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Internet-of-Things-Based Multiple-Sensor Monitoring System for Soil

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Introduction:

Precision agriculture, also known as precision farming or fine farming, originated in the United States in the 1980s. Precision farming is a new type of agriculture supported by information technology and represents a complete set of modern farming operations and management systems that can be positioned, timed, and quantified according to spatial variation. However, at present, the scale of precision agriculture globally is quite limited, and the vast majority of countries still rely on traditional manual farming and human experience for management, which wastes large amounts of human and material resources and generally creates problems such as high costs and low efficiency. These techniques are also no longer applicable to the urgent needs of the current developments in modern agriculture. At the same time, the rapid development of sensors and the Internet of Things (IoT) has brought new development opportunities to the farming industry. The application of IoT technology in farm production practices to gain timely access to production information is of great significance in changing present agricultural processes and ensuring high crop yields and green health.

In order to meet these growing demands, IoT-based smart agriculture must be intensively studied. This will enable growers and farmers to reduce waste and increase productivity through a variety of methods, from optimizing fertilizer use to improving the efficiency of farm vehicle routes. Smart farming is the application of smart sensors and software to control agricultural production through mobile or computer platforms, making traditional farming more intelligent. In general, the role of the IoT is to connect agricultural animals or plants, agricultural equipment, and agricultural facilities to a network through wireless or wired communications, so that every animal and plant can be managed accurately to

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achieve the best possible yield and minimize costs. In recent years, IoT technology has been applied to many areas of agriculture, including agricultural environmental monitoring, greenhouse gas emission control, water-saving irrigation, weather monitoring, product safety and traceability, and intelligent equipment diagnosis and management. Its main goal is to enable the combination of historical analyzed data and real-time inspection data to provide a more accurate model and optimization solution, with the ultimate aim of achieving sustainability in future intelligent agriculture.

Soil is one of the environmental factors that cannot be ignored in the cultivation of crops. As an important medium for the survival of crop roots, the soil tillage layer contains the nutrients and water needed for crop growth. The suitability of the soil environment for the growth of crop roots is of great importance for high-quality and efficient crop cultivation. Thus, more attention and research are needed regarding the soil layer, especially its moisture content (MC) and temperature. High-quality time-series predictions of soil MC and temperature in the tillage layer are significant for both scientific study and practical agricultural production .

In terms of the smart soil monitoring process, the IoT is divided into three parts, including the sensing device part, the communication part, and the intelligent processing part, which involves using various intelligent technologies to sense and transmit data. Simultaneously, the information is analyzed and processed to achieve optimal monitoring and control, as shown in Figure 1. Our contributions are briefly described as follows:

(1) A complete wireless measurement system used to measure the soil temperature and MC was constructed, and the detailed indicators can be viewed in real time on a mobile phone application.

(2) A deep Q network (DQN)-based soil temperature and MC prediction method was proposedin order to make an informed decision in cases where uncontrolled variations in the soil properties occur.

(3) A measuring campaign was carried out on a farm for 12 months, and the multi-layer soil temperature and MC were recorded and analyzed; the results show that the soil properties can be predicted accurately and efficiently.

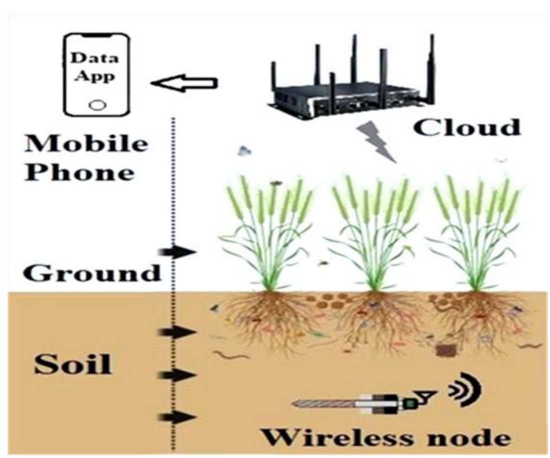

Figure 1. Soil information diagnosis system architecture

Many researchers have now developed a variety of agricultural information systems to meet the needs of different developments. Sun Yanjing et al. described an overall framework for the implementation of agricultural information systems [; the overall system consists of a three-layer network: a wireless sensor network at the bottom, a GSM/GPRS/GPS network in the middle, and an internet network at the top. The bottom and middle layers are connected by gateway nodes, while the middle and top layers are connected by public telecommunication gateways. Jirapond Muangprathub et al. designed and developed a control system using node sensors in the crop field with data management via a smartphone and a web application; the system can send notifications through LINE API on the LINE application, and the results showed that this method was useful in agricultural applications [12]. Shadi Atalla et al. proposed a new classification method for the agricultural IoT based on multiple factors and introduced performance evaluation indicators for fixed and mobile scenarios in 6LowPAN networks for precision agriculture [13]. Huan Juan et al. developed a narrow band (NB) IoT-based water quality monitoring system for aquaculture ponds, using a cloud platform for data monitoring.

Components of the System

An IoT-based soil monitoring system consists of several essential components. The primary components include multiple soil sensors, a microcontroller, a wireless communication module, a cloud platform, and a user interface such as a mobile or web application.

Soil sensors play a crucial role in gathering real-time data on different soil

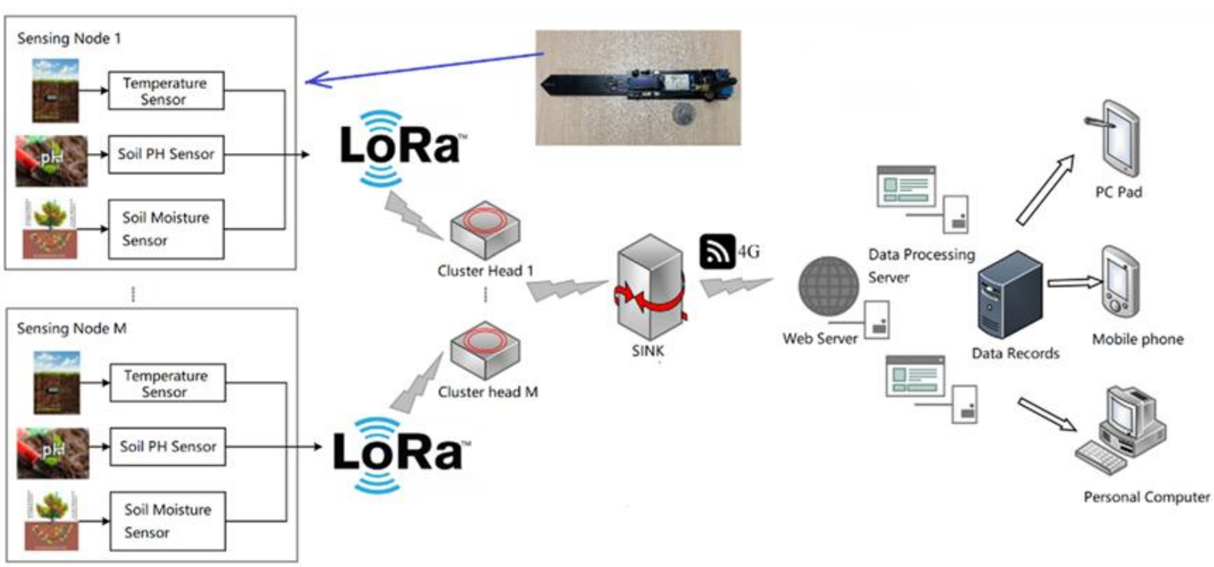

Figure 2. Diagram of the proposed soil monitoring system

The microcontroller, often an Arduino, Raspberry Pi, or ESP32, acts as the central processing unit. It collects data from the sensors and transmits it to the cloud using a wireless communication module. Common communication protocols used in these systems include Wi-Fi, Bluetooth, LoRa (Long Range), and Zigbee, depending on the location and connectivity requirements.

The cloud platform stores, processes, and analyzes the collected data. Platforms like Amazon Web Services (AWS), Google Cloud, and Microsoft Azure are commonly used for real-time data storage and processing. The cloud also enables predictive analytics, which can generate recommendations for farmers based on historical data trends. The data can be accessed through a mobile or web-based application, providing farmers with real-time insights, alerts, and suggestions for improving soil health.

Working Principle

The system operates through a sequence of steps. First, the sensors placed in the soil measure different parameters such as moisture, temperature, pH, and nutrient levels. The collected data is then transmitted to the microcontroller, which processes the information and sends it to the cloud platform using a wireless communication module.

Once the data reaches the cloud, it undergoes analysis to identify trends and patterns. If certain parameters fall outside the optimal range, the system generates alerts and notifications, prompting farmers to take necessary actions such as irrigation or fertilizer application. Additionally, advanced algorithms can be integrated into the system to provide predictive insights, helping farmers anticipate and prevent potential soil-related problems.

Benefits

An IoT-based soil monitoring system offers several advantages. One of the most significant benefits is real-time monitoring, which allows farmers to assess soil conditions continuously and make timely decisions. This leads to improved resource management, ensuring that water, fertilizers, and pesticides are used efficiently, reducing waste and lowering costs.

Precision agriculture is another key benefit, as the system helps optimize inputs such as water and fertilizers based on actual soil conditions. This results in better crop yields and higher productivity. Additionally, the system promotes environmental sustainability by preventing over-irrigation, reducing excessive fertilizer use, and minimizing the risk of soil degradation.

Remote accessibility is another advantage, as farmers can monitor soil health from anywhere using a mobile application. This reduces the need for frequent field visits and allows for more efficient farm management. Furthermore, predictive analytics can help farmers prepare for potential issues such as drought stress, nutrient deficiencies, or soil erosion, enabling proactive soil management.

Challenges and Considerations

Despite its many benefits, implementing an IoT-based soil monitoring system comes with challenges. One of the primary concerns is power supply, especially in remote areas where electricity is not readily available. Solar-powered sensors and low-energy devices can help mitigate this issue.

Another challenge is maintaining stable wireless connectivity. In areas with poor network coverage, alternative communication methods like LoRa or satellite-based communication may be necessary. Additionally, sensor calibration is crucial to ensure accuracy, as incorrect readings could lead to poor decision-making.

Data security is also an important consideration, as cloud-based systems must be protected against cyber threats. Ensuring secure data storage and transmission through encryption and authentication mechanisms is essential for preventing unauthorized access.

Applications

IoT-based multiple-sensor soil monitoring systems have a wide range of applications, primarily in agriculture. They are used to optimize irrigation schedules, monitor soil health, and improve crop productivity. Additionally, they are valuable in agricultural research, enabling scientists to study soil behavior under different treatments.

Beyond agriculture, these systems are useful for land management, helping assess soil quality across large areas for sustainable land use planning. Governments and environmental agencies can also use these systems for monitoring soil health in forests, wetlands, and other ecosystems.

Future Scope

As technology continues to evolve, IoT-based soil monitoring systems are expected to become even more advanced. The integration of artificial intelligence (AI) and machine learning can enhance predictive capabilities, allowing for automated decision-making in agriculture. For instance, AI can analyze historical data to predict the best times for irrigation or fertilization, reducing manual intervention.

The development of more sophisticated sensors, such as those capable of measuring microbial activity and soil organic matter, could provide deeper insights into soil health. Additionally, integrating these systems with drone technology could enable large-scale monitoring of agricultural fields, further improving precision farming techniques.

Conclusion: An IoT-based multiple-sensor monitoring system for soil is a revolutionary tool in modern agriculture. By providing real-time data and predictive insights, it enables farmers to make informed decisions, leading to improved crop yields, efficient resource management, and sustainable farming practices. Despite some challenges, the continuous advancement of technology promises even more innovative solutions for soil monitoring in the future.

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