



Review Paper

Advances in Nanotechnology for Forensic Applications: A Review of Current Trends and Future Perspectives

Tanveer Hashmi* and Samal Aditya

Department of Forensic science, Indrashil University, Mehsana, Gujarat, India
tanveerhasmi25@gmail.com

Available online at: www.isca.in, www.isca.me

Received 8th December 2025, revised 7th January 2026, accepted 24th January 2026

Abstract

The Nanotechnology is the branch of chemistry that deals with nanoscale particles interacting with molecules. In forensic science, nanotechnology aids in analyzing microscopic trace evidence collected from crime scenes. Modern nanotechnology involves manipulating individual atoms and molecules with remarkable precision for various practical applications. Applications of nanotechnology span electronics, pharmaceuticals, engineering, materials science, and forensic analysis such as latent print visualization, explosives detection, DNA detection, narcotic drugs analysis, gunshot residues, have been detected by the unique characteristic's structures of nanotechnology. This review indicates detailed acquaintance of nanotechnology's roles in forensic perspective and possible future approach.

Keywords: Nanotechnology, Forensic science, crime scene investigation, Application of Forensic.

Introduction

There are many different techniques in the domain of forensic science, but nanotechnology is the widely useful techniques that can be applied for criminal investigation. Drugs and poison samples can be analyzed using nanoparticles, which may help identify suspects or victims. In forensic ballistics, nanoparticles can be used to detect gunpowder residues for identified gunshot residue. The DNA analysis would be possible by the use of nanoparticles taken from samples obtained from biological sources, which might be useful for conducting personal identity between suspect and victim for criminal investigation purposes. The fingerprints would also be identified by gold and silver nanoparticles that might help in chance prints between suspect and crime scene. The unique characteristics of nanomaterials have enhanced the ability to detect and recover crucial evidence that was previously unattainable. The People believe that biotic processes for the production of NPs are environment-and human-safe. They make sure that all dangerous substances are removed and are also quite affordable.

The latest technologies in extracting DNA from fingerprints/palm prints, analysis of heavy metals, gunshot residues, and traces of explosives are some altogether new innovative breakthroughs that add more value to the presentation of conclusive evidence in a courtroom setting. Various uses of this technology are being generated in the area of nano-forensics. Therefore, this paper endeavors to showcase a new approach to nanotechnology and its numerous uses in various forensic disciplines, which will be collectively known as nano-forensics¹.

Uses of Nanotechnology in Forensic science

Nanotechnology in Forensic medicine: The estimation of the time since death-also commonly termed the time of death-is one of the most critical aspects of forensic medicine and law. Various physical and chemical postmortem changes in the body are very useful in providing an approximate Time Since Death (TSD). Further, observable changes in certain body fluids like blood, spinal fluid, pericardial fluid, aqueous humor, vitreous humor, and synovial fluid are highly useful indicators of estimating TSD shortly after death. Of these, VH is considered most reliable because of the stability it exhibits to postmortem changes and other influences, including putrefaction in general, for longer periods. This means that biochemical changes in VH-notably, concentration variations of amino acids-occur at a slow rate. These changes form the basis for more accurate estimates of TSD. Therefore, detection of cysteine, an amino acid, is possible with the help of a recently developed smart, sensitive, and low-cost lab-on-a-chip technique. This technique makes estimation of TSD feasible up to a period of 96 hours since the concentration of cysteine in VH builds up sufficiently as part of the postmortem process and increases linearly with time elapsed since death¹.

Nanotechnology in Forensic Chemistry & Toxicology:

Nanotechnology may help to detect the trace number of toxic materials through several visceral organs. The detection of Clonazepam has been done with a few nanoparticles, that is, gold nanoparticles, silver nanoparticles, titanium nanoparticles; this helps in inspecting a criminal suspect or a criminal victim in a criminal justice system. Nanotechnology can also be used to detect poisons from blood samples. In the future, there will be a

huge scope for nanotechnology in forensic medicine, especially for post-mortem identification of deceased individuals. Due to their smaller size, nanoparticles can contact a larger surface area and can therefore react with more active sites. Screening and confirmation are the two main methods used in forensic drug detection. The molecular receptors of a nano sensor act as templates for the material being detected. Some nanoparticles also serve as effective fluorescent agents to confirm the presence of drugs in visceral samples².

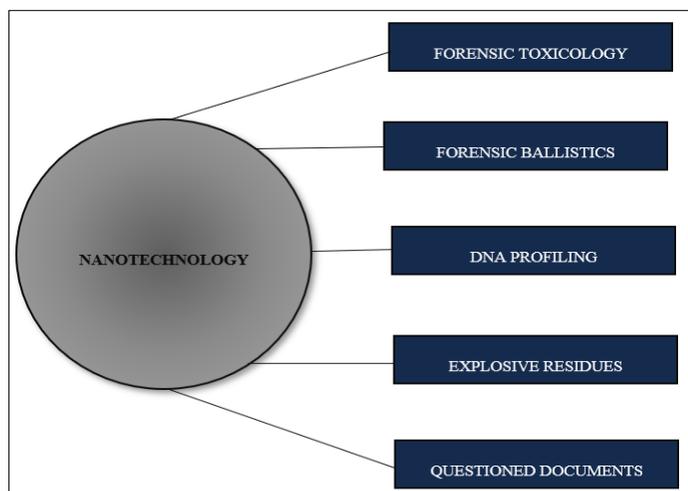


Figure-1: Role of nanoscience in forensic investigation.

Colorimetric analyses employ nanoparticles for highly complex drug and contaminant finding. The gold nanoparticles can be easily detected because they respond with certain medications or contaminants by changing color. Forensic experts analyzed a victim of environmental poisoning cases by using nanomaterial-based sensors that determined the toxins present³. Nano science has also been used for the identification of illegally additional dexamethasone to cosmetic products, which may cause harmful affect to body⁴.

Nanotechnology in DNA analysis: Nanoparticles can help in PCR by increasing the rate of DNA quantification, which reduces the time required for DNA identification. Gold nanoparticles, in particular, can enhance the detection of DNA samples, even from very small biological traces such as skin cells collected from under a victim’s nails in cases like rape or murder investigations. Magnetic nanoparticles, silica magnetic nanoparticles, and copper magnetic nanoparticles are active to obtain quality DNA that can be used to increase the efficiency of the PCR process. Gold nanoparticles (AuNPs) also possess excellent heat-transfer properties and can enhance Electro-Chemiluminescence (ECL). Because of these properties, they help decrease the heating and cooling time during thermal cycling, thereby increasing the overall reaction rate⁵. Multiple DNA targets can be detected simultaneously in a single assay due to the strong and consistent fluorescence of quantum dots⁶.

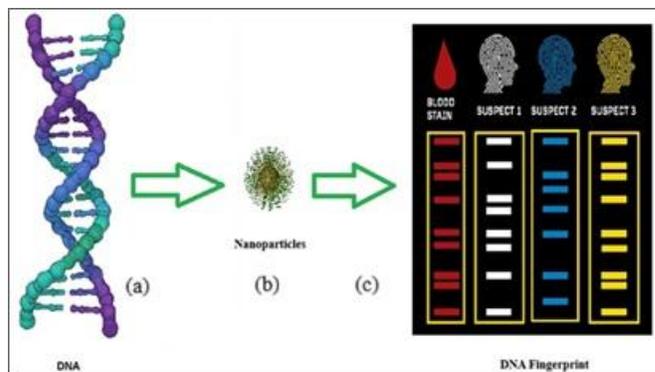


Figure-2: Analysis of DNA by Nanoparticles (a) DNA⁷ (b) Nanoparticle (c) DNA Fingerprint⁸.

Nanotechnology in fingerprint detection: New scientific techniques have been developed in the areas of microbial forensics and nanotechnology, replacing traditional methods like the use of smidgen in fingerprint development and the fluorescent X-ray tube. Scientists have demonstrated the use of gold nano particles to detect amino acids even on non-porous surfaces to increase the accuracy and efficiency of latent fingerprint analysis⁹. The development of latent fingerprints using by different kinds of nanoparticles which can be easily investigate from scene of crime. Each nanoparticle only performs better on specific surfaces because of its unique structure and chemical characteristics¹⁰. Nanocarbon powder is very active at positioning latent fingerprint on a variety of nonporous and semi-porous surfaces because it exactly interacts with fingerprint residue, and it show images of fingerprint ridges separately¹¹.

Nanotechnology in Questioned Document: Nanoparticles can be used as an excellent tool for ink detection in forensic document examination. They help identify differences between disputed samples and specimen samples from suspects by allowing analysis of the elemental profile and morphological characteristics of pigments present in writing and printing inks. Different ink samples can be examined using gold and silver nanoparticles, which provide strong luminescence and fluorescence under UV light—especially useful when detecting overwriting in questioned documents. Nanomaterials incorporated into a document can also be analyzed using Atomic Force Microscopy (AFM). AFM provides qualitative information regarding ink depth, ink-crossing patterns, amplitude and phase changes on paper, and the sequence of strokes, all of which are crucial in establishing the authenticity of a questioned document¹². The printing inks and writing inks contain nanoparticles due to the dispersion of nanoscale pigments within the medium. Gel inks frequently use nano-scale pigments, and recent developments in inkjet printing include nanoscale pigments to increase light fastness. Forensic experts must precisely characterize materials containing nanoparticles for investigative purposes¹³. Nanotechnology is used in security document to advance their security system and prevent counterfeiting¹⁴.

Nanotechnology in forensic serology: Identification of bloodstains at crime scenes is done by a number of reliable forensic investigation methods. However, estimation of bloodstain age remains as one of the demanding tasks in routine forensic analysis. Although precise estimation of bloodstain age is difficult, this information is important to reconstruct the timeline of criminal events. The morphological and cellular changes in blood cells provide valuable quantitative information for estimating the age of dried bloodstains. Recent literature has pointed out Atomic Force Microscopy as one of the advanced methods that may help to solve this problem. AFM opens up new perspectives for age estimation of bloodstains and determination of the post-mortem interval, which is particularly important for legal and medical investigations in crime cases. This approach assesses changes in the morphology and surface elasticity of RBCs by recording force–distance curves.

Temporal reduction in elasticity is mainly determined by the processes of coagulation and degradation of the bloodstain. Calibration of elasticity values with respect to time allows obtaining more accurate estimation of bloodstain age by the AFM technique, which makes an important contribution to crime scene reconstruction and solution of criminal cases¹⁵. The identification of biological fluids using a nano-biosensors technology has been recently employed without needing a complex laboratory set-up. This will easily extract the DNA isolation on a timely manner¹⁶. Raman spectroscopy technique can overcome this by using gold nanoparticles, which will produce separate spectra lines for peripheral and menstrual blood¹⁷.

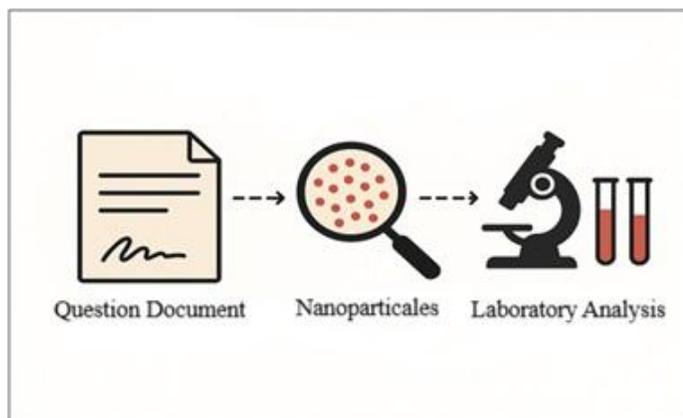


Figure-3: Analysis of ink examination by using nanoparticles in forged document.

Nanotechnology in Post blast Investigation: According to current global affairs, the world is increasingly facing problems related to war and explosive-based terrorism. The use of explosive weapons has grown significantly because they are simple, easy to deploy, and capable of causing enormous damage. The detection of explosives is still a great challenge for the police departments around the world, as the investigation of the blast sites to detect the explosive residues is a very difficult

task. The reason for this is that there are not many cheap sensors with high sensitivity and selectivity. Highly sensitive nano-sensors can be very effective in the detection of the explosive residues. Nanopolymers and nanoparticles are also useful for detecting explosive materials due to their structural composition at the nanoscale and molecular level. Nanostructures have the ability to function as sensors for a wide range of chemical and biological compounds¹⁸. Exploding residuals could be searched by the nano technology at a crime site that will be functionalized by complex molecules' structure targeting residuals¹⁹. Detection of tracing explosives, the recent technique nano sensor concept device or nanotube are used for post blast investigation²⁰. Detection of trinitrotoluene were investigate by curcumin base nanoparticle²¹. Investigation of explosive residues were identification by biosensor based on ion selective field effect transistor²².

Table- 1: Importance of nano technology in Forensic science.

Scientific Perspective	Nanoscience
DNA Profiling	Intact gold nanoparticles layered with citrate anions.
Explosive residue	Nanoscale cables Small, spherical nanostructures Particles in nanoscale minute particles of Carbon tubes at the nanoscale
Drug analysis	Identification of quantify codeine sulfate can be detected by the gold nanoparticle. Narcotic drugs have been investigated by Ag nanoparticles from saliva sample.
Fingerprint	CdS, ZnS, ZnO-SiO ₂ nanopowder, Au-NPs& FeO ₂ that is successfully used for improving latent fingerprints.
Question document	Using AgNPs-Acts as self-erasing ink.

Conclusion

Thus, we conclude that nanotechnology possesses tremendous potential and prospects in forensic science. In the near future, it is going to play a major role in DNA fingerprinting, advanced sensor systems, and post-mortem autopsy investigation. Several diagnostic kits based on nanotechnology are already being used for the detection of diseases such as HIV, and this technology is also becoming increasingly important in cancer treatment. Nanotechnology opens up new horizons of more efficient investigation techniques regarding crime scenes and forensic evidence analysis, leading to quicker and more effective solving of crimes. Thus, nanotechnology is not only a huge area of development in many scientific fields but it is also going to play a very crucial role in the near future of forensic science by offering highly advanced, sensitive, and precise investigative techniques.

Acknowledgement

The authors significantly acknowledged the help and cooperation of the Research Director, Dean School of Sciences and other staff members of SoS, Indrashil University, Kadi, Mehsana, Gujarat, India.

References

1. Ganesh, E. N. (2016). Application of nanotechnology in forensic science. *Journal of Medical and Allied Sciences*, 4(5), 3306–3312.
2. Anand, S. L., Alok, P., & Ritesh, K. S. (2016). Nanotechnology: An applied and robust approach for forensic investigation. *Forensic Research & Criminology International Journal*, 2(1), 00044–00048. <https://doi.org/10.15406/frcij.2016.02.00044>.
3. Mullai, M. K., Kavitha, R., & Krushna, S. S. (2024). Nanoforensics: Revolutionizing crime scene investigation with nanomaterials. *International Journal of Novel Research and Development*, 9(11), 377–389.
4. Francis, T. (2020). A review on the role of emerging revolutionary nanotechnology in forensic investigations. *Journal of Applied & Natural Science*, 12(4), 582–591.
5. Srividya, B. (2016). Nanotechnology in forensics and its application in forensic investigation. *Research and Reviews: Journal of Pharmaceutics and Nanotechnology*, 4(Special Issue 2).
6. Balwan, U. P., & Ganesh, B. A. (2024). Nanotechnology applications in forensic analysis: A review. *International Journal of Scientific Research in Science and Technology*, 11(16), 142–150. <https://ijsrst.com/index.php/home>. doi.org/10.32628/IJSRST.
7. Craiyon. (2025). *A colorful illustration of a DNA double helix*. <https://media.craiyon.com/2025-04-13/DdHP5ynlTnIDzBTswNnSA.webp>.
8. Hudson Alpha Institute for Biotechnology. (2021). *Forensics and DNA: How genetics can help solve crimes*. <https://www.hudsonalpha.org/forensics-and-dna-how-genetics-can-help-solve-crimes/>
9. Chauhan, V., Singh, V., & Tiwari, A. (2017). Applications of nanotechnology in forensic investigation. *International Journal of Life-Sciences Scientific Research*, 3(3), 1047–1051. <https://doi.org/10.21276/ijlssr.2017.3.3.13>.
10. Muskan, S., Anuj, S., Divyansh, J., Varad, N., Swaroop, S. S., Swapnali, V. J., Kumud, K. A., & Mahipal, S. S. (2024). Unveiling the power of nanoparticles: A comprehensive review on revolutionary techniques for development of latent fingerprints. *Letters in Applied Nano Bioscience*, 13(3), 1–13. <https://doi.org/10.33263/LIANBS133.110>.
11. Shailja, S., & Kimee, H. M. (2024). Development of latent fingerprints by nanomaterial: An update. *Journal of Forensic Science and Medicine*, 10(3), 246–254. https://doi.org/10.4103/jfsm.jfsm_187_23.
12. Richa, R., & Femin, D. (2022). Application of nanotechnology in forensic science. *Journal of Forensic Research*, 13(8), 1–5.
13. Priyanka, V., Poorvi, U., Bhavika, M., & Debhjit, M. (2024). Nanoparticles as silent witnesses: Significance, challenges and ethical considerations in forensic analysis. *Rasayan Journal of Chemistry*, 17(1), 297–305. <https://doi.org/10.31788/RJC.2024.1718665>
14. Antonio, A. C. (2008). Nanoparticles in forensic science. In *Proceedings of SPIE*, Vol. 7119, 134–148. <https://doi.org/10.1117/12.800784>.
15. Vardana, P., Lalit, P., & Sally, L. (2016). Emerging forensic applications of nanotechnology. *International Journal of Engineering and Allied Sciences*, 2(2), 42–48.
16. Priya, M., Heena, K., Brijendra, S. T., & Satbir, K. C. (2025). Nanotechnology in forensic toxicology: Emerging tools for justice. *World Journal of Pharmaceutical and Medical Research*, 11(9), 450–453.
17. Megha, Y., Riya, T., Blessi, N. U., Ashish, K. S., & Ajay, A. (2024). Nanoparticles as an emerging tool for forensic investigation. In *Futuristic Trends in Social Sciences* (Vol. 3, Book 19, Part 2, Chapter 7, pp. 194–226).
18. Muhammad, F. U., Yousaf, K. M., Ijaz, K., Barno, S. A., & Waqas, M. (2024). Exploring nanotechnology in forensic investigation: Techniques innovation, and future prospects. *Journal of Sensing and Bio-Sensing Research*, 45(1), 100674. <https://doi.org/10.1016/j.sbsr.2024.100674>.
19. Udaynadh, B. V. S. S., Vilas, A. C., Arpita, S., Ameesh, V., & Erra, A. (2024). Applications of nanomaterials in forensic science. In *Futuristic Trends in Chemical, Material Sciences & Nano Technology* (Vol. 3, Book 13, Part 1, Chapter 1, pp. 1–17).
20. Srividya, B. (2016). Nanotechnology in forensics and its application in forensic investigation. *Research and Reviews: Journal of Pharmaceutics and Nanotechnology*, 4(2), 1–7.
21. Sweta, S., & Nilimamayee, S. (2021). Nanotechnology: A powerful tool in forensic science for solving criminal cases. *Arab Journal of Forensic Sciences & Forensic Medicine*, 3(2), 273–296.
22. Palak, S., & Atul, K. D. (2024). Advances in the detection of explosives and chemical weapons: A comprehensive review. *IP International Journal of Forensic Medicine and Toxicological Sciences*, 9(2), 57–62.