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A Review of Scientific Techniques and Modern Technologies in Criminal Investigation and Crime Detection

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Abstract: *Scientific techniques and modern technologies have significantly transformed criminal investigation and crime detection by improving the accuracy, efficiency, and reliability of evidence collection and analysis. Traditional investigative methods are increasingly supported by advanced forensic technologies, including DNA profiling, fingerprint identification, forensic toxicology, ballistics examination, digital forensics, biometric identification, artificial intelligence, machine learning, geographic information systems, and advanced surveillance systems. These developments have strengthened the ability of law enforcement agencies to identify suspects, reconstruct crime scenes, establish criminal connections, and present scientific evidence before judicial authorities.*

Keywords: Criminal Investigation, Forensic Science, DNA Profiling, Digital Forensics, Artificial Intelligence, Crime Detection, Fingerprint Analysis, Criminal Justice System

I. INTRODUCTION

Criminal investigation is an essential component of the criminal justice system because it involves identifying offenders, establishing the circumstances of criminal incidents, collecting relevant evidence, and supporting the administration of justice. Traditionally, criminal investigations depended considerably on eyewitness statements, interrogation, physical observation, documentary evidence, and conventional investigative procedures. Although these methods continue to play an important role, the increasing complexity of modern crimes has created a greater need for scientific and technological approaches. Scientific developments in forensic science have introduced advanced methods for examining biological materials, fingerprints, firearms, questioned documents, toxic substances, and other physical evidence.

Modern technologies have further expanded investigative capabilities through digital evidence examination, artificial intelligence, facial recognition, biometric systems, surveillance cameras, and computer-assisted data analysis. These technologies enable investigators to identify relationships between suspects, victims, locations, and criminal activities more efficiently. According to the National Institute of Justice (2013), systematic crime scene investigation requires proper documentation, evidence identification, collection, preservation, and submission for forensic examination. Similarly, NIST (2022) explains that digital forensic investigation applies scientific methods to understand information and traces generated through digital devices. Therefore, the integration of scientific techniques and modern technologies has become increasingly important for developing accurate, reliable, and evidence-based criminal investigations.

OBJECTIVES OF THE REVIEW

To examine the major scientific techniques used in criminal investigation and crime detection.
To study the role of forensic science in collecting, examining, and interpreting criminal evidence.
To analyse the applications of modern technologies, including artificial intelligence and digital forensics.
To evaluate the importance of DNA profiling, fingerprint identification, and biometric technologies.

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To identify the major challenges associated with technological developments in criminal investigation.
To explore future opportunities for improving scientific investigation and criminal justice administration.

SCIENTIFIC TECHNIQUES USED IN CRIMINAL INVESTIGATION

1. DNA Profiling and Genetic Analysis

DNA profiling is one of the most important scientific techniques used in modern criminal investigations. It involves analysing specific genetic regions of biological samples such as blood, saliva, semen, hair roots, bones, and other human tissues. Short Tandem Repeat analysis is widely used to develop DNA profiles and compare biological samples recovered from crime scenes with reference samples. DNA evidence can help establish biological relationships, associate individuals with investigated events, and identify unknown persons. Advanced developments such as Rapid DNA analysis, next-generation sequencing, and probabilistic genotyping have expanded the possibilities of forensic genetic examination. However, DNA evidence must be interpreted carefully because contamination, sample degradation, mixed DNA profiles, and secondary transfer may affect investigative conclusions (Dash & Al-Snan, 2025).

2. Fingerprint Identification

Fingerprint examination is a traditional but highly significant forensic identification technique. Fingerprints contain distinctive ridge characteristics, including ridge endings, bifurcations, and other minutiae patterns. Investigators recover latent fingerprints from surfaces using powder techniques, chemical treatments, and specialised lighting methods. Modern Automated Fingerprint Identification Systems assist forensic experts in comparing recovered impressions against large fingerprint databases. Digital enhancement and automated matching have increased the speed of fingerprint examination. Nevertheless, automated results require appropriate expert evaluation and verification before being treated as meaningful evidence.

3. Forensic Toxicology

Forensic toxicology examines drugs, alcohol, poisons, and other chemical substances in biological and non-biological samples. It is particularly useful in suspected poisoning, drug-related offences, impaired driving, suspicious deaths, and cases involving substance abuse. Techniques such as Gas Chromatography-Mass Spectrometry (GC-MS), Liquid Chromatography-Mass Spectrometry, and High-Performance Liquid Chromatography help identify and quantify chemical compounds. These techniques provide scientific information about the presence of substances and may assist investigators in reconstructing the circumstances surrounding an incident.

4. Ballistics and Firearms Examination

Forensic ballistics involves examining firearms, ammunition, bullets, cartridge cases, and firearm-related marks. Experts study characteristics such as rifling impressions, firing-pin marks, breech-face impressions, and other microscopic features. Modern comparison microscopes and digital imaging systems assist forensic examiners in comparing recovered ammunition components. Three-dimensional surface measurement and advanced imaging may further support the examination of firearm-related evidence. However, conclusions must reflect the limitations of the available samples and the scientific validity of the examination method.

5. Forensic Document Examination

Questioned document examination is used to investigate suspected forgery, altered documents, disputed signatures, fraudulent certificates, counterfeit currency, and other document-related offences. Experts examine handwriting characteristics, ink composition, paper properties, printing methods, indentation marks, and alterations. Digital imaging, infrared examination, ultraviolet illumination, and specialised document-analysis instruments help reveal features that may not be visible through ordinary observation.

MODERN TECHNOLOGIES IN CRIMINAL INVESTIGATION

1. Digital Forensics

Digital forensics is an important modern investigative discipline concerned with identifying, acquiring, preserving, examining, and interpreting electronic evidence. Computers, smartphones, tablets, cloud platforms, storage devices, and

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communication systems may contain information relevant to criminal investigations. Digital evidence can include messages, emails, photographs, videos, browsing records, application data, metadata, and system logs. Forensic investigators use specialised tools to create forensic copies, calculate cryptographic hashes, recover deleted information where possible, and examine digital artefacts while preserving evidentiary integrity. NIST (2022) highlights the scientific foundations and limitations that must be considered when conducting digital investigations.
NIST Publications+1

2. Artificial Intelligence and Machine Learning

Artificial Intelligence (AI) and Machine Learning (ML) are increasingly being explored for crime detection and forensic investigation. These technologies can analyse large datasets, identify patterns, classify digital images, support facial image comparisons, detect suspicious financial transactions, and assist in cybercrime investigations. Machine learning models can also help investigators prioritise information and identify relationships among different pieces of evidence. However, algorithmic bias, inaccurate predictions, insufficient training data, and a lack of transparency may create serious investigative risks. Therefore, AI-generated results should support rather than replace human expertise and independent verification (Fähndrich 2023).

3. Facial Recognition Technology

Facial recognition systems use computer-based algorithms to analyse facial characteristics and compare facial images with available reference databases. They may assist in identifying individuals from surveillance footage, photographs, and other digital images. Modern systems use deep learning and neural networks to process facial features and calculate similarity scores. Their effectiveness may be influenced by lighting, camera quality, image resolution, facial orientation, and demographic performance differences. A facial recognition match should therefore be treated as an investigative lead requiring additional verification, rather than conclusive proof of identity.

4. CCTV and Video Surveillance

Closed-Circuit Television systems are widely used in public places, commercial establishments, transportation facilities, and residential areas. Video recordings may help establish the movement of individuals, identify possible witnesses, reconstruct timelines, and locate relevant vehicles. Advanced video analytics can assist in detecting objects, recognising movement patterns, and identifying unusual activities. Investigators must ensure that original recordings are preserved, timestamps are examined, and image enhancement does not introduce misleading information.

5. Geographic Information Systems

Geographic Information Systems provide tools for collecting, analysing, and presenting location-based information. GIS technology can assist investigators in mapping crime locations, analysing geographical patterns, identifying crime hotspots, and studying relationships between incidents. Spatial analysis can support resource allocation and investigative planning. However, geographical patterns indicate possible associations rather than automatically establishing the identity or responsibility of an offender.

6. Biometric Identification Systems

Biometric identification uses measurable human characteristics to identify or verify individuals. Common biometric methods include fingerprint recognition, facial recognition, iris scanning, voice recognition, and palm-print examination. Automated biometric systems can compare large quantities of identification data and support law enforcement investigations. Standardised data formats and performance evaluation are important for reliable biometric information exchange (NIST, 2026).

COMPARATIVE ANALYSIS OF SCIENTIFIC TECHNIQUES AND MODERN TECHNOLOGIES

Table 1. Major scientific techniques used in criminal investigation

Scientific technique	Evidence examined	Major investigative application
DNA profiling	Blood, saliva, tissues	Biological identification
Fingerprint analysis	Latent and visible prints	Individual identification
Forensic toxicology	Blood, urine, tissues	Drug and poison detection

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Ballistics examination	Bullets and cartridge cases	Firearm-related investigation
Document examination	Handwriting, signatures, ink	Forgery and fraud detection
Forensic anthropology	Skeletal remains	Human identification
Forensic odontology	Dental records and structures	Identification of individuals

Table 2. Modern technologies and their applications

Modern technology	Application	Investigative benefit
Artificial Intelligence	Pattern recognition and data analysis	Faster information processing
Machine Learning	Crime data classification	Identification of patterns
Digital Forensics	Electronic evidence examination	Recovery and interpretation of digital traces
Facial Recognition	Facial image comparison	Investigative identification leads
CCTV Analytics	Video examination	Event reconstruction
GIS Mapping	Spatial crime analysis	Identification of geographical patterns
AFIS	Fingerprint database comparison	Automated fingerprint searching
Cloud Forensics	Cloud-based evidence examination	Analysis of remotely stored information

ROLE OF FORENSIC LABORATORIES IN CRIME DETECTION

Forensic laboratories provide specialised scientific facilities for examining evidence collected during criminal investigations. They include divisions for DNA analysis, fingerprint examination, chemical analysis, toxicology, questioned documents, ballistics, digital forensics, and other specialised disciplines. Modern laboratories use validated analytical instruments, standard operating procedures, quality assurance systems, and trained scientific personnel to ensure that examination results are reliable and reproducible. Laboratory accreditation, proficiency testing, equipment calibration, and appropriate reporting procedures are essential components of quality management. Cooperation between investigating agencies and forensic laboratories also helps ensure that relevant evidence is submitted in suitable condition and examined according to the requirements of each case.

DISCUSSION

The reviewed scientific techniques and modern technologies demonstrate that criminal investigation is increasingly becoming an interdisciplinary activity. Traditional forensic methods continue to provide essential physical and biological evidence, while modern digital systems expand the scope of investigation into electronic communications, online activities, surveillance records, and geographical information. DNA profiling and fingerprint identification are valuable for individual identification, whereas toxicology and ballistics help examine specific circumstances of criminal incidents. Digital forensics and artificial intelligence offer additional capabilities for investigating technologically complex offences.

However, no single technique can independently establish every aspect of a criminal event. Effective investigation requires combining different forms of evidence, considering alternative explanations, and ensuring that each analytical method is scientifically appropriate. The review also highlights that technology does not automatically guarantee accuracy. Its contribution depends on validation, the quality of collected evidence, professional competence, and responsible interpretation. Thus, a balanced approach combining human expertise, scientific knowledge, modern technology, and legal safeguards is essential for improving criminal investigation.

II. CONCLUSION

Scientific techniques and modern technologies have become essential instruments in contemporary criminal investigation and crime detection. Developments in DNA profiling, fingerprint examination, forensic toxicology, ballistics, digital forensics, artificial intelligence, facial recognition, biometric identification, and GIS have improved the ability of

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investigative agencies to collect, analyse, and interpret evidence. These technologies support suspect identification, crime scene reconstruction, digital evidence recovery, and the examination of complex criminal activities.

Nevertheless, their effectiveness depends on scientifically validated procedures, trained professionals, reliable equipment, evidence preservation, and appropriate legal safeguards. Issues such as privacy violations, algorithmic bias, evidence contamination, technological costs, and insufficient forensic infrastructure must receive adequate attention. The review concludes that the integration of scientific forensic methods and modern technologies can strengthen the efficiency, transparency, and reliability of the criminal justice system and promote evidence-based justice.

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