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Review Article

Graphene's Role in Forensics: Enhancing Accuracy in Crime Investigations

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Abstract

Nanotechnology, on its part, is at the cutting edge in forensic science and leading the revolution of approaches groundbreaking in crime investigation. This paper has been researched in an intense manner so as to discover the wide range of applications that nanotechnology has accrued within the domain of forensic analysis. These range from important spheres, including questioned documents examination, bloodstain ageing and estimation of post-mortem interval, as well as DNA profiling, explosive detection and identification of illicit drugs. With nanotechnologically based approaches, the efficiency and precision of forensic instruments are therefore dramatically increased, thereby proving that credible results can be provided within a significantly lesser amount of time. Remarkably, the discovery of graphene an exclusive two-dimensional carbon material, well known for its unequaled qualities by any other material is but a great potential. Capabilities of graphene come to the fore in bio-sensing, at levels of sensitivity and accuracy particularly for DNA detection that can be described as never seen before, due to its unique characteristics. In turn, this means that the general potential of nanotechnology carries its repercussions for the development of forensic analysis, both in its effectiveness and in its progress. It gives the researcher revolutionary instruments that enable him to solve riddles and make definite and reliable judgments, shaping a future where forensic science leads to more clarity and a sort of justice that finds no parallel.

Keywords: Nanotechnology; Forensic science; Crime investigation; Bloodstain age determination; Graphene; Magnetic nanoparticles; AFM; Bio sensing; Dependable outcomes; Novel techniques

Introduction

Nanotechnology is the branch which deals with particles less than 100 nanometers. Specifically, nanotechnology has gained increased significance in forensic applications. It can help create and study material at the nanometer scale so that accurate results can be obtained in the smallest quantity of samples. There are numerous forensic applications of nanotechnology including detection of blood stains, fingerprints, and gunshot residue besides identification of material and comparison of materials used in cosmetics. The level of precision and efficiency in forensic research has advanced manifold with the use of nanomaterials and Nano sensors. Criminal investigations require forensic science because it can be used to identify suspects, identify crimes, and produce physical proof. The area of forensic science has recently included cutting-edge techniques from the natural sciences, including nanotechnology. The manipulation of matter at the nanoscale, a size so small that it can alter a material's chemical and physical properties is known as nanotechnology. Nanotechnology-based nanoparticles are used in the creation of dietary supplements with natural herbal remedies, gas sensor applications, improved drug delivery, medical treatment, and diagnostic devices, and many other scientific applications. Fingerprint analysis has been an inseparable part of crime scene investigation. The pattern on the fingers is called Frictional Ridge Skin (FRS) and it can be used as a prime biometric predictor of a person. FRS starts developing in the fetus and the flow of the amniotic fluid, and the position of the fetus influences the detail of the fingerprint [1]. It is a type of evidence for recovering fingerprints from porous and non-porous surfaces, and it can be done in two ways: patent and latent (not visible). Revolutionary nanotechnology with the integration of graphene-based biosensors has made a vast difference in DNA detection within the analysis of fingerprints. The substrate-free, label-free, and outermost sensitive methods developed will be used to get the DNA material in the fingerprints [2-4]. In forensic science, nanotechnology has opened fascinating new doors through its capability in the detection and analysis of samples at the nanoscale that, until recent times, was difficult. This has even been advanced when hail by tools such as the AFM, the SPM, and the HPLC [5]. Nanomaterials including quantum dots, nanocrystals, nanoparticles, and nanocomposites were used in a number of detections such as explosives, heavy metals, residues of gunshots, and DNA extraction. The application of nanotechnology in forensic science works has opened up new dimensions in realizing investigations with efficiency, accuracy, and real-time analysis [6]. Nanotechnology has a great deal of promise and potential in this area [7].

Nanotechnology in a questioned document

Advancements in technology have allowed the examination of questioned documents at the Nano-scale level [8]. A questioned document is a piece of evidence with markings that are in doubt, whether they are handwritten, typewritten, or printed. Forensic document examination involves distinguishing an original document from a forgery or fraudulent copy. To analyze nanoparticles added to documents, AFM is used. Examining the tiniest features of the ink can yield important hints in cases of inked documents that have been falsified. With the aid of specialized microscope called an AFM, it is possible to see the ink on a document's surface and determine the order of the ink strokes. Moreover, it provides 3-D surface morphology, which provides details on the order in which the ribbon dye or ball pen strokes were applied to the page so, For the purpose of using the surface-assisted laser desorption mass spectrometry to examine disputed documents, scientists have created metal, carbon, and silicon nanostructures.

Nanotechnology for detecting explosives

The ease of obtaining such weapons has made the emergence of explosive-based terrorism a serious issue. They can create a great deal of destruction and are simple to manufacture and use. These explosives come in a variety of forms, have undergone countless developments, and it is difficult to find sensors that are both economical and sensitive to detect them. A sensitive sensor system is used to analyses vapor or particulate matter traces that are collected as part of the detection procedure. The key difficulty lies in creating a method that offers excellent selectivity and sensitivity while minimizing sensor costs and obtaining a low limit of detection [5]. An innovative branch of nanotechnology has emerged as a result of recent research and development, focused on non-structured sensors that have high sensitivity, as well as specificity, and immediate detection and also regeneration times for diverse chemicals and explosive compounds [9]. In gunshot cases, analyzing gunshot residue with cutting-edge methods like high-resolution Scanning Electron Microscopy (SEM) as well as X-ray spectroscopy is an essential step. As a result of this method's extensive supporting documentation, criminality can be prevented (Figure 1). A novel sensing technique was proposed by Chu et al. in 2015 for the analysis of 2,4,6-Trinitrotoluene (TNT) utilizing amine-terminated nanoparticles [6,7].

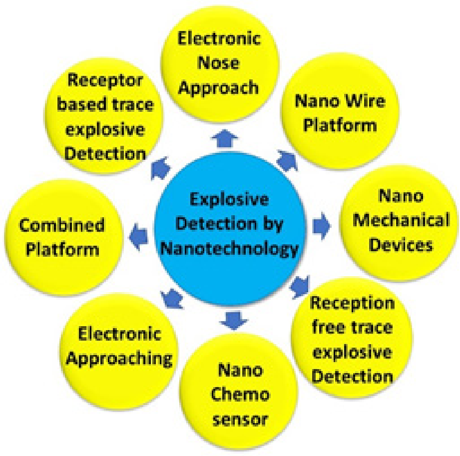

Figure 1: Explosive detection by nanotechnology.

Nanotechnology: Estimation of time since death

A crucial component of forensic medicine and law is determining the time of death, commonly referred to as the time of death. The procedure considers various physical and chemical alterations that take place in a body after death. The time since death can be determined by observing particular changes in body fluids such spinal fluid, blood pericardial fluid, vitreous humor, as well as synovial fluid [10]. Moreover, the vitreous humor remains unchanged, not succumbing to even little metabolic changes, even when enough time has elapsed since death. Estimation based on these metabolic changes can, therefore, be carried out in a very exact and accurate manner pertaining to the time that has elapsed since death [11]. A sensitive, cost-effective lab-on-chip technique has been optimized for detecting cysteine in vitreous humor with recent technological developments. By using this technique, one can extend the postmortem interval up to 96 hours [12]. Such recent advances in nanotechnology have opened the possibility for the development of sensitively low-cost lab-on-chip methods for the detection of biomarkers in vitreous humor to estimate TSD [13]. The studies address the potentiality of using the nanoscale biomarker cysteine as a TSD determinant. This feature of TSD and the concentration of cysteine, however, has never been studied in any previous literature. The researchers designed a lab-on-chip technology that measures and specifies the concentration of cysteine in vitreous humor samples. The system is cost-active than conventional laboratory technologies, faster than conventional techniques and highly sensitive to its analysis. The lab-on-a-chip technique enhances the identification capabilities by tapping into unique properties of nano-materials. For example, nanoparticles or nanostructured surfaces enhance the sensitivity and specificity of the cysteine assays. They could measure the dynamics of the concentration of cysteine in the vitreous humor with time, and model that can determine postmortem interval a very critical step in forensic science. The flow cytometric approach was also able to model the TSD, in that the degradation of DNA of the brain and spleen tissue was monitored for 96 hours. Using fluorescence nanoparticles to model the vitreous humor concentrations via flow cytometry is one possible approach in the future to model a more accurate TSD [14]. Flow cytometry-based methods are valid to estimate DNA degradation in post-mortem samples and the assessment of time since death. The first 72 hours after death were suggested to be the most useful observational time for the assessment of DNA degradation by flow cytometry [15,16]. The rate of DNA degradation in organs, most commonly the brain and spleen, is established over a fixed time period, usually up to 96 hours, in order to establish a link between DNA degradation and time since death. A close match has been observed to be between in vitro and corpse tissues between 24 and 36 hours PMI, while a less close match is reported between 36 and 72 hours in a study of DNA degradation in spleen tissue [15]. After 72 hours, DNA denaturation leads to an elongation that impairs the merit provided by the cytofluorimetric measurements. In fact, the same study also indicated that the brain may be a superior organ to the spleen for PMI estimation via flow cytometry since it showed much less DNA degradation [17]. Generally, flow cytometry techniques will assess postmortem DNA degradation in tissues by using fluorescently labeled antibodies and markers and provide important novel data about the link between DNA breakdown, cell death, and the estimation of the time since death with immense details. It provides a systematic way to study the postmortem interval and the changes in the tissues after death. In the coming days, the estimated techniques to estimate the TSD would be through fluorescent nanoparticles to identify the quantity of the vitreous humor and its evaluation with flow cytometry [14,18].

Nanotechnology in bloodstains age estimation

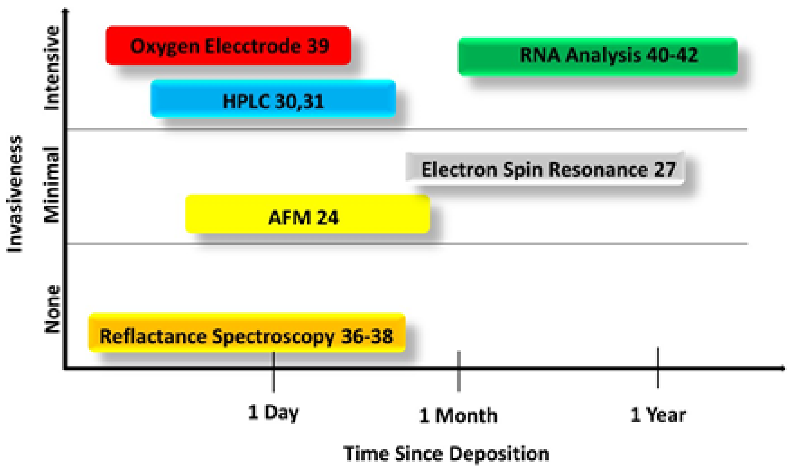

Figure 2: Forensic quest for age determination of bloodstains.

In forensic investigations, accurately identifying bloodstains is crucial. However, estimating the age of bloodstains remains a challenging and unresolved issue in routine analysis, making it difficult to determine the age of bloodstains with certainty [19]. AFM (Atomic Force Microscopy) is a new instrument that has the power to find the age of bloodstains and the moment of death, providing forensic experts with important information for solving crimes. Inforensic investigations, AFM (Atomic Force Microscopy) has demonstrated encouraging promise in measuring the Time Since Death (TSD) and establishing the age of bloodstains. The essential idea is that the mechanical characteristics of Red Blood Cells (RBCs), such their flexibility, alter noticeably as the cells age and dry out in a bloodstain. These Nano-mechanical alterations in individual RBCs inside a bloodstain can be precisely measured by AFM [20]. Specifically, research has shown that as RBCs get stiffer and more rigid during the drying and coagulation process, their Young's modulus, a measurement of elasticity increases over time. Researchers have created calibration curves that link the age of the bloodstain with the RBC elasticity data by examining the elasticity patterns of the RBCs in the stain [20-22]. Additionally, when blood is deposited, AFM can identify minute variations in the shape of red blood cells and their adhesion characteristics [23]. These biophysical changes might potentially offer extra indicators to gauge how long it has been since a bloodstain was deposited [21-23]. These AFM based methods have the potential to give forensic analysts precise and impartial information to assist in determining the age of bloodstains and possibly even the time of death in criminal investigations, however further research is still required. By capturing force distance curves, AFM analyses changes in the shape and surface elasticity of red blood cells (Figure 2). Because bloodstains coagulate and degrade with time, the elasticity pattern weakens over time. Bloodstains' age may be determined by calibrating the elasticity curve over time, which helps in criminal investigations [24].

DNA analysis using nanotechnology: improving PCR effectiveness

DNA analysis contributes a technique in which genetic sequences can be read and interpreted to differentiate between species and make individual variations. DNA tests that are commonly used include Y-chromosome, autosomal, and mitochondrial DNA testing. Among the key pieces of evidence is genetic material, DNA, and nanotechnology enables the recovery of the source of the DNA samples that are recovered from the crime scene. DNA can be recovered from biological material including skin, blood, hair, semen, and saliva of any organism by the use of magnetically active nanoparticles. The particles have been applied to isolate DNA recovered from different types of biological material, including blood and hair [25].

Researchers have used the extraction of DNA from several biological materials, including blood and hair, through the use of magnetic nanoparticles. Their application of magnetic nanoparticles has been indispensable in the features such as a large surface area, good dispersion, and easy separation in buffer systems. Nucleic acids are isolated very efficiently with the aid of these nanoparticles through the separation of target-bound molecules from undesired constituents without disturbing the nucleic acid of interest. The DNA extraction procedure has been highly revolutionized by the use of magnetic nanoparticles for target-bound molecule separation, which is advantageous in terms of its cost factor, reduced processing time, and ease of procedure. Moreover, several works of bacterial infections, drug development, gene therapy, mutation analysis, gene sequencing, clinical diagnostics, and DNA damage have been vastly eased by the use of magnetic nanoparticles in the recovery of DNA. These methods have been made far more affordable and accessible to life science research considering the use of magnetic nanoparticles in combination with high-throughput sequencing methods. Nucleic acid detection of viruses and other pathogens using magnetic nanoparticles in combination with novel procedures such as loop-mediated isothermal amplification and enzyme-linked immunosorbent assay are quick, timely, and, in particular, feasible from a series of samples, including human blood and liver tissues [26].

AFM has been utilized in the analysis of the DNA sequence by the use of carbon nanotubes to contain the DNA molecule [27]. Such is the case when one encapsulates the DNA molecule within carbon nanotubes, which might be the only shape and type of material known that constitutes an appropriate probe for high-resolution AFM imaging of biologic material. Carbon nanotubes having small outer diameters and very high aspect ratios, they are able to get access to this complex three-dimensional structure of the DNA molecules and scan these with potentials of extremely high resolution. This then keeps this functionalized carbon nanotube probe able to sequence and deduce the order of the DNA by selecting the carbon nanotube AFM probe in a manner that interfaces and bonds with the DNA in a certain manner. With this excellent sensitivity that is brought about in the carbon nanotube AFM probe, it becomes able to be identified for a single base pair of DNA, effectively making a medium for DNA molecular sequencing. The high resolution or genetic sequencing sought to be brought about by the carbon nanotube probe for details of DNA structure and topography, including interactions and conformation, is the technique utilized by the carbon nanotube AFM probe (Figure 3). On the other hand, the Fe3O4-a magnetic nanoparticle-has found utility in the generation of magnetic separation tools in the extraction of DNA from samples such as hair, saliva, and semen [28,29].

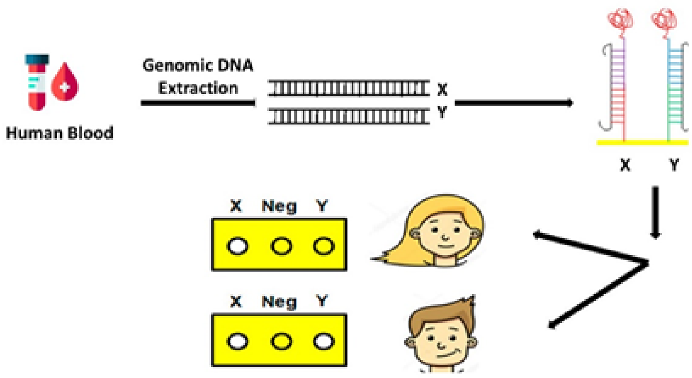

Figure 3: Amplification by polymerization in bio-sensing for human genomic DNA detection.

Nanotechnology in fingerprint development and identification

Fingerprints are vital evidence discovered at every crime scene and serve as essential elements for identifying individuals. The technique of micro-X-ray fluorescence is utilized in order to see latent fingerprints, which offers numerous advantages. However, its successful application requires appropriate instruments and trained analysts to conduct the analysis [30]. Modern nano-based technology is significantly aiding in the rapid development and analysis of fingerprint evidence with minimal chances of error on the spot. The quick development and processing of fingerprint evidence is made possible by contemporary nanotechnology, which also improves forensic investigation efficiency and precision. Nanomaterials, which are used to make latent fingerprints on different surfaces: silver, zinc oxide, silicon dioxide, aluminum oxide, gold, carbon, and silica. These are the materials that have been used for making fingerprints because the materials that used the gold nanoparticle might see the sweat pores, ridge patterns, and other features of fingerprints much better than the others. This enhances the quality and stability of the fingerprints and gives the forensic investigators accurate and complete information regarding the criminal identifications [31].

Fingerprint detection with higher sensitivity and reliability is allowed by nanotechnology, compared to conventional methods of detection. The particles, with the likes of zinc oxide, titanium oxide, and gold and silver structures, are used for detecting latent fingerprints on a variety of surfaces. For example, nanoparticles made to measure less than 10nm, which are made to luminesce in UV light, are used to make fingerprints accepting the advanced analytical methods like SALDI-TOF2-MS, in which the chemicals included in the fingerprint residue are identified. It has also been demonstrated by scientists that the success of procedures is increased remarkably with the use of nanotechnology, for instance, polymerase chain reaction, which is used for forensic DNA analysis to extract, analyze, and amplify copies of the trace evidence. Nanotechnology also plays an essential role in forensic science, as it not only helps to discover evidence but also helps to analyze materials in explosives, paint, glass, hair, and fibers, paint, and gunshot residue, helps discover cases that are sensitive and reliable, and ultimately help to increase the occurrence of accuracy and reliability of analysis of fingerprints in criminal investigations [32,33]. These days, a variety of nano powders are used to see latent fingerprints. Especially in the creation and identification of latent fingerprints, nanotechnology has completely transformed the field of forensic research. For this, a variety of nanomaterials more especially, Nano powders are employed. Latent fingerprint visibility is improved by the use of gold nanoparticles. They are employed in a two-step procedure called Multimetal Deposition (MMD), in which the fingermark-marked surface is submerged in an AuNPs stabilized in citrate solution and subsequently swapped out with the Ag-PD solution [31]. On a variety of non-porous and semi-porous surfaces, latent fingermarks can be detected with great effectiveness using nanocarbon powder. It efficiently interacts to make latent fingerprints visible. Because silica nanoparticles may coat surfaces, they are used as labeling agents that help latent fingerprints form. Fluorescent Amphiphilic Silica Nano powder is well-known for its effective ability to generate latent fingerprints on a variety of surfaces when exposed to particular lighting conditions. These Nano powders are essential for increasing latent fingerprint quality, stability, and visibility, which greatly improves forensic investigative procedures. On both porous as well as non-porous surfaces, the use of nanoparticles such as Au-NPs, ZnS, CdS, iron oxide, TiO_2, and molybdenum disulphide has shown outstanding results in greatly improving latent fingerprint approaches (Figure 4). This improvement comprises heightened selectivity, greater sensitivity, and improved background contrast [34,35].

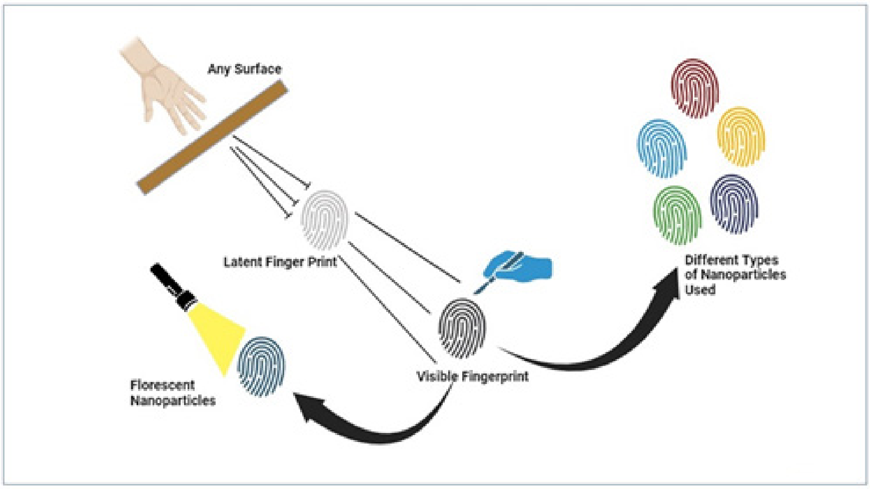

Figure 4: Latent fingerprint development.

Use of nanoparticles in body fluids

Investigation of body fluids is essential because the presence of fluids like blood, saliva, and sperm can reveal critical information that helps identify criminals. Traditional techniques, including chemical assays, protein catalytic activity, and immunological studies An et al. 2012, are used for identifying these fluids. These techniques can only identify one kind of fluid at a time, thus they are time- and money-consuming. To address these challenges, nanoparticles have been evolved for the detection and identification of bodily fluids. Nanoparticles create highly contrasting images, making it easier to visualize these fluids, which are often difficult to see with the naked eye. Iron oxide nanoparticles, specifically created by Frascione et al. are equipped with antibodies specific to blood and saliva constituents. These nanoparticles allow for the detection of minute amounts of chemicals on surfaces like ceramic, tile, and paper, which lack natural contrast for conventional detection methods (Figure 5).

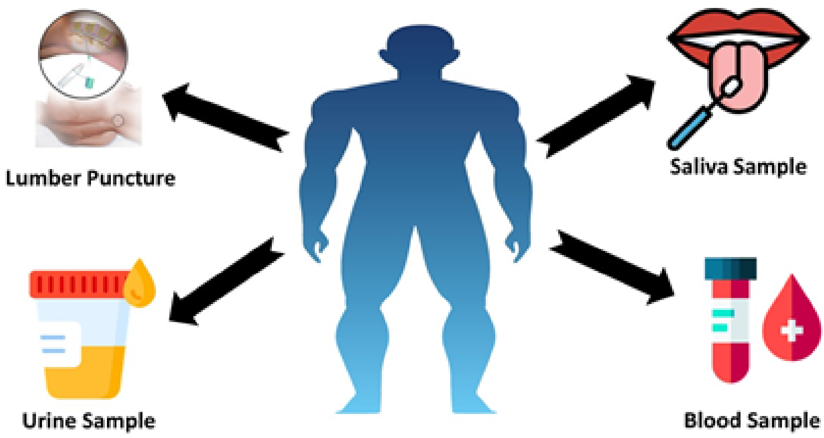

Figure 5: Use of nanoparticles in body fluids.

Law enforcement and nanotechnology

In forensic science, evidence from crime scenes is analyzed to pinpoint offenders and prove that a crime actually occurred. These pieces of evidence are essential for the capture and conviction of criminals, which leads to the resolution of the crime [36]. According to Henry Lee (Setia & Gupta, 2004), based on the nature of the crime and the issues that need to be addressed, forensic science evidence can be divided into biological, fingerprint, document, and impression categories. The forensic value of the evidence is severely impacted by improper identification, collection, preservation, and testing procedures. This might lead to the loss of important data, which would ultimately compromise the administration of justice [37]. In forensic science, evidence is crucial for clearing people of wrongdoing and for strengthening analyses and investigations. Enhancing the identification, and analysis of affirmation from crime scenes has been made possible in large part by nanotechnology. Various methods and tools that are used in the forensic laboratories have been modified for the characterization of nanomaterials in this newly developed use of nanotechnology. These methods include transmission electron microscopy, Raman micro spectroscopy, Scanning Electron Microscopy (SEM), and atomic force microscopy [38]. Forensic scientists' use in criminal investigations now have access to vital and cutting-edge Nano sensors [39].

Nanotechnology in biotechnology and forensic science

The field of forensic biology and biotechnology is concerned with the analysis of biological evidence, such as blood, semen, saliva, sweat, and tears, for the purpose of identification through genetics and DNA analysis. While Single Nucleotide Polymorphisms (SNPs) and Short Tandem Repeats (STRs) have been employed in the past, they may not always be successful in identifying donors of biological evidence found at crime scenes through comparative DNA profiling, necessitating the use of other techniques capable of looking into, identifying, and tracking down offenders. DNA phenotyping forensic is used to identify missing persons as well as victims of disasters based on their skeletal remains. Hiris plex-S systems can predict eye, skin hair color from the DNA, offering valuable information for identification purposes [40]. Identification plays a important role in crime scene investigations, especially when analyzing body fluids. Nanotechnology, specifically Raman micro spectroscopy, has been utilized to identify individual red blood cells. Saliva, a common biological fluid found at crime scenes, have various biochemical components that can be analyzed through DNA analysis for identification purposes. The glycosylation in saliva, that is influenced by biochemical environment, can also be examined for identification purposes. Nanotechnology has become essential in this area by investigating post-mortem changes in saliva glycan using Nano LC/MS and LC/MS/MS. This helps determine the likelihood of saliva glycosylation as a powerful method for estimating the Post-Mortem Interval (PMI) [41].

Nanotechnology in forensic physics

Nano Fingerprints is an emerging field that utilizes nanotechnology to improve fingerprint development. While patent prints are visible to the naked eye and can be directly used in investigations, latent prints need to be developed before analysis. Silver nanoparticles stabilized by cationic surfactants were a new nanotechnology development used, but they faced challenges with reproducibility and poor contrast. As a more advanced approach, the Multimetal Deposition (MMD) method has been introduced. In recent times, there have been exciting developments in nanotechnology applications for fingerprint development. For instance, Zine Sulfide/Cadmium selenide nanoparticles have been used to enhance and visualize fingermarks under ultraviolet light [42], The Silver physical developer (Ag-PD) method and the use of Silica nanoparticles (SiO2-NPs) and aluminum oxide nanoparticles have also shown promise in fingerprint development [39].

Various techniques utilized for forensic analysis of fingerprints

Human perspiration and sebum have a unique makeup that is affected in different ways by things including age, health, and diet. The composition may change over time as a result of things like volatile components evaporating, diluting into porous surfaces, exposure to light, changes in temperature and humidity, and more. Fingerprints are used to identify people, but they can also reveal information about a person's occupation and the things they have come into contact with, such as bodily secretions. Through the body's hormones, researchers can assess the physical characteristics of individuals using Time-of-Flight Secondary Ion Mass Spectrometry (ToF-SIMS) and Desorption Electrospray Ionization Mass Spectrometry (DESIMS). They calibrate their mass spectrometry methods by measuring minute amounts of the compounds with an ink-jet-printed array of known drug concentrations. Then, they use a 3-D printed plastic finger and synthetic sebum to make drug-tainted fingerprints and press them onto silicon or paper to study how the matrix and substrate affect the analyte signal response. Magnetic powder, aluminum flake powder, luminescent powder, and iron flake powder is only a few of the tools used for fingerprint analysis. Along with Surface Assisted Laser Desorption/ Ionization (SALDI) coupled with mass spectroscopy, methods like chromatography and mass spectroscopy are used [43], Desorption Electrospray Ionization (DESI) mass spectroscopy [44], Matrix Assisted Laser Desorption/ Ionization mass spectroscopy (MALDI) [45], Raman spectroscopy, Infrared spectroscopy, cutting-edge techniques.

Role of nanotechnology in forensic analysis

To increase the clarity of fingerprints, nanoparticles like gold nanoparticles, zinc sulfide/cadmium selenide, and other organic-inorganic silica-based particles are used. The DNA research and development program in forensic science uses micro-device or chip-based technology to analyse DNA [46]. In recent times, the presence of illegal drugs, such as cocaine, in fingerprint samples is quantified by studying the spectroscopic properties of nanoparticles [47]. Gold nanoparticles that have been changed by melamine are used in a nano sensor to identify the drug clonazepam in blood and bone samples. Using PCR amplification, magnetic nanoparticles, copper nanoparticles, and magnetic nanoparticles containing silica are used to separate high-quality DNA samples from a variety of skeletal remains and bodily fluids. These forensic analysis techniques rely on nanotechnology [48,49]. This method involves diagnosing and examining samples and operates at the nanoscale scale. It includes many different aspects, including the choice of materials, analysis, synthesis, and measurements made using nanoscale equipment. Individual atoms or molecules inside a material can be changed. This method allows for the control of a material's chemical and physical properties [50]. Gold nanoparticles, Zinc sulfide/cadmium selenide, and various organic-inorganic silica-based particles are employed to improve the clarity of fingerprints [51].

Numerous techniques are employed to examine nanomaterials, such as micro-Raman, Scanning Probe Microscopy (SPM), Transmission Electron Microscopy (TEM), and Scanning Electron Microscopy (SEM). Nanoparticles, peptide nanotubes, carbon nanotubes, quantum dots, and other semiconductor nanostructures are a few examples of nanomaterials. Numerous industries, including communication, consumer goods, quantum computing, and environmental engineering, use these nanoparticles. Important samples include skeletal remains, hair, blood, saliva, and palm- or fingerprint samples. By examining the spectroscopic characteristics of nanoparticles, it is possible to detect the presence of illicit narcotics in fingerprint samples, such as cocaine. Using silver, gold, and titanium oxide nanoparticles increases the sensitivity of these illicit substance detection in fingerprint analyses [52]. A nano sensor was developed using melamine-modified gold nanoparticles to detect the presence of the clonazepam drug in blood and skeletal samples [53]. In order to enable quicker and more affordable on-field testing, new sensors have been developed. The commonly available and reasonably priced Agilent 2100 bioanalyzer can considerably improve the effectiveness of DNA tests, even at a nanoliter size, in a very short period of time. These sensors are therefore employed in forensic investigations to measure mitochondrial DNA tests [54]. For forensic investigation, magnetic nanoparticles, copper nanoparticles, and magnetic nanoparticles containing silica can be used to recover high-quality DNA from various skeletal remains and bodily fluids. Visible patent fingermarks can be employed right away in the course of an investigation because they are readily apparent. However, to make latent fingermarks visible and useful during the inspection procedure, they must first be developed [55].

Role of nanotechnology in fingerprint analysis

Nanotechnology's operation in point analysis has significant counteraccusations, especially in enhancing the clarity of point development. relating latent fingerprints on wet paper is challenging as water wetlands down the sweat's amino acids, which are essential for point improvement. To ameliorate the clarity of idle fingerprints, gold nanoparticles with long hydrocarbon chains can be employed to produce hydrophobic relations with the sweat remainders, alongside tableware physical inventor. In the process of point development, a tableware physical inventor (Ag-PD) using a waterless result of tableware nanoparticles stabilized by cationic surfactants is employed, but it has downsides like weak discrepancy and lack of reproducibility. To overcome these issues, the Multimetal Deposit (MMD) approach is employed. In this system, gold nanoparticles (AuNPs) interact with fingermark residue through ionic relations, promoting the rush of metallic tableware from the Ag- PD result. Another effective and unremarkable fashion involves using modified gold nanoparticles (AuNPs) that preferentially attach to paper through relations with cellulose, creating a subtle coating on the paper face while keeping the sebaceous crests undressed.

Bifunctional reagents with active heads that have a high affinity for the paper and active tails that can bind to the metallic nanoparticles are used to bind the AuNPs. posterior treatment with a conventional AgPD result results in darkening of the gold- carpeted region due to the rush of black tableware over them [56]. idle fingermark analysis greatly benefits from cold-blooded organic- inorganic silica-grounded patches. Another enhancement in point development is achieved through the creation of zinc sulfide/ cadmium selenide nanoparticles. These nanoparticles have a fresh advantage of glowing under UV light, allowing fingerprints to be visible without the need for a microscope [57], mongrel cadmium sulfide amount blotches (QDs) nanocomposites, modified with mercaptopropyl (PPHSH) and pionitrile (PPHCN), and incorporated into pervious phosphate hetero structures (PPH), are promising campaigners for point analysis due to their luminescence parcels [58].

Alternately, the use of mongrel Nano powders and gold nanoparticles carpeted with Poly (styrene- alt- maleic anhydride)-b- Polystyrene (PSMA- b- PS) allows for the clear visualization of idle fingerprints on patterned or varicolored backgrounds. When applied to a face containing idle fingerprints, a mix of magnetically responsive acetylene (DA) greasepaint and magnetite nanoparticles adheres to the crest patterns of the fingerprints under the influence of a glamorous field. Upon exposure to UV light, this compound admixture immobilizes on the idle point and generates blue-multicolored polydiacetylenes (PDAs). Further, with heat treatment, the blue- colored image undergoes a transition to red, enabling effective visualization of the idle point through luminescence turn on [59-61]. The clarity of idle fingerprints can be bettered by using gold nanoparticles carpeted with long hydrocarbon chains, which interact hydrophobically with the sweat remainders. also, the tableware physical inventor is employed in this process [62]. The use of a waterless result containing tableware nanoparticles stabilized by cationic surfactants serves as the tableware physical inventor (Ag-PD) in point analysis. still, this system has downsides similar as poor reproducibility and low discrepancy. To overcome these issues, the Multimetal Deposit (MMD) system can be employed. In MMD, gold nanoparticles (AuNPs) interact with the fingermark residue through ionic relations between negatively charged gold colloids and appreciatively charged factors of the fingermark. Likewise, zinc sulfide/ cadmium selenide nanoparticles are developed to enhance fingerprints, and they also parade luminescence under UV light. This luminescence allows for direct observation of fingerprints without the need for fresh styles. In addition, mongrel cadmium sulfide amount blotches (QDs) nanocomposites functionalized with mercaptopropyl (PPH-SH) and propionitrile (PPH-CN) and constructed in Pervious Phosphate Heterostructures (PPH) retain luminescence parcels, making them potentially precious for point analysis. For idle fingerprints present on patterned or varicolored backgrounds, the use of mongrel nano maquillages and gold nanoparticles functionalized with Poly [63].

Advancements in nanoparticle-based DNA detection and sequencing technologies

Essence oxide nanoparticles, when present, have been set up to induce the fragmentation of DNA motes through an oxidation process [64]. Graphene nanoparticles have been proposed as a feasible option for colorful biochemical operations, particularly in DNA sequencing. Nanopore- grounded DNA sequencers incorporating graphene are considered a promising fourth-generation sequencing technology. This advancement holds the implicit to sequence the entire mortal genome fleetly and directly at a cost of lower than 1000. Graphene nanopore device comprises a many- subcaste graphene structure deposited on a silicon nitride membrane suspended above a silicon chip. It includes microfluidic channels and an external circuit for applying voltage and recording current signals. While the eventuality of graphene nanoparticle-grounded bias for DNA discovery has been demonstrated, it remains uncertain whether they can achieve single- base resolution for DNA sequencing [65]. To probe this possibility, experimenters have explored the feasibility of DNA sequencing using graphene nanopores and ionic current discovery through ab initio viscosity functional proposition (DFT) and Molecular Dynamics (MD) simulation [66].

Through theoretical styles, experimenters have demonstrated that the DNA sequence discovery resolution can be enhanced by reducing the periphery of the nanopore [67]. Expansive exploration has been conducted on graphene- grounded accoutrements, including graphene oxide and reduced graphene oxide (GO, rGO), due to their implicit operations in DNA discovery. Graphene's remarkable electronic parcels and large face area render it largely sensitive and specific for DNA discovery [68]. Studies have explored the use of pristine graphene wastes, as well as Graphene Oxide (GO) and reduced graphene oxide (rGO), for DNA discovery, using their substantial face area and exceptional electrical conductivity. The process of functionalizing graphene wastes with DNA examinations improves the selectivity and perceptivity of DNA discovery. Graphene oxide (GO) with its oxygen functional groups and large face area enables picky discovery of DNA sequences through reciprocal base pairing. On the other hand, reduced graphene oxide (rGO) exhibits enhanced electrical conductivity and reduced non-specific list of DNA examinations, performing in heightened particularity and perceptivity for DNA discovery (Figure 6).

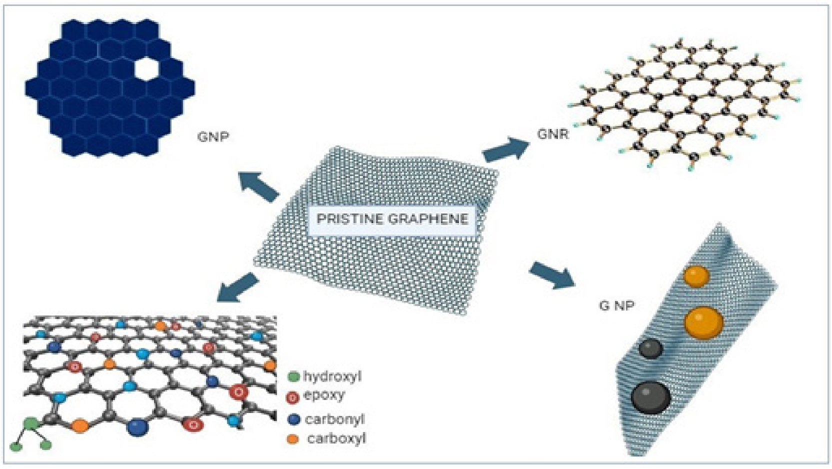

Figure 6: Nanoparticle-based DNA detection and sequencing technologies.

In exploration disquisition, scientists employed pristine graphene as a platform for genosensing. The commerce between the nucleobases in hairpin DNA (hpDNA) and the graphene hexagonal cells is primarily told by π- π mounding. The charge transfer resistance (Rct) of the graphene-modified electrode clearly enhanced as a result of the experimenters paralyzing hairpin DNA (hpDNA) on the detector face. Later, a notable decrease in the Rct value was seen upon hybridization with the wild-type target, signifying the effective identification of the target DNA. In this study, impedimetric genosensing was employed, which measures changes in the electrical parcels of a material upon the list of a reciprocal DNA target. The change in charge transfer resistance after hybridization served as a dependable system for detecting the presence of the target DNA. Electronic DNA biosensors are bias that use electrical signals to descry DNA motes. A extensively used type of these biosensors is grounded on Field- Effect Transistors (FETs), where a gate electrode functionalized with DNA examinations controls the electrical conductivity of a semiconductor material when DNA hybridization occurs. Changes in the threshold voltage of the FET, which are commensurable to the quantum of target DNA, can be employed to determine the DNA attention. FET-grounded biosensors have several advantages, including high perceptivity, particularity, and real- time monitoring capabilities. Still, they also have limitations, taking technical instrumentation and careful optimization of inquiry design and face chemistry. Optic DNA biosensors are another type of biosensor that detects and quantifies specific DNA sequences or motes using optic signals. These biosensors use colorful ways similar as luminescence, face plasmon resonance (SPR), and colorimetry to transform the list event into a measurable optic signal. They've different operations in complaint opinion, environmental monitoring, forensic analysis, and the study of gene expression and protein- DNA relations [2].

To cover the real- time hybridization of single- stranded DNA (ssDNA), (Electrochemical DNA Sensor by the Assemblage of Graphene and DNA- Conjugated Gold Nanoparticles with tableware improvement Strategy- Critic experimenters developed a compound conforming of platinum nanoparticles (PtNPs) and Reduced Graphene Oxide (rGO). This compound was used as the transmissive channel in a solution-gated Field- Effect Transistor (FET). The PtNPs were effective in detecting DNA by causing a reduction in current when the target DNA adsorbed onto them, forming a hybridization with reciprocal inquiry DNA on the PtNPs. In recent advancements, gold nanoparticles (AuNPs) with colorful shapes have been employed in electrochemical detectors for DNA discovery. Lin and her associates Yin et al. 2012 constructed an electrochemical DNA biosensor by assembling a graphene platform and DNA- conjugated AuNPs. Using a mounding technique, the single-stranded DNA was heaped on an electrode modified with graphene. The target DNA sequence and oligonucleotide examinations labeled with AuNPs were found to be suitable to hybridize in a sandwich assay format by discriminational palpitation voltammetry. This was evident because AuNPs accelerated the deposit of material.

Challenges of nanotechnology in forensic science

Exposure risk Airborne solid ultrafine particles, including nanoparticles, may pose a risk to human health, particularly when they meet the balmy mucosa in the nasopharyngeal region. These particles can translocate via the olfactory nerve and potentially impact the central nervous system and respiratory organs, leading to adverse effects on the whole body. Sample Degradation Nanoparticles are widely used in latent fingerprinting techniques, but their application on surfaces containing biological materials, such as blood fingerprints, can be problematic. Nanoparticles, especially metal oxide particles, have the potential to cause damage to DNA molecules through oxidation processes, leading to the degradation of valuable biological evidence.

Outlook and Future Directions

Traditional dust powders, such as carbon black, were frequently employed to extract fingerprints in the past. However, a fundamental flaw in these powders was that they had a propensity to stick to background surfaces as well as fingerprint marks, making it difficult to tell the prints apart properly. Nanotechnology has intervened to solve this problem by offering powders with nanoscale dimensions. These nanoparticles eliminate the previously problematic background surface interference by sticking just to the required fingerprint impressions. Additionally, there is ongoing debate regarding the possible uses of nanotechnological fingerprints in disease diagnosis. For instance, fingerprints may be used to determine a person's smoking status. solutions containing gold nanoparticles and antibodies that attach to a nicotine metabolite called cotinine have been utilized for this purpose in latent fingerprints. By utilizing the special qualities of nanoparticles, nanotechnology has play a significant role in forensic science. The surface area to volume ratio of smaller particles grows noticeably. This property creates new opportunities for surface-based science, such as forensic fingerprint identification. Gold nanoparticles are one of the most commonly used nanoparticles. They are suspended in petrol ether and have lengthy hydrocarbon chains. Through hydrophobic interactions, these nanoparticles cling to the fingerprint. A reaction then takes place when the fingerprint is submerged in a silver ions solution, producing a dark silver metal outline that matches the fingerprint. Evaluation and analysis are made simpler by the very clear and distinct print produced by this procedure. Additionally, the quantum yield of these nanoparticles can be used for detection, improving the power of nanotechnology in forensic fingerprint analysis.

Many fluorescent semiconductors are utilized as labeling agents for the fingerprint that provides a very clear print. Due to their optical properties and chemical stability, nanoparticles are highly prized. TiO2 nanoparticles have been taken into consideration for fingerprint development. However, they acquire luminous qualities when doped with particular dyes, making them appropriate for this application. Chinese academics have been looking into the possibility of using cadmium selenide (CdSe) nanocrystals as a fingerprint-depositor. The stabilizing agents for these nanoparticles include mercaptoethanol and mercaptoacetic acid. Fingermark detection can be achieved with titanium dioxide (TiO2). Furthermore, its versatility over porous and nonporous surfaces renders it effective in fulfilling the intended function. It has been proven that molybdenum disulfide (MoS2) particles can interact with the fatty components of latent fingerprints to produce a grey deposit that can be photographed and examined. Small Particle Reagent (SPR) is a technology that makes use of these particles. Additionally, fluorescent dye that produces fluorescence against a dark background can be employed in conjunction with SPR. In order to detect latent fingerprints, multimetal deposition, or MMD, is a two-step wet chemical process that combines the ideas of a physical developer with SPR. First, the object is immersed in a 2.5–2.8 pH aqueous gold nanoparticle solution. The object is treated with physical developer in the second step of the process to improve the contrast of the fingermark. This results in fingermark ridges stained from light gray to black. It has been demonstrated that fluidic channels with a size of less than 1 ml make it simple to detect DNA molecules, and that sophisticated electric field control can cut reaction time to just a few milliseconds.

Mitochondrial DNA post-Polymerase Chain Reaction (PCR)

"Light it up," a tool developed by researchers at King's College London's Forensic Science & Drug Monitoring Department, helps distinguish different bodily fluids like seminal fluid, blood, and saliva. The University of Surrey has created a pollen grain nanoparticle coating called nano tagging that can be used to cover gun cartridges. The researchers claim that nano tagging can be used in situations when knives or other readily accessible weapons are involved.

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