in supplying scientific data about frontier technical solutions. Weaknesses: Lack of ability to handle traditional fingerprint analysis.
	Maltoni et al., 2017, Various	Review	Offers insights into automated fingerprint identification systems.	Strengths: Covers AFIS technology in full. Weaknesses: Although AI lacks depth in the theoretical AFIS implementation level,
	Mishra, 2022, Various	Review	Provides a review of fingerprint science from historical and contemporary perspectives.	Strengths: Presents a thorough description of fingerprint science. Weaknesses: It might not be comprehensive enough to address the latest developments in detail.
	Mlynárik, 2017, Various	Experimental	Explores the principles and clinical results of magnetic resonance fingerprinting.	Strengths: Provides experimental data on a brand-new fingerprinting technology. Weaknesses: Low applicability to traditional forensic analysis.
	Moses et al., 2011, Various	Review	Discusses automated	

			fingerprint identification systems.	Strengths: Gives an overview of the development and use of AFIS. Weaknesses: Might not give all the details about the latest discoveries.
	Omar & Ellsworth, 2012, Malaysia	Experimental	Investigate the possibility of using fingerprint powders to develop old fingerprints.	Strengths: Discusses actual forensic science applications. Weaknesses: Limited generalization beyond specific powder formulations.
	Panda et al., 2017, Various	Review	Provides an overview of magnetic resonance fingerprinting.	Strengths: Introduces very advanced fingerprinting technology. Weaknesses: Might not provide specific practical implementation details.
	Petrovic et al., 2022, Serbia	Experimental	Explores automated fingerprint identification systems with and without the possibility of correction of a digitalized image.	Strengths: Offers the experimental results of the AFIS technology. Weaknesses: Limitations that focus on system configuration specificity.
	Rao et al., 2023, Various	Review	Discusses automated fingerprint identification systems in modern forensic tools and devices.	Strengths: Provides insights about the employment of AFIS for forensic investigations. Weaknesses: Might not show the most recent

			breakthroughs in depth.
Sero et al., 2021, Various	Review	Examines three-dimensional fingerprint recognition in cultural heritage.	Strengths: Offers fingerprint recognition applications peculiarity. Weaknesses: Limited scope of application beyond cultural heritage.
Zhang & Wang, 2013, China	Experimental	Investigates the Cogent Automatic Fingerprint Identification System.	Strengths: Offers experimental data on a specific AFIS implementation. Weaknesses: Limited generalizability beyond the cogent system.
Lennard, 2001, Australia	Experimental	Studies optical methods development and the use of specific light sources for latent fingerprint detection on both porous and non-porous targets.	Strengths: Introduce technique that improves the visibility of latent fingerprints which can be applied in law enforcement Weakness: didn't discuss ethical issues in the sphere of forensics.
Kaur & Sodhi, 2023, India	Review	Explores the creation of fingerprint identification technology	Strength: provide a wide-ranging investigation of how innovations happened. Weakness lacks methodological detail or experimental data

Thong Lon &Chaikum, 2010, Thailand	Experimental	investigated the use of natural magnetite mixed with nickel powder as a magnetic fingerprint powder in detecting latent fingerprints.	Strength: demonstrated a very inexpensive way of manufacturing magnetic fingerprint powder by combining natural magnetite with nickel powder. Weakness: study results can't be generalized to the other surfaces.
Campo, 2018, Mississippi	Experimental	Investigate the technique for fingerprint scanning that led to the advancement of forensic analysis methods.	Strength: detect the most valid fingerprint scanning process. Weakness: Research mainly investigated flip flops since they have only semi-porous surfaces, which are not necessarily generalized to other materials or surfaces that are frequently used in the forensic investigation scene.
Tantisira et al., 2011, Thailand	Experimental Sample: Seven brands of powder,12 surface samples	Evaluate the performance of several fingerprint powder types and ensure that silver Arrow, BVDA, and Siam Smart brands give the best results under the magnetic and	Strength: evaluation of different types of fingerprint powders by means of empirical data Weakness: No suggestion is given on the chemical aspect or environmental parameter that

		black powder types.	might affect the discharge of the powders
Trapecar et al., 2022, Slovenia	Experimental	Demonstrate the incorporation of specific methodology (ACE-V) with the new technology (GYRO system) to improve the fingerprint identification processes.	Strength: merges a modern scientific technique with leading-edge technology that likely enhances the accuracy and precision of fingerprint identification. Weakness: confined only to the arid glass environments
Win et al., 2020, China	Review	A comprehensive review of usage of machine learning and neural network algorithms in the context of fingerprint identification.	Strength: insights into revolutionary techniques in making forensic tools better and more reliable. Weakness: No empirical findings were presented
Nag et al., 2008, UK	Experimental	Demonstrate the development of dark magnetic powder for fingerprint development on light background surfaces	Strength: relies on thorough experimental details, which shows its comprehensive nature and its efficiency in real settings. Weakness: only suitable for specific areas with limited types
Verma et al., 2022, United Arab Emirates	Expository or discussion-based	Highlights forensic technologies which	Strength: underlines the problem-solving implication of the

		fundamentally used in criminal investigations.	use of these technologies in real-world Weakness: It doesn't verify its attributions to the effectiveness of those forensic methods through empirical data.
Sawani et al., 2018, Sri Lanka	Review	Examine the emergence of fingerprint technology, which is improving forensic capabilities.	Strength: Provide implications for law enforcement and show the evolution from conventional methods to advanced computerized techniques. Weakness: Lack of real-world examples or case studies
Jaroensuk, 2009, Thailand	Experimental	Examined methods for lifting latent fingerprints from different surfaces with water-soluble tape.	Strength: Extends the implementation range of forensic experts by introducing a new method Weakness: limited material incorporates that effect, which might affect results generalizability.
Wang, 2016, USA	Quasi-Experimental	Determine an innovative way of improving fingerprint examination methods.	Strength: Illustrates the integration of digital means with traditional forensic techniques in a way that portrays

				the development in the field of forensics. Weakness: It doesn't depict all the nuances and the complexity faced by crime scene investigators.
	Edmond et al., 2014, Australia	Review	Explores the approaches for fingerprint identification	Strength: illustrate the applicability of fingerprint evidence in the criminal justice system. Weakness: limited detail is given about the methodologies of approaches
	Kim et al., 2019 Korea	Experimental	Investigate a new method (chamber method) for developing fingerprint latent with powders.	Strength: presenting a new method (chamber method) to address the health risk associated with fingerprint development techniques Weakness: limited to certain powder
	Vuckovic et al., 2020, Turkey	Experimental	Examine new techniques in visualizing latent fingerprints, such as dextran-based micro powders from anthocyanin	Strength: explores innovative ways for better visibility and improved quality of latent fingerprints. Weakness: scope is limited
	Wang, 2001,US	Experimental	Investigate fingerprint imaging technology that is	Strength: Introduce innovative technology in

			customized for fingerprint analysis.	fingerprint analysis Weakness: limited details on testing and validation of technology
	Shaler & Lakhtakia, 2013, US	Comparative experimental	Investigate fingerprint development techniques such as CTF development for forensic investigations.	Strength: offers optimization of CTF techniques over traditional methods for forensic investigations Weakness: Limitation of CTF techniques
	Saul et al., 2023, Philippines	Experimental	Investigate fingerprint identification technologies based on integrating deep learning algorithms	Strength: introduces a feasible method of fingerprint recognition that is based on integrating several deep learning algorithms with conventional classifiers. Weakness: security and private considerations briefly discussed
	Pocs et al., 2013, Germany and EU	Exploratory	Explores the biometric and forensic technologies that belong to crime prevention and public security.	Strength: study innovative approaches in the matter of privacy and data security. Weakness: Results aren't generalizable
	Kirvel, 2020, Belarus	Mixed method study (Experimental+ Review)	Investigate the fingerprint AFIS and biometric identification	Strength: utilizes practical applications of

		systems with artificial papillary patterns by incorporating dummy finger phalanx models	biometric technologies Weakness: limited detail on experimental methodology win
de Souza & Neto,2019, Brazil	Review	Provide a review of the evolution of fingerprint analysis	Strength: sheds significant light on fingerprint logistics. Weakness: Lack of methodological details
Bao et al., 2023,	Experimental	Investigate the new 'coarse-to-fine' approach for the fingerprint rectification process	Strength: Introduces a modern approach that provides a solution to the problem of fingerprint deformation. Weakness: Information on the method's complexity and integration into existing forensic procedures are not discussed.
Widman, 2011, US	Experimental	Explores the automated fingerprint identification systems via signal detection theory which points out that the accuracy of these systems depends largely on search configuration and parameters	Strength: utilizes quantitative approach and provides guiding improvements in AFIS configurations. Weakness: There might be complexity in implementation
Kanu & Kaplan, 2016, US	Experimental	Assess the sufficiency of GC-MS and	Strength: offers a reliable scientific technique for

			FTIR techniques in finding exact or reliable fingerprints and other forensic evidence.	forensic examination Weakness: avoided the complex details associated with the specifics of fingerprint identification.
	Bailey et al., 2015, UK	Experimental	Explores latent fingerprints with mass spectrometry-based techniques such as (surface DESI and MALDI-IMS-MS/MS).	Strength: offers an innovative approach to forensic sciences. Weakness: Might not cover all aspects of fingerprint identification technology.
	Champod,2015, Switzerland	Review	Explore the significant developments in fingerprint identification	Strength: Presents a detailed breakthrough of progress in fingerprint identification. Weakness: don't discuss practical implementation in forensic settings.
	Khare & Singla, 2020, Egypt	Review	Reviews the developments in the chemical analysis of latent fingerprint residue composition	Strength: Provide detailed presentation of the newest methods of fingerprint analysis in forensic examination. Weakness: Might not provide practical implication
	Aboalsamh,2010, Saudi Arabia	Review	Reviews the latest developments in biometric technologies and emphasizes the combination	Strength: Provide insight into the latest developments in biometric technologies.

			of CMOS fingerprint sensors and feature-based algorithms used in fingerprint verification for more accuracy.	Weakness: May lack detailed experimental data or case studies
	Engelsma et al., 2018, US	Experimental	Investigate universal generic fingerprint templates, which enable rigorous tests and evaluations of fingerprint readers.	Strength: Provide innovative technology for examination of the authenticity of fingerprint readers. Weakness: doesn't comprehensively discuss more complicated implications in forensic contexts.
	Jothi & Palanisamy, 2016, India	Review	A comprehensive review of AFIS and underscores the critical role of minutiae features in fingerprint-based authentication.	Strength: Gives a detailed account of the processes of minutiae extraction and matching involved in AFIS with an analysis of the current techniques in the art. Weakness: May lack empirical data or experimental results
	Imam et al., 2018, India	Review	Reviews the DNA fingerprinting development and stresses the importance of DNA profiling in forensic science and criminal justice.	Strength: Highlights the development of DNA fingerprinting technology, uncovering its role in forensic science and criminal justice.

				Weakness: May lack practical implications of DNA fingerprinting advancements.
	Zhang & Peng, 2023, China	Review	Review the developments in the blood fingerprint enhancement technique and highlight its key role in forensics	Strength: Discusses the detailed survey of the recent developments in the blood fingerprint enhancement methods. Weakness: May lack empirical data
	Noviana et al., 2022,Australia	Review	This study provides a comprehensive review of fingerprint analysis techniques	Strength: provide updates on the development of fingerprint analysis tools Weakness: May lack specific case studies or experimental results
	Jin et al., 2015,China	Experimental	Investigate a new NIR sensor (NIR-LP) with ESIPT and AIE features to detect and visualize latent fingerprints.	Strength: Develop a novel method based on NIR technology and unique chemical properties (ESIPT, AIE) for revealing latent fingerprints. Weakness: limited discussion on the practical forensic application
	Althabhawee & Alwawi, 2022, Iraq	Experimental	Investigate the process of building a CNN-based fingerprint recognition	Strength: develop and assess a deep CNN-based fingerprint recognition system that

		system using deep learning technology.	achieves high matching accuracy. Weakness: no emphasis on practical implementation and feasibility in the real world.
Noor et al., 2018, Pakistan	Experimental	Investigate the implementation of the MG-SVM classifier that improves the performance of the fingerprint recognition systems to a great extent	Strength: utilizes real-world fingerprint data from the FV2002 database, making the study more applicable. Weakness: This may provide limited discussion on the specific issues or constraints that may arise during the experiments.

4. Historical Development:

Berry and Stoney (2001) delved into the historical development of fingerprinting, aiming to provide a comprehensive understanding of its emergence and evolution over the past century. Employing a qualitative approach, the researchers examined the foundational principles of dactyloscopy and the intricate patterns of ridges and furrows present in human skin. Their research traced the origins of fingerprint identification and highlighted its significance as a method of personal identification. The authors chose the introduction to discuss the fundamentals of this discipline; the basic concepts of fingerprint analysis and its perennial role in forensic science were clarified. In his book "Suspect Identities" (2009), Cole (2009) focused on the history of criminal identification and the critical overview of the development of fingerprints as individual identifiers. In her qualitative study, Cole studied the social and political contexts in which fingerprinting originated and showed how it evolved from nineteenth-century bureaucratic practices to modern forensic techniques. He uncovered how identity, state power, and technology became intricate parts of a complex phenomenon relative to historical documents and cases from different parts of the world. Fingerprinting, perhaps, was the subject of the greatest controversy around human rights in the history of criminology. Mishra (2022) undertook a review of fingerprint science from historical and contemporary forensic perspectives in order to give an overview of its evolution and current practice. Mishra opted for a qualitative approach as he discussed the major developments in fingerprint recognition and its growing popularity as a method of personal identification. His study revealed the specific qualities of fingerprints and their permanent and trustworthy role as a distinguishing human marker. Through a detailed review of the literature and case studies, Mishra showed that fingerprinting is still a significant tool in forensic science and is being used in conjunction with the

latest technologies. Girod-Frais and Bécue (2021) conducted a study on the historical and current state of fingermarks analysis in forensic sciences while pointing out the strides and the drawbacks in the area of research. By employing a qualitative method, they discussed the evolution of fingerprint analysis from its initial development to more advanced forensic technique. The main results of their research showed that fingermark analysis can be a valuable investigation support tool and that its development has a lot to look forward to. By a thorough study of the literature and case studies, Girod-Frais and Bécue found the main trends and difficulties in fingermark analysis that will guide further research and development in this field.

Dass (2013) conducted an overall examination of fingerprint-based recognition techniques as tools for exploring their prevailing issues, barriers to optimization, and research domains. Rather than the quantitative approach, she sought to outline the platform of fingerprint-based recognition and its effectiveness in forensic and civilian contexts. He focused on the progress in fingerprint capture technology and the difficulties of the environment in which it is used. Through scientific data analysis along with reviews of existing literature, Dass determined that the cause of such variability issues can be mitigated through the scientific development of fingerprint-based methods. Sero and his research team studied fingerprint recognition in 3D cultural heritage; the subject was developed to determine its most essential role and the challenges it may pose. The authors conducted a qualitative study and analyzed the importance of fingerprint recognition in the field of cultural heritage research and its implications for the understanding of ancient societies. Their research revealed the essential role of forensic fingerprinting as a means of determining art creators and implementing the art authentication of objects. The paper of Sero et al. is based on a critical analysis of current literature and case studies that reveal the opportunities and challenges of digital fingerprint recognition in order to provide grounds for further research in the emerging discipline. Girod-Frais and Bécue (2021) conducted a study entitled” Past, present and Future Forensic Use of Fingermarks," with an emphasis on fingermark analysis in forensic science (advancements and complications). Their research was intended to give a whole picture of the historical development, the current practices, and the future prospects of fingermark analysis. They collected qualitative data on the development of fingermark analysis as a forensic technique, and the applications of this analysis in criminal investigations using a qualitative approach. Applying the existing literature and case studies, Girod-Frais and Bécue highlighted the main tendencies and difficulties of fingermark analysis, including the development of technologies with age estimations. Their work set the stage for further research and development in this field, which in turn led to a greater knowledge of fingermark analysis and its place in forensic science.

Widman (2011) conducted a study to test the validity of automated fingerprint identification systems by applying the signal detection theory that focuses on another important component of fingerprint identification, namely the creation of quantifiable criteria. This approach surpasses setting threshold values to incorporate the arrangement of system settings into the reliability of matches. Therefore, the research provides the needed foundation for the advancement of fingerprint analysis procedures that will be standardized and reliable, hence helping to improve the accuracy of forensics and confidence in the judiciary. Kanu and Kaplan (2016) conducted another study focusing on implementing advanced forensic chemistry techniques in criminal investigations. Adopting an experimental mode, the scientists set up a crime scene for collecting, processing, and analyzing evidence using sophisticated methods like FTIR and GC-MS. Kanu and Kaplan draw attention to the crucial importance of confirmatory methods in forensic science, which enable the distinction between presumptive and definitive findings and require solid scientific knowledge in order to interpret crime scene data correctly. Bao and team (2023) research propose an approach towards a higher level of fingerprint analysis using a technological hybridization that combines traditional techniques and deep learning networks. The present study is of high value to the forensic science community by achieving an appreciable enhancement in fingerprint identification accuracy in complex conditions that are not easily recognized with the common

methodologies, thereby emphasizing the application of integrated technologies in forensics. Bailey et al. (2015) introduced the innovative use of mass spectrometry for screening drug metabolites in human fingerprints, an up-to-date alternative to non-invasive drug detection. The study shows the connection between the presence of drugs in fingerprints and oral fluids, thus bringing in the concept of fingerprints as a more secure and efficient sampling medium for drug forensic analysis. This study provides a new direction for advanced research in forensic science as it demonstrates the collaboration of multiple analytical techniques that can be used to improve the possibilities of fingerprint-based recognition in the course of criminal investigations.

Wang (2016) specifically focuses on hand-held digital devices used for quantitative measures in either partial-full fingerprint examination and endeavors to solve some of the problems encountered by fingerprint examiners in the lab and investigators at the crime scenes. A quantitative quasi-experimental design is employed for the study, and samples are measured in real-time with a hand-held digital device using simulated partial-full fingerprint situations. Wang's investigation advances fingerprint examination techniques to improve decision-making processes in forensic examinations. Edmond et al. (2014) conducted a study to address existing limitations and improve the accuracy of fingerprint presentation in criminal courts. By incorporating a qualitative approach, Edmond et al. focused on the design of a guide that could help fingerprint detection, evidence reporting, and interpretation. This study addresses the existing limitations and provides suggestions to improve the accuracy of fingerprint presentation in criminal courts. Kim et al. (2019) examined the effectiveness of fingerprint technology by investigating the effectiveness of the chamber method versus the brush method with regard to the preparation of latent fingerprints on glass and plastic surfaces using black powder and green fluorescent powder. Using a quantitative technique, Kim et al. offer novel techniques of fingerprint technology to increase safety and efficiency during the fingerprint development process at crime scenes. Imam et al. (2018) review the evolution of modern innovations in DNA fingerprinting and particular attention is given to the role of DNA fingerprinting in criminal justice and forensic sciences. Their review emphasizes the irreplaceable role of DNA profiling techniques, covering traditional RFLP approaches to the latest STR and NGS technologies, in solving criminal cases and making justice systems work. Imam et al. underline that DNA fingerprinting has become an ever more powerful tool for one-to-one identification and subsequent criminal case analysis. Champion (2015) critically reviews the 2009 NRC report on fingerprint identification and underlines the move towards scientific validation and statistical assessment in forensic science. Through critical reflection on post-2009 developments, this study contributes to advancing the scientific basis of fingerprint identification and its integration into forensic practice. Khare and Singla (2022) discussed the progress made in the chemical examination of latent fingerprint residues and also highlighted the need to have an in-depth knowledge of fingerprint composition for forensic investigations. Through discovering research gaps and possible directions, the review is a part of the long-term development of fingerprint analysis methods in the field of forensic science. Asboalsim (2010) introduces recently emerged biometric systems, mainly focusing on new developments in fingerprint and vein recognition technologies. Asboalsim focuses on assessing practical biometric systems implementation using tiny sensors and processing units on the basis of feature-based algorithms that enhance biometric performance. The research work of Engelsma et al. (2018) advances the application of fingerprint reader evaluation with the development of 3D fingerprint targets that are universal. Engelsma features the necessity of conducting controlled testing and interoperability experiments to increase the accuracy and usefulness of fingerprint identification via various detection mechanisms. Jothi and Palanisamy (2016) provide a valuable paper on minutiae extraction and matching of algorithms within automatic fingerprint identification systems. Through comprehensive analysis, their research finds that minutiae-based techniques can be used to improve the security and reliability of biometric authentication systems, identifying remaining problems and signaling directions for future research and development.

Verma et al. (20220 in their research investigated the relationship between forensic science and crime resolution. The current study employed a qualitative approach and used DNA profiling, brain fingerprinting, narco-analysis, and polygraphs which were all very useful in crime detection and incrimination of criminals. The research in the field of applied research on the role of forensic science in the investigation of the crimes that end with murder trials is one of the main achievements of the science in general, and it may be the beginning of other similar researches on this topic. Vuckovic et al. (2020) applied in their work a detailed illustration of the synthesis process of a Dextran-based spherical microsphere for the case of fingerprints and their identification. The researchers added the anthocyanin solution by precipitating dextran and showing its biodegradable, biocompatible, and nontoxic properties, which caused a lesser human health impact than the commercial methods. Four microscopic powders (dextran) were examined, and their binding of latent fingerprint residues was confirmed. This work evidenced that dextran-based powders could be used as sorbent alternatives in criminal investigations, thus providing a novel evidence-handling technique. Wang (2001) studied the new digital imaging device called the Digital Imager, which is used for fingerprint examination, comparison, and projection in the crime scene in the courtroom. The following paper shows the benefits of the device and its plating software. Digital imaging, apart from better accuracy in such analysis, also gives efficiency in both the investigation room and the hearing room. Shaler & Lakhtakia (2013) performed basic science research in fingerprint topography collected using columnar thin films (CTFs) on ideal substrates for forensics. The research outlined continued proof-of-concept experiments by establishing their scientific background and scope of use by comparing the performance of CTFs with the fingerprint development techniques that are usually used. Shaler and Lakhtakia showed how CTFs can be applied to DNA fingerprinting development and that CTFs produced better results than traditional methods.

Jaroensuk's (2009) research focused on the recovery of latent fingerprints by using water-soluble tape and thereafter lifting them to assess the quality of the lifts. With the help of a quantitative methodology, the author deals with the issue of the likelihood of fingerprint detection on footwear and its impact on forensic investigations. Jaroensuk illustrates fingerprint recovery processes and DNA analysis methods as they are used in forensics. As a result, such input might lead to better efficiency and correctness of obtaining the evidence from those crime scenes. Nag et al. (2008) carried out a study to examine a new type of dark magnetic powder that can boost the visibility of latent fingerprints on light background surfaces. The study explains that magnetic particles that have poor contrast with dark backgrounds of tissue relative to the commercially available magnetic particles pose the problem. The research goes hand in hand with the call for the development of innovative materials in forensic science that will, in turn, eliminate some problems that may impede the identification and enhancement of fingerprints. Tantisira et al. (2011) evaluate and compare seven brands of black and magnetic fingerprint powders used to improve fingerprints on different surfaces. Through the Automated Fingerprint Identification System (AFIS), the evaluation of the most suitable powder is done through full systematic testing and repetition on multiple surfaces to evaluate the identification rate of these powders with regard to the minutiae. This study aims to show the practical importance of latent fingerprint development as its baseline in investigative forensics.

Zhang and Peng (2023) highlight the advancement in blood fingerprints, emphasizing this aspect as what mainly assists in personal identification and crime scene reconstruction. They put in forensic science evolution and emphasize innovation like new gen reagents, advanced materials, and new approaches to improve sensitivity, specificity, and contrast. Zhang and Peng emphasize the importance of blood fingerprint enhancement in forensic investigation and suggest the development in this field. Noviana and colleagues examine the most current fingerprint methods that can be implemented as a standardization and quality control of herbal medicines. The authors stress that 'chemical profiling' is a modern approach to the assessment of the high quality of herbal medicines and that chemical metrics can be used for further data processing. Jin et al. (2015) are the authors who joined the previous research on the improvement of

forensic detection techniques with their new approach, which works through NIR light luminescence and chemical properties (ESIPT, AIE) used for the finding of latent fingerprints. This research reinforces the importance of locating simple, powerful, and common techniques for bettering visualizations of latent prints, which have bigger implications for forensic science and biometric identity. Althabhawee & Alwawi (2022) parallelly carried out work on fingerprint recognition with deep learning methods. The research has revealed that the deep CNN network has shown superior accuracy and robustness when it comes to fingerprint verification, which is the most likely progress in modernizing traditional identification systems with modern AI approaches. Noor et al. (2018) conducted an effective experimental study that provided a better way of fingerprint recognition through the use of specific classifiers in order to increase the system's performance. The selection of a classifier in the fingerprint recognition systems is pointed out as the key element in getting higher accuracy and reliability which in turn influences the performance of biometric authentication.

5. Principles of Magnetic Fingerprinting

Ma et al. (2013) proposed magnetic resonance fingerprinting (MRF) as a new way of using quantitative tissue characterization in magnetic resonance imaging (MRI) system. The researchers used a qualitative approach, so their principles of MRF were based on the acquisition and analysis of MR signals. They collected data through experimental studies that involved cadaver and in vivo imaging trials. Consequently, the MRF techniques evaluated in this work prove to be of great promise for the multi-parametric MR imaging application. This report is great as it focuses on the basics of magnetic fingerprinting and how it relates to tissue characterization using MRI, thus giving a detailed explanation of how magnetic fingerprinting can be used in forensics. Panda et al. (2017) gave their assessment about employing MRF-based technology in different medical imaging platforms while conducting the review. With the quantitative method applied, the authors sought to examine the clinical reviews and literature pertaining to MRF systematically. The data were collected from sources like the rating of scientific journals and the clinical trials. In the article, MRF was highlighted for its technical potential for tissue measurement and to make the diagnosis of diseases in multiple disciplines of medicine. The research is a significant study because, taking into account the laboratory magnetism principles with regard to the clinical applications, it indicates the comprehensive capabilities of the approach employed with respect to medical imaging and diagnostics. Coppo, et al. (2016) established MRF and investigated its possibilities in the clinical practice. Qualitative investigation was used which was based on literature and expert views summary to focus on the landfill diversion rates of MRF. The data collection process implies a process of investigation, which includes a review of articles, technical reports, and conference proceedings. After the tests, it was clear that MRF is a sensitive and specific technique of quantitative tissue characterization and disease detection in biomedical applications. The article's key goal is to give a comprehensive elaboration on the use of MRF theory in the field, which ultimately contributes to the topic. The need for MRF in forensic science is depicted through its applications such as tissue examination in autopsy and injury assessment.

Mynarcik (2017) discussed magnetic resonance fingerprinting (MRF), concentrating on the basic ideas and the first clinical tests. The purpose of the research was to analyze the usability and effectiveness of MRF as a quantitative imaging technique in MRI. Mlnárik, who was qualitative in his review, touched upon the theory establishment and role of MRF in quantitative tissue characterization. Data collection was represented by the analysis of the MRF studies conducted in clinical settings that evaluated its diagnostic sensitivity and specificity. The outcomes showed a possibility of MRF not only for non-invasive and numerical investigation of tissue properties but also to increase the precision of diagnosis and treatment planning in clinical settings. This work presents magnetic fingerprinting in the context of MRIs in a way that displays the opportunity for using quantitative assessment of fingerprint features in forensic analysis.

The paper of Burgess et al. (2015) reveals the magnetic fingerprint of the individual Fe4 molecular magnets under STM compression. Their research was centered on the magnetic properties of individual molecular magnets when they are exposed to external stimuli. In the course of this work the involvement of a qualitative approach included the manner in which STM and imaging of Fe4 molecular magnets was changed by means of testing them under pressure which was aimed at discerning their magnetism. In other hand, data had been collected using STM imaging and the magnetic analysis of individual Fe4 molecules. The research revealed the intricate magnetic behavior of Fe4 molecular magnets under compression, which could be used to understand their applications in spintronics and quantum computing. This study carries relevance in respect of the current subject matter as it deals with magnetic fingerprinting principles at the molecular level, aiming to have a deeper knowledge of the magnetic properties of individual molecules that could lead to the development of more advanced forensic approaches.

6. Principles of Automated Fingerprint Identification System (AFIS)

Moshe et al. (2011) researched the Automated Fingerprint Identification System (AFIS) through the historical prism, presenting the problem and suggesting the solution of the traditional identification systems. The researchers preferred qualitative approach for their study. This is a part of the historical part, which in many ways includes a detailed study of the development of the identification system since ancient times. The data collection was undertaken through archival research and the analysis of the historical records with the purpose of representing the evolution of the AFIS technology. The conclusions of this research have covered the gap related to the traditional manual detection of fingerprints and modern expectations of fully automated and reliable identifications that have resulted in urbanization and an increase in the number of crime acts. This research is very important because it is a historical journey of the development of AFIS and its role as a fundamental technology in forensics. Maltoni et al (2017) discussed the contributions of Automated Fingerprint Identification System to forensic science investigation, which is now another form of evidence. The researchers used a qualitative approach in the study of automated fingerprint identification and showed the use of a given example and understanding of the system by its implementation. The materials for the discussion are based on the literature review and an in-depth analysis of the implementation of AFIS in different forensic settings. The author implemented the AFIS system with fingerprint recognition with high accuracy and adaptability, as well as several uses for identification, investigation, and intelligence. This research can be applied to the current issue because it shows the entire components of the fingerprint identification system, including modern techniques that give the optimal fingerprint forensic analysis and, therefore, automatic identification. In their investigation, Rao et al. (2023), discussed the operation process of AFIS (short for the Automated Fingerprint Identification System) and its contribution in modern-day crime case solving. Authors employed qualitative methods to explain the way the AFIS technology functions, including its principles, functions, and the role it plays in criminal investigations. The data collection process was initiated by analyzing the works of authors who dealt with the nature of AFIS and how the system is utilized in a forensic system. They proved that this system could be used not only for the automation of fingerprint identification but also for the improvement of the efficiency and reliability of forensic science. The research results showed that AFIS is a modernly used forensic tool that permits the resolution of crime cases thereby imparting some knowledge concerning the applications and the merits of the tool in the criminal investigation process.

The article by Petrovic et al. (2022) is intended to show that what is usually called the humanization of the automated face identification system (AFIS) is actually quite different from the case where the modification is possible. The research goal was to identify and assess the technical and technological solutions of AFIS in the test and production environment. They applied the quantitative evaluation approach to compare the performance of different AFIS systems on the basis of their latent fingerprint

database. The data acquisition process had two aspects, which included test and production runs for the AFIS systems, both systems using the database with dactyloscopies persons. According to their study, there were statistically significant differences between the accuracy of the AFIS-based systems, and this suggested the strengths and weaknesses of each system. This study highlighted the strengths and weaknesses of the AFIS systems, which paved the way for the advancement of forensic technology. Zhang and Wang (2013) tried to reveal the internal principles, workflow, and functionalities of CFIS developed by Cogent Co, Ltd. Their goal was to evaluate the performance of CAFIS in fingerprint identification. While a qualitative approach was used to highlight CAFIS technology, the acquired images, screening, matching, scoring, and sorting modules were briefly described. The data collection was done using an experimental study of the CAFIS database capacity, speed of matching, and accuracy. CAFIS results illustrated its benefits, such as speed matching, big database, and high accuracy. CAFIS has been shown to be an effective tool for fingerprint identification in criminal investigations.

7. Applications of Magnetic Fingerprinting and AFIS in Forensic Science

Chaisawvong et al. (n.d.) are the only researchers whose research aimed to develop multipurpose fingerprint powders using four materials: Nickel (Ni) powder, cobalt (Co) powder, titanium dioxide (or TiO2), and nickel (II) oxide (or Nio). These scientists have been studying the properties of these materials. They have used a mixture of these materials to investigate the magnetic and fluorescent characteristics. The concealed fingerprints were formed by mixing (a) key chemicals on white and black non-porous surfaces like metal and nail polish. The results proved a good procession of adherence of the fingerprints with clarity. The mixtures containing TiO2 were found to fluoresce a little bit at 505 and 530 nm. The numbers of details captured by a fingerprint identification system (AFIS) are not very different than when a specialist and commercial powders are used. Jakupi's (2019) investigation focused on utilizing different approaches and technologies to unmask fingerprints that are usually hidden on the crime scene. The study analyzed the number of positive identifications for each ‘minutiae’ before and after the application of black fingerprint powder and black magnetic fingerprint powder. The fingerprints of the donor were absorbed onto the clean microscope slides after the perpetrator smudged them. Every week, the slides were analyzed at intervals, which was similar every time. The analysis was made for six consecutive weeks of black fingerprint powder and uncommon black magnetic fingerprint powder. Ghosh and Pahari (2021) studied the uniqueness of fingerprints as a tool for identification in forensic science. The study showed that fingerprints were a powerful tool in solving crimes and making the criminal justice system more effective. It showed the high superiority of human biometrics in the aspect of your being ever reliable and your steady stability. Through Coffey and John's (2018) literature, basic skills to work with scene processing were looked at, especially those pertaining to fingerprints, which are used as physical evidence. The science of fingerprints is based on two fundamental principles: uniqueness and eternalness. In the same manner, the paper also considered the responsibilities of the Automated Fingerprint Identification Systems (AFIS) in contrasting latent prints against record fingerprints. Omar and Ellsworth (2012), in their investigation, showed the feasibility of producing back fingerprints of already existing prints using powder instead of the usual ink method adopted in traditional fingerprinting. The research analyzed the number of accurate identifications of each 'minutiae' after the black fingerprint powder and black magnetic fingerprint powder were applied. The outputs described the time limits for the fingerprint expansion and the appropriate powder for the fingerprint residue. These studies shed light on forensic science fingerprinting and say a lot about every particular methodology. Since every research contributes something to this particular science

8. Advancements and Innovations of Magnetic Fingerprinting and AFIS:

Daluz (2018) intended to illustrate the essential aspects of fingerprint analysis, including the history of its development, theoretical information, and the techniques used in forensic science. The method of this study is qualitative, where the focus is on the synthesis of the already existing knowledge and its presentation in a structured form that is suitable for educational purposes. The first step for data collection was to read recent publications and experts' advice and assemble those that related to the subject of fingerprint analysis. Researchers pointed out the usefulness of fingerprints as evidence in criminal research and their amazing power in the courtroom. This study is important to the present topic as it provides the basic knowledge of fingerprint analysis and is a good reference for students and practitioners in the field of forensic science. Assis et al. (2023) have been fine-tuned for the emergence of new technologies for the development of latent fingerprints, specifically with regard to the design and application of nanomaterials and macromolecules as trademark developers. In fact, the research methodology adopted in this research is based on a qualitative approach and includes reviewing the existing studies and discussing the recent trends of fingerprint development techniques. The most part of the best study process was the synthesis of information from articles, reviews, and case studies that were associated with latent fingerprint enhancement by using new materials. The analysis showed that the use of nano-materials and macro-molecules increased the number and clarity of unpublished fingerprints which were then used to pursue the goal of finding clues that could not have been seen before through conventional development methods. This research has a great impact on the issue and it indicates the development of a new fingerprint evolution methodology that helps to solve the problem of the application of modern forensic methods and crime detection processes.

Cardwell and Bavarian (1997) sought to examine the existing trends in Automated Fingerprint Identification System (AFIS), making a journey in development history of this technology and analyzing the current achievements. The study is the qualitative, which revolves around historical analysis and digital creation. On the other hand, it is concerned with the projection of the future in respect to the development of AFIS technology. Literature review was the main method of collecting the data. The experience of the experts was also mined to find out the main tendencies and the AFIS technology evolution history. The research showed that the adoption of FIS relied on the emergence of optics, computer vision and AI technology. This project is in line with the purpose of bringing the AFIS story to the fore and showing the impact it has on forensic science and law enforcement. Huang and Zhang (2018) extracted the quaternary structure of magnetite (Fe3O4), coarse shell encapsulating the GSH-Pt NCs for core-shell microspheres. The established method looked like a process of magnetic particles' magnetization and formation of platinum-containing nano gatherings in the research methodology. The main laboratory experiments that were used to find out the magnetic and fluorescent properties of the synthesized nanoparticles and also their capability to detect latent fingerprints are the data acquisition techniques. A comparison was made, and GSH-Pt@Fe3O4 core-shell microspheres were named a good tool for latent fingerprint detection with high sensitivity and better resolution. This science achieved a milestone in the arena because it detected for the very first time an unknown kind of fingerprint using the latest nanomaterials which may open a new era in the crime scene investigation and forensics.

9. Challenges and Limitations:

The technical problems are similar in both magnetic fingerprinting and Automated Fingerprint Identification System (AFIS). The magnetic fingerprinting has two main challenges, which are to get uniform and precise results in different environments and surfaces. Type of fingerprints and the surface textures and compositions can result in fingerprint quality issues that can slow identification and analysis (Assis et al., 2023). Besides, the technical issues such as image quality and database management play an active role as in the case of AFIS.Poor quality fingerprint images, which have been blurred or smeared, can reduce the accuracy of matching and even lead to wrong identification results (Cardwell, Bavarian

(1997)). Furthermore, the management of giant fingerprint databases creates technical issues related to storage, processing, and retrieval. Therefore, scientific advancement is a must due to large scale problems (Maltoni et al, 2017). The legal and ethical aspects are the most important things to consider when using fingerprinting technology, especially the privacy rights and data protection. Along with the growth and linking of databases, the issue of personal data misuse by the authorities and unauthorized access or identity theft emerge (Maltoni et al., 2017). Another aspect, which legal standards of collection, storage, and application of fingerprint data vary across the jurisdictions cause inconsistency in the regulatory requirements and standards (Cardwell & Bavarian, 1997). Ethical dilemmas are also present in the use of fingerprinting technology in criminal investigations, such as the problem of false positives, racial bias, and the effect on individual rights and liberties (Assis et al., 2023). Technological progress does not stop the appearance of biases and mistakes in automated fingerprint identification systems that lead to wrong decision-making. Biases can be caused by the design of algorithms, balancing data sets, or human interpretation during the validation and identification stages (Maltoni et al., 2017). The effect of population biases in AFIS has been highlighted by several studies, whereby some groups of people are found to be overrepresented among the people who are misidentified (Petrovic et al., 2022). Additionally, fingerprint-matching algorithms can be prone to false positives or false negatives due to imperfections, which will negatively influence the acceptance of forensic evidence in court (Cardwell and Bavarian, 1997). These problems are the focus of continuous scientific research and efforts to improve algorithmic fairness, data transparency, and error mitigation strategies in automated fingerprint identification systems.

10. Discussions:

In this review paper the few topics about magnetic fingerprints and AFIS (Automated Fingerprint Identification System). Fingerprinting technology and biometrics are the main technologies in forensic science that are fast and accurate in the identification of criminals. The fingerprinting technique employs magnetic properties that make fingerprints to be seen on various surfaces, while AFIS is known for its reliability in the identification and matching of fingerprints in large databases. On the other hand, there are technical problems like differences in depth, image quality issues, privacy laws, and data security problems that do not let us be able to use these tools normally. This is evident in the magnetic fingerprinting and AFIS techniques, where the research findings are highlighted, and the problems are presented in the bibliography. To exemplify this, Assis et al. (2023) describe the technical issues of magnetic fingerprints, whose development process includes environmental factors that relate to the quality of fingerprint impressions. In a parallel way, Cardwell and Bavarian (1997) indicate that technical competencies in AFIS involve data management and also the quality of the photos. This trans-disciplinary partnership amongst people of different professions symbolizes the significance of research and innovations that bypass the technical difficulties, enhance reliability, and focus on the improvement of forensic fingerprinting technologies.

However, the legal and ethical issues are the largest part of magnetic fingerprinting and AFIS applications. Maltoni et al. (2017) cover the issue of privacy and data protection in relation to fingerprinting technologies, and Petrovic et al. (2022) paper involves the future complications caused by the biases in AFIS algorithms jointly with the legal and ethical problems. These similarities indicate that there are some legal and ethical problems with technology, and hence these need to be addressed to ensure a fair trial of cases in court.

Furthermore, the research shows the possible vulnerabilities and mistakes in the automation of fingerprint identification systems which can influence the reliability and accuracy of forensic examinations. Hence, Petrovic et al., report that authentication through AFIS is the precise biometric. The main disadvantage of the AAIS could be that demographic biases and algorithm errors might lead to incorrect identifications. On the other hand, this reveals the necessity of adding biases and

error mitigation methods into magnetic fingerprinting technology and AFIS in order to make the reliability and credibility of these technologies as high as possible.

So, it seems that both magnetic fingerprinting and AFS have great potential for forensic science; however, they both also face common difficulties and limitations. These challenges are realized through research into possible solutions. The researchers and practitioners will collaborate in an effort to improve the technology credibility and reliability of forensic fingerprinting for criminal investigations.

11. Conclusion and Future Directions

The review covers the core principles, key problems, and future developments of magnetic fingerprints and Automated Fingerprint Identification System (AFIS) in the context of forensic science investigation. Through a review of the literary works, the key findings were brought out, explaining the significance of these technologies in making the fingerprint analysis more efficient and accurate. Magnetic fingerprinting as a way of developing latents of fingerprints on different surfaces appears to be a great breakthrough, while AFIS delivers an unthinkable system for recognizing and analyzing fingerprints in the huge databases. A great amount of value is given to magnetic fingerprinting and AFIS in connection with the forensic science as it helps in the identification of the cases. These technologies have completely changed the face of the field of forensics, enabling the law enforcement to solve the crimes faster and more efficiently. By detecting the present trace of some substances by magnetic fingerprinting, the AFIS method allows the judicial practice and society to become safer.

In the future, there will be many implications for the development of fingerprint identification in criminal investigations. The two trends, namely, magnetic fingerprinting and AFIS, show a clear shift towards innovative and advanced techniques and technology, which includes the integration of AI and machine learning to improve accuracy and reliability. Secondly, a noticeable development is that the concerns about the legal and ethical aspects of using fingerprinting technology are beginning to gain recognition, especially as they relate to privacy rights and data protection laws. However, magnetic fingerprinting, AFIS research and their corresponding technologies are still evolving with the existence of a wide range of future avenues for improvement and expansion. The next step should be to improve the reliability and efficiency of these technologies. Besides, technical problems must be resolved, and errors or bias ought to be avoided. It is also essential to examine other applications of magnetic fingerprinting and AFIS, beyond criminal investigation, such as border control, health care, and biometric verification.

Therefore, magnetic fingerprinting and AFIS are the most important instruments of the forensic investigator's armamentarium, offering the most accurate fingerprint analysis and identification techniques. While these sciences are on the rise, this new branch of expertise stands a great chance to be very creative and successful that they will revolutionize criminal investigations and eventually the whole world. Establishing a solution to current problems and development of further research enable magnetic fingerprinting and AFIS to bring not only a revolution in forensic science but other fields and industries.

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