Smart Soil Moisture Monitoring Using IoT and Wireless Sensor Network for Precision Agriculture

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Abstract: Combining Internet of Things (IoT) technology with Wireless Sensor Networks (WSNs) has enormous potential to improve agriculture and address its pressing issues. Globally, and particularly in nations like China and India, agriculture is a vital economic engine. IoT adoption is widespread across several industries, but its full potential in agriculture is unmoving largely unrealized. Growing consumer demands and environmental issues similar soil quality and rainfall patterns present challenges for farmers. IoT use in agriculture offers a revolutionary way to effectively revolutionize the industry. The four primary components of an IoT-based soil moisture sensor prototype, a sensing unit, a connectivity module, a data processing unit, and a data analysis module, are presented in this paper. The sensor provides real-time soil moisture data, according to the results, and offers useful analysis for controlling moisture. Better production and resource efficiency can be achieved by enhancing real-time monitoring, forecasting, and management of agricultural activities through the integration of sensors with Internet of Things systems.

Keywords: IOT, Sensor, Agriculture, Smart Agriculture

Introduction:

As the main source of food and a significant employer, agriculture is essential to the economic growth of our nation. It employs almost half of the workforce and makes a substantial contribution to the national GDP [1]. With the worldwide demand for food production is expected to increase exponentially by 2050, when the world's population is expected to increase by about 25% [2]. At the same time, development is accelerating quickly; estimates indicate that by 2050, roughly 70% of people on Earth will live in urban areas, up from 49% at the moment [2]. Increased food production and tremendous strain on traditional agricultural systems will result from this rapid growth and rising incomes, particularly in developing nations. The government is investing heavily in modernizing agriculture and ensuring food security, especially in rural areas, in order to meet this challenge. However, the complicated factors of resource scarcity, unpredictable weather, and climate change are frequently not adequately addressed by traditional farming methods [3]. To overcome these limitations, there is a growing shift towards smart agriculture solutions. One such innovation is the implementation of smart agriculture monitoring systems that utilize the Internet of Things (IoT). These systems integrate various types of sensors to collect crucial data about soil moisture, temperature, humidity, crop health, and environmental conditions [4]. This real-time information is transmitted through wireless technologies to cloud-based platforms such as ThingSpeak, which serve as the central hub for data analysis and visualization [5]. ThingSpeak presents the collected data in user-friendly graphical formats, allowing farmers and agricultural experts to make informed decisions about irrigation schedules, fertilizer application, and other critical farming activities. By leveraging this technology, farmers can take timely actions to prevent crop failure and maximize yield. Additionally, it offers the benefit of remote monitoring, enabling farmers to manage their fields efficiently even from a distance [5].

In essence, smart agriculture monitoring systems help create a resilient and sustainable food supply chain for the future in adding to making farming more data-driven and approachable. In the agricultural industry, these systems are a revolutionary step toward reaching sustainability and productivity

IOT Architecture in Smart Agriculture

Initially, in the early stages of IoT, the architecture consisted of only three layers: perception, network, and application. However, to enable large-scale applications of IoT and ensure proper management and communication, it became necessary to combine certain fields of telecommunication for network management. Figure 1 illustrates the modern working architecture of IoT, which now includes five layers, with the middleware layer and business layer added to the previous three layers. The addition of the business layer has added value to digital industrialization, and the introduction of cloud computing alongside IoT has opened up new paradigms such as smart homes, smart farming, and smart agriculture [6][7]

Perception layer: In this layer, physical objects are equipped with various sensors, tags, embedded microchips, and actuators. Here, sensors or tags automatically detect properties of their environment, such as movement, temperature, and location, while actuators provide local services. Each object is uniquely identified with a digital identity for tracking purposes.[8]

Network layer: The network layer is responsible for transmitting data from the perception layer to decision-making centres via any wireless or wired network, ensuring global accessibility through the internet. Various communication technologies (such as Wi-Fi, Bluetooth, 3G, Zigbee, etc.) can be implemented for data transmission, along with devices like switches, hubs, and gateways, depending on the specific requirements.[9]

Processing/Middleware layer: The sensors and chips in the perception layer continuously sense the environment, generating substantial amounts of data. This information is stored in databases for intelligent processing to trigger actions by the actuators in response to specific events. Cloud computing has emerged as a prominent backend technology for this layer, providing extensive coverage and data transmission capabilities. It serves as a central repository for data storage, offering virtually infinite storage capacity and facilitating access to large pools of resources for complex computations and storage.[10]

Application layer: The primary function of the application layer is to provide web services or access to users, allowing them to leverage the functionalities of the previous layers globally. Depending on the requirements, various web applications can be developed to exploit IoT functionalities remotely, such as for smart healthcare, smart homes, smart agriculture, and more.[11]

Business layer: The business layer, which sits above the application layer, is in care of controlling and modifying different applications to fit the profit and business models. This layer helps organizations use the insights from IoT data and applications to inform future business initiatives and actions.[12]

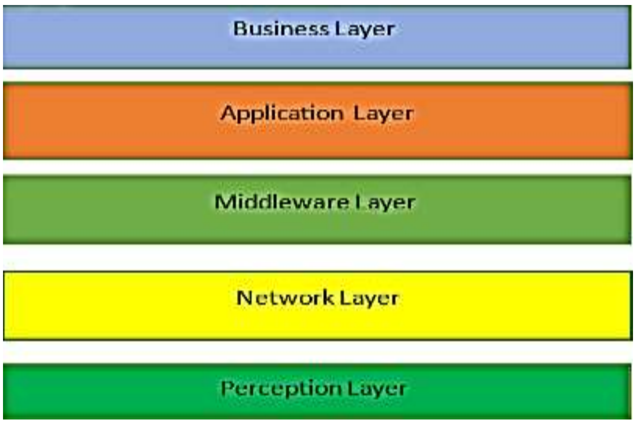


Fig 1. Layer of IOT

LITERATURE REVIEW

Agriculture is undergoing a main transformation due to the rise of smart farming technologies powered by the Internet of Things (IoT). These innovative systems are transforming traditional farming by enabling real-time monitoring of significant factors like crop health, soil moisture, and environmental conditions. By connecting a network of sensors, actuators, and wireless communication devices, IoT-based smart agriculture systems allow farmers to make data-driven decisions that improve efficiency, reduce waste, and funding sustainable practices.

This move toward smart agriculture is not just a passing trend—it's a necessary evolution. As the global population grows and climate change degenerates, there is a pressing need for more productive and resource-efficient farming methods. While traditional agriculture has been reliable over time, it often faces issues like unpredictable weather, labour shortages, and overuse of resources. Smart systems, however, introduce precision and automation, making farming more reliable and adaptable for the future [13]. One key advantage of IoT in agriculture is its ability to facilitate seamless communication between devices. Farmers can monitor field conditions, equipment status, livestock movement, and crop health all from a mobile device or computer. This continuous flow of data helps them respond quickly to emerging problems, optimize input use, and increase overall farm productivity [14]. An excellent example of IoT in action is the development of automated irrigation systems. Using sensors such as the DHT11 and microcontrollers like the Node-MCU, these systems can measure soil moisture levels and activate irrigation exactly when needed. Data is also uploaded to cloud platforms like Thing Speak for remote monitoring. This smart irrigation conserves water and boosts crop yields by ensuring plants receive the right amount of moisture at the right time [15].

With more than 64% of the workforce employed, agriculture remains to be the main economic sector in many developing nations. However, productivity is frequently hampered by antiquated practices and restricted access to technology. In areas where farming is both traditional and necessary, modernizing agriculture with smart monitoring systems is a practical means of enhancing soil management, conserving water, and promoting resilient crop production [16]. In rural areas, manual irrigation techniques are still prevalent despite advancements in technology. In addition to being time-consuming, these methods are also prone to human error, particularly in situations where farmers are unable to incessantly monitor their fields. To get past these obstacles,

Intelligent irrigation systems that use sensor inputs to automate watering have been developed as a solution to these problems. This automation minimizes manual labour, maintains ideal growing conditions, and guarantees timely, accurate irrigation [17].

Furthermore, a number of environmental parameters, including temperature, humidity, water levels, soil fertility, and even the existence of invasive plants, are being tracked by combining remote sensing and Internet of Things technologies. Farmers can make better decisions thanks to this all-encompassing approach, which provides them with a full picture of their fields. Farmers can remotely manage their operations and react swiftly to changes in the environment when they have access to this data from any location [18]. The literature concludes that there is a great deal of promise for smart agriculture powered by IoT and sensor technologies. In addition to addressing the drawbacks of conventional farming, these systems also produce

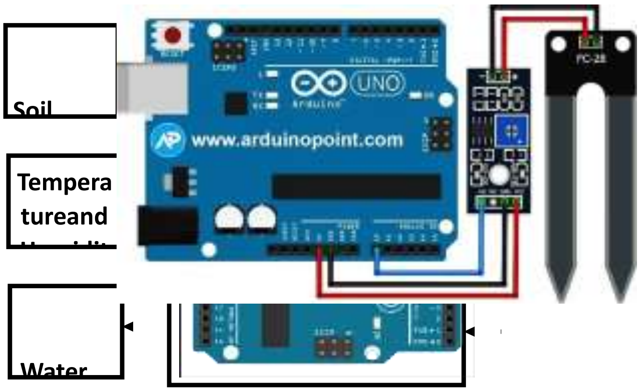
In addition to addressing the drawbacks of conventional farming, these systems lay the groundwork for an agricultural future that is more resilient, sustainable, and productive.

INTEGRATED HARDWARE ARCHITECTURE AND SENSOR-BASED IOT FRAMEWORK

SYSTEM OVERVIEW

Smart farming is turning agriculture into a high-tech, data-driven sector equipped to handle the challenges of the future, from automated irrigation to real-time crop and soil monitoring.

To handle various farming challenges and efficiently practice their capabilities based on particular needs, the Smart Agriculture Monitoring System makes use of a variety of sensors. The system seeks to increase crop yields and implement new agricultural technology trends by effectively utilizing these sensors. By combining various sensors with microcontrollers, smart farming enables each sensor to efficiently carry out its designated function. Soil moisture sensors, for instance, aid in addressing water scarcity concerns and improving environmental conditions. These sensors provide precise measurements.



HARDWARE INTEGRATION AND SENSOR NETWORK

The system is designed with one mesh containing two nodes, with each node equipped with a sensor unit responsible for receiving data from sensors. This data is then transmitted to a microcontroller to convert analog data into a digital format before being sent to a NODE MCU ESP8266 module, which facilitates communication with the main controller.

- All sensors and the NODE MCU ESP8266 module are connected to the microcontroller, and the collected data from these sensors is transmitted to Thing Speak through the NODE MCU ESP8266. Each sensor collects data based on its specialized function.
- The microcontroller is linked to the NODE MCU ESP8266, serving as the intermediary for receiving data from sensors and forwarding it to the NODE MCU ESP8266. Subsequently, the NODE MCU ESP8266 communicates with the IoT platform.

COMMUNICATION AND DATA FLOW

Two nodes make up the system's single mesh design, and each node has a sensor unit that collects data from sensors. After being converted from analog to digital by a microcontroller, this data is sent to a NODE MCU ESP8266 module, which enables communication with the main controller. Each node continuously gathers environmental data. The Arduino Uno at each node receives this raw sensor data and converts it into a digital format. This data is then transmitted to the Node-MCU ESP8266, which acts as the communication bridge to the internet. Finally, all the information is sent to ThingSpeak, a cloud platform that visualizes the data for farmers or system supervisors. Through this smart setup, farmers can monitor conditions like soil moisture or air quality in real time, even when they are away from the field. This allows better decision-making when it comes to watering crops, correcting environmental conditions, or responding to potential threats like gas exposure.

SYSTEM IMPLEMENTATION & MOISTURE DATA PROCESSING

WIRELESS DATA ACQUISITION FRAMEWORK

A wireless sensor network is a system that can be integrated with the Internet of Things to enable smart farming with a monitoring system for measuring farming parameters like soil moisture, temperature, and humidity. In this paper, we discuss in detail the soil moisture data collection process.

The figure 2 shows the data flow from the farm's physical environment.

Physical Earth Condition Monitoring

Data about the soil's moisture content is collected by a soil moisture sensor and sent to an ATmega328 Uno microcontroller. The microcontroller transforms the analog data from the sensor into a digital format. The microcontroller then sends this information to a microcontroller transforms the analog data from the sensor into a digital format. The microcontroller then sends this information to an ESP8266 Node-MCU that can establish an internet connection. After that, the data is sent to a ThingSpeak channel by the Node-MCU ESP8266 for analysis and storage. This configuration makes it possible to remotely monitor and analyze soil moisture levels in real time.

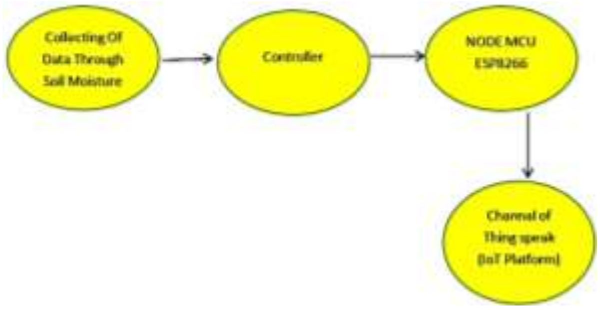


Fig 2. Soil Moisture Data Collection Process

Soil Moisture Data Collection Process

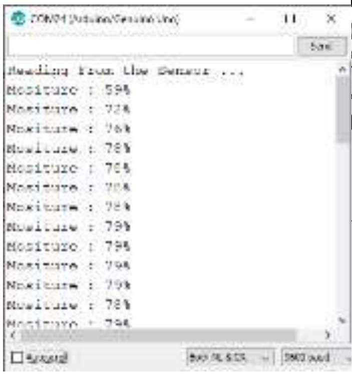
First, the sensor receives power. Other sensor pins, such as the ground (GND) and analog pin (A0), must be connected to the Arduino correctly. The sensor might not work properly without these connections. Before turning on, check the entire setup for any mistakes made during the wiring process. A digital device is connected to the Vcc pin. to a digital pin, which ought to be designated as an output. As an alternative, the sensor can be powered by an external source. Until the power LED illuminates, it is essential to supply the sensor with full voltage. We can easily set the threshold voltage thanks to the sensor's integrated potentiometer. A minimum threshold voltage produces HIGH sensitivity, whereas a maximum threshold voltage produces LOW sensitivity. While a sensor with a high sensitivity can quickly identify slight variations in moisture content, one with a low sensitivity might take longer to detect moisture. The threshold voltage can be changed during operation to suit your requirements. The sensor will be prepared to measure moisture level once the setup is complete.

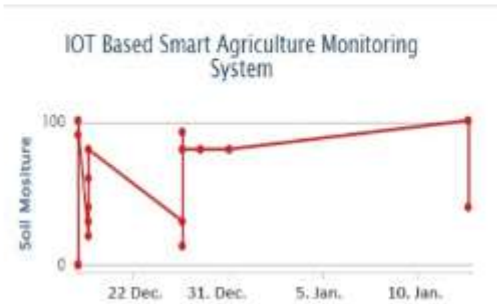
- **Code for it:**

```
// Define the pin that the soil moisture sensor is
connected toconst int soilMoisturePin = A0;
void setup ()
{

   // Start the serial communication at 9600 baud
   Serial.begin(9600);
}

void loop ()
{

   // Read the value from the soil moisture sensor int
soilMoistureValue = analogRead(soilMoisturePin);
// Convert the analog value to a percentage
  (assuming a range of 0-1023)int
  soilMoisturePercentage = map
  (soilMoistureValue, 0, 1023, 0, 100);
   // Print the soil moisture percentage to the serial
  monitorSerial.print("Reading From the Sensor…");
  Serial.print("Moisture:   ");
  Serial.print(soilMoisturevalue);
  Serial.println("%");

   // Wait for 1 second before reading againdelay
   (1000);
}
```

Serial Monitor

The Output of soil moisture Sensors is Shown Below





CONCLUSION

In conclusion, the Internet of Things-based smart agriculture monitoring system provides farmers with a useful and efficient way to track and maximize crop growth. The agricultural industry has been greatly impacted by this technological revolution. By analysing the mineral content of the soil, soil checkers enable farmers to compare it with ideal levels and identify the fertilizers that are required. In addition to improving crop growth, this also saves water and fertilizer. Furthermore, real-time monitoring and well-informed decision-making are made possible by the ability to store the collected data in the cloud for later use. Soil checkers analyse the soil's mineral content, allowing farmers to compare it with optimal levels and determine the necessary fertilizers. This not only promotes better crop growth but also conserves water and reduces fertilizer usage. Additionally, the gathered data can be stored in the cloud for future use, enabling real-time monitoring and facilitating informed decision-making. Overall, the integration of IoT technology in agriculture not only enhances productivity and resource efficiency but also ensures sustainability for future generations.

In terms of suggestions, it is critical that future studies concentrate on making smart agriculture technology more affordable and accessible, particularly for small-scale farmers who cannot afford pricey equipment. Addressing possible privacy and security issues affecting to the gathering and all things considered, incorporating IoT technology into agriculture guarantees sustainability for coming generations while simultaneously increasing productivity and resource efficiency.

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