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REVIEW PAPER

Development of Nanotechnology by Artificial Intelligence: A Comprehensive Review

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ABSTRACT

The integration of Nanotechnology (NT) and Artificial Intelligence (AI) promises significant benefits across industries like medicine, energy, and materials science. This study examines AI-driven NT development, highlighting AI's potential to revolutionize nanomaterial and nanosystem creation through accelerated discovery, design, and growth. Some potential applications include enhanced medication delivery, AI-optimized nanosensors for biological monitoring, and material property prediction for energy use. However, current AI systems face limitations, such as the need for robust datasets and methods to link theoretical models with practical validation. Ethical considerations encompass algorithmic bias, data privacy, and societal impacts. The study emphasizes the importance of responsible and ethical development, transparent regulations, and stakeholder communication to ensure fair and beneficial AI-driven NT integration. Realizing the potential of this convergence requires addressing technical challenges and ethical concerns while fostering academic interdisciplinary collaboration and public engagement. This approach aims to maximize the positive impact of AI-NT synergy across various fields.

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INTRODUCTION

Transdisciplinary dynamics enable a global effort to create an inclusive vision of AI–NT, learning from our past and developing our future under the increasingly visible global mind emerging in this accelerating 21st century[1]. The multidisciplinary study of artificial intelligence (AI) and nanotechnology (NT) has the ability to transform numerous sectors, with far-reaching beneficial effects on economies and society around the world. Their unique compatibility is based on NT's expert material management and their ability to achieve atomic precision. Changing or making new nanostructures is a big deal in

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nanoscience [2,3]. The approaches to altering the overall properties of a substance are categorized based on the interactions between atoms/ molecules and the substrate or surface of an object. Nanotechnology focuses on understanding and controlling matter at dimensions between approximately 1 and 100 nanometers. This can be achieved with both naturally occurring substances and those purposefully developed for their nanoscale properties[4]. Two primary approaches guide nanostructure fabrication: “bottom-up” and “top-down.” The bottom-up method assembles structures from atomic or molecular components, while the top-down reduces larger materials to the nanoscale. A hybrid approach combines these strategies, utilizing natural molecular assembly processes to create miniaturized systems (bottom-up informing top-down), and applying precision engineering techniques to guide molecular arrangements (top-down enhancing bottom-up). This synergy allows for more versatile and efficient nanofabrication, leveraging the strengths of both methodologies[5].

In antiquity, technological advancements were primarily based on empirical knowledge and characterized by slow demand. In fields like modern warfare, urban development, and economy, macroscopic investigations were primary, while in others like industrial chemistry, medicine, biology, and astronomy, mechanisms and forces were applied practically despite lacking accurate underlying theories [6](Fig. 1). Nanotechnology, involving the controlled manipulation of atoms and molecules, operates at scales below 100 nm, where phenomena differ significantly from those observed in conventional materials. This field is often described as a multidisciplinary playground, where quarks and galaxies, biological cells and electronics, polymers and diamonds, superconductors and heat transport phenomena challenge collective creativity[7-10]. This study explores the synergistic relationship between AI and NT and their potential to revolutionize various fields, including medicine, energy, biology, and materials science. It examines current applications, limitations, and future directions of AI-driven NT development, highlighting potential ethical and regulatory considerations.

Nanotechnology and ai integration

An interdisciplinary field, nanotechnology encompasses a wide range of techniques for precisely determining and manipulating matter on an atomic and molecular scale [11]. When it comes to forecasting material qualities and phenomena and balancing the experimental effort needed, artificial intelligence (AI) has the potential to take nanotechnology to new heights [12]. In order to address preprocessing issues with AI used for cancer cell segmentation, which necessitates specific image contraste methods for optimal detection [14], researchers are using AI frameworks to study the shape of nanoparticles and the influence of biomolecules, leading to the development of more specific and efficient image contrast agents [13]. To create a new high-produced contrast within the theoretical limits, scanning transmission electron microscopy

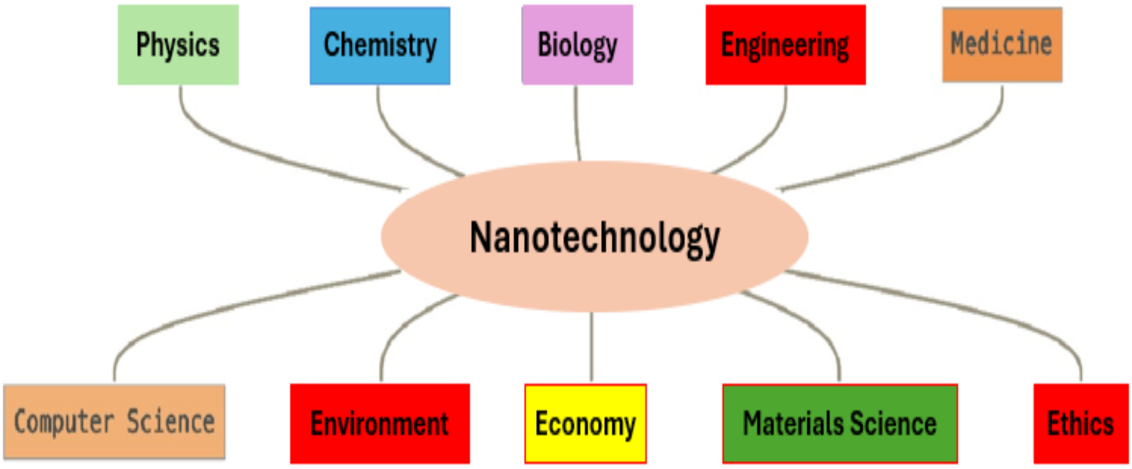

Fig. 1. Multidisciplinary areas of nanotechnology

(STEM) imaging primarily relies on phase contrast detection, which can be achieved by combining AI techniques from a deep learning framework with a classical physical model approach in a single AI simulation program [15]. By combining AI with electron microscopy, the interaction between nanoparticles and cells can be better understood. The intricacy of dynamic biological properties can be managed by using AI to anticipate surface-interface-environment interactions of any nanomaterial, according to recent work using hybrid techniques [16]. In addition, there are AI-powered methods for predicting the body's chaotic reaction to nanoparticles while keeping tabs on the residence time (a critical parameter for predicting how nanomaterials will behave in the human body) and the equilibrium binding constant, which is influenced by surface charge and encapsulation [17].

Nanorobotics

As pivotal components in local systems independent of external infrastructure, nanorobots show promise in intracellular medicine for combating diseases. For instance, self-organized drug administration could potentially reduce or eliminate chemotherapy doses, while minimizing off-target effects. These systems might utilize wireless energy supply and multi-level communication networks within the body [18]. This section explores crucial aspects such as localization, movement control, communication, and cooperation, which are essential for developing 3D nanorobot swarm operating techniques. These techniques envision the use of area-specific online robots and cell-swarm robots equipped with advanced technologies like machine intelligence [19]. Concurrently, numerous studies focus on nanorobotic applications involving single-axis motion [20-22]. Various nanorobot designs have emerged (Fig. 2), including the lens-shaped "cheetah" nanorobot, the kener parapheto nanorobot, and the lemniscate nanorobot, all utilizing bounce motion for propulsion [23]. This groundbreaking work has inspired subsequent research aimed at exploring the potential of

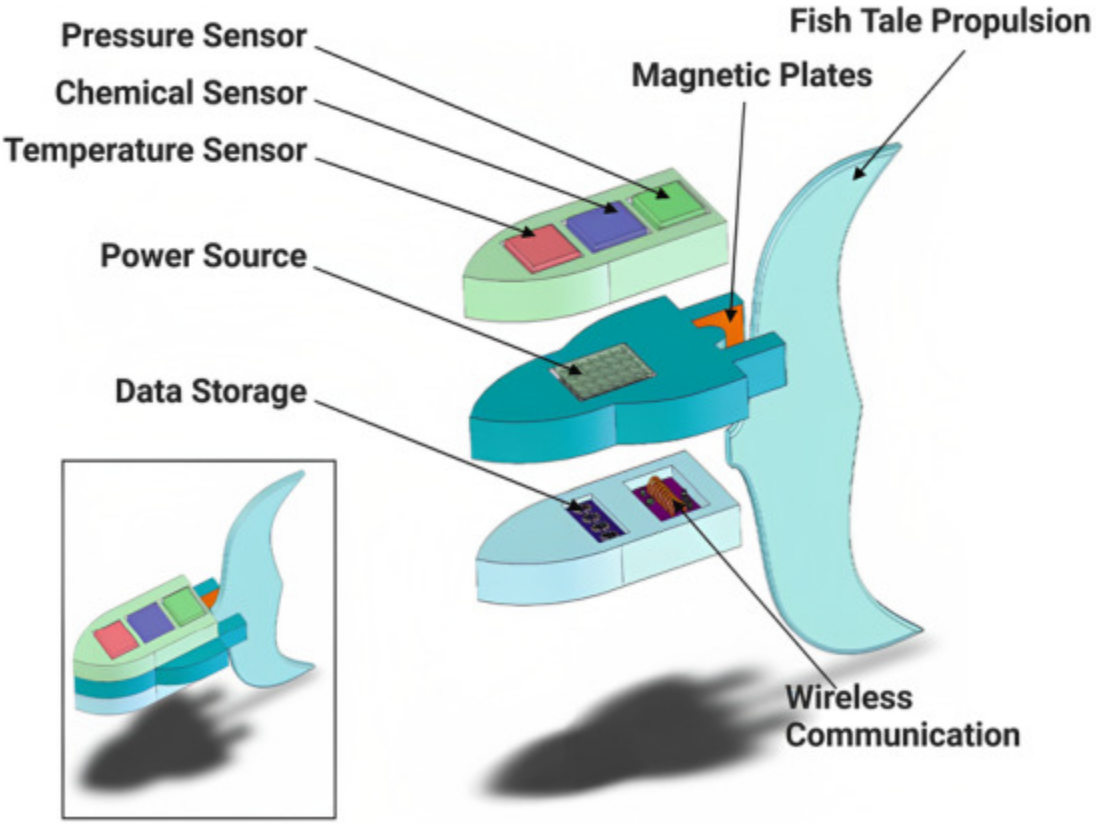

Fig. 2. Core structure of nanorobots with their components [29]

mesoporous "nanotube-based" structures as carriers for "short strand" media containing single or multiple tumor cells [24, 25].

These advancements in nanorobotics demonstrate the field's potential to revolutionize targeted drug delivery and cancer treatment (Fig. 3). By combining precise localization, controlled movement, and intelligent communication systems, nanorobots could offer unprecedented accuracy in navigating the complex cellular environment. Furthermore, the development of specialized nanorobot designs tailored to specific medical applications highlights the versatility and adaptability of this emerging technology [26-28].

As a commercial sector, nanorobotics—the use of nanotechnology to robotics—is still in its early stages. Advanced group-oriented nanorobots are planned for use in broader contexts, like industrial processes and environmental cleaning, while autotelic and localized nanorobots are anticipated to primarily operate in-vivo in the near future [30]. Heavy research is being conducted on high-level supervisory challenges for big groups of offline, networked robots in many prospective applications because to the lack of relevant practical experience at the idea level. Starting with nanorobot operating platforms in 3D environments, where practical problems do not greatly impact movement strategies, the next step is to realize these platforms in order to test critical clustered autonomous technologies. This will guarantee that communication, energy collection, localization, and localized collaborations are all properly addressed for any specific formation type.

Nanosensors

As far as nano-sensors and AI are concerned, human health might be among the most dynamic areas where the fastest progress has been observed. Fabricating nano-sensors is now possible thanks to advancements in nanotechnology and manufacturing. The great sensitivity and selectivity of the point-of-care system are achieved by using nano-scale polymeric materials, metals, graphene, carbon nanotubes, and quantum dots [31]. Although systems based on nano-sensors have the potential to be useful, the use of big data and AI to achieve these goals raises ethical questions because they involve the collection of vast quantities of personal and in-vivo data. Their current uses are the Internet of Things technologies that people use. Once again, sensors integrated with nano-technological breakthroughs fall within the category of communication and networking. The future of bio-electronic devices will be determined by the extent of integration of nano-sensors, AI, and the Internet of Things [12].

The capabilities of nano-sensors (NS) have been enhanced through the integration of artificial intelligence (AI). Machine learning (ML) techniques and artificial intelligence (AI)

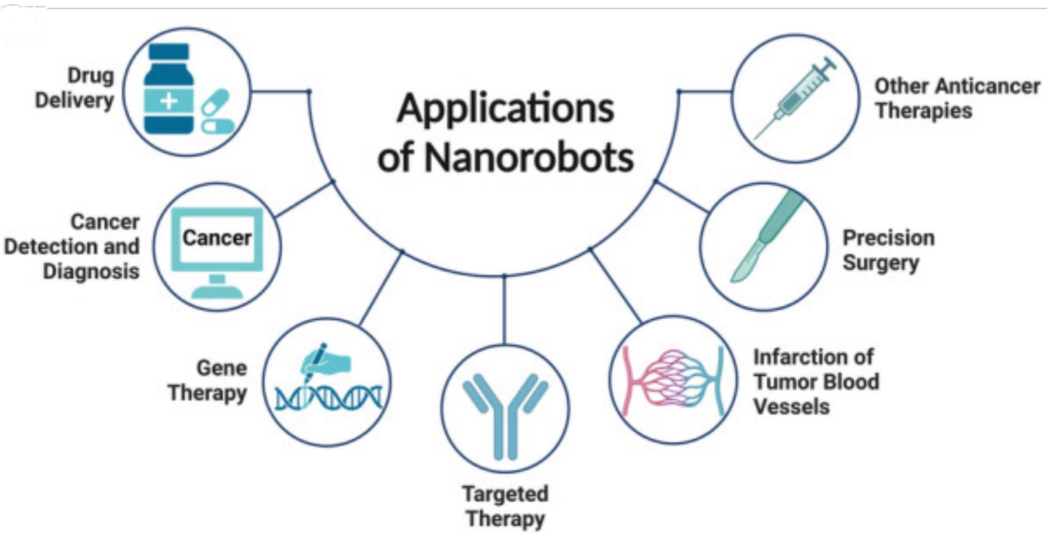

Fig. 3. Illustration of the potential applications of nanorobots in combating cancers [28]

have made it possible to accurately recognize and identify target molecules. Making sensors that are both smaller and more sensitive and repeatable has been the primary focus of most recent developments in nano-sensors. But there have been higher-level reports of applications where nano-sensors and AI have demonstrated the capacity to work on real-time data acquisition and accurate prescriptive solutions for cancer genetics [32], pathogen detection (Fig. 4), bio-marking [35], agriculture [36], etc. (Fig. 5). A low-cost sensing system that is secure, accurate, and made possible by the successful combination of two fast-growing technologies—nano-sensors and AI. There is almost limitless potential in healthcare (Fig. 6), the food sector, mobile applications, energy conversion, and social life [39, 40,41], although most applications and research studies in these areas have been primarily concentrating on industrial and military uses now.

Smart Nanomaterials

Nanotechnology developments have necessitated multifunctional materials. Nanomaterials have excellent physio-chemical properties for their small size, including enhanced absorption and reactivity, surface area, molar extinction coefficients, tunable plasmonic capabilities, quantum effects, magnetic and optical properties. Non-biocompatible, poor photostabilities, low targeting capacity, rapid renal clearance, side effects on other organs, insufficient cellular uptake, and small blood retention make nanomaterials difficult to use for better therapeutics in biomedicine, so "smart" nanomaterials must be developed (Fig. 7). Modern science developed a nanomaterial that changes its physical, chemical, or biological properties significantly in response to modest environmental changes [42].

Rapid microbial lysis was achieved by interacting with the bacterial cell membrane using nanoparticles of titania (nano-TiO_2) in conjunction with vancomycin or gramicidin S [42]. such as the production of ROS and the subsequent triggering of cell death in response to bacterial cell disruptions. By releasing oligodynamic ions, metallic silver inhibits microbial development by severely damaging microbial DNA and proteins as well as bacterial anions. The weakening of the influenza virus envelope and a decrease in the virus's infectivity are the first two causes of antiviral activity in nanomaterials like TiO_2-Vanc or TiO_2-GS. The second cause is the development of huge Mont. By attaching to lipids on the influenza virus's envelope, mont complexes establish robust HC contacts with the virus [43]. Zinc oxide and silver nanoparticles bound to acrylonitrile, sodium dodecyl sulfate, trisodium citrate, and citric acid, in varying proportions, may also possess antiviral properties[44]. Beyond their antimicrobial and antiviral effects, nanomaterials can also exhibit antioxidant properties[45], which are essential for human health. Antioxidants protect cells from the damaging effects of reactive oxygen species (ROS), which are implicated in a wide range of diseases, including cardiovascular disease, cancer, and neurodegenerative disorders[46].

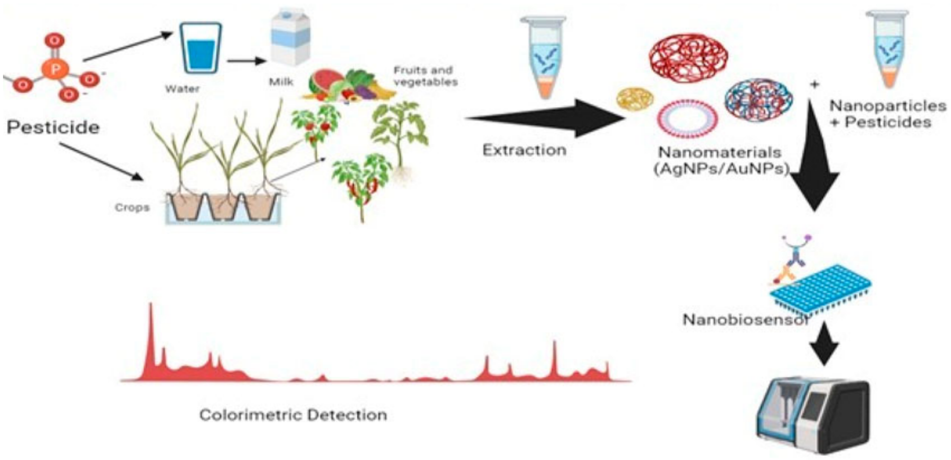

Fig. 4. Nanosensors in the detection of pesticides [34]

Some nanomaterials, such as those containing selenium or zinc, have shown promise as antioxidants in preclinical studies. The ability to design nanomaterials with tailored antioxidant properties could lead to the development of novel therapies for these conditions. The fight against popular parasites such as *Plasmodium* lead to malaria [47], and biofilms [48] also benefits from nanotechnology. These microorganisms can cause severe complications. Nanomaterials have been investigated as potential anti-parasitic and anti-bacterial agents, targeting various stages of their life cycle. For example, nanoparticles can be designed to disrupt the cell membrane, inhibit metabolic processes, or even deliver drugs directly to the site of infection. This area of research holds immense promise for developing novel treatment strategies for many diseases caused by microbes[49]. Nanomaterials with biocompatibility, directed cell proliferation and destruction, resistance to macrophage recognition, immune response inhibition, and controlled release of therapeutic agents that interact with target cells specifically are ideal for nanosmart functionality [50].

Challenges and opportunities

Artificial intelligence (AI) will be an integral part of the upcoming scientific and industrial revolution, both as a tool for cooperation and in practical industrial applications. The use of AI in conjunction with human supervision has the potential to greatly facilitate the processing

Fig. 5. Nanosensor architecture and its application by [37,40] with modification

of anatomical and functional images, the enhancement of human knowledge agents, and the acceleration of the exceedingly complicated processes involved in human cell and tissue cultures. In light of the worldwide demand for cutting-edge AI treatments and the present rate of

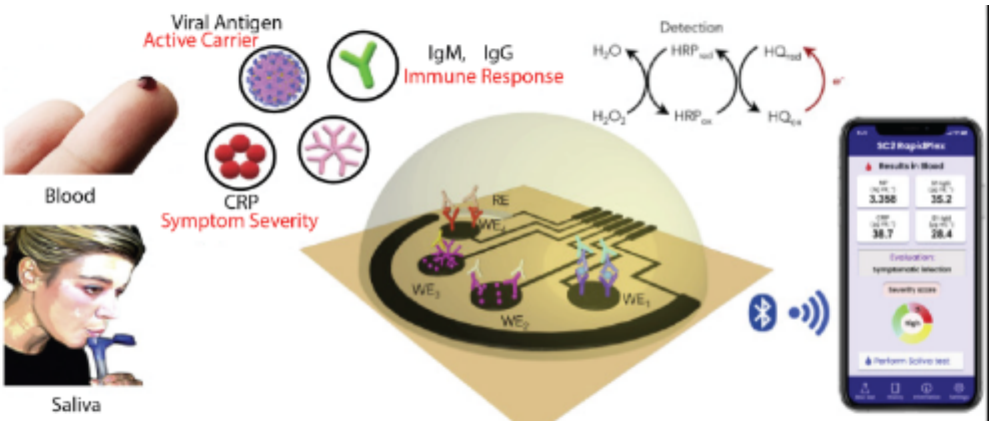

Fig. 6. SARS-CoV-2 schematic RapidPlex multisensor telemedicine platform analyzes SARS-CoV-2 viral proteins, antibodies (IgG and IgM), and CRP. Wirelessly deliver data to a mobile interface. CE, counter electrode; RE, reference electrode [38].

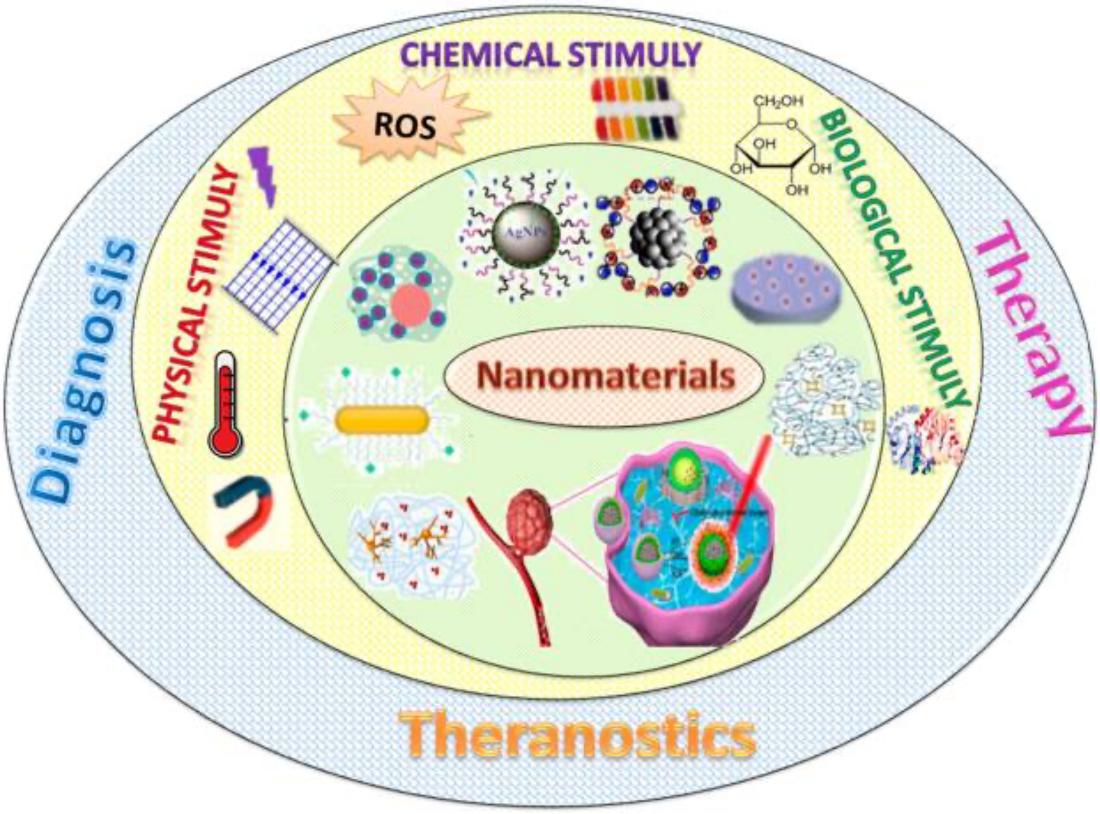

Fig. 7. Classification and biomedical applications of smart nanomaterials as a function of their nanostructure [42].

AI medical device development, nanomaterials will play an essential role in AI interventions within the pharmaceutical and healthcare industries. In the future, AI can help in the design and development of smarter, more efficient, and more tailored nano-therapies for human disease [41,51].

Innovative nanomaterials, nanodevices, and nanosystems form the basis of the fast expanding field of nanotechnology. Nanotechnology has come a long way since its inception, with notable advancements in fields including electronics, biosensors, field effect transistors, and nanoparticles. There are several important challenges that need to be addressed when applying artificial intelligence (AI) to nanosciences. These include ensuring the reliability of methodologies and results, balancing physical and algorithmic models, adaptability of materials, and predicting the accuracy and uncertainty of generative models. One area of nanomedicine that is seeing fast growth is artificial intelligence (AI) in medication delivery. By combining AI with nanotechnology, researchers and pathologists can overcome medical challenges [52,53,54]. Indeed, models powered by AI can be employed to expedite the creation of medication delivery materials and to evaluate anomalies that are specific to both the system and individual tissues. Robust designs, guided by genetic and evolutionary algorithms, can produce new smart nanomaterials that overcome many biological obstacles and pathological causes, leading to successful targeted drug delivery in cancer treatment [17].

Ethical considerations

Ethical considerations surrounding artificial intelligence in nanotechnology extend far beyond the realm of employment and into every aspect of life on Earth. Additionally, AI now has several ramifications for development, privacy, security, and safety [51,55,56]. Structures are often amplified by AI. The historically oppressed in nano-tech may find themselves further excluded as a result. The medium of human understanding will be used by AI to support human meaning and culture infrastructures, and by scientists and doctors to consider the social and cultural impacts of AI-assisted systems [57]. AI also has plans for future formal moral agency.

The Anthropocene or Multitudeocene, a world that is becoming more algorithmically interfacialized, has ethical issues that connect with human knowledge and action. Within the more specific realm of unsocialized nano-AI evaluations, there are ethical considerations regarding operationalization and the handling of nano-AI mobile devices in a space-sharing setting [58].

Numerous moral concerns arise from the potential use of AI in the advancement of nanotechnology. Combining nanofabrication with molecular computation, for instance, has the ability to bring forth new degrees of control and new physical systems (such synthetic molecular systems or biological cells). Elaborate analysis of the sociological, economic, and technical effects of this convergence is necessary. The purpose of this chapter is to analyze the potential ethical problems that might arise from using AI to advance nanotechnology. New methods of conducting ethical assessments are necessary in light of the emerging technology of global nano-transformations [59,60]. Given the abundance of other applications for artificial intelligence and nanotechnology, this raises concerns about how to balance the potential benefits of nano-AI systems on human health with the potential risks that unsocialized, worldwide nano-AI systems pose to human health [8,61].

The integration of AI and NT in medical applications must be approached with careful consideration of ethical and regulatory issues. These include ensuring patient data privacy, addressing algorithmic biases, and developing transparent regulatory frameworks to oversee the development and deployment of these technologies. Continuous stakeholder communication and collaboration are essential to address these concerns and ensure the responsible development of AI-driven NT in medicine [81].

Current applications and limitations

Nanomedicines improve cancer cell drug delivery compared to free pharmaceuticals in lab experiments. Nanoparticles with targeting components can take in more cancer cells. A successful target is the scavenger receptor class B type I (SR-B1), which is abundantly expressed in numerous malignant cancer cells and murine HSCs. SR-BI-functionalized nanoparticles improve cancer cell uptake and restore HSC function in gene therapy. Nanomedicines' uneven human performance is the main impediment to clinical translation, despite encouraging preclinical outcomes. Understanding how nanomedicine's key components—polymer, drug, and active tumor-target ligand (P, D, A)—interact in healthy and malignant tissues is essential to closing this gap. Here, AI is powerful. AI may improve nanomedicine clinical outcomes by analyzing nanomedicine properties and their interactions with target cancer cells across models [10, 62].

AI also aids in the design of nanoformulations for specific therapeutic targets. A key premise of nanotechnology is its ability to design formulations that overcome biological barriers and enhance the efficacy of therapeutic drugs. For these formulations to effectively reach cells responsible for the pathology, they must be recognized by these target cells. Cell-based screens have proven valuable in providing critical information about the cellular uptake of nanomedicines. However, these screens are time-consuming, involving numerous low- and high-throughput experiments. To address this challenge and identify optimal nanocarriers more efficiently, researchers have developed new computational approaches utilizing AI. These AI-driven methods can predict nanocarrier uptake by specific cells, streamlining the design process and potentially accelerating the development of effective nanomedicines [12]. Multimodality therapy utilizing nanomedicines and conventional pharmaceuticals can be better planned and executed with the use of artificial intelligence.

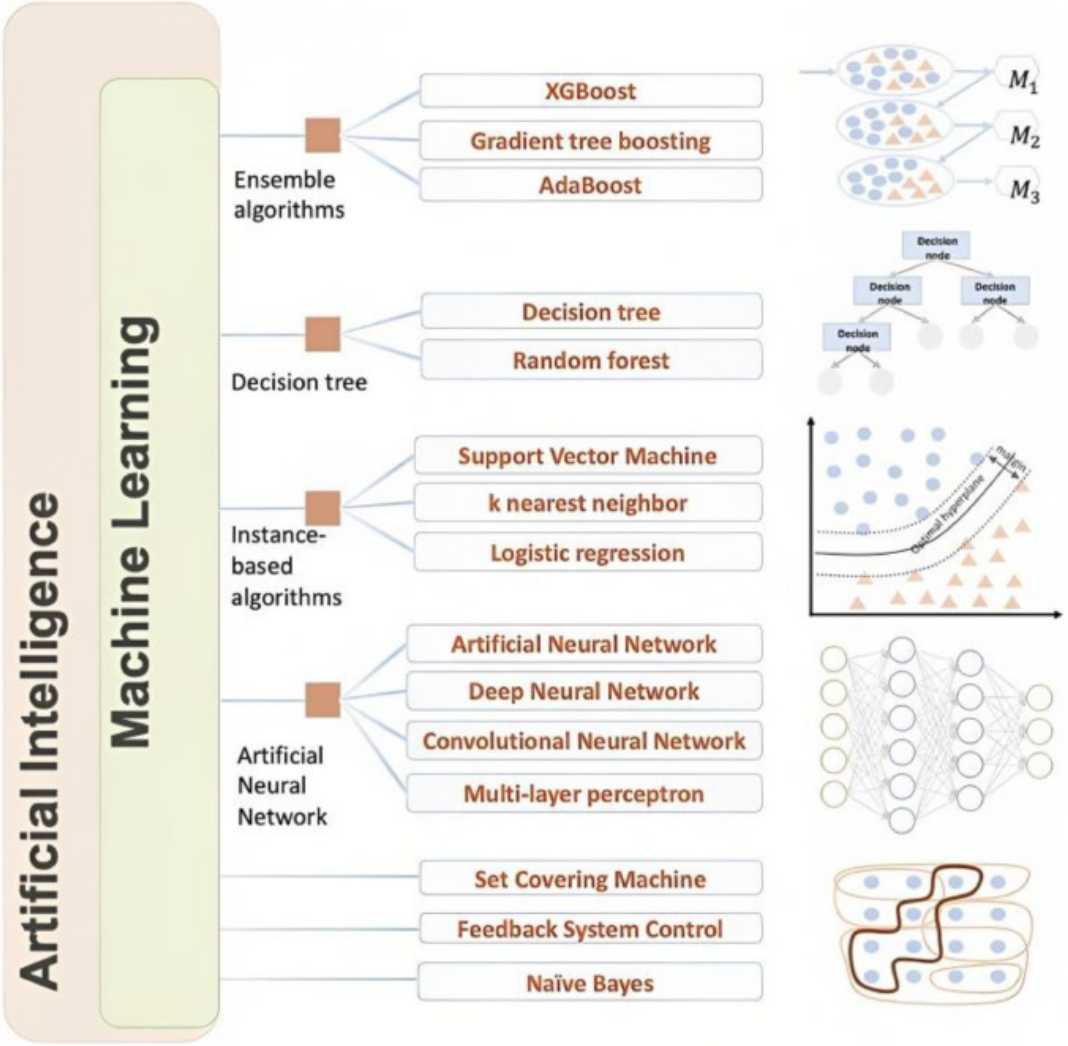

Fig. 8. Drug delivery using machine learning algorithms is utilized to treat infectious diseases [65]

Traditionally, trials that take a very long time to find formulations or dosages exhibiting certain behavior have been used to evaluate the synergistic or antagonistic effect of various medications. Consistent with these limitations, AI has demonstrated the ability to foretell drug-nanoparticle interactions, which may pave the way for the development of nanomedicines with fewer side effects for patients [63].

Machine Learning

Artificial Intelligence (AI), Machine Learning (ML), and Deep Learning (DL) have changed the field of sophisticated robotics in recent years. AI, ML, and DL are changing the field of advanced robotics, making robots more intelligent, efficient, and adaptive to complicated jobs and situations. Some of the applications of AI, ML, and DL (Figs. 8 and 9) in advanced robotics include autonomous navigation, object recognition and manipulation, natural language processing, and predictive maintenance. These technologies are also being employed in the development of collaborative robots (cobots) that can work alongside humans and adapt to changing environments and tasks. The AI, ML, and DL can be applied in sophisticated transportation systems in order to bring safety, efficiency, and convenience to the passengers

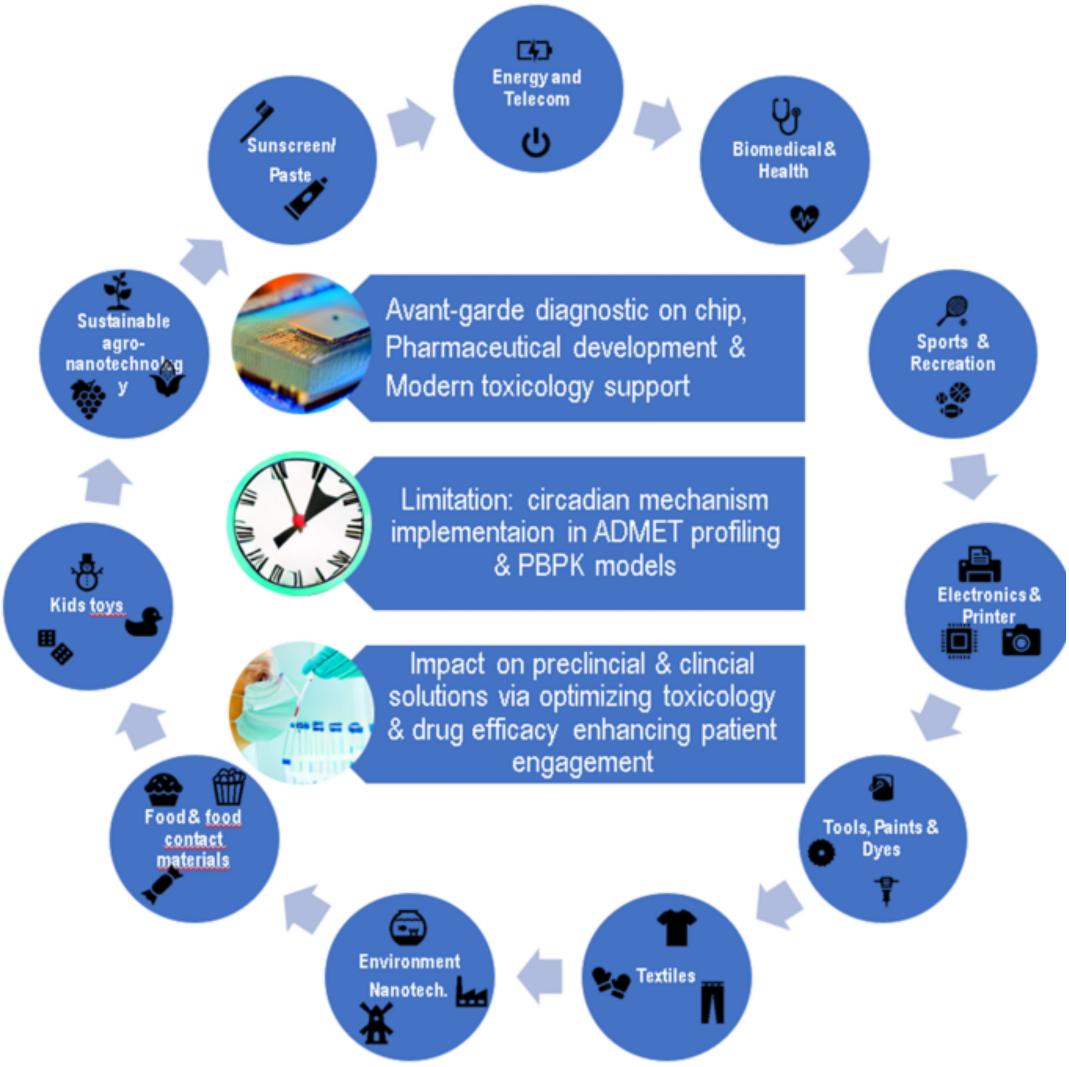

Fig. 9. AI-ML application in wide sectors and their intrinsic worth in shaping human life [66]

and transportation businesses . Also, the AI, ML, and DL are playing a crucial role in the evolution of manufacturing assembly robots, enabling them to work more efficiently, safely, and intelligently. Furthermore, they have a wide range of applications in aviation management, helping airlines to enhance efficiency, cut costs, and improve customer happiness. Moreover, the AI, ML, and DL can enable taxi firms in order to give better, more efficient, and safer services to clients [64].

Natural Language Processing

A significant link between carbon material structure and qualities is scientifically intriguing and promising for practical applications, according to [67]. Pressure coatings, sensors, fuel cells, catalysts, supercapacitors. Systematic research in this field are difficult because they require a diversity of carbon materials and physical–chemical characteristics. Thermogravimetric analysis provides crucial structural transformation data [68]. Many articles have examined carbonized pitches and syncarbons' supercapacitor characteristics. The quantity of affordable carbon materials and the ability to alter their properties are driving interest in their application in electrodes. Recent applications like controlling cytochrome c aggregation, manipulating iron–sulfur protein structural differences, and precisely decorating proteins with small molecules show great promise in this area. While it is still difficult to link structural changes to functionality in catalytic cycles, this research can help rationally design next-generation biomimetic systems that retain the redox and reactivity properties of natural metal centers while rationally incorporating protein-derived structural and dynamic features. The genotype/phenotype inconsistencies discovered during viral shedding indicate that the chemo-enzymatic synthesis of glycoproteins is still poorly understood. Assembly and modulation of signaling complexes can occur quicker than enumerating all conceivable interactions, and relative free energy

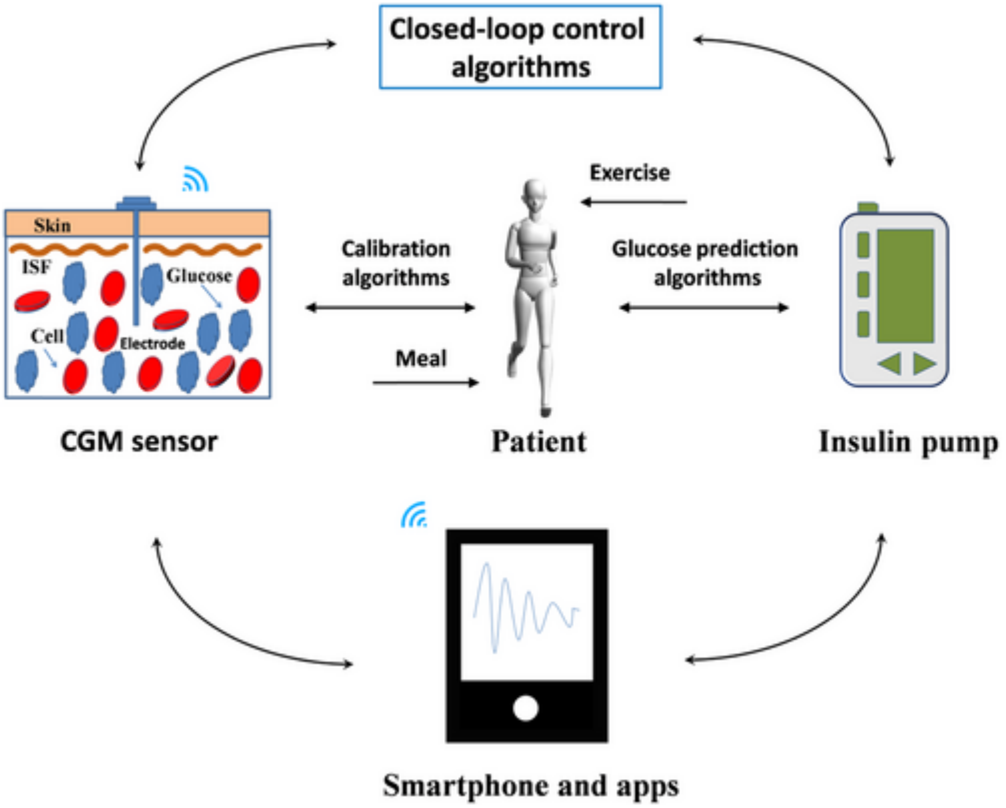

Fig. 10. Applications of artificial intelligence algorithms in diabetes management. CGM, continuous glucose monitoring; ISF, interstitial fluid [75].

calculation outperforms explicit thermodynamics. Kinases and multi-domain targets give a model for promiscuity and molecular recognition in networks using non-random, organized excitations [69].

Diagnostic Applications and Data Analysis

AI-enhanced nanosensors represent a groundbreaking advancement in medical technology, combining the sensitivity and specificity of nanotechnology with the data processing and predictive capabilities of artificial intelligence. These sensors are capable of detecting minute biological and chemical changes within the body, enabling early diagnosis and precise monitoring of diseases. AI algorithms process the vast amounts of data generated by these nanosensors, identifying patterns and providing actionable insights for medical professionals. Nanosensors are devices that operate at the nanoscale (1 to 100 nanometers) and can detect physical, chemical, or biological signals. They typically consist of a sensing element and a transducer that converts the detected signal into a measurable response. In medical applications, nanosensors can be designed to detect specific biomarkers—molecules that indicate the presence or progression of a disease[70].

AI algorithms, particularly machine learning and deep learning models, can analyze the data generated by nanosensors. These models are trained on large datasets to recognize patterns and anomalies that may be indicative of disease. For instance, in cancer detection, AI can analyze the concentration and behavior of specific biomarkers detected by nanosensors, distinguishing between benign and malignant cells with high accuracy. AI can optimize the sensitivity and specificity of nanosensors by fine-tuning their design and functionality. This involves adjusting parameters such as the type of sensing material used, the configuration of the sensor, and the signal processing methods. In detecting viral infections, AI can enhance nanosensors to differentiate between various strains of a virus, providing precise diagnostics and aiding in timely treatment decisions[52].

PRACTICAL APPLICATIONS

Cancer Diagnosis

AI-enhanced nanosensors can detect cancer biomarkers at very low concentrations, enabling early diagnosis when the disease is more treatable. For example, they can identify circulating tumor DNA or specific proteins associated with cancer. Conduct clinical trials with patients at high risk of cancer to validate the efficacy of AI-enhanced nanosensors in early detection. These trials can compare the performance of traditional diagnostic methods with AI-enhanced nanosensor technology. The steps of nanotechnology test the sensitivity and specificity of AI-enhanced nanosensors in detecting various biomarkers associated with diseases such as cancer, cardiovascular diseases, and infectious diseases. Develop nanosensors with different sensing materials and configurations. Use AI algorithms to process the data and compare the results with traditional diagnostic methods [71,72].

Infectious Disease Detection

Nanosensors can be used to detect pathogens such as bacteria and viruses. AI can analyze the sensor data to quickly identify the type of pathogen and its concentration. During an outbreak of a novel virus, AI-enhanced nanosensors can be deployed in hospitals and clinics to rapidly identify infected individuals, enabling swift isolation and treatment [73,74].

Chronic Disease Management

Wearable devices with nanosensors can continuously monitor glucose levels in diabetic patients (Fig. 10), while AI algorithms analyze the data to provide personalized insulin dosage recommendations. Additionally, AI-driven analysis can improve the accuracy of insulin dosing and heavily reduce the risk of complications compared to patient or algorithmically driven dosing [75,76].

Personalized Medicine

As shown in Fig. 11, AI-enhanced nanosensors can monitor how a patient’s body responds to a particular medication, providing real-time data on drug efficacy and side effects. These sensors can be implemented in clinical settings to tailor treatments based on individual responses, optimizing therapeutic outcomes and minimizing adverse effects [77,78].

Nanorobots or nanoparticles can be designed to deliver drugs directly to cancer cells, minimizing side effects on healthy tissues. For this, AI can optimize the delivery process, ensuring the right quantity of drug reaches the target cells at the right time. Clinical trials can be conducted with AI-controlled nanorobots loaded with chemotherapy drugs, monitoring their ability to selectively target and destroy cancer cells while sparing healthy tissues [28]. AI can enhance the precision of drug delivery systems, leading to more effective treatments with fewer side effects. AI can analyze genetic and molecular data to design personalized nanomedicines tailored to an individual's specific disease profile [63]. AI algorithms can be used to identify genetic mutations in patients (Fig. 12), and nanoparticles can be engineered to deliver treatments that specifically address these mutations [79]. Personalized nanomedicine, guided by AI, can significantly improve treatment outcomes by targeting the unique aspects of each patient's disease [17].

EXPERIMENTAL RESEARCH

Integration with IoT

AI-enhanced nanosensors can be integrated with Internet of Things (IoT) devices and systems to create a comprehensive and bespoke health monitoring system, Developing a network of connected devices that continuously collect and transmit data to a central AI system for analysis. The system can be tested in a healthcare setting, evaluating its effectiveness in monitoring and managing patient health [80].

Ethical and Regulatory Considerations

The integration of AI and nanotechnology in medical applications raises several ethical and regulatory challenges. Continuous communication with stakeholders, including patients, healthcare providers, and regulatory bodies, is essential to address these concerns and ensure the responsible development of AI-enhanced nanosensors [81].

Imaging and Detection

AI can improve the imaging capabilities of nanoparticles used in MRI, CT scans, and other imaging techniques, providing clearer and more detailed images of tissues and organs. Nanoparticles can be engineered to target specific tissues, and AI algorithms can be used to analyze imaging data, distinguishing between healthy and diseased tissues with high precision. AI-driven analysis of nanoparticle-based imaging can lead to better differentiation between various types of tissues, aiding in more accurate diagnosis and treatment planning [82].

Real-Time Monitoring

Wearable devices with embedded nanosensors

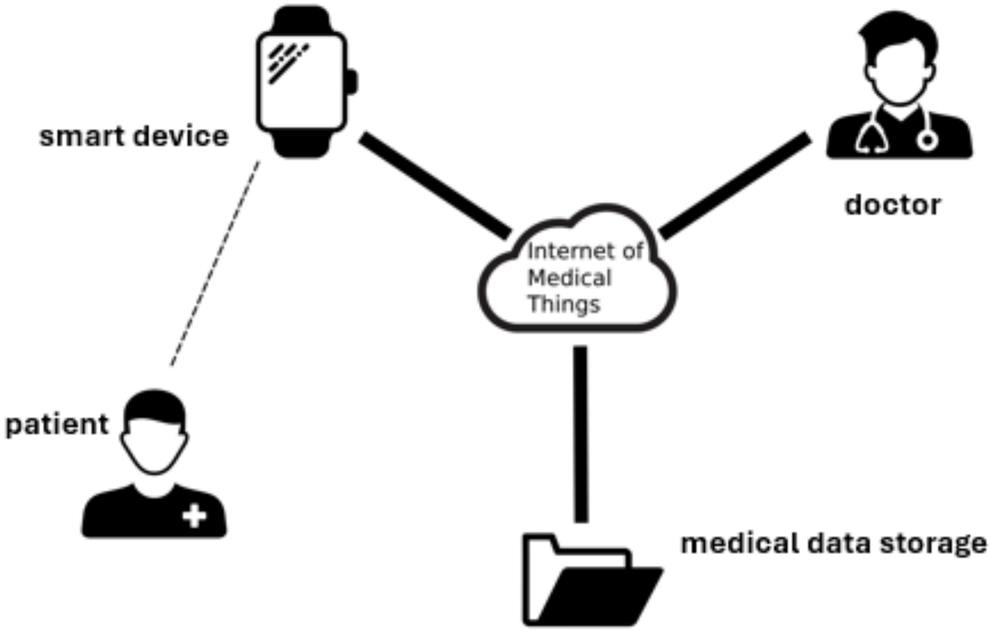

Fig. 11. A sophisticated solution involving nanotechnology forming an IoMT, could take the form above, incorporating patients and their smart devices (left), medical data storage (bottom) and personal practitioners (right).

can continuously monitor vital signs and biochemical markers, with AI analyzing the data in real time to detect any abnormalities. Develop and test wearable devices in a controlled study, monitoring participants' health metrics and using AI to predict potential health issues before they become critical. Continuous real-time monitoring with AI analysis can lead to early intervention and better management of chronic diseases [83].

Regenerative Medicine

AI can design and optimize nanomaterials for tissue engineering, promoting the regeneration of damaged tissues and organs. Conduct studies on the effectiveness of AI-designed nanomaterials in promoting cell growth and tissue repair in animal models. AI-optimized nanomaterials can significantly enhance the body's natural healing processes, leading to breakthroughs in regenerative medicine [84].

Future prospective

The field of materials research known as "informatic tools" has achieved tremendous strides. To this day, investigating high-dimensional possibilities—where the guiding principle is that only machine-learning models can manage such complicated data sets—has been the most prevalent and fruitful generic use of "informatics" in the context of materials development [85]. New tools and procedures, for instance, have much shorter development cycles thanks to machine learning models used in medication and material development. New thermoelectric materials can be suggested by utilizing global substitution sites, clusters of substitutions, intrinsic substitution

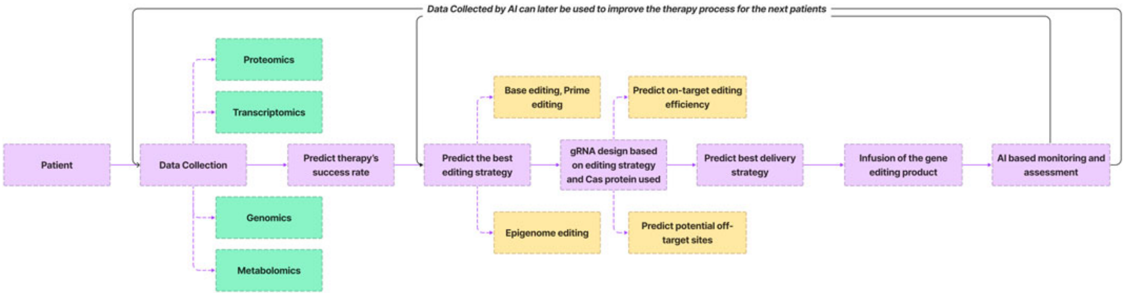

Fig. 12. AI driven gene therapy process [79].

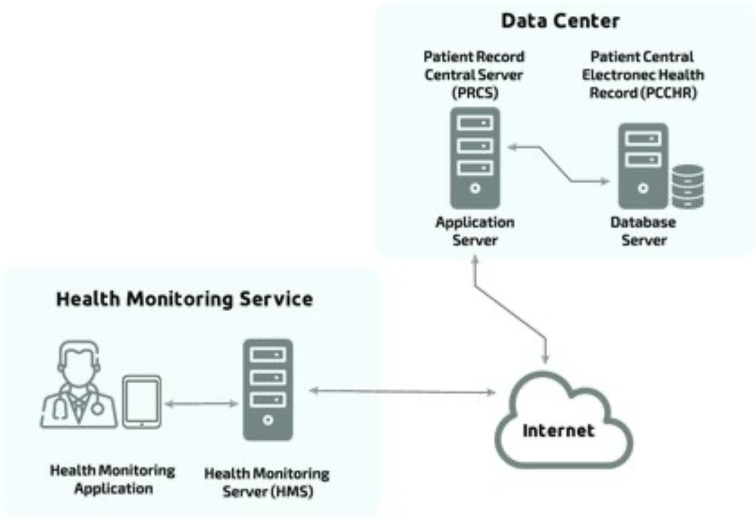

Fig. 13. Simplified technology architecture for smart healthcare services [80].

effects, and potential dopants; however, these ideas are complex and costly to implement in practice. Another area where machine learning has proven to be highly effective is high-entropy alloying. This field makes use of tools like "data mining" to discover patterns, like combinatorial mixing of materials, or Venn diagrams that show distributions of elemental species, which allow for the rapid exploration of regions where many possible elements are mixed in a many-dimensional phase space [86,87].

It is necessary to create efficient computational prediction methods and high-throughput experimental methods in order to comprehend and manipulate nanoscale natural phenomena. Coming from a computational standpoint, the majority of the advancements in materials simulation methods and other fields during the last twenty years have resulted from meticulously combining expert-crafted approximations like force fields and density functional theory with predictive modeling techniques like molecular dynamics and density functional theory. This has been done in an effort to fit these to as much high-quality experimental data or higher-level theory as can be found. Here, the human predictions made during method selection and parameter fitting determine the computer technique's quality. There are many things that can't be seen or predicted in large-scale data sets at the nanoscale, including surface and quantum behaviors, flaws, nonequilibrium, stochastic systems, and goals. As a result, physical modeling and its incorporation into experiments require a paradigm shift [88,91].

CONCLUSION

Models that integrate quantum and classical descriptions of systems are essential to the advancement of AI-based nanotechnology. When it comes to explaining features at scales ranging from the atomic to the macro, chemistry and solid-state physics typically discriminate between multiple model levels. Developing and improving efficient algorithms and software to address the remaining unanswered issues is crucial because to the exponential growth in computational cost as these systems become larger and more sophisticated. Properties of systems ranging from small biomolecules to big proteins are included in this category, along with open chains of interactions and phase transitions in condensed matter. Various scientific and technological domains can benefit from systematic investigations performed with dedicated computer programs, which can lead to the development of novel solutions. New types of nanostructures applied, for instance, in molecular electronics or innovative healthcare tools using electrochemical detectors, as well as confirmed or undiscovered ideas pertaining to interactions between the environment and quantum systems, methods for power and communication filtration at dimensions up to new types of nanostructures, and so on will all be attainable. We have seen a rise in interest in the design and development of intelligent software systems across several domains in recent years. Numerous publications not only investigate the potential uses of emerging technologies and software development methodologies (such as deep learning) but also test the veracity and explain the inner workings of intelligent algorithm software in various domains, such as medical diagnosis, meteorology, structural analysis, and the design of advanced materials. Several of our publications demonstrate that artificial intelligence (AI) offers numerous new, unanticipated possibilities when used to the design of new modern materials, particularly those based on nanotechnology. Applying the right software and hardware is essential for making fine-grained optimization advances. Because of the critical importance of modeling, synthesis, optimization, and material science in nanotechnology, AI technologies are seeing increased application in this area.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

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