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Investigating the Future: Integrating Biotechnology, Artificial Intelligence, and Digital Science in Criminal Justice

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Abstract

Biotechnology, artificial intelligence (AI), and digital science are rapidly changing the way criminal investigations are conducted into an intelligent and evidence-based investigation process. The review will explore the benefits of these technologies in improving the effectiveness and accuracy of the modern criminal justice system and their impact on reliability. It covers important advancements in forensic biotechnology, such as DNA profiling, next generation sequencing, rapid DNA analysis, molecular biomarkers for human identification and forensic microbiology. The review also delves into AI's capabilities for crime pattern recognition, forensic image analysis, biometric identification, predictive policing, and explainable decision support. Furthermore, it emphasizes the emerging importance of digital science in the areas of digital forensics, Internet of Things (IoT) evidence, big data analytics, blockchain-based evidence management, and integrated forensic workflows. Finally, the review explores privacy, cybersecurity, algorithmic bias, and legal admissibility, as well as highlights the future trajectory of criminal justice technology, which should be multidisciplinary, and the role of smart forensic laboratories.

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1 Introduction

Investigating the Future is the process of how criminal investigations are changing by incorporating cutting-edge scientific and digital technologies that improve the accuracy, efficiency and reliability of forensic evidence analysis. It is not just about future innovation but the evolution of the investigative process toward intelligent, data-driven and multidisciplinary approaches in which biotechnology, artificial intelligence (AI) and digital science come together to face increasingly sophisticated criminal activities. The technological sophistication of the crime is matched by the scientific and legally reliable technologies of criminal justice investigations, which are increasingly able to analyze a variety of biological and digital evidence without compromising the integrity and authenticity of the investigations.

In the past, criminal investigations were based on eyewitness evidence, physical evidence, manual fingerprint examination, forensic microscopy, and the knowledge and experience of the investigator. Although these conventional methods established the foundation of forensic science, they were often time-consuming and dependent on human interpretation. The recent developments in computing, molecular biology, and digital technologies have revolutionized the nature of criminal investigations, making them a technology-driven process and aiding with automated analysis, high throughput biological tools, intelligent algorithms, and digital forensic tools. This has greatly enhanced evidence collection, interpretation and case resolution speed and accuracy.[2]

Biotechnology has enhanced forensic investigations by means of DNA profiling, next generation sequencing and molecular biomarkers, which are used for human identification and analysis of biological evidence, among these innovations. AI empowers investigators to identify patterns, learn from forensic images, aid biometric identification and aid crime pattern analysis. In the meantime, digital science has evolved, including the digital forensics, cloud forensics,

[2] K. TIWARI, "Digital Revolution in Criminal Procedure of India: An In-depth Examination of the Impact of Emerging Technologies," Int. J. LAW Manag. Humanit., vol. 6, no. 6, pp. 3573–3588, 2023, doi: https://doij.org/10.10000/IJLMH.116540.

blockchain, and big data analytics, which are vital to gathering, preserving, and interpreting the electronic evidence formed within the modern digital landscape.[3]

But in today's world, criminal investigations demand more than a simple use of technologies. The integration of biological, digital and analytical evidence is increasingly linked, and requires a multidisciplinary approach for full investigation. Bioteknology, Artificial Intelligence and Digital science optimise evidence correlation, further investigative accuracy, speed up case resolution and enable well informed decision making by the judiciary.[4] This review explores the merging of these complementary technologies and their impact on the modern criminal justice system and the future of forensic science.

2 Biotechnology in Modern Criminal Investigations

Biotechnology has led to the revolution of forensic science as it enables highly sensitive, accurate and rapid analysis of biological evidence. Conventional serological methods have largely been superseded by molecular methods that are able to detect people from tiny or degraded biological specimens. Recent developments in genomics, molecular biology, and microbiology have broadened the scope of forensic evidence that can be used, thereby enhancing the criminal investigation and judicial process. In addition to the use of biotechnology for human identification, the use of innovative analytical techniques to reconstruct a crime scene and for the identification of a crime victim is also supported today.[5]

A. DNA Profiling and Next-Generation Sequencing (NGS)

The high discriminatory power of DNA profiling makes it the basis for forensic human identification. The traditional method of using short tandem repeat (STR) analysis for identification of individuals from biological evidence is a very common technique. The introduction of next-generation sequencing (NGS) has since advanced forensic genetics, by

[3] R. S. A. Faqir, "Digital Criminal Investigations in the Era of Artificial Intelligence: A Comprehensive Overview," Int. J. Cyber Criminol., vol. 17, no. 2, pp. 77–94, 2023, doi: 10.5281/zenodo.4766706.

[4] S. Y. Prayoga, "The Criminal Justice System And Technology In The Digital Age," Edunity, vol. 3, no. 7, pp. 550–557, 2024, doi: 10.57096/edunity.v3i7.287.

[5] S. Antil and V. Joon, "Biotechnology in Forensic Science: Advancements and Applications," J. Forensic Sci. Res., pp. 7–14, 2025, doi: https://doi.org/10.29328/journal.jfsr.1001073.

allowing the analysis of multiple genetic markers at once, enabling the interpretation of degraded, mixed and low-template DNA samples, and enabling more analytical resolution.[6]

B. Rapid DNA Analysis for Faster Investigations

Rapid DNA technology involves the automation of DNA extraction, amplification, separation and profiling within a few hours, which can drastically reduce the turn around time in the laboratory. This technology provides for faster identification of suspects, disaster victims and screening at the borders and standardized forensic procedures in controlled environment.

C. Forensic Microbiology and Environmental DNA (eDNA)

Forensic microbiology involves studying the microbiological communities found on humans and crime scenes to determine PMI and to determine human-environment relationships. Also, environmental DNA (eDNA) is a powerful tool for identifying genetic material in soil, water or air, which can help in finding crime scenes, tracing environmental evidence, and in in situ wildlife forensic investigations.[7]

D. Emerging Molecular Biomarkers for Human Identification

The research has recently identified molecular biomarkers such as patterns of DNA methylation, messenger RNA (mRNA), micro-RNA (miRNA), and protein biomarkers which enhance the forensic identification. The use of these biomarkers will help extend the spectrum of forensic molecular analysis such as for identification of body fluids, age determination, tissue source identification, and post mortem interval estimation.[8]

E. Advantages and Current Limitations of Forensic Biotechnology

Forensic biotechnology has unique sensitivity, accuracy and capacity to analyze minute or degraded materials of biological origin, significantly enhancing criminal investigations. But there are still problems, such as cost of instrumentation, the complexity of data interpretation, the risk of contamination, privacy issues involving genetic data, and standardized protocols and trained personnel that allow for reliable forensic use.

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[6] P. Dessai et al., “A Review on Emerging Trends in Forensic DNA Profiling and Analysis,” Int. J. Drug Deliv. Technol., vol. 16, Jun. 2026, doi: 10.25258/ijddt.16.46s.34.

[7] N. Moreira et al., “Biotechnology Applied to Forensic Sciences,” Appl. Sci., vol. 16, no. 5899, pp. 1–24, 2026, doi: https://doi.org/10.3390/app16125899.

[8] M. T. Zaatar et al., “Molecular Age Estimation: Current Perspectives and Future Considerations,” Int. Jourbal Mol. Sci., vol. 27, no. 3104, pp. 1–18, 2026, doi: https://doi.org/10.3390/ijms27073104.

3 Artificial Intelligence as a Decision-Support Tool in Criminal Justice

Artificial intelligence (AI) is an important decision support tool in the modern criminal justice system that helps investigators process the vast amounts of data they have to work with, find hidden patterns, and better understand evidence. AI is not meant to take the place of human forensic expertise or law enforcement personnel; instead, it is designed to assist and augment them by automating repetitive analytical work and providing data-driven insights to aid in informed decision-making. Recent developments in machine learning, deep learning and computer vision have broadened the use of AI in forensic science and improved the speed and consistency of both biological and biometric and digital evidence and crime-related evidence analysis.[9]

A. Machine Learning for Crime Pattern Recognition

The machine learning algorithms examine historical crime data, geographical information, and behavioural patterns to find similarities and trends in massive amounts of data. These analytical models help investigators identify crime hot spots, connect related crimes and prioritize investigative resources to enhance operational efficiency and planning.[10]

B. AI-Assisted Forensic Image and Fingerprint Analysis

AI-powered computer vision systems enhance the examination of forensic images by automatically detecting, classifying, and comparing fingerprints, footwear impressions, and other visual evidence. Deep learning algorithms boost the accuracy of fingerprint matching, improve the quality of surveillance images, and speed up the amount of time spent on manual comparison, all whilst assisting forensic experts during evidence evaluation.[11]

C. Facial Recognition and Biometric Identification

Facial Recognition Technology uses Artificial Intelligence algorithms to match facial features from digital images or surveillance video to a facial reference database. These systems, coupled

[9] Y. Agarwal, P. Rawat, S. Kathuria, R. Singh, K. R. Chythanya, and M. Sahu, "Artificial Intelligence Contribution to Forensic Science Crime Investigation," in 2023 3rd International Conference on Innovative Sustainable Computational Technologies (CISCT), 2023, pp. 1–5. doi: 10.1109/CISCT57197.2023.10351482.

[10] D. Dunsin, M. C. Ghanem, K. Ouazzane, and V. Vassilev, "A comprehensive analysis of the role of artificial intelligence and machine learning in modern digital forensics and incident response," Forensic Sci. Int. Digit. Investig., vol. 48, p. 301675, 2024, doi: https://doi.org/10.1016/j.fsidi.2023.301675.

[11] Manisha, C.-T. Li, And K. A. Kotegar, "AI-Synthesized Image Detection: Source Camera Fingerprinting to Discern the Authenticity of Digital Images," IEEE Access, p. 1, 2025, doi: 10.1109/ACCESS.2025.3537558.

with other biometric modalities like iris and voice recognition, enable suspect identification, missing person investigations, border security and access control. However, they are not being used in a forensic capacity and must be properly validated to reduce the likelihood of mistakes and demographic bias.

D. Predictive Policing and Crime Forecasting

Predictive policing refers to the application of AI algorithms that analyse data on past crimes, populations and environmental cues to forecast where crime is likely to occur next. These predictions enable proactive policing, resource optimization and crime prevention measures. But predictive models should not be used in criminal investigations as standalone evidence but rather for planning operations.

E. Human Oversight and Explainable AI

While AI's analytical power is impressive, it is important to remember that it is not a decision-maker itself, but rather a tool that can help support decision-making. While algorithms are valuable tools, human interpretation and validation of the results are still crucial to ensure adherence to legal and ethical guidelines, and to interpret the findings from forensic analysis. Explainable AI (XAI) enhances transparency by providing a clearer understanding of how AI-driven decisions are made, helping to promote accountability, reliability, and public confidence in technology-assisted criminal justice.

4 Digital Science and Smart Forensic Investigation

As the increasing use of electronic devices, online communication and interdependent digital systems in criminal activity, digital science is now an integral part of modern criminal investigation. The widespread proliferation of smartphones, cloud computing, social media and connected devices has created a tremendous volume of digital evidence that can help investigators piece together what happened in a crime and who is responsible. Modern Digital Forensic Science brings together sophisticated analytical capabilities and computational technologies to obtain, preserve, analyse, interpret and preserve the integrity and admissibility of electronic evidence. As a result, digital science has revolutionized forensic investigation to be more thorough, data rich, and technologically stimulated.[12]

[12] A. M. Alenezi, “Digital Forensics in the Age of Smart Environments: A Survey of Recent Advancements and Challenges,” arXiv, pp. 1–17, 2023, doi: https://doi.org/10.48550/arXiv.2305.09682.

A. Digital Forensics

Digital forensics is the process of identifying, preserving, acquiring, and analyzing electronic evidence in computers, cellphones, storage media, and the cloud. Investigators can also find deleted files, communication records, browsing history, geolocation data, and multimedia content, and piece together the activities of the criminals. Cloud forensics has also broadened the scope of investigations, allowing the collection of digital evidence stored remotely in the cloud without compromising the integrity of the case.[13]

B. Internet of Things (IoT) and Smart Devices as Evidence

Forensic evidence is increasingly coming from the Internet of Things (IoT) devices such as smart home systems, wearable devices, connected vehicles, and surveillance cameras. The devices keep logging data about the users' activities, location and environment, and can help investigators reconstruct crime scenes, verify alibis, and establish timelines.[14]

C. Big Data Analytics for Criminal Intelligence

The use of big data analytics helps law enforcement agencies to process and analyze large amounts of structured and unstructured data that comes from criminal databases, surveillance systems, social media, and financial transactions. Advanced analytical techniques reveal underlying relationships and detect criminal networks and emerging crime trends, which helps to facilitate intelligence-led policing and strategic decision making.[15]

D. Blockchain for Evidence Integrity and Chain of Custody

Secure, tamper-proof, and time-stamped records are provided by the blockchain along the entire forensic process, enhancing the management of digital evidence. The decentralized design allows for better chain-of-custody documentation, evidence tracking, and assurance of authenticity and admissibility of digital evidence in court cases.[16]

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[13] S. Iqbal and S. Alharbi, "Advancing Automation in Digital Forensic Investigations Using Machine Learning Forensics," B. S. K. Shetty and P. Shetty, Eds., London: IntechOpen, 2019. doi: 10.5772/intechopen.90233.

[14] A. A. Ahmed, K. Farhan, W. A. Jabbar, A. Al-othmani, and A. G. Abdulrahman, "IoT Forensics: Current Perspectives and Future Directions," Sensors, vol. 24, no. 5210, pp. 1–16, 2024, doi: https://www.mdpi.com/journal/sensors.

[15] A. Kamal and C. Mukhtar, "The Use of Bioinformatics and Genetic Data Analytics for Criminal Justice," Sci. Law, vol. 2024, pp. 39–48, May 2024, doi: 10.55284/sol.v2024i2.131.

[16] N. Bhatti, "The Use of Digital Evidence in Criminal Proceedings," Am. J. Soc. Law, vol. 5, no. 1, 2026, doi: https://doi.org/10.54536/ajsl.v5i1.7211.

E. Integration of Digital Evidence with Biological Evidence

In recent years, the combination of digital evidence with biological evidence is becoming ever more common in forensic investigations, which aims at enhancing case reconstruction and suspect identification. Combining DNA markers with biometric attributes, geolocation data, surveillance video and digital communications provides investigators with greater evidence correlations, confirmation of investigative leads, and improves the accuracy and reliability of criminal investigations.

5 Integration, Challenges, and Future Directions

Forensic science is undergoing a major change as biotechnology, artificial intelligence (AI), and digital science merge into a technology-driven process that can analyse all forms of evidence quickly and effectively. Each technology has its own merits and capabilities, but their synergy can facilitate full-scale crime reconstruction, aid in interpretation of evidence and enhance the effectiveness of investigations. Implementing technology-assisted investigations is equally dependent on addressing ethical, legal, and technical issues to maintain the scientific integrity, transparency, and admissibility of investigations.

A. Integration of biotechnology, AI, and digital science

The incorporation of biotechnology, AI, and digital science into single forensic workflows can provide investigators with the ability to integrate the biological, biometric, and digital evidence into a single analytical framework. AI-powered platforms can combine DNA profiles, forensic imagery, digital communications, geolocation data, and crime scene information to enhance the correlation of evidence and aid in making more informed investigative decisions. This collaborative process with multidisciplinary workflow also saves on processing time and supports cooperation among forensic laboratories, law enforcement and judicial authorities.

B. Challenges

While there has been much progress in technology, there are still some factors that prevent the wider spread of adoption. Genomic and digital data, which is growing in volume, poses issues in terms of privacy, secure storage, and cyber security, necessitating protection against unauthorized access and cyberattacks. An algorithmic bias is another possible fault of AI systems, which can result from an unrepresentative training set and impact the fairness and accuracy of forensic analyses. Moreover, numerous AI models are complex, making it hard to offer transparency, and there is a growing demand for explainable AI (XAI), so investigators and courts can better understand how a conclusion is drawn from an algorithm. To overcome

these challenges, there is a need for standardisation of validation processes, ethical governance and ongoing monitoring.[17]

6. Future Directions

Future forensic science lab is likely to be a smart lab, combining laboratory automation, robotic systems, AI-aided analysis, cloud computing, and secure digital evidence management system. These smart labs will facilitate real-time evidence processing, automated quality control, and improve inter-disciplinary partnerships between forensic scientists, molecular biologists, computer scientists, cyber security experts and legal professionals. At the same time, the admissibility of technology-assisted evidence will rely on the acceptance of validated technologies, on the transparency of the analytical process and the standardized procedures to be followed and on compliance with judicial requirements. Future research investment, staff development, collaboration with other nations, and regulatory policies will play a key role in making sure that new technologies are used responsibly and continue to have scientific credibility and public trust, and that criminal justice systems are fair.[18]

6 Conclusion

Biotechnology, artificial intelligence, and digital science have revolutionized criminal investigations with the ability to make investigations faster, more accurate, and evidence based. New developments in DNA technologies, molecular biomarkers, and forensic microbiology have had a profound impact on the ability to analyze biological evidence, and AI has enhanced crime pattern analysis, biometric identification, and forensic decision support. At the same time, digital science has found new tools to investigate with digital forensics, IoT evidence, big data analytics, and blockchain based evidence management. While these developments are significant, issues of data privacy, cybersecurity, algorithmic bias, transparency, and the admissibility of technology-assisted evidence in court proceedings must be thoroughly considered for ethical and reliable implementation. The future of criminal justice systems relies increasingly on smart forensic laboratories, interdisciplinary work and uniform regulatory frameworks which combine the biological, digital and computational sciences. These multi-

[17] D. O. M. Alakayleh, "The Use of Artificial Intelligence Systems in Crime Detection and Prevention: Applications and Challenges," SSRN, 2025, doi: http://dx.doi.org/10.2139/ssrn.5132225.

[18] M. Elgabry, D. Nesbeth, and S. Johnson, "The future of biotechnology crime: A parallel Delphi study with non-traditional experts," Futures, vol. 141, p. 102970, 2022, doi: https://doi.org/10.1016/j.futures.2022.102970.

disciplinary approaches will contribute to more accurate investigations, better trust in the judiciary and the strengthening of effective, clear and modern criminal justice systems.

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[1] K. TIWARI, “Digital Revolution in Criminal Procedure of India: An In-depth Examination of the Impact of Emerging Technologies,” Int. J. LAW Manag. Humanit., vol. 6, no. 6, pp. 3573–3588, 2023, doi: https://doij.org/10.10000/IJLMH.116540.

[2] R. S. A. Faqir, “Digital Criminal Investigations in the Era of Artificial Intelligence: A Comprehensive Overview,” Int. J. Cyber Criminol., vol. 17, no. 2, pp. 77–94, 2023, doi: 10.5281/zenodo.4766706.

[3] S. Y. Prayoga, “The Criminal Justice System And Technology In The Digital Age,” Edunity, vol. 3, no. 7, pp. 550–557, 2024, doi: 10.57096/edunity.v3i7.287.

[4] S. Antil and V. Joon, “Biotechnology in Forensic Science: Advancements and Applications,” J. Forensic Sci. Res., pp. 7–14, 2025, doi: https://doi.org/10.29328/journal.jfsr.1001073.

[5] P. Dessai et al., “A Review on Emerging Trends in Forensic DNA Profiling and Analysis,” Int. J. Drug Deliv. Technol., vol. 16, Jun. 2026, doi: 10.25258/ijddt.16.46s.34.

[6] N. Moreira et al., “Biotechnology Applied to Forensic Sciences,” Appl. Sci., vol. 16, no. 5899, pp. 1–24, 2026, doi: https://doi.org/10.3390/app16125899.

[7] M. T. Zaatar et al., “Molecular Age Estimation: Current Perspectives and Future Considerations,” Int. Jourbal Mol. Sci., vol. 27, no. 3104, pp. 1–18, 2026, doi: https://doi.org/10.3390/ijms27073104.

[8] Y. Agarwal, P. Rawat, S. Kathuria, R. Singh, K. R. Chythanya, and M. Sahu, “Artificial Intelligence Contribution to Forensic Science Crime Investigation,” in 2023 3rd International Conference on Innovative Sustainable Computational Technologies (CISCT), 2023, pp. 1–5. doi: 10.1109/CISCT57197.2023.10351482.

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[10] Manisha, C.-T. Li, And K. A. Kotegar, “AI-Synthesized Image Detection: Source Camera Fingerprinting to Discern the Authenticity of Digital Images,” IEEE Access, p. 1, 2025, doi: 10.1109/ACCESS.2025.3537558.

[11] M. Alenezi, “Digital Forensics in the Age of Smart Environments: A Survey of Recent Advancements and Challenges,” arXiv, pp. 1–17, 2023, doi: https://doi.org/10.48550/arXiv.2305.09682.

[12] S. Iqbal and S. Alharbi, “Advancing Automation in Digital Forensic Investigations Using Machine Learning Forensics,” B. S. K. Shetty and P. Shetty, Eds., London: IntechOpen, 2019. doi: 10.5772/intechopen.90233.

[13] A. Ahmed, K. Farhan, W. A. Jabbar, A. Al-othmani, and A. G. Abdulrahman, “IoT Forensics: Current Perspectives and Future Directions,” Sensors, vol. 24, no. 5210, pp. 1–16, 2024, doi: https://www.mdpi.com/journal/sensors.

[14] Kamal and C. Mukhtar, “The Use of Bioinformatics and Genetic Data Analytics for Criminal Justice,” Sci. Law, vol. 2024, pp. 39–48, May 2024, doi: 10.55284/sol.v2024i2.131.

[15] N. Bhatti, “The Use of Digital Evidence in Criminal Proceedings,” Am. J. Soc. Law, vol. 5, no. 1, 2026, doi: https://doi.org/10.54536/ajsl.v5i1.7211.

[16] O. M. Alakayleh, “The Use of Artificial Intelligence Systems in Crime Detection and Prevention: Applications and Challenges,” SSRN, 2025, doi: http://dx.doi.org/10.2139/ssrn.5132225.

[17] M. Elgabry, D. Nesbeth, and S. Johnson, “The future of biotechnology crime: A parallel Delphi study with non-traditional experts,” Futures, vol. 141, p. 102970, 2022, doi: https://doi.org/10.1016/j.futures.2022.102970.