5G-Enabled Smart Soil Monitoring System using Moisture and NPK Sensor

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***Abstract*—In today's world, the need for smart and efficient agricultural practices has increased due to growing food demand and limited resources. The proposed 5G-enabled smart soil monitoring system uses soil moisture and NPK sensors to monitor soil conditions in real time. The sensors, integrated with an ESP32 microcontroller and enclosed within a sensor unit, collect data related to soil moisture and essential nutrients such as Nitrogen, Phosphorus, and Potassium. This data is transmitted to the IoT gateway (RUTX50), which provides a wireless network for communication. Users can connect their devices to the gateway's Wi-Fi and access real-time data through the VVDN dashboard. The system operates automatically once powered, without requiring manual configuration. This approach helps in efficient irrigation and fertilizer management, reduces resource wastage, and improves crop productivity. Overall, the system provides a reliable and scalable solution for precision agriculture using IoT and 5G technology.**

I. INTRODUCTION

Agriculture is the backbone of the Indian economy, yet many farming practices are still carried out using traditional methods. These methods are time-consuming, require a large amount of manpower, and often result in inefficient use of resources, affecting soil fertility, crop quality, and overall yield. In addition, unpredictable climatic conditions, irregular rainfall, and excessive use of fertilizers further degrade soil health and reduce agricultural productivity.

Although modern machinery has improved activities such as plowing and seed sowing, the application of fertilizers is still mostly done randomly without proper soil testing. This leads to nutrient imbalance in the soil, negatively impacting plant growth. Soil fertility mainly depends on the availability of essential nutrients like Nitrogen (N), Phosphorus (P), and Potassium (K), which must be maintained in proper proportions for optimal crop development.

To address these challenges, smart and automated agricultural systems are being developed. One such approach is the 5G-enabled smart soil monitoring system using moisture and NPK sensors. This system continuously monitors soil moisture levels and nutrient content in real time. The collected data is transmitted through 5G technology, which provides high-speed, reliable, and low- latency communication, allowing farmers to access accurate information remotely.

Based on real-time data, farmers can make informed decisions about irrigation and fertilizer use, avoiding overuse or underuse. This improves crop yield, reduces costs, and supports sustainable agriculture through efficient resource management.

Furthermore, the integration of IoT and 5G technology in agriculture enables continuous monitoring and data-driven decision-making. It reduces human effort and increases accuracy in farming operations. Real-time analysis of soil conditions helps in early detection of deficiencies and prevents crop damage. Thus, smart soil monitoring systems play a vital role in transforming traditional farming into modern, efficient, and technology-driven agriculture.

II. METHODOLOGY

The proposed system is implemented in the 5G Lab at Government Pharmacy College, Amravati, using soil moisture and NPK sensors to monitor soil conditions in real time. Among the 100 5G labs established across India by the Government of India, one such lab is located at Government Pharmacy College, Amravati, where this project has been developed. The sensors, pre-configured by technical experts, are connected to an ESP32 microcontroller enclosed within the sensor unit. The ESP32 collects the sensor data and sends it to the RUDX50 IoT gateway. For output, users connect their devices such as laptops or monitors to the Wi-Fi network of the IoT gateway and open the VVDN dashboard to view real-time sensor data. This system enables continuous monitoring of soil moisture and nutrient levels, helping users make accurate decisions regarding irrigation and fertilizer application.

III. FLOW CHART

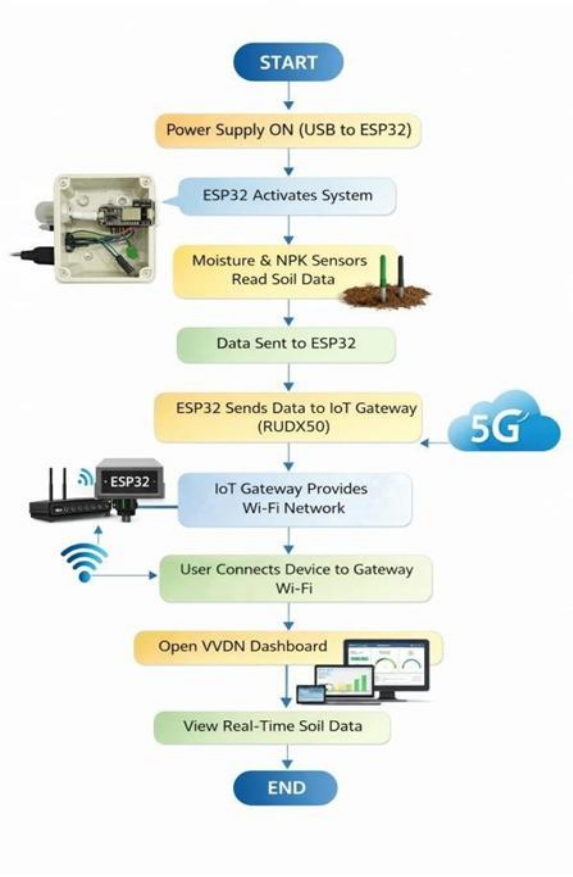


Figure 1. Flow Chart

III. HARDWARE COMPONENTS

This project uses simple and efficient hardware components to build a 5G-enabled smart soil monitoring system. The system includes soil moisture and NPK sensors, an ESP32 microcontroller, and an IoT gateway (RUTX50). These components work together to collect, process, and transmit real-time soil data for monitoring and analysis.

- ESP32 Microcontroller

This is the main part of the system, like its brain. It controls all the operations, connects to Wi-Fi, and manages both online and offline communication.

Figure 2. ESP32 Microcontroller

- RUTX50 IoT Gateway

The Teltonika RUTX50 is used in the proposed system as a communication device that connects the sensor node to the user interface. It is a high-performance industrial IoT gateway designed for real-time data transmission in smart applications. The device supports 5G connectivity along with backward compatibility for 4G and 3G networks, ensuring reliable and high-speed communication.

In this system, the RUTX50 receives processed data from the ESP32 microcontroller and transmits it over a wireless network. It also provides a Wi-Fi interface, allowing users to connect their devices such as laptops or monitors and access real-time sensor data on the VVDN dashboard. The gateway ensures low latency, stable connectivity, and efficient data transfer, which are essential for precision agriculture applications.

Figure 3. RUTX50 IoT gateway

- Key Features
- Supports 5G high-speed communication
- Provides dual-band Wi-Fi (2.4 GHz & 5 GHz)
- Equipped with multiple Ethernet (LAN/WAN) ports
- Supports dual SIM with auto failover
- Ensures low latency and reliable connectivity
- Suitable for industrial and IoT applications

- NPK Sensor

The NPK sensor is used to measure the concentration of essential nutrients in the soil, namely Nitrogen (N), Phosphorus (P), and Potassium (K). These nutrients are important for plant growth, and their monitoring helps in proper fertilizer management.

Figure 4. NPK Sensor

- Key Features
- Power supply: 5V Only
- Maximum power consumption: ≤ 0.15W
- Operating temperature: -40 to 80°C
- NPK parameters Range: 0–1999 mg/kg (mg/L)
- Resolution: 1 mg/kg (mg/L)
- Precision: ±2% FS
- Response time: ≤ 1 s
- Protection grade: IP68
- Probe material: 316 stainless steel

- Moisture Sensor

The soil moisture sensor is used to measure the water content present in the soil. It helps in determining whether the soil is dry or wet, which is useful for irrigation management. The sensor provides real-time data to the ESP32 for further processing.

Figure 5. Moisture Sensor

- Key Feature
- Operating Voltage: 5V
- Temperature Range: -40 to 125°C
- Humidity Range: 0–100% RH
- Probe Material: Plastic + Metal Type
- Temperature Accuracy: ±0.3°C (Typical)
- Humidity Accuracy: ±3% RH

IV. SOFTWARE REQUIRMENT

The system requires software components to monitor, process, and display real-time soil data efficiently.

- VVDN Dashboard

It is used to visualize real-time data received from the sensors. Users can monitor soil moisture and NPK

values through a graphical interface.

- Embedded Firmware (ESP32)

The ESP32 is pre-programmed with firmware that collects data from sensors and transmits it to the IoT gateway automatically.

- IoT Gateway Interface (RUTX50)

The gateway software manages network connectivity and data transmission between ESP32 and the dashboard.

- Web Browser

A standard web browser is used to access the VVDN dashboard by connecting to the gateway's Wi-Fi network.

V. WORKING

The 5G-enabled smart soil monitoring system operates by integrating sensors, a microcontroller, and an IoT gateway to provide real-time soil data. Initially, the system is powered through a USB connection, which activates the ESP32 microcontroller embedded inside the sensor unit. Once powered, the ESP32 automatically initializes and starts communication with the connected sensors. The soil moisture sensor measures the water content present in the soil, while the NPK sensor detects the concentration of essential nutrients such as Nitrogen (N), Phosphorus (P), and Potassium (K). These sensors continuously collect data from the soil and send it to the ESP32 microcontroller for processing.

After collecting the data, the ESP32 processes and formats it into a suitable form for transmission. Since the sensors are pre-configured, no manual setup is required, and the system operates automatically. The processed data is then transmitted wirelessly to the RUTX50 IoT gateway.

The RUTX50 gateway plays a crucial role in communication by receiving the sensor data and providing a stable network using 5G technology. It creates a Wi-Fi network that allows user devices such as laptops or monitors to connect easily.

The use of 5G ensures high-speed data transmission, low latency, and reliable connectivity.

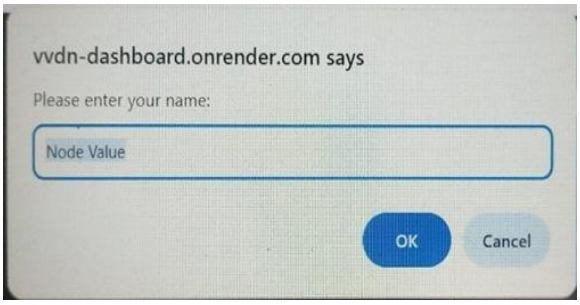
Once the user connects to the gateway's Wi-Fi network, the VVDN dashboard can be accessed through a web browser. The dashboard displays real-time soil parameters, including moisture levels and NPK values, in a user- friendly format. This enables continuous monitoring and analysis of soil conditions.

Based on the displayed data, users can make informed decisions regarding irrigation and fertilizer application. This reduces unnecessary use of water and fertilizers, improves crop productivity, and promotes efficient resource management. Thus, the system provides an automated and effective solution for smart agriculture.

VI. DASHBOARD STEP 1

Open url: https://vvdn-dashboard.onrender.com

Enter the node of the sensor mentioned on sensors Keep same node at same site example: All sensor should have same node mentioned on there box



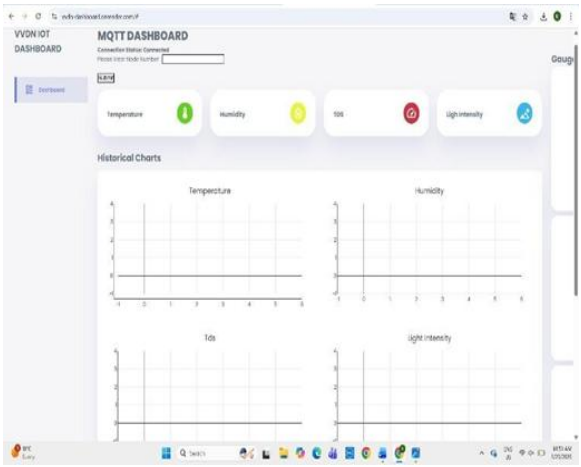


Figure 6. VVDN Dashboard

VII. RESULT

The 5G-enabled smart soil monitoring system was successfully implemented and tested in the 5G Lab at

Government Pharmacy College, Amravati.

The system effectively monitored soil moisture and NPK (Nitrogen, Phosphorus, Potassium) values in real time using pre-configured sensors connected to an ESP32 microcontroller.

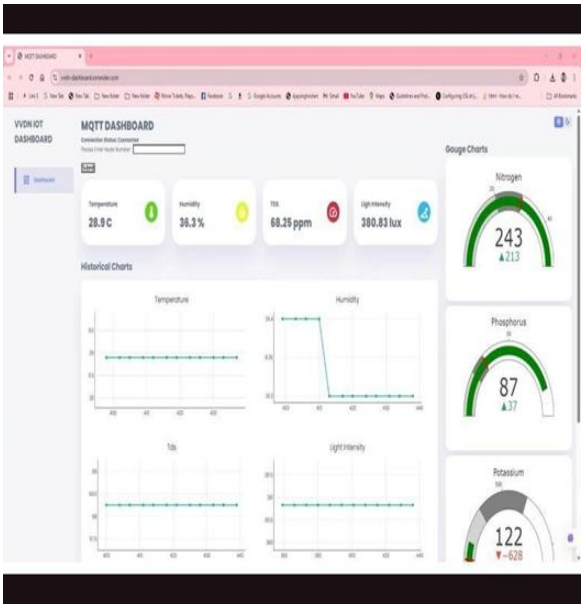


Figure 7. Result

The results showed that the system was capable of providing continuous and accurate real-time readings of soil parameters. Variations in soil moisture and nutrient levels were clearly observed on the dashboard, allowing users to analyze soil conditions effectively. The use of 5G-enabled infrastructure ensured low latency and reliable data transmission, making the system responsive and efficient.

From the observations, it was found that the system reduces the need for manual soil testing and helps in making informed decisions regarding irrigation and fertilizer application. This leads to better crop management, improved soil health, and efficient utilization of resources.

VIII. CONCLUSION

The 5G-enabled smart soil monitoring system using moisture and NPK sensors was successfully implemented in the 5G Lab at Government Pharmacy College, Amravati. The system efficiently monitors soil parameters in real time using ESP32 and RUTX50 IoT gateway. The data is accurately transmitted and displayed on the VVDN dashboard. It helps in better irrigation and fertilizer management while reducing manual effort. Overall, the system improves crop yield and supports smart and sustainable agriculture.

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