The Laboratory of Tomorrow: Automation, Robotics, and Innovation in Smart Forensic Science

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Abstract

Traditional forensic labs are becoming smart lab, technology-driven labs and transforming the modern forensic science. The use of automation, robotics, artificial intelligence (AI), Laboratory Information Management Systems (LIMS), and digital technologies are improving the speed, accuracy, and reliability of forensic investigations and minimizing human effort and error. This review focuses on the transition of forensic laboratories from manual to integrated and automated processes and the role of robotic platforms, digital workflow management and intelligent forensic laboratory infrastructures. It also emphasizes on the use of smart technologies in Forensic Pathology, Digital Forensics, Biometrics, Crime scene investigation, Forensic chemistry and Forensic genetics. The review also looks at the key advantages and implementation constraints of smart forensic laboratories and forecasts future trends such as incorporation of artificial intelligence into robotics, Internet of Things (IoT) enabled monitoring, cloud data management, digital twins, and interoperable laboratory systems. The developments are expected to enhance the efficiency of the laboratory and also contribute to the scientifically sound and legally defensible forensic practices.

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1 Introduction

"The Laboratory of Tomorrow" is the idea of turning the conventional forensic laboratory into a smart, technology-driven space that features automation, robotics, digital information systems and sophisticated analytical instruments to enhance the efficiency, speed and reliability of forensic investigations. In recent years, digital technologies and automated workflows are being integrated into forensic laboratories as a means to improve performance and ensure scientific integrity and human oversight over manual procedures. This shift is part of a growing trend of moving scientific research toward laboratory automation, which has enhanced productivity, reproducibility, and quality assurance in all branches of science.

Forensic laboratories had to rely on manual evidence handling, sample preparation, evidence documentation and analytical procedures. While these techniques laid the groundwork for forensic science, they were time-consuming, cumbersome, and prone to error, especially in the case of large volumes of evidence. The move towards forensic practice has been a gradual one, with the majority of laboratories now operating under integrated systems that are able to prepare samples automatically, handle liquids automatically, track evidence with a barcode, and have an automated workflow for management. The use of robotic workstations, automated analytical instruments, and Laboratory Information Management Systems (LIMS) has greatly enhanced laboratory efficiency, analytical procedures, and shortened turnaround time.[2]

The need of automation has been escalating due to rising case backlogs, variety of forensic evidence and timelines for case resolution. The amount of both biological and chemical, trace evidence and digital evidence collected in modern laboratories is extremely high and both resources and analytical tools are under strain. Forensic laboratories are thus transitioning toward smart forensic laboratories, which are digitally connected laboratories that combine automated instruments, robotics, and information management systems to enhance evidence processing from the beginning to the end of the forensic process. These systems increase traceability, minimize human error, enhance chain-of-custody control, and allow forensic scientists to

[2] A. Kloosterman et al., "The interface between forensic science and technology: how technology could cause a paradigm shift in the role of forensic institutes in the criminal justice system," Philos. Trans. B, vol. 370, 2015, doi: http://dx.doi.org/10.1098/rstb.2014.0264.

concentrate on data interpretation and expert decision-making, instead of tedious laboratory work. With the advent of digital transformation in forensic science, smart laboratories are anticipated to be a key enabler to provide faster, reliable and uniform forensic services to the modern-day criminal justice.[3]

2 Automation and Robotics in Modern Forensic Laboratories

As the analytical needs grow and the need to operate forensic laboratories efficiently increases, the adoption of automation, robotics, and digital technologies has been a key factor in the modernization of these facilities. Modern forensic laboratories use automated systems, which can perform repetitive tasks quickly, accurately, and repeatably, unlike conventional laboratories, where manual procedures are required. These technologies are not only beneficial for minimizing human error and sample contamination but also facilitate easier evidence processing, improve traceability, and promote consistent lab practices. The technological backbone of the smart forensic laboratory is the robotic platforms, automated analytical instruments, Laboratory Information Management Systems (LIMS), and digital evidence tracking technologies.[4]

A. Laboratory Automation and Robotic Systems

Laboratory automation is defined as acquiring a lab process using automated equipment and robotic platforms and running it with minimal human involvement. The automation can be partial (some processes in the lab are automated, like DNA extraction, pipetting, etc. but others are not) or total laboratory automation (TLA) (several analysis instruments and pre-and post-analysis processes are automated and linked together in an integrated workflow). Robotic workstations are widely used in forensic labs for liquid handling, automated pipetting, DNA extraction, PCR reaction set-up and for transferring samples. These systems increase sample throughput, decrease operator variability, minimize contamination risks, and increase analytical consistency, especially in high volume forensic DNA laboratories. Also, with the help of robots, the forensic team can save more time on data interpretation and quality control, and less time on repetitive tasks.[5]

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[3] G. C. Omari, S. V. Manyele, and G. Mwaluko, "Analysis of Stress Backlogs during Case-File Processing in Forensic Science Laboratory," Engineering, vol. 9, pp. 1060–1096, 2017, doi: https://doi.org/10.4236/eng.2017.912063.

[3] K. Thurow, O. Peter, P. Courtney, K. Széll, and Á. Wolf, "Editorial: Robotics in laboratory automation," SLAS Technol., vol. 36, p. 100373, 2026, doi: https://doi.org/10.1016/j.slast.2025.100373.

[4] A. Asquith and G. Horsman, "Let the robots do it! – Taking a look at Robotic Process Automation and its potential application in digital forensics," Forensic Sci. Int. Reports, vol. 1, p. 100007, 2019, doi: http://doi.org/10.1016/j.fsir.2019.100007.

B. Integrated Laboratory Workflows and Digital Laboratory Management

Modern forensic laboratories are not only automating individual instruments, but are also developing platforms that connect their analytical system to digital workflow management systems. Automated analytical instruments such as DNA sequencers, chromatographic systems, mass spectrometers, and digital imaging platforms are able to communicate directly with Laboratory Information Management Systems or LIMS, allowing for an easy fetch and flow of data into and out of the system for reporting. Compliant with accreditation standards, LIMS is also used as the focal point of sample registration, workflow scheduling, quality control, result management and audit documentation. Additionally, barcode and Radio Frequency Identification (RFID)-based evidence tracking offers constant evidence that will be tracked throughout the chain of custody, minimizing the potential of evidence being misidentified or lost. When combined, automation, robotics, LIMS and digital tracking technologies enable to enhance laboratory workflows for better efficiency, traceability and data integrity, which leads to quicker and more accurate forensic analyses.[6]

3 Applications of Smart Technologies Across Forensic Disciplines

Automation, robotics, artificial intelligence (AI), and digital technologies have revolutionized certain forensic science disciplines by enhancing evidence analysis speed, accuracy, and consistency. Smart technologies are used throughout the investigation process, from evidence collection to laboratory analysis to data interpretation and reporting, to help forensic experts. While the level of automation differs across forensic fields, it has contributed significantly to the analytical efficiency, minimized manual mistakes, and improved quality assurance. Below are the main applications of smart technologies in the various forensic fields.[7]

- **Forensic Pathology and Medicine:** The use of automation and digital technology in forensic pathology is growing, with an aim to enhancing post-mortem examinations and medico-legal investigations. Advanced imaging techniques such as post-mortem computed tomography (PMCT), magnetic resonance imaging (MRI) and 3D (three dimensional) reconstruction allow non-invasive or minimally invasive examinations

[6] A. Opalinski, K. Regulski, J. Swadzba, P. W̨asowicz, A. Kwietniewska-Smietana, and P. Sitkowski, “Optimizing Laboratory Workflow Through Prediction of Test Demand and Quality Control,” Appl. Sci., vol. 16, no. 4865, pp. 1–17, 2026, doi: https://doi.org/10.3390/app16104865.

[6] X. Chango, O. Flor-unda, P. Gil-jiménez, and H. Gómez-moreno, “Technology in Forensic Sciences: Innovation and Precision,” Technologies, vol. 12, no. 120, 2024, doi: https://doi.org/10.3390/technologies12080120.

prior to the conventional autopsy. AI-powered image analysis can aid in the diagnosis of skeletal injuries, haemorrhages and pathological abnormalities, and robotic systems can help with standardising tissue sampling and documenting digitally. The technologies increase the accuracy of diagnostics, enable the saving of digital records and increase collaboration between forensic pathologists.

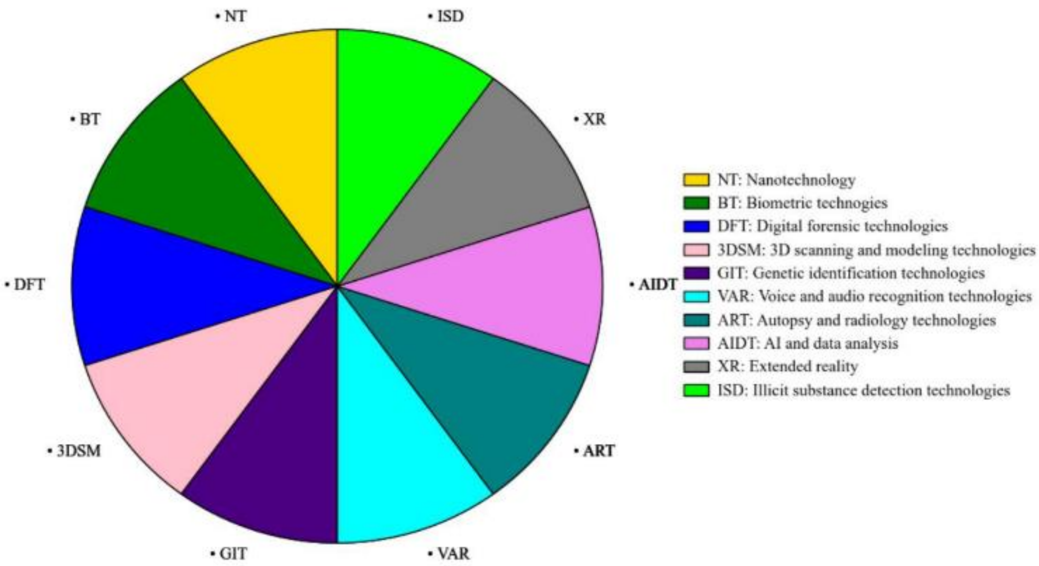

Figure 16: Technologies for Advancing Forensic Science[8]

- **Digital Forensics and Cybersecurity:** Digital forensics is one of the fastest-changing (and growing) forensic fields, because of the rapidly increasing volume of electronic evidence. Stepped up with the introduction of Robotic Process Automation (RPA) and AI powered software, repetitive tasks like evidence acquisition, file classification, malware detection, metadata extraction and log analysis are automated. Machine learning algorithms help investigators to detect suspicious activities in massive data sets, and automated forensic platforms streamline and ensure the consistency of digital

[8] M. L. Comeaga, "Digital transformation of the laboratories," IOP Conf. Ser. Mater. Sci. Eng., 2022, doi: 10.1088/1757-899X/1268/1/012001.

[8] S. Bakyt, A. Zhanibekov, A. Paridinova, Y. Karzhaubayev, And N. Poshanov, "Application of AI capabilities in forensics and criminal proceedings: Innovative technologies in forensic examinations," Oñati Int. Inst. Sociol. Law Avenida Univ., pp. 1–23, 2026, doi: HTTPS://DOI.ORG/10.35295/OSLS.IISL.2555.

evidence processing. Cybersecurity technologies also safeguard forensic databases and maintain integrity of digitized evidence throughout the investigation.[9]

- **Forensic Identification and Biometrics:** The human identification has been greatly improved by the use of smart technologies via automated biometric systems. AI and computer vision algorithms can be used to match biological traits with a vast reference database with high accuracy, such as automated fingerprint identification systems (AFIS), facial recognition, iris recognition, and voice biometrics. Robotic platforms used in forensic DNA laboratories streamline DNA extraction, polymerase chain reaction (PCR) setup, and sequencing processes, provide increased throughput and reduce contamination and human error. All of these technologies are integrated and contribute to the reliability and efficiency of forensic identification.[10]
- **Crime Scene Investigation (CSI):** The use of drones, laser scanning, photogrammetry, robotic imaging systems and portable digital evidence collection devices have advanced the documentation of a crime scene. A 3-D reconstruction of the crime scene allows the accuracy of preserving scene geometry for further analysis and courtroom presentations. Chain of custody documentation using barcode and RFID technology coupled with Laboratory Information Management Systems (LIMS) contain the proper documentation from the crime scene to the laboratory examination, minimizing evidence loss or misidentification.
- **Forensic Chemistry and Genetics:** Forensic chemistry and forensic genetics laboratories cannot exist without automation, where workflows are high throughput and analysis is indispensable. Automated sample preparation for chromatographic and spectrometric analyses such as gas chromatography–mass spectrometry (GC–MS) or liquid chromatography–mass spectrometry (LC–MS/MS) is enhanced by robotic liquid-handling systems, which ensures analytical precision and good analytical repeatability. In the same way, the automated extraction, amplification, sequencing, and data interpretation of integrated DNA analysis platforms are available in standardized workflows. These technologies allow case processing to be completed sooner, improve laboratory productivity, deliver consistent analytical performance and meet forensic quality standards.

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[9] H. Y. Hailu, G. A. Mitiku, D. W. Seboka, and M. A. Gobena, "Advancing Forensic Science through Artificial Intelligence: A Systematic Review," Ethiop. J. Police Stud., vol. 1, no. Ii, pp. 1–22, 2026, doi: https://doi.org/10.20372/ejpos.v1iII.12989.

4 Benefits and Challenges of Smart Forensic Laboratories

Forensic labs have seen automation, robotics and digital technologies greatly enhance operational efficiency. Smart laboratory systems improve the efficiency and reliability of forensic analysis, as well as facilitate the standardisation of procedures and aid in the management of evidence. But to be successful, a significant investment, strict validation, and ethical and cyber security concerns must be addressed. It is important to be aware of the pros and cons of both technologies to utilize them responsibly in the practice of forensics.

A. Benefits of Smart Forensic Laboratories

The principal advantages of smart forensic laboratories include:

- **Faster evidence processing:** Automated sample preparation, liquid handling solutions and integrated analytical instruments significantly improve case turnaround and lower processing time.
- **Improved analytical accuracy and reproducibility:** The standardized automated procedures reduce variability of the procedures and ensure uniformity of the analytical results for repeated examination.
- **Reduced human error and contamination:** Automation reduces the amount of manual evidence handling, reducing risks for transcription errors, cross-contamination and sample mix-ups.
- **Better chain of custody through digital documentation:** Laboratory Information Management Systems (LIMS), in conjunction with barcode and RFID evidence tracking, enable a complete audit trail of the movement of evidence, ensuring evidence traceability and forensic quality standards are met.
- **Increased laboratory productivity:** Automated workflows help labs increase the volume of samples processed with staff and resources available, and free up time for forensic scientists to focus on data interpretation and expert reporting.

B. Challenges in Implementing Smart Forensic Laboratories

Although these benefits exist, there are certain challenges that are blocking the proliferation of smart forensic laboratories. Robotic platforms, automated analytical instruments, and digital infrastructure systems have a high implementation and maintenance cost, which may be challenging for resource-limited labs. Before being used in forensic casework, all automated systems have to be validated and accredited to ensure reliability and adherence to international quality standards like ISO/IEC 17025. As more and more systems rely on digital processes, the issue of cyber security and data privacy has also become a concern, especially if sensitive forensic data is kept or communicated digitally. Additionally, introducing new technologies to existing lab facilities can be technically challenging and can impact the existing workflow. Finally, technical skills are needed to ensure that automated systems are used and maintained properly, and ethical issues, including issues related to algorithm transparency, accountability, and the continued use of human expertise in forensic judgment, are important to consider when ensuring that automation benefits human experts rather than supplants their judgment.[11]

5 Future Perspectives: Towards Intelligent and Autonomous Forensic Laboratories

As the use of Artificial Intelligence (AI), robotics and digital technologies continues to progress at a rapid pace, forensic laboratories are likely to become even smarter and more interconnected. Smart forensic labs will not just renew the existing automation but also incorporate more advanced features such as real-time monitoring, predictive analytics, cloud computing, and autonomous decision support systems in the future. These innovations seek to enhance the reliability of operational analysis and evidence management, operational effectiveness, and scientific transparency, all while retaining human oversight. Future developments such as the ones listed below are expected to affect the future of forensic laboratories.[12]

- **AI-Integrated Robotic Laboratories**

Future forensic laboratories are expected to incorporate intelligent laboratory environments, based on the combination of robotic automation and AI driven analytical systems. Optimized Robotic Workflows, Sample Prioritization, Instrument Performance Monitoring and Data Interpretation will be provided by AI algorithms. The artificial intelligence (AI) powered robotic systems will not be used to make decisions, but used to automate repetitive lab tasks and provide decision support to forensic scientists to enhance efficiency, consistency, and analytical quality.[13]

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[11] D. Magherescu, “Challenges of the forensic science facing new technologies,” IUS Sci., vol. 7, no. 1, pp. 48–61, 2021, doi: https://dx.doi.org/10.12795/IETSCIENTIA.

[11] D. T. Handa, D. P. Chakraborty, D. G. Kaur, D. A. Verma, and D. P. Arora, “Shaping the Future of Forensic Science by Smart Technology,” INDIAN J. Soc. Stud. Humanit., vol. 1, no. 17, pp. 1–8, 2024.

[13] R. M. Montgomery, “Augmenting Forensic Science Through AI: The Next Leap in Multidisciplinary Approaches,” Preprints, pp. 0–9, 2025, doi: 10.20944/preprints202501 .1951 .v1.

- **Internet of Things (IoT)-Enabled Laboratory Monitoring**

In the Internet of Things (IoT) era, a network of instruments, environmental sensors, and storage units in laboratories can communicate with each other. An IoT monitoring system can automatically track temperature, humidity, equipment status, and storage conditions of the biological and chemical evidence, all the time. Immediate warnings of equipment failure or environmental fluctuation boost laboratory quality assurance and ensure the integrity of evidence along the analytical process.[14]

- **Cloud-Connected Forensic Data Management**

It is believed that cloud computing will play an integral part in future forensic laboratories and will provide secure storage, centralized data management, and collaborative access to forensic information. Cloud based Laboratory Information Management Systems (LIMS) can help in sharing data with accredited laboratories, enhance disaster recovery, enable remote quality auditing and ensure secure access controls and encrypted data transfer.

- **Digital Twins and Predictive Maintenance**

Digital twin technology is the development of a virtual copy of a laboratory device, which is constantly updated with operational information from physical equipment. Digital twins can be combined with predictive analytics to proactively detect when equipment is deteriorating before it fails, enabling predictive maintenance and reducing instrument downtime. These technologies promise to increase laboratory reliability, minimize maintenance expenses and guarantee forensic continuity.

- **Human–AI Collaboration in Forensic Science**

Forensic scientists will continue to play an important role in the interpretation of evidence and expert decision making in the face of increased automation. While AI systems can swiftly process vast amounts of data and recognize intricate patterns, the human interpretation of the forensic evidence, the contextual information, and the expert's opinion must also be provided.

[14] A. N. Banagar and R. Khattar, “IoT based Smart Laboratory System,” Int. J. Eng. Res. Technol., vol. 9, no. 01, pp. 315–318, 2020, doi: 10.17577/IJERTV9IS010178.

This has led to the expectation that future laboratories will have collaborative processes involving human and AI, where AI is used to augment the capabilities of the forensic scientists.

- **Standardized and Interoperable Smart Laboratory Systems**

A growing number of intelligent forensic laboratories will require the creation of standardised and interoperable digital infrastructures. Harmonized communication protocols, instruments that are compatible in laboratories, standardized data formats, and internationally accepted validation frameworks will allow seamless integration among automated platforms, LIMS, and analytical software. The development of common standards will help to enhance data sharing, promote collaboration between laboratories and provide for the reliability, transparency and legal defensibility of smart forensic technologies in the various forensic jurisdictions.

6 Conclusion

The application of automation, robotics, artificial intelligence, and the use of digital technologies have revolutionized forensic laboratories, making them more efficient, accurate and standardized laboratories. Automated workflows, robotic sample processing, connected analytical instrumentation, and digital information management systems enable smart forensic laboratories to boost evidence processing, minimize human error, ensure evidence reproducibility and record chain of custody. These technologies have proven to be quite useful in forensic pathology, digital forensics, biometrics, crime scene investigation and forensic chemistry and genetics. While these benefits are promising, implementation costs, system validation, cybersecurity, interoperability, and training of the workforce are all challenges that need to be addressed for reliable and ethical uptake. In the future, the use of emerging technologies like AI-powered robotic laboratories, internet-of-things applications for monitoring, cloud-based data management, digital twins, and standardized smart laboratory infrastructures will continue to enhance the future of forensic practice. In the end, the lab of the future will not supplant forensic scientists, but complement their skills by offering intelligent decision-support systems that support and enrich the quality, efficiency and credibility of forensic investigation and the administration of justice.

7 Reference

[1] Kloosterman et al., “The interface between forensic science and technology: how technology could cause a paradigm shift in the role of forensic institutes in the criminal justice system,” Philos. Trans. B, vol. 370, 2015, doi: http://dx.doi.org/10.1098/rstb.2014.0264.

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[4] Opalinski, K. Regulski, J. Swadzba, P. W¸asowicz, A. Kwietniewska-Smietana, and P. Sitkowski, "Optimizing Laboratory Workflow Through Prediction of Test Demand and Quality Control," Appl. Sci., vol. 16, no. 4865, pp. 1–17, 2026, doi: https://doi.org/10.3390/app16104865.

[5] X. Chango, O. Flor-unda, P. Gil-jiménez, and H. Gómez-moreno, "Technology in Forensic Sciences: Innovation and Precision," Technologies, vol. 12, no. 120, 2024, doi: https://doi.org/10.3390/technologies12080120.

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[7] S. Bakyt, A. Zhanibekov, A. Paridinova, Y. Karzhaubayev, And N. Poshanov, "Application of AI capabilities in forensics and criminal proceedings: Innovative technologies in forensic examinations," Oñati Int. Inst. Sociol. Law Avenida Univ., pp. 1–23, 2026, doi: HTTPS://DOI.ORG/10.35295/OSLS.IISL.2555.

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