An Internet of Things-based Precision Agriculture with Biosensors Enabled by Nanotechnology

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The fusion of Nanotechnology (NT) and the Internet of Things (IoT) has completely transformed Precision Agriculture (PA), providing unparalleled prospects for instantaneous monitoring and data-centric decision-making. Nanomaterials (NM) and NT have greatly enhanced the capabilities of biosensors (BS), making them very effective in detecting and measuring different analytes in agricultural environments. This study examines the collaborative interaction between BSs, NT, and the IoT, investigating its uses in PA. BSs achieve exceptional sensitivity, specificity, and quick response by using the distinctive characteristics of NMs, such as their high surface-to-volume ratios, adjustable optical and electrochemical characteristics, and enhanced catalytic capabilities. The study examines the core ideas, manufacturing methods, and effectiveness measures of BSs that use NMs. This study investigates incorporating such biosensors into IoT networks, allowing for real-time monitoring of soil situations, crop well-being, and environmental factors. The study extensively examines the possible effects on agricultural output, the optimization of resources, and the sustainability of the surroundings. The research discusses present obstacles, such as sensor security, data administration, and system flexibility, while suggesting future areas of study and possible uses in smart agricultural methods.

Keywords: Internet of Things, Precision Agriculture, Biosensors, Nanotechnology.

1. Introduction

Concerns over the safety of agricultural goods have progressively increased over the last several decades [1]. Customers expect agricultural food to possess freshness, nutritional value, palatability, and, most importantly, safety. They want the food they purchase and eat to be high quality and have a sufficient shelf life. Ensuring the safety of agricultural goods continues to be a significant global issue [12]. The safety and purity of agricultural goods are

influenced by several factors and entities along the whole food supply chain, from the field to the consumer. The e-commerce environment necessitates a comprehensive evaluation index system for assessing agricultural goods' quality and security supervision [2]. This system evaluates six critical agricultural production areas: surroundings, manufacturing, initial processing, transportation, storage, and distribution [10].

The Internet of Things (IoT) technologies will usher in a new era in the global information economy following the advancements of computers, the Internet, and wireless communication networks [9]. This technology disrupts conventional notions and paves the way for a novel technological domain. The composition of this entity consists of three distinct aspects: information things, independent systems, and intelligent applications. IoT technology integrates diverse smart gadgets and compatible communication methods to identify, track, communicate, monitor, and interact with various objects.

Precision Agriculture (PA) depends on data analytics and sensor technology to collect up-to-date information on soil conditions, climate trends, crop wellness, and other relevant factors [4]. Farmers use this information to make intelligent decisions about how to fertilize, water, control pests, and handle their crops, which helps them get the best results while using fewer resources and having less of an impact on the environment [6]. Biosensors (BS) have become very important for PA because adding Nanotechnology (NT) has changed how they are made [5]. Because they have unique physical properties and high surface-to-volume rates [13], nanomaterials (NMs) have made biological sensors much more sensitive, specific, and quick to respond [3]. These high-tech monitors can find and measure many things, such as nutrients, infections, and environmental factors, with great accuracy and dependability [8].

This study looks at the critical role that NT-enabled BSs play in improving PA through IoT tracking. This study looks into the basic ideas behind this cutting-edge sensing technology, how it is made, and how well it works. The study looks at adding BSs to IoT systems. This lets data be collected immediately, evaluated, and decision-supporting systems for PA operations be implemented.

2. Proposed IoT-based WSN networks

Wireless Sensor Networks (WSN), comprised of nodes that work together, are considered an essential technology for the 21st century [7]. A WSN shall consist of four main parts: a sensing element, a processing element, a radio element, and a power element. Figure 1 shows how the WSN network is put together. It did three things: it collected data, analyzed it, and sent it to other devices using battery-powered computers and sensors. A conventional WSN has several small sensor nodes scattered and organized into multi-hop WSNs. These nodes operate on restricted battery power and collaborate to accomplish a shared job or monitor a specific region.

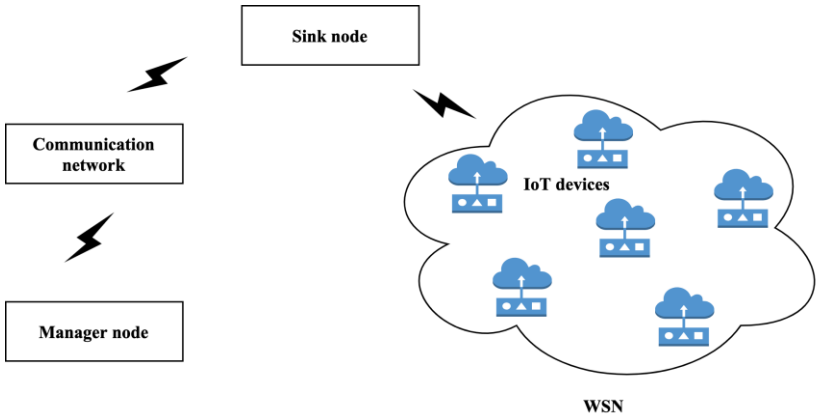

Figure 1. The architecture of the IoT-based WSN network

As living conditions have improved, food consumption has moved from focusing on keeping food warm to prioritizing safety, environmental friendliness, and organic qualities. To enhance the quality and security of agricultural goods, it is essential to provide a seamless process from the farm to the consumer's plate (Figure 2). The quality and security of farming goods have emerged as a worldwide concern, impacting both public health and the pace of rural globalization. The IoT technology plays a significant role in addressing these concerns. Subsequently, an assessment was conducted on the utilization of IoT technologies in overseeing the quality and security of agricultural goods throughout four critical phases of the entire value chain: manufacturing, processing, distribution, and sales tracking and traceability.

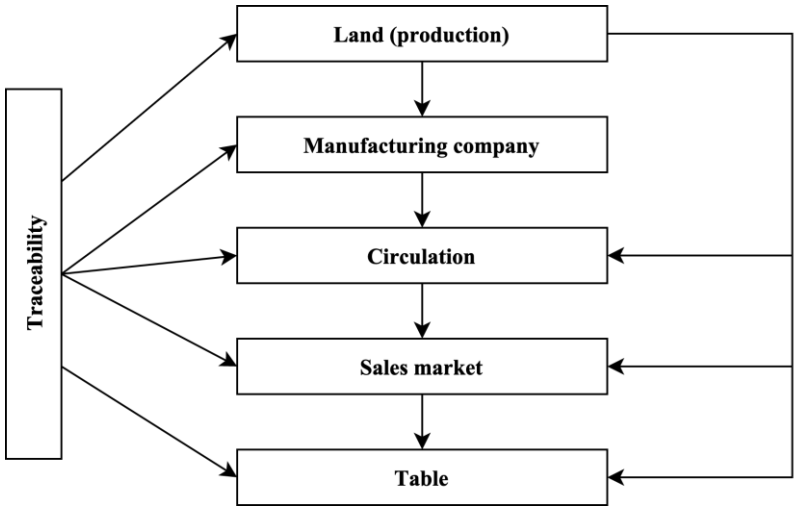

Figure 2. Quality and safety for precision agriculture

3. Nanomaterials

NMs have been pivotal in revolutionizing the advancement of BSs, thanks to their distinct

characteristics and ability to improve sensor efficiency [11]. These substances, which are between 1 and 100 nanometers in size, have unique chemical, optical, and physical qualities used for sensing.

Carbon Nanotubes (CNTs) are very interesting to people in the biosciences field because they have unique properties like good electrical conductivity, a large surface area, and high mechanical strength. Because of their unique properties, CNTs are the best choice for many uses, especially in electrochemical and Field-Effect Transistors (FET) BSs. Electrochemical basic systems use CNTs as electrode parts because they have unique qualities, like faster electron transfer rates and the ability to stick proteins in place.

Graphene and its analogs, including Graphene Oxide (GO) and reduced GO (rGO), are unique materials that are very good at sensing living things. A honeycomb design is made up of carbon molecules that make up graphene. It is very good at conducting electricity and heat and is mechanically solid.

Gold nanoparticles (AuNP) are absorbed in biosensing because they can change how light interacts with them. People talk about the features because of Localized Surface Plasmon Resonance (LSPR), which lets AuNPs talk to light very clearly and causes color changes that are easy to spot. AuNPs are very useful in colorimetric BSs because they have a unique property that makes them stand out. When specific analytes are present in these sensors, the NMs either group together or spread out.

Nanoparticles of silver (AgNPs) have plasmonic properties similar to those of AuNPs and are now essential for biosensing technology. AgNPs have a strong LSPR, just like AuNPs. This lets them interact with light efficiently, creating more vital electromagnetic fields near their sides. This is why they are often used in BSs that depend on Surface-Enhanced Raman Scattering (SERS). These BSs work well as surfaces to boost the Raman readings of specific molecules.

Quantum dots, or QDs, are unique NMs with unique visual properties that have been widely used for biosensing. The size of these semiconductor nanocrystals changes their fluorescence emission range, which makes them very useful for BSs that use fluorescence. Changing the emission wavelength of QDs correctly is possible by changing their sizes during the synthesizing process. Multiplexed identification makes it possible to identify many analytes at the same time.

4. Applications, Challenges, and Future Scope

4.1 Applications

Today, keeping an eye on the amounts of nutrients in the soil is an integral part of farming, and BSs are an excellent way to do this. These sensors can find and measure essential things in the earth, like nitrogen, phosphate, and potassium.

By giving farmers real-time information on nutrient levels, BSs let them use fertilizer transport methods that work best in certain areas. This focused approach not only helps plants absorb nitrogen better but lessens the harmful effects of using too much fertilizer on the environment, like the runoff of nutrients into lakes and rivers, which causes

eutrophication and other issues.

To keep agricultural output high and prevent crop loss, finding infections early in plant health management is essential. BSs with special tools can quickly find fungi, bacteria, and viruses that cause plant diseases. Early detection lets farmers rapidly take the proper steps to stop the spread of diseases and lower crop losses, like changing how they use pesticides or setting up isolation rules.

Monitoring the environment is essential for Pennsylvania because it gives us helpful information about the many things that affect the growth and development of crops. BSs, which include humidity, moisture, and air quality detectors, can keep an eye on changes in agricultural settings all the time. Live data gives farmers the information to make intelligent decisions that protect crops, help them grow, and boost total production.

Controlling irrigation wells is a big part of using water efficiently in Pennsylvania, especially in countries that don't have a lot of water and are competing for it with other countries. By keeping track of the soil's moisture levels all the time, BSs are a valuable way to improve watering methods. Farmers can correctly plan irrigation when they have access to up-to-date information. This ensures crops get the necessary water while reducing water waste and runoff.

4.2 Challenges

NT-enabled BSs have shown a lot of promise in PA, but there are still some problems that need to be fixed:

Although NMs have unique qualities, they have problems with sensor longevity and lifespan when used in BSs, especially in harsh environmental conditions.

Many people are using IoT BS networks, which has created a lot of data that needs to be managed well.

As PA systems keep getting bigger, it's essential to make sure they can scale and connect different kinds of sensors and IoT systems.

To make and use NT-enabled BSs, the proper rules and standard processes must be followed.

Even though BS technology has gotten better, it still needs to be made more cost-effective and easier to get, primarily for farming.

4.3 Future scope

Future research projects should focus on eliminating these problems while exploring new territory in NT and BS progress. Some possible directions to explore are:

It can do many things and generate power. BSs could change things a lot in agriculture and make it easier to sense and find biological substances.

Biocompatible and harmless NMs are needed to solve the environmental problems caused by making BSs.

Putting Artificial Intelligence (AI) and Machine Learning (ML) to use in PA systems is a great way to make progress.

Sensor downsizing and connectivity are two critical factors that must be met for BSs to be widely used in agriculture.

Advanced images and spectroscopy techniques give us a lot of information about plants' health, nutrient levels, and stress tolerance.

Sharing information through collaborative networks is vital to encouraging creativity and making PA easier to use.

5. Conclusion and findings

The coming together of NT, BSs, and IoT is a big step forward in PA; it will completely change how farming is done and monitored. NT has made it possible to manipulate materials at the nanoscale level, developing very sensitive and specific BSs made explicitly for use in agriculture. These BSs can accurately find and measure various chemicals, such as nutrients, pesticides, infectious agents, and environmental contaminants. Adding BSs to IoT technology has made it easier for detectors and cloud-based systems to communicate and share data without problems. This has made it possible to keep track of things and make farming decisions based on data. With the help of cloud computing and wireless communication, farmers can remotely check on and analyze sensor data. This helps them make the best use of their resources, lower the risk of harm, and increase farm output.

Researchers kept working on multifunctional and self-sustaining BSs, substances that can work with live things. By breaking down AI naturally, they can make sensors smaller, and PA will continue to move forward thanks to platforms that urge people to work together. As the world's population grows, it is more important than ever to put food safety first and use healthy farming methods. When combined with IoT tracking, NT-based BSs are essential to realizing the whole capabilities of PA, hence facilitating a more effective, fruitful, and ecologically aware future for the agricultural sector.

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