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A Comprehensive Overview of Internet of NanoThings and its Applications

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Abstract

INTRODUCTION: Internet of NanoThings (IoNT) is regarded as the next generation of the Internet of Things due to its bright future and wide range of applications . According to the global "Internet of Nanothings (IoNT) Market" research, there has been good growth in recent years, and this trend is expected to continue until 2030. IoNT is basically the Internet of Things on a nanoscale. IoNT essentially describes how nanoscale devices are connected to one another within current networks. A high-speed network can be used to connect different nanodevices through the IoNT. This study provides a comprehensive overview of the architecture, benefits and applications of IoNT.
OBJECTIVES: The objective is to provide insights into IoNT framework and it applications in fields like healthcare, food industry, agriculture, environment monitoring etc,
METHODS: This study explored the IoNT architecture and its applications. The exploration involves reviewing the articles, journals and other web resources.
RESULTS: Highlights the aspects of IoNT and emphasizing the importance of its applications in various fields. The need to combine this research and emphasize the IoNT related applications stems from the dearth of research in the field.
CONCLUSION: The world is becoming increasingly developed as a result of ongoing technological advancements. Future developments, which are expected to peak in the next one to two decades, will be led by IoT and nanotechnology. IoNT offers potential and means to enhance numerous facets of individuals' lives. Its primary characteristics are monitoring and diagnostic services, which support and improve decision-making and outcomes across a range of application domains.

Keywords: Internet of NanoThings, Nanotechnology, Nanosensors, Healthcare, Food Industry, Agriculture, Environmental Monitoring

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1. Introduction

The technology that has revolutionized nearly every area of our life is the Internet of Things (IoT), which emerged early in the twenty-first century along with the development of Internet and Information Communication (ICT) Technologies. Currently, the IoT serves practically every domain, enabling the Internet to be connected to digital things in our environment. This allows for remote surveillance, supervision, and execution of actions depending on underlying conditions, thereby increasing the intelligence of these devices.

Internet of NanoThings (IoNT) is regarded as the next generation of the Internet of Things due to its bright future and wide range of applications. According to the global "Internet of Nanothings (IoNT) Market" research, there has been good growth in recent years, and this trend is expected to continue until 2030. IoNT market shows a steady and optimistic development trajectory from 2024 to 2030, suggesting a promising future for the sector. This surge is being driven by a number of significant factors, including evolving consumer preferences, technology advancements, and increased customer demand.

IoNT is basically the Internet of Things on a nanoscale. IoNT essentially describes how nanoscale devices are connected to one another within current networks. A high-speed network can be used to connect different nanodevices through the IoNT. IoNT combined with complementary innovations like big data, cloud computing, and Artificial Intelligence can lead to a variety of new opportunities. IoNT makes it possible to access networks of nanoscale devices and obtain incredibly detailed data. The scope and depth of the nano-sensors helps to accomplish new insights that would not have been possible to obtain otherwise. Data collection from locations that are very difficult to access is made possible by IoNT networks. This article examines the role of IoNT its architecture and applications related to several disciplines.

1.1. NanoTechnology

Physicist and Nobel laureate Richard Feynman first introduced the idea of nanotechnology back in 1965. The primary goal of nanotechnology was to take use of the benefits of material shrinkage and investigate the possibility of making fascinating technologies that are much smaller in the future. Nanomaterials have seen significant usage in the last ten years in the disciplines of imaging, medicines, and disease diagnostics. Nanoparticles are well known due to their dimensions, shape, composition, structure, as well as additional physical and chemical characteristics that can be used to build materials with specific absorptive, emissive, and light-scattering features.

The advancement of devices ranging in size from one to several hundred nanometers is made possible by nanotechnology. At this size, a nano-machine is the simplest functional unit made of nano components that can carry out easy operations like sensing or actuation [2]. The development of nanotechnology has led to the creation of nanodevices, which are made of nano components and are capable of sensing or actuation. It also communicates and provides information by establishing a seamless connection through nanoscale communication technologies through the internet [1].

The nanomachine, a fundamental functional unit combined through nano-components that carries out fundamental tasks like sensing or actuating, is the foundation of nanotechnology. These nanomachines' cooperation and coordination enable ever-more complicated activities to support a wide range of applications. Some fundamental parts are present in all nanomachines and is shown in figure 1.

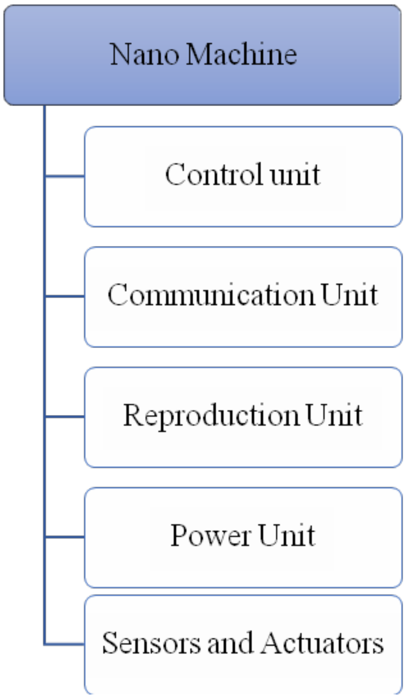

Figure 1. Fundamental parts of Nanomachine

- Control unit: a control unit that carries out all instructions needed to complete a task and maintains the relevant data
- Communication unit: A communication device that transmits and receives information at the nanoscale
- Reproduction unit: creates every component utilizing external components
- Power unit: A power supply that gathers energy for distribution and consumption from a variety of external sources, including light and temperature
- Actuators and sensors that serve as links between the nanomachine and its surroundings

1.2. Internet of NanoThings

Nanotechnology is the fundamental structural element of IoNT. IoT is essentially brought down to the nanoscale by combining it with nanotechnology, which is how the idea of IoNT originates. IoNT uses nanosensors, sometimes known as "nano things," that are linked by a nano-scale network and communicate with each other via nano-communication technologies [2]. An IoT system is made up of several networked sensors that collect data on their own and exchange it with other sensors via the cloud. Modern systems are integrated with state-of-the-art technologies like AI to process information and make decisions without human intervention. IoNT comprises of an IoT system of nano devices The physical dimensions of these devices vary from 0.1 to 100 nanometers in size.

This is being accomplished by employing nano-networks to integrate nano-sensors into various things. This gives users access to data from live locations that were formerly hard to perceive or to use with particular instruments because of their hefty sensor sizes. This will make it possible to gather fresh atmospheric and health-related data, which could result in new discoveries, improved medical diagnoses, and a refining of already known information [3]. IoNT consists of nano nodes, nano routers, gateways, and nano-micro interface devices and the communication between the components are presented in figure 2.

a) Nano nodes: The most small and most fundamental kind of nanomachine is a nano-node, which can carry out very simple processing, store a tiny quantity of information storage devices, and transfer the information to a very small distances due to its limited bandwidth and power. Biomedical nanosensor nodes found in human bodies and nano machines with communicating capabilities incorporated into a smart home devices are two examples of nano-nodes [2,4]

b) Nano routers: Nano-routers possess more omputational capabilities than regular nano-nodes. It acts as information aggregators in an IoNT network. Networking nano-routers are also able to manage the way they operate among the nano-nodes by sending control signals. [5].

c) Nano-micro interfaces: Devices known as nano-micro interfaces serve as an intermediary that connects the network's nano- and micro-scale units. They function as combinations of technologies that provide transmission through the use of both conventional communication protocols and nanotechnology. [2,5,6, 7]

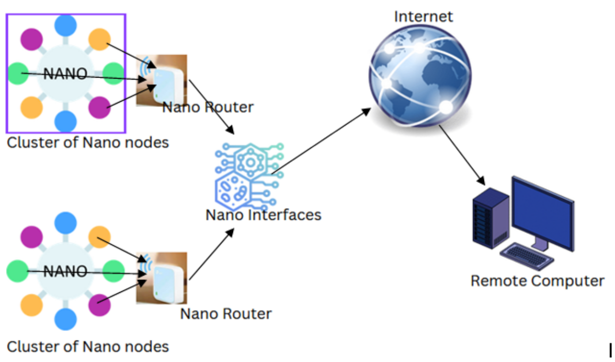

Figure 2. Components of IoNT

d) Gateways: A gateway makes it possible to manage the entire nano-network from the internet.For instance in medical applications, If a medical device is implanted or a multitude of nanosensors are positioned within the human body, a gateway is the part of the system that allows doctors to view and edit the data over the internet [3,5,7,20].

Furthermore, IoNT networks cannot function properly without efficient integration and communication between nanodevices and macro scale components. This explains the recent exponential rise in the development of network topologies that include multiple paradigms of communication, such as acoustic, mechanical, electromagnetic, and molecular communication [7,8,9,10,11,12].

1.2. Architecture of IoNT

An IoNT architecture model is made up of several components that are interconnected through the use of nano-devices. The basic elements of in the architecture of IoNT is shown in figure 3.

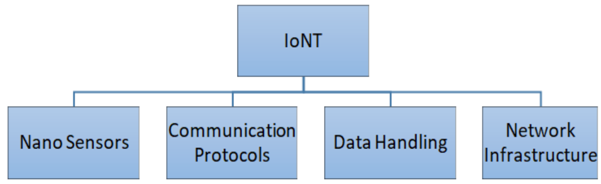

Figure 3. IoNT Architecture

a) Nano sensors and Actuators

Nano sensors are one of the main topics of research in nano science because of its usefulness in computer technology, healthcare, the agricultural sector, and ecology. By connecting these nano sensors to the current wireless communication networks, a new realm known as the IoNT is created [13]. These are the main components of the IoT and it is able to identify and quantify an extensive range of biological, chemical, and mechanical components, as well as take necessary steps based on the collected data. Nano robots, nano sensors, and nano catalysts are a few types of nano sensors and actuators (4,5,14). Figure 4 depicts the various categories of sensors used for various applications in IoNT.

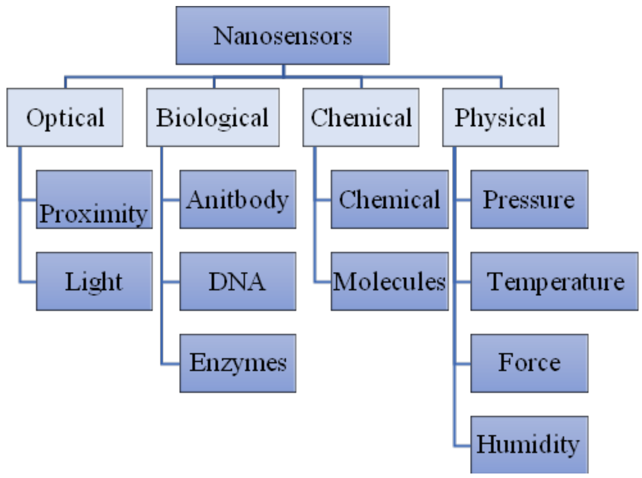

Figure 4. Different types of Nanosensors

b) Communication protocols

The Internet of Nanotechnology (IoNT) depends on a variety of communication protocols, including wired (such as nano wires and nano tubes) and wireless (such as Bluetooth, RFID, and near field communication, or NFC) technologies, to facilitate communication amongst nano scale devices. These methods enable short-range data transmission and reception for nano scale devices(4,5 7]. With the various nano scale restrictions on wireless sensor nano networks (WNSN) and IoNT, routing protocol is one of the most important required mechanisms. This routing technique needs to ensure the data and information transmission while taking into account the features of nano scale communication [15].

The architecture is made up of network switches, routers, and other networking devices to enable communication between nanoscale devices and other devices on the Internet. Both traditional networking techniques and specialized nanoscale methods are part of this system [14, 16]. In general, the IoNT architecture is intricate and encompasses a broad spectrum of techniques and protocols that facilitate nanoscale data transmission and communication. The capabilities of the IoNT are expected to grow as nanotechnology progresses, opening up a wide range of possible applications across numerous areas. Depending on the application context, new network architectures may need to be designed to connect nano machines to existing networking infrastructure.

The term "Internet of Multimedia Nano-Things" (IoMNT) is a new communication model formed by the integration of widely implemented multimedia nano devices with the World Wide Web and current communication networks[17].

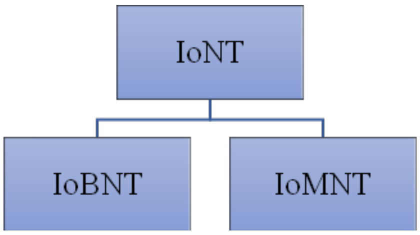

Figure 5. Forms of IoNT based on the usage

The Internet of Bio-Nano Things (IoBNT) is viewed as a diverse network of biological and nanoscale devices, referred to as IoBNT, that communicate in non-conventional contexts, such as the human body, using specialized techniques, such as molecular communications (MC). This new networking framework's primary goal is to facilitate direct, fluid communication with biological systems so that precise dynamics monitoring and control may be done in real time. It is anticipated that this intimate relationship between the bio and cyber worlds, together with their exceptionally high spatiotemporal resolution, will create a plethora of new application options, particularly in the healthcare sector with intrabody continuous health monitoring. However, in order to fully harness the immense potential of the IoBNT, many obstacles must be addressed [4].

Although it has a significantly greater collection of data capabilities than IoT, the IoNT functions the same as IoT. The system's tiny sensors can gather data based on the user's choices. These components communicate with each other through electromagnetic waves and molecules that have been designed to transport information.

2. Literature Review

Various studies in the literature discuss the current state, and the applications and challenges of IoNT [6, 9, 18, 19, 20, 21, 22, 23, 24, 25]. The idea of IoNT is based on the networking of nano devices, motivated by the characteristics of newly investigated nano materials, such as graphene. The artificial character of IoNT devices can be harmful in situations where the deployment of NanoThings could have unintended repercussions on pollution or health, even as they enable various applications. The study introduces the unique paradigm referred as IoBNT, which originates from technologies in nanotechnology and synthetic biology that enable the designing of biological embedded computing devices. Bio-NanoThings, which are based on cells in biology and their biochemical functions, hold the potential to facilitate various applications, including environmental pollution control, intra-body sensing and actuation networks, and toxic agent management [2]. A review of the IoNT's network architecture and the different uses for IoT and nanotechnology integration is discussed in [5].

A novel approach to communication networks that leverages nanotechnology and the Internet of Things (IoT) to link nanoscale objects via pre-existing networks. The world is being offered this new paradigm, dubbed IoNT, as an alternative for a number of application domains. As a result, fresh difficulties and chances for research have emerged. As a result, the work examines the current state and evaluates trends regarding the usage of IoNT, its applications, and upcoming problems in several socially relevant domains [21]. For example, the major obstacles in integrating this innovation in healthcare, it will also expedite the diagnostic and prognostic procedures and help treat patients by facilitating precise and localized drug delivery as well as the detection of tumors and diseases [23].

The state of sensor and nanosensor network research and development, as well as the telemedicine standards, were examined, and development paths for the challenges raised were suggested. It is possible to successfully apply telemedicine in contemporary war theater settings. Test results from a nanosensor network operating in the human circulatory system are used to support the analysis [27].

A framework of a bio-cyber interface that connects the biological signaling-based bio-nano network to the traditional Internet. Biological ideas, such as the reactivity of some bio-molecules to temperature and light stimuli and the bio-luminescence phenomena of certain biochemical events, are utilized in the design and modeling of the bio-cyber interface [28].

PANACEA's architecture is specifically implemented to concentrate on infectious disease identification and treatment. A sub-milimeter implantable bio-electronic device called a Bio-NanoThing is used in PANACEA to track the communication inside the body cells to infer the degree of infection. Using a wearable hub or gateway outside the body, BNT can remotely send the infection data that has been discovered. The healthcare providers who can remotely operate the BNTs can be contacted by the hub via mobile devices and the backbone network, which can be the Internet or cellular systems. In order to provide a dependable and responsive disease detection and infection recovery system, PANACEA offers a system in which sensing,actuation, and computation operations are closely integrated [29]. The next section discusses the applications of IoNT.

3. Applications of IoNT

The Internet has a wide range of uses that are growing every day. The terms "Internet of Things," "Internet of Everything," and "Internet of Nano-Things" refer to novel ways of integrating the Internet into everyday social, professional, and personal interactions as well as the impersonal realm of inanimate, seemingly intelligent objects. The figure-5 presents the applications, which make use of this sophisticated IoNT procedure and technique.

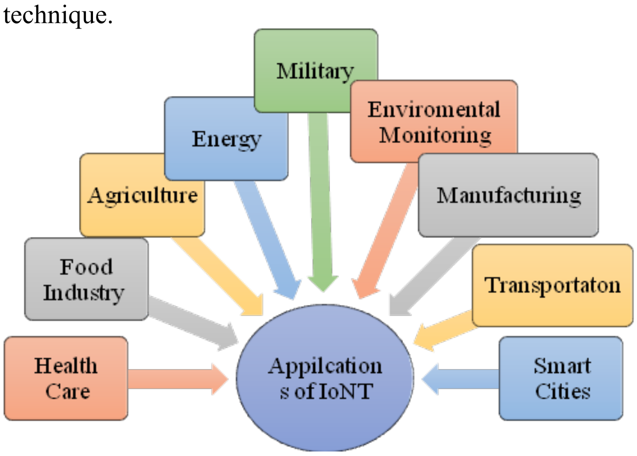

Figure 6. Applications of IoNT

3.1 Health Care

Healthcare systems undergoes a revolution with the advent of IoNT[30,31,32].The ability to offer managing, tracking and diagnosis services from remote place is made possible by advancements in sensing and communication technology, which are helping to bring ubiquitous healthcare closer to life. The primary paradigm for connecting medical devices to the Internet is IoT, which will enable real time health services and turn a patient's physical environment into a smart place[31]. Patients and physicians can get vital healthcare information instantly by utilizing IoNT. This kind of data can be quite helpful in generating medical reports and determining how certain procedures affect a patient.

The patient's body is fitted with nanosensors that assist in gathering health data and provide a warning in the event of an anomaly. When physicians can now monitor patients in real-time rather than needing to take manual measurements as in the past, IoNT significantly advances the field of healthcare. Additionally, viruses and bacteria can be detected by nanoparticles, alerting physicians and patients. Based on the studied state of the art, researchers have observed that, in comparison to all other areas, the healthcare domain is one where IoNT solutions are currently highly used.

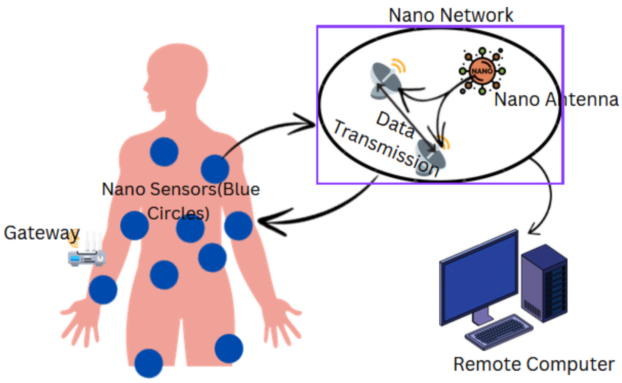

Figure 7. IoNT and Body sensor Networks

In the modern world, the most popular use for IoNT devices is body sensor networks (BSN). A Body Sensor Network (BSN) is established using the IoNT and in-body nano sensors to readily observe a patient's physiological state and overall health. A BSN is a device that extends the reach of conventional diagnostic methods by utilizing a variety of sensors inserted into the human body to obtain relevant data useful for diagnosis. The internal workings of the human body can now be more fully understood due to these nano scale biosensors. Both physicians and patients can view this data from the nano sensors on a wearable device. It is not possible using the conventional diagnostic methods [2,3, 5, 27,33,34,35].

Molecular communication-based IoBNT opens up a wide range of new eHealth applications by facilitating communication over the widely distributed network of blood vessels including veins,arteries and capillaries). An organ tracking sensor, for instance, can send internal body signals to health-monitoring services over the Internet [36].

These days, nano sensors are employed in the bio-nano area to monitor the level of a particular chemical and administer a medication to particular human body devices when they experience any problems [37]. Intracorporal health monitoring and drug delivery are two examples of these nano-sensors. It is possible to use nano sensors to identify infections that are difficult to identify otherwise. Nano sensors can detect viruses or bacteria of this kind and then notify physicians and patients so they may make educated decisions regarding treatment. Health professionals may be able to recognize viral abnormalities like the Nipah virus with the use of nano sensors. Nano sensors can also be used to monitor the temperature of a person's breathing cells within their body.

The application of nano sensors in DNA testing is another significant example. Nano sensors can be used for cell studies, allowing one to compare and contrast different cell types at the nucleus level. This clarifies problems that remained unexplained, contributing to a deeper comprehension of existence. IoNT is probably going to have a significant impact on how healthcare is provided in the future.

3.2 Food Industry

Food production quality, safety, and status can all be monitored with nano sensors. For example, a nano sensor inserted into a soda bottle may detect the presence of particles in the drink and show whether the liquid is coherent. Additionally, nano sensors can confirm if each container contains the anticipated amount of components required. Similarly, food producers can use IoNT to monitor the quality of a variety of food items. Food manufacturers can determine how long their products can be maintained by using data collected by nano sensors.

The food storage with nano nodes is fitted in the warehouse or storage unit, which reads the levels of various parameters like temperature, humidity, gaseous substance or odour sensing etc, to monitor the quality of food items. The nano nodes in represented in different colors in figure 8 ,to indicate the different types of sensors to read different aspects. The data collected by the nano nodes is then processed by the remote computer for decision making.

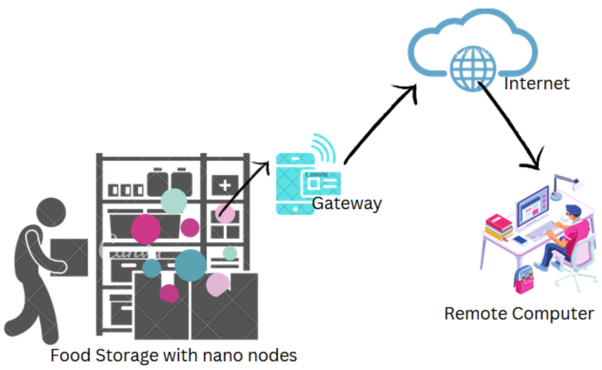

Figure 8. Food Storage with nanonodes

Networks of wireless nano sensors are being created to track the quality of food along its supply chain. In order to produce and distribute safe, nano-enabled products with minimal negative effects on people's health or the ecosystem, the food industry will need to integrate nano sensor technology with the IoT in the future. Food nano sensing and food nanostructured components are the two main types of nanotechnology applications in the food sector. Food processing and packaging are just two examples of the large spectrum of food ingredients that are nanostructured, while food nano sensing improves food quality and safety.

However, enhanced, active, smart and bio-based packaging are taken into consideration in the context of food nano-packaging [38,39,40,41]. The use of nanosensors with their clever or intelligent properties for the identification of products, operative stage, and gas and tiny organic molecule detection is known as "smart packaging" [42].

3.3 Agriculture

Real time monitoring of agricultural productivity, soil condition, and moisture content is made possible by nanosensors in facilities. Chemical substances that release and exchange with plants are observed and managed with nanosensors [7]. Accurate farming can be implemented with the help of Internet of Nano Things technology, which tracks vital soil and production data. Real-time data on crop salubrity and growth, soil quality and moisture, and pesticide and insecticide management can be gathered via nanosensors. Farmers may be able to gather extremely detailed data with IoNT, which will enable them to optimize agricultural operations and raise yields. The figure 8 depicts the various monitoring systems in agriculture using IoNT.

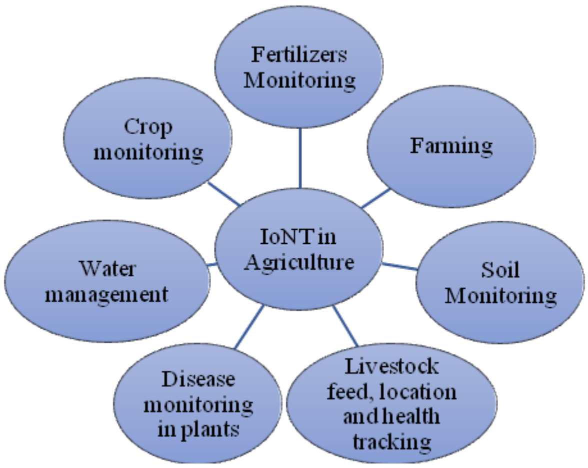

Figure 9. IoNT in Agriculture

Nanosensors are also utilized in livestock management to monitor and control feed, trace the locations of farm animals like cattle, and closely monitor their health.. They might also be used to control agricultural animals' behavior and diets, as well as keep an eye on their health. It's possible that these systems have biosensors embedded in animals at the nanoscale. These sensors have the potential to provide us with previously unattainable levels of insight into the unique dietary and medical needs of farm animals, which will probably increase farmers' earnings. The potency of soil animals and how they eat may also be observed with the help of these centralist sensors. Farmers may get comprehensive information about the health of their animals with the use of nanodevices, which will enable them to make wise decisions when purchasing food and medicine for their animals. Furthermore, to monitor underlying diseases and improve animal health, nanoscale biosensors are injected into animals. These sensors provide previously unheard-of access to data regarding the dietary and medical requirements of farm animals (kuscu, Naser, Alabdulatif).

3.4 Energy

Energy systems' dependability and efficiency are also increased by the IoNT. The smart grid uses nanodevices to monitor and optimize energy output and consumption, as well as to detect and interrupt system issues. [5,7,12,23].

3.5 Military

It is possible for the military to recognize chemical and biological attacks by using IoNT nano sensors to determine the presence of chemical composites at concentrations as low as one molecule [6,12,23,43]**.** The size of nano-networks in this field might vary; for instance, in a battlefield, where there is a high need for nano-network connectivity, the region is significantly less than when troops' health is being monitored by nano-body sensors [27].

3.6 Environmental Monitoring

Nano sensors are employed in environmental monitoring to keep track and record environmental parameters such soil conditions, weather patterns, and the quality of the air and water. Today, we can utilize nano sensors to determine the precise amount of pollutants in the air around us. They assist us in determining the source of the air pollution, which enables us to take appropriate action and lower the air pollution level. The figure 10 presents the various aspects in environmental management and assists in controlling the pollution through IoNT.

The earth is affected by both global warming and climatic variance. There are already numerous extinct mammals as a result of climate change. Therefore, it is imperative that we lessen the effects of weather change and, by extension, global warming. For example, the current level of air pollution and temperature in public spaces such as parks, airports, train stations, bus stops, and restaurants may be precisely monitored and checked utilizing IoNT.

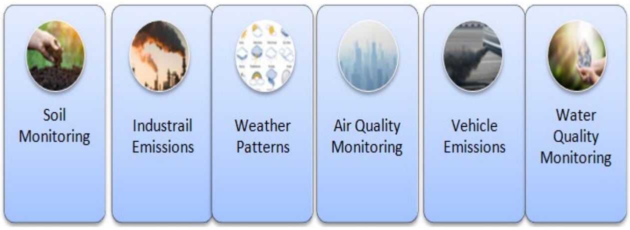

Figure 10. Environmental Monitoring -IoNT

Detailed weather and emissions of carbon reports can be produced by management and smart towns using the data collected by nanosensors. Governments can develop programs that efficiently tackle changes in the environment by using these specialized releases. Enhancing managing the resources, safeguarding the ecosystems, and lessening the consequences of climate change are all possible with the use of this information. IoNT systems are utilized in the context of smart cities to track environmental conditions in real time and produce alerts or replies based on underlying factors [4,5 6.17, 23].

3.7 Manufacturing industry

Production line monitoring and control in real time is made possible by the IoNT, which has the potential to increase industrial processes' precision and efficiency. Nanodevices could be utilized for tracking materials, defect detection, and production optimization to cut waste and boost efficiency [5,17]. Touch technology is the foundation of one of the current nanotechnology trends. Thus, using nano-sensors that recognize motion and translate it into signals, IoNT could be used to increase the sensitivity of touch on air surfaces [37] Furthermore, nanosensors have the ability to maintain particular temperatures, identify dangerous chemicals, and regulate carbon emissions in businesses thereby improving the factory safety through IoNT. Many businesses and organizations could benefit from improved production and quality control procedures thanks to IoNT [44].

3.8 Transportation

Transportation systems can operate more safely and efficiently thanks to the IoNT. Nano sensors are utilized, for instance, to detect and avoid accidents or to track patterns of traffic and manage routes [5,43.45].

3.9 Smart Cities

In a smart city, nanosensors can be used to monitor a wide range of activities. The enormous volumes of data that are gathered can be utilized in real time to develop new services, optimize existing ones, and enhance the general quality of life for city dwellers. For instance, nanosensors might track and locate areas with high levels of air pollution, prompting cleanup efforts there.

3.10 Challenges

IoNT is considered to be the most compact nano sensor network, with great potential for use in real-time applications across various domains. However, despite all of its advanced benefits, IoNT has certain problems and difficulties that need to be resolved. The primary concerns presented are those of privacy and security because nano devices rely heavily on personal data from individuals to perform their functions. and this needs to be addressed; it cannot be ignored. The ability of attackers to obtain private information sent by these devices is one of the primary security issues associated with the IoNT. Since these devices are frequently dispersed and small, it could be challenging to determine whether they have been compromised. Comprehensive security procedures must be put in place to guard against cyberattacks and guarantee that data gathered by IoNT devices is managed safely in compliance with relevant laws and regulations to solve the protection and confidentiality issues associated with IoNT [46,47,48,49].

There is no worldwide standard that addresses the pertinent concerns about security, privacy, and the architecture of IoNT nanonetworks. Establishing standard interfaces with protocols and primitives to enable communication through nano-device interfaces compatible with systems of a higher scale and offer network monitoring capabilities would be a step in the right direction. The primary obstacle to the widespread use of the medical nanosensors is compatibility. The designers must ensure that these nanosensors won't harm a patient's body in any way or interfere with wearable technology's ability to connect continuously.

IoNT presents both enormous opportunities as well as challenges for big data analytic research in a number of different domains, including healthcare, environmental monitoring, and next-generation heterogeneous networks. The vast amount of varied real-time data may be too large for conventional processes to manage well, which calls for the creation of better data analysis techniques.

4. Conclusion

The world is becoming increasingly developed as a result of ongoing technological advancements. Future developments, which are expected to peak in the next one to two decades, will be led by IoT and nanotechnology. IoNT offers potential and means to enhance numerous facets of individuals' lives. Its primary characteristics are monitoring and diagnostic services, which support and improve decision-making and outcomes across a range of application domains. Experts are presently engaged in the creation of nano devices that comprise IoNT for immediate implementation in many fields. IoNT-based Nano Sensor Network development for and industry, energy management and transportation needs to be explored and worked on in order to facilitate a variety of monitoring tasks.

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