RECENT TRENDS IN NANO TECHNOLOGY

Abstract

Nanotechnology has emerged as a revolutionary field of science and engineering, dealing with the manipulation and control of materials at nanoscale level. In recent years, significant progress had been made in various aspects of nanotechnology, paving the way for groundbreaking advancements and the creation of mobile and deployable forensic instruments has been made possible by nanotechnology diverse applications. This abstract highlight some of the recent trends in nanotechnology, focusing on key areas of researching and development. Real-time, on-site analysis of evidence from crime scenes is possible with miniature analytical instruments based on nano sensors and micro fluidics. With the help of these small gadgets, forensic investigators may get rapid answers and make crucial judgments quickly and effectively. Additionally, advancements in forensic DNA analysis are being driven by nanotechnology. The creation of DNA-based nanotags and nano tracers, which can be used in forensic intelligence gathering and tracking, is also facilitated by nanotechnology. Furthermore, nanotechnology is advancing the field of forensic imaging and visualization. Nano-enhanced contrast agents, such as quantum dots and up conversions nanoparticles, enable more precise imaging of latent fingerprints and bloodstains, even on challenging surfaces.

Keywords: Nanotechnology, nanoscale, nanotags, nanoparticles, nano sensors.

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I. INTRODUCTION

Nanotechnology involves manipulating materials at the atomic level to craft innovative structures, substances, and devices. Its potential impact spans diverse domains like manufacturing, consumer products, energy, and healthcare. The outcomes of this manipulation are termed nanotechnology, encompassing engineered structures and systems. Nanomaterials occupy the 1 to 100 nanometer size range, exhibiting unique traits that influence their interactions in physics, chemistry, and biology. This exploration and utilizations of distinctive characteristics underpin the heart of this burgeoning technology. Nano sensors are essential to the growth and advancement of nanotechnology research as the need to identify and quantify the molecular attributes of toxins, pollutants, and various analytes grows, there has been a notable surge in interest surrounding these devices. This chapter will delve into the advancement of nano sensors and nano biosensors, exploring overarching ideas linked to nano sensors, as well as delving into principles associated with atomic force microscopy (AFM) and atomic force spectroscopy (AFS) [1]. The use of AFM tips and (micro) cantilevers in nano sensors will be discussed, with a focus on theoretical ideas, their benefits and drawbacks, and key applications.

Nanosensors are tiny operate on the "Nano" scale. The term "nano" refers to a unit of measurement about 109 m. A nanosensors is a device that can transmit data and information on the features and behavior of particles from the nanoscale to the macroscopic level [2]. Nanosensors find application in monitoring nanoscale temperature and detecting chemical or mechanical data, including the presence of nanoparticles or chemical species. Nanosensors can be classified based on their structure and use. Nanosensors can be divided into two types depending on their structural makeup into optical nanosensors and electrochemical nanosensors. The nanosensors can be classed as a chemical nanosensors, biosensor, electrometer, and deployable nanosensors depending on the application. The applications for the nanosensors are numerous [3].

Chemical nanosensors convert data from analytes with different concentrations into a detectable signal using techniques like colorimetry, gravimetry, or visually. This is dependent on the analytical capabilities of nanosensors and their chemical selectivity Chemical nanosensors find synergy with nanomaterials like nanotubes and nanowires [4]. These nanosensors operate through the binding of antibodies to conductive nanomaterials, like carbon nanotubes (CNTs), causing a shift in material conductivity upon antibody attachment. To detect the food-borne pollutant known as Ochratoxin A, immunosensors composed of CeO_2 NPs and chitosan are another type of electrochemical nanosensor. A silicon nanowire transistor detects staphylococcal endotoxin B, and a CNT detects cholera toxin. Microorganisms can also be found using nanomaterials. TiO_2-coated nanowires can be used to make [5].

In the realm of optoelectronics, the captivating optical and electrical traits of inorganic nanomaterials like quantum dots, nanowires, and nanorods can be harnessed. These characteristics can be tailored through synthetic techniques, leveraging the material's size and structure [6]. This paves the way for the integration of these materials into optoelectronic devices based on organic materials, including OLEDs and organic solar cells. Such devices' operation is dictated by photoinduced processes including electron transport and energy transfer. The effectiveness of the photoinduced process, which is responsible for the devices'

operation, affects how well they perform. To employ them in organic optoelectronic devices, a greater understanding of those photoinduced processes in composite systems of organic/inorganic nanomaterials is therefore required [7].

Nanoparticles or nanocrystals composed of metals, semiconductors, or oxides possess captivating attributes, spanning mechanical, electrical, magnetic, optical, and chemical domains, among others. Examples such as quantum dots and chemical catalysts crafted from nanomaterials showcase the diverse applications of nanoparticles [8]. For biomedical applications such as tissue engineering, medication delivery, and biosensors, a variety of nanoparticles are now being researched in depth since they serve as a link between bulk materials and atomic or molecular structures, nanoparticles are of significant importance to science. Although a bulk material's physical characteristics thought to remain constant regardless of its size, this is frequently not the case at the nanoscale. Surface plasmon resonance in certain metal particles, quantum confinement in semiconductor particles, and super Para magnetism in magnetic materials are examples of size-dependent phenomena that have been discovered Compared to bulk material, nanoparticles display a number of unique features [9]. For instance, the movement of copper atoms and clusters at roughly the 50 nm scale causes the bending of bulk copper (wire, ribbon, etc.). Smaller than 50 nm copper nanoparticles are thought to be extremely brittle and lack the malleability and ductility of bulk copper [10]. It's not always preferable for properties to alter. Ferroelectric materials smaller than 10 nm can change the direction of their magnetization using heat energy at ambient temperature, rendering them unusable for memory storage. Nanoparticle suspensions are conceivable because the particle surface's contact with the solvent is powerful enough to overcome differences in density, which typically cause a substance to either sink or float in a liquid [11].

II. RECENT TRENDS IN NANOTECHNOLOGY

1. **Nano -Enhanced Imaging And Visualization:** Advancements in latent fingerprint imaging the integration of nanomaterials with advanced imaging techniques, such as quantum dots and up conversion nanoparticles, enables more precise imaging of latent fingerprints on challenging surfaces, nanotechnology has revolutionized the precision and efficacy of crime scene investigations, enhancing the capabilities of law enforcement agencies in identifying suspects and analyzing evidence [12]. This section explores how nanotechnology is enhancing fingerprint visualization and aiding in the identification of suspects. Latent fingerprint imaging has long been a staple of forensic investigations, providing crucial links between individuals and crime scenes [13]. However, the challenging surfaces or under adverse conditions, making traditional visualization methods less effective. This is where nanotechnology steps in quantum dots and up conversion nanoparticles, engineered at the nanoscale, offer unique optical properties that greatly amplify the contrast and resolution of latent fingerprints, leading to their enhanced visibility even on difficult surface such as textured or porous materials [14].

   A chemical composition analysis use nanomaterial in conjunction with Raman and infrared spectroscopy for chemical composition analysis of evidence is discussed. This technique provides valuable insights into the composition of materials found at crime scenes, facilitating the identification of illicit substances and counterfeit materials [15]. Raman spectroscopy exploits the interaction between light and molecular vibrations,

providing a fingerprint like spectral pattern unique to each substance [16]. Infrared spectroscopy on the other hand, identifies molecular bonds based on their absorption of infrared light. Integration nanomaterials with these techniques boosts sensitivity and resolution, enabling the identification of even trace number of substances. This holds significant implications for identifying illicit drugs, counterfeit goods, and other materials of interest in criminal investigations.

The convergences of nanotechnology and advanced imaging methods provide a powerful toolkit for law enforcement and forensic teams. The enhanced visualization of latent fingerprints helps reconstruct crime scenes with unparalleled accuracy, aiding in the identification of individuals involved. Simultaneously the ability to analyze the chemical composition of evidence contributes of solving intricate cases involving illicit substances, hazardous materials, or counterfeit products. This integrated approach significantly expedites the investigative process, providing law enforcement agencies with more precise and comprehensive data to make informed decisions.

2. **Progress in Forensic DNA Analysis:** Nanopore sequencing for DNA profiling use a cutting-edge technique utilizing nanoscale pores, allows for rapid sequencing traditional DNA profiling methods often involve complex and time-consuming procedures, such as PCR amplification and gel electrophoresis [17]. Nanopore sequencing eliminates the need for these steps, allowing for real-time sequencing without the delay associated with traditional techniques. This translates to faster results, which can be crucial in time-sensitive criminal investigations. Single-molecule DNA sequencing conventional DNA analysis methods rely on bulk samples or contamination. Nanopores sequencing, on the other hand, enables the analysis of individual DNA molecules. This minimizes the risk of errors caused by sample mixtures and ensures a higher degree of accuracy in DNA profiling. The chapter delves into how this advancement reduces processing time and enhances the accuracy of DNA profiling, revolutionizing forensic DNA analysis.

DNA-Based nanotags and nano tracers this application of DNA-based nanotags and nano tracers in forensic intelligence gathering and tracking is explored. These nanotechnology-driven tools have the potential to provide valuable information in cases involving missing person's DNA based nanotags offers an inconspicuous and potent means of tracking individuals. These nanotags can be discreetly applied to personal belongings or even individuals themselves, providing law enforcement agencies with a covert mechanism to monitor movement. In cases of missing persons, these nanotags have the potential to bridge critical information gaps and aid in locating individuals. In Human trafficking the use of DNA based nano tracers has profound implications for combating human trafficking. By embedding these nano tracers in victim's belongings, authorities can track their movements identify transit routes, and ultimately dismantle trafficking networks [18]. This technology not only empowers law enforcement but also provides a voice to the vulnerable. Unidentified remains present a challenge to forensic investigators, especially when traditional identification methods fall short. DNA based nano tracers offer an innovative solution by enabling unique DNA signatures to be linked to remains. This approach can bridge gaps in conventional identification methods, providing closure to families and aiding law enforcement in solving cold cases.

3. **Applications in Forensic Toxicology:** Nanosensors for drug and toxin detection by using nanosensors to detect and quantify drugs and toxic substances at ultralow concentrations are discussed [19]. This section highlights how nanotechnology is advancing forensic toxicology and contributing critical evidence in case involving drug-facilitated crimes and post-mortem analysis. Forensic toxicology, a crucial discipline within forensic science, has been invigorated by the deployment of nanosensors for drug and toxin detection. This innovative application is reshaping the landscape of forensic investigation by offering the remarkable ability to identity and quantifies drugs and toxic substance at levels previously unattainable [20]. At the heart of this advancement lies the utilization of nanosensors, ingeniously designed nanomaterials engineered to interact selectively with specific molecules, thereby generating detectable signals that provide critical information. This progression holds profound implications for forensic toxicology; particularly in cases involving drug-facilitated and quantification of substances play a pivotal role [21].

Nanosensors, through their exceptional sensitivity, enable the detection of drug and toxins even when present in ultralow concentrations. Traditional methods often struggle to capture such minute amounts, especially within complex biological matrices. Nanosensors surmount this challenge by employing signals responses, enabling the identification of trace substances that might otherwise escape detection. Moreover, the selectivity and specificity of nanosensors ensures that only the target molecules trigger the signal, minimizing false positives and inaccuracies in analysis [22]. Drug facilitated crimes cases involving often hinge on the ability to establish the presence of illicit substance in victims' system. Nanosensors provide a breakthrough solution by enabling the detection of minute quantities of drugs, even when administered covertly [23]. This capability not only strengthens the evidentiary foundation but also expedites investigations, aiding law enforcement agencies in swiftly apprehending perpetrators. Post-mortem analysis examinations, nanosensors have emerged as game-changers in deciphering the cause of death. By identifying infinitesimal amount of toxic substance within bodily fluid, tissues, or organs these sensors assist forensic experts in ascertaining whether substances contributed to the demise of an individual [24]. This capability enhances the precision of determining the cause and manner of death, providing families and legal authorities with accurate insights. Analytical precision nanosensors improve the accuracy of toxicology analyses, addressing challenges associated with sample degradation and the presence of interfering compounds. This heightened precision ensures reliable result and reduces the risk of misinterpretation, offering a more robust scientific basis for conclusions in forensic investigations [25].

4. **Nanotechnology in the Field of Agriculture:** Recent developments in nanotechnology have impacted agriculture in a variety of ways. In addition to reducing waste and increasing plant intake, nano-fertilizers release nutrients gradually. This not only increases the efficiency of nutrient utilization but also reduces waste and risk of over-fertilization, mitigating the environmental concerns associated with nutrient runoff. A precision agriculture system integrates nanosensors to monitor soil conditions, moisture levels and nutrient content, providing real-time data to inform in order to make informed decisions. This precision approach enables farmers to optimize irrigation, fertilization, and pest management strategies, thereby increasing resource efficiency and crop yields. Nano pesticides are precise and eco-friendly, curbing contamination risks [26-27]. As nanomaterials such as nano clays aid in water retention and root growth, nano genomics

aids in the understanding of genetics. Nutrients and genetic material are delivered more effectively to cells using nanocarriers. In addition, nanoparticles can be used to purify water and remediate soil post-harvest soil remediation, addressing water scarcity and soil contamination challenges. The use of nanotechnology enhances crop resilience to climate stresses and increases the ability to detect stresses [28]. Regulations continue to evolve, but it's important to balance innovation with environmental and safety concerns. The agricultural sector embraces these transformative technologies; responsible implementation is paramount. Evolving regulations are shaping the adoption of nanotechnology in agriculture, focusing on environmental and safety considerations. Striking a balance between innovation and sustainable practices is essential to ensure that the benefits of nanotechnology are harnessed without compromising ecosystem health or human well-being [29].

5. **Trends in Textile Industry with Nanotechnology:** Nanotechnology is reshaping the textile industry with recent trends focusing on innovation, comfort, and sustainability. Smart textiles, embedded with nanoscale sensors and communication capabilities, monitor health and adapt to surroundings conditions and even communicate vital information [30]. Nanocoatings repel water and stains while maintaining breathability, these coating comprised of nanoparticles offer multifaceted benefits. They create water-repellent and stain-resistant surfaces while maintaining breathability, revolutionizing functionality in outdoor and everyday wear [31]. Additionally, these coatings can enhance durability, fire resistance, and odour control. Antimicrobial textiles, infused with nanoparticles like silver and copper, combat bacterial and viral contamination. Nanoparticles that absorb or reflect UV radiation enhance textiles' UV protection. Thermal regulation is achieved by modifying textiles' thermal properties through nanotechnology. Self-cleaning textiles prevent dirt accumulation, preserving a clean appearance [32-33].

   Nanofibers, produced with high surface area and unique properties, bolster textiles' strength, filtration, and barriers. Flexible electronics integrated into textiles result in wearable devices and interactive garments. Nanomaterials in textiles convert mechanical or thermal energy to electricity for self-powered wearables. Sustainability is addressed through improved dyeing efficiency, water reduction, and recyclability. Shape memory textiles respond to external stimuli by changing and retaining shape. Nanocoated fibres imbue textiles with fire resistance, durability, and Odour control. Enhanced dye and pigment attachment, enabled by nanoparticles, yield vibrant [34].

6. **Nanotechnology in Security and Defence:** Nanotechnology's influence on security and defence is evident through emerging trends. Nanosensors excel in threat detection, rapidly identifying chemical, biological, and explosive agents. Lightweight Armor benefits from nanomaterials, offering robust protection without compromising mobility. Advanced nanocoatings enhance durability and radar invisibility across equipment and vehicles. Textiles infused with nanotechnology bolster military gear, providing resistance to hazards while ensuring comfort. Energy storage gains traction with nanomaterial-enhanced batteries, improving endurance for electronics and unmanned vehicles. Optics are revolutionized by nano-enhanced devices, including superior night vision and high-resolution sensors. Stealth capabilities expand through nanomaterials that manipulate radar waves, enhancing military platform concealment. Nano drones and unmanned

systems integrate nanocomponents, delivering reconnaissance and communication advantages. Nanoparticles-based drug delivery optimizes medical response, addressing battlefield medical needs. However, ethical considerations and security risks demand attention, emphasizing the importance of comprehensive regulations and frameworks to ensure responsible deployment. Nanotechnology's advancements in security and defence elevate protection, communication, and operational effectiveness, underscoring the significance of balanced progress. The progress within the intersection of nanotechnology, security, and defence brings forth ethical considerations and potential security risks that demand vigilant attention. Striking a balance between technological advancement and responsible deployment is crucial to ensure that the benefits to nanotechnology are maximized while potential pitfalls are mitigated [35-38].

7. **Nanomedicine:** Nanomedicine, a forefront of nanotechnology, exhibits key trends reshaping healthcare. Targeted drug delivery deploys nanoparticles for precise treatment, reducing side effects. Personalized medicine tailors' therapies to genetics, boosting efficacy and minimizing reactions [39]. Cancer treatment benefits from nanoparticles pinpointing tumour cells, enhancing therapy accuracy. Nanoparticles advance diagnostics through superior imaging and sensitive biomarker detection. Regenerative nanomedicine aids tissue regrowth by providing cell scaffolds, aiding wound healing [40]. Nano vaccines mimic pathogens, revolutionizing infectious disease prevention. Surgical precision improves via nanoscale tools, fostering minimally invasive procedures. Neurological applications tackle neurodegenerative diseases, facilitated by blood-brain barrier penetration. Lastly, while nanomedicine holds vast potential, ethical, safety, and regulatory concerns require vigilance for responsible advancement [41]. Nanotechnology impact on surgery cannot be understood. The development of nanoscale tools has enabled surgeons to achieve unparalleled levels of precision in minimally invasive procedures. In neurological applications, nanomedicine holds promise for addressing neurodegenerative diseases, which have proven particularly challenging to treat due to the blood-brain barrier's restrictive nature. Personalized medicine is another crucial facet of nanomedicine that is gaining momentum. By tailoring medical therapies to an individual's genetic makeup, this approach maximizes treatment efficacy while minimizing adverse reactions. Nanotechnology facilitates the customization of treatments, allowing for drugs to be designed with patient- specific factors in mind. While nanomedicine offers vast potential, it is not without its challenges. Ethical considerations, safety concerns, and regulatory frameworks must be diligently navigated to ensure responsible advancement. The potential risk and benefits of nanomedicine must be carefully evaluated to ensure patient safety and the ethical use of these technologies [42].

8. **Contemporary Developments in Nanotechnology's Impact of Forensic Science:** Nanotechnology has risen to prominence within the field of forensic science, undergoing extensive research across various domains. It has found practical application in the identification and analysis of evidence, such as the utilization of single-crystalline semiconductor CdS nano slabs for detecting explosives. The essence of forensic science lies in the scrutiny of evidence from incident scenes, aimed at pinpointing culprits or establishing the occurrence of a crime. This evidence serves as the linchpin for apprehending and prosecuting offenders or ultimately resolving criminal cases. Henry Lee's classification delineates evidence into categories like biological, weapon-related, fingerprint, drug-related, impression-based, and trace evidence. Furthermore, evidence is

categorized based on its physical state, inherent nature, composition, the nature of the crime, and the specific questions that demand answers. Recognizing these categorizations forms a pivotal step in the investigative journey. Failures in recognizing, collecting, preserving, and accurately testing evidence can substantially erode its forensic value, potentially leading to its degradation or even loss, thereby compromising the dispensation of justice. Consequently, evidence extracted from crime scenes assumes a critical role within the purview of forensic discipline, being instrumental in either exonerating the innocent or incarcerating the guilty [43].

This underscores the necessity for an improved technological landscape or process to augment the analysis and investigative processes. Herein, Nanotechnology has emerged as a transformative catalyst, elevating the realms of evidence recognition, detection, and analysis [44]. The integration of nanotechnology into forensic science seamlessly amalgamates diverse scientific fields including biology, physics, chemistry, and material science. This collaborative convergence is harnessed to birth multifaceted technologies and processes, thereby enhancing and refining the available techniques and methodologies. The marriage of nanotechnology and Nano-forensics predominantly revolves around scrutinizing evidence at the nanoscale level or harnessing the unique properties of nanomaterials to recognize, assemble, collect, or detect evidence in the context of criminal investigations. Within the context of tool development, nano-forensics has emerged as a nascent frontier, with nano-sensors taking center stage as a novel and indispensable instrument for forensic scientists engaged in criminal inquiries. Nano-sensors have found significant traction in diverse applications, spanning the detection of explosives, heavy metals, fortification of fingerprint analysis, identification of gun residues, and advancement of DNA fingerprinting techniques. This category of technology is lauded as an innovative approach that not only furnishes conclusive evidence but also streamlines the workflow of forensic scientists, notably simplifying their tasks [45].

9. **Synopsis of Nano-Forensic: Advances in Nanomaterials and Nano-Sensors:** Nano forensics encompasses the utilization of nanotechnology-driven methodologies to tackle obstacles within the domain of forensic science. Forensic science operates as a multidisciplinary structure that employs scientific approaches to expedite criminal investigations and contribute to the resolution of cases within the legal system. Nevertheless, conventional forensic practices encounter certain limitations, which can be effectively addressed by integrating nanotechnology. The realm of nano-forensics revolves around the development of innovative tools tailored for various objectives such as DNA isolation, amplification of fingerprint details, detection of explosives, analysis of gunshot residues, differentiation of bodily fluids, identification of illicit drugs, and advancements in forensic toxicology, among a multitude of other applications. Central to the progress of nano-forensics is the strategic utilization of a wide array of nanomaterials. This assortment includes nanoparticles, nanocrystals, quantum dots, nanocomposites, nanobelts, nanoclusters, nanorods, nanotubes, and other variants. These nanomaterials serve as versatile tools applied across a diverse spectrum of forensic methodologies, elevating the accuracy and effectiveness of conducted analyses. Despite the vast untapped potential residing within nanotechnology, its integration into the realm of forensic science stands as a sector ripe for continued investigation and scholarly exploration [46].

A select number of research teams have directed their focus toward the integration of nanotechnology within the field of forensic science. This has encompassed the exploration of reactive or 'smart' materials, microchip technology, nanomanipulators, as well as nanoimaging tools for visualization. Moving forward, the utilization of nanoplatforms in isolation or conjunction with other technologies is poised to make significant strides in security, drug screening, explosive detection, and DNA analysis. These applications empower forensic investigators to undertake intricate analyses and detect even the most minuscule traces of evidence at crime scenes [47].

Advanced nanomaterials and polymers have revolutionized a range of instrumentation techniques, enabling the analysis and detection of trace evidence or samples at the nano-scale level, which was previously unattainable. The latest generation of nanomaterials presents innovative solutions for the collection and detection of various forms of evidence, including DNA extracted from fingerprints, heavy metals, explosives, and gunshot residues (GSR). The synthesis of these novel nanomaterials has yielded distinctive mechanical, electrical, optical, chemical, and magnetic properties, broadening the horizons of forensic analysis. Prominent examples of nanomaterials include nanoparticles, carbon nanotubes, quantum dots, supramolecular, nanorods, and nanofibers. Their nanoscales dimensions' result in a significantly enlarged surface area, facilitating enhanced molecular interactions due to the heightened availability of active reaction sites. Nanodevices have also emerged as crucial tools due to their exceptional selectivity and sensitivity. Nanochips, nano-biosensors, and nanoprobes play a pivotal role in diverse research fields such as metal detection, disease diagnosis, and hybridization assays [48].

10. **Innovative Nanopowders for Enhancing Fingerprint Detection:** In present-day forensic investigation procedures, various types of Nano powders have emerged for the revelation of latent fingerprints across diverse surfaces. One such instance involves the employment of photoluminescent CdS semiconductor nanocrystals capped with dioctysulfo-succinate, which has proven instrumental in enhancing fingerprint detection. Recent endeavors by a group of researchers have resulted in the synthesis of novel ZnO-SiO2 Nano powders using conventional heating techniques. This Nano powder has been adeptly deployed in conjunction with powder dusting and small particle reagent (SPR) methods for the development of fingerprints. The efficacy of this approach has been successfully demonstrated across both dry (semi-porous and non-porous) and wet (non-porous) surfaces, facilitating the visualization of latent fingerprints. Notably, the outcomes reveal that ZnO-SiO2 Nano powders showcase remarkable potential in capturing intricate finger ridge details at an elevated level, surpassing the discernibility offered by other commercially available white powders [49].

III. CONCLUSION

The convergence of nanotechnology with diverse fields such as healthcare, forensics, agriculture, and security has ushered in a new era of possibilities and advancements. From personalized medical treatments and precise forensic analyses to sustainable agricultural practices and enhanced defense strategies, nanotechnology's influence is profound. However, as we navigate this transformative landscape, responsible development, ethical considerations, and regulatory frameworks remain pivotal to harness its potential for the

greater benefit of society. Embracing innovation while safeguarding ethical principles will ensure that nanotechnology continues to shape a more promising and sustainable future across these vital domains.

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