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IoT-Based Smart Soil Monitoring and Fertilizer Recommendation System

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Abstract: *Agricultural productivity is strongly influenced by soil health and the availability of essential nutrients. Conventional soil testing methods generally require sample collection, laboratory analysis and manual interpretation, which may delay decisions related to irrigation and fertilizer application. Internet of Things (IoT) technologies provide an opportunity to monitor important soil parameters continuously and make the information available remotely. This review paper studies IoT-based approaches for soil monitoring and fertilizer recommendation, with emphasis on measurement of nitrogen, phosphorus, potassium (NPK), soil pH and soil moisture. The reviewed approaches use sensors, embedded controllers, communication interfaces and cloud-based monitoring platforms to collect and process soil information. Particular attention is given to STM32F103C8T6 as the proposed processing controller, RS485 Modbus for sensor communication and ESP8266 for wireless connectivity. The paper also reviews existing methods, identifies limitations such as sensor accuracy, calibration, communication reliability and recommendation complexity, and discusses the role of data analysis in converting measured soil conditions into useful fertilizer recommendations. Based on the review, an IoT-based architecture integrating NPK, pH and moisture sensing with remote monitoring can provide a practical foundation for smart and precision agriculture.*

Keywords: IoT, Smart Agriculture, Soil Monitoring, NPK, Soil pH, Soil Moisture, STM32F103C8T6, RS485 Modbus, ESP8266, Fertilizer Recommendation..

I. INTRODUCTION

Agriculture depends on the physical and chemical condition of soil. Soil properties such as nutrient availability, pH and moisture directly influence crop growth and fertilizer requirements. Conventional soil testing generally involves collecting soil samples and performing laboratory analysis. Such testing may require
time and manual effort and may not provide continuous real-time information in the field.

Recent developments in IoT, embedded systems and wireless communication have enabled soil parameters to be sensed, processed and monitored digitally. Sensor nodes can acquire information from soil, an embedded controller can process the measurements, and a communication module can transfer the data to a cloud or IoT platform. The information can then be viewed through a mobile or web dashboard.

This survey reviews technologies relevant to IoT-based soil monitoring and fertilizer recommendation. It focuses on NPK, pH and moisture measurement, embedded processing, RS485/Modbus communication, wireless IoT connectivity and fertilizer decision support. The proposed project uses STM32F103C8T6 for processing and ESP8266 for Wi-Fi connectivity.

1.1 Background and Motivation

Traditional soil analysis can provide useful information, but laboratory-oriented testing is not continuous and may require additional time and effort. A smart monitoring system can reduce the delay between soil measurement and

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decision-making by collecting several parameters at field level. The motivation is to combine soil sensing, embedded processing and IoT monitoring in one practical architecture.

NPK information is important because nitrogen, phosphorus and potassium are major nutrients required for plant growth. Soil pH affects nutrient availability, while moisture indicates the water condition of the soil. Considering these parameters together can provide a more useful representation of soil condition.

II. REVIEW OF EXISTING IOT-BASED SOIL MONITORING APPROACHES

Existing smart-agriculture systems generally follow a sequence in which sensors collect soil information, a microcontroller or embedded processor handles the data, a communication method transfers the readings, and a user interface presents the results. Some systems emphasize real-time soil monitoring, while others combine soil information with crop or fertilizer recommendations.

IoT-based approaches differ in sensor selection, controller architecture, communication technology, cloud platform and decision-making method. Wireless technologies support remote monitoring, while wired interfaces such as RS485 can provide reliable sensor communication. Cloud platforms can store data and make it accessible through dashboards.

2.1 Soil Parameters Considered

Nitrogen (N): important nutrient parameter used in assessing soil nutrient status.

Phosphorus (P): supports plant development and nutrient management.

Potassium (K): contributes to plant growth and crop health.

Soil pH: indicates acidity/alkalinity and influences nutrient availability.

Soil moisture: indicates the water condition of soil.

2.2 Sensor and Communication Technologies

The proposed project uses an NPK sensor, pH sensor and soil-moisture sensor. RS485 Modbus is considered for sensor data exchange, while ESP8266 provides Wi-Fi connectivity between the processing system and the IoT/cloud platform. STM32 handles sensing and local processing.

III. PROPOSED SYSTEM ARCHITECTURE

The proposed system follows: Sense → Collect → Process → Analyze → Recommend → Monitor. NPK, pH and soil-moisture sensors acquire soil information. STM32F103C8T6 receives and processes the readings. The information can be displayed locally on an LCD/OLED and transmitted through ESP8266 to an IoT platform such as ThingsBoard, Blynk or Firebase. The system can generate fertilizer recommendations according to the analyzed nutrient condition.

Stage	Component	Function
Input	NPK Sensor	Measures N, P and K.
Input	pH Sensor	Measures soil pH.
Input	Soil Moisture Sensor	Measures soil moisture.
Processing	STM32F103C8T6	Processes sensor data.
Communication	RS485 Modbus	Sensor/controller communication.
Wireless	ESP8266	Wi-Fi and IoT transmission.
Output	LCD/OLED	Local display.
Cloud	ThingsBoard / Blynk / Firebase	Remote monitoring.
Decision	Fertilizer Recommendation	Supports fertilizer decisions.

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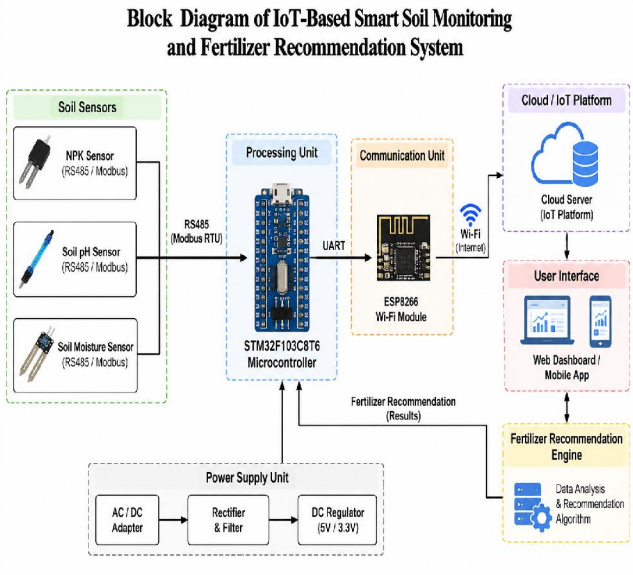

3.1 Hardware Requirements

- STM32F103C8T6 controller
- NPK sensor
- pH sensor
- Soil moisture sensor
- RS485 interface
- ESP8266 Wi-Fi module
- LCD/OLED display
- Power supply and supporting components

3.2 Software and IoT Requirements

The software side includes STM32 firmware for sensor interfacing and data processing, RS485 Modbus communication handling and ESP8266 wireless communication. The IoT side can use ThingsBoard, Blynk or Firebase according to the final implementation. A mobile or web dashboard can present sensor readings.

IV. METHODOLOGY

The methodology consists of six stages: sensing, data collection, processing, analysis, recommendation and monitoring. Sensors acquire soil values. STM32 collects and processes the data. The values are analyzed to identify soil conditions and nutrient requirements. A fertilizer recommendation is generated according to the selected decision rules. Finally, readings and recommendations are displayed locally and monitored remotely.

- Sense: acquire NPK, pH and moisture values.
- Collect: receive sensor data through the selected interface.
- Process: use STM32F103C8T6 to process measurements.
- Analyze: compare and interpret nutrient values.
- Recommend: provide fertilizer decision support.
- Monitor: display and upload information through IoT.

4.1 Fertilizer Recommendation Concept

The recommendation stage converts measured soil nutrient information into an actionable suggestion. It can consider NPK together with pH and moisture. Exact threshold values, crop-specific rules and fertilizer quantities are

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implementation-dependent and should be finalized after calibration and field testing. This review therefore treats recommendation as decision support and does not claim fixed fertilizer quantities.

V. TECHNOLOGIES USED

Technology	Role
STM32F103C8T6	Embedded processing and sensor data handling.
NPK Sensor	N, P and K measurement.
pH Sensor	Soil pH measurement.
Soil Moisture Sensor	Moisture measurement.
RS485 Modbus	Sensor/controller communication.
ESP8266	Wi-Fi and IoT connectivity.
ThingsBoard / Blynk / Firebase	Cloud monitoring.
LCD/OLED	Local display.

VI. OPEN ISSUES AND CHALLENGES

- Sensor accuracy and calibration.
- NPK measurement complexity and soil-dependent response.
- Variation of pH and moisture with soil and environment.
- RS485/Modbus and wireless communication reliability.
- Network availability for IoT monitoring.
- Crop-specific and validated fertilizer recommendation rules.
- Power, enclosure and field deployment.
- Data reliability and security.

VII. APPLICATIONS

- Smart agriculture and precision farming.
- Real-time soil health monitoring.
- Fertilizer decision support.
- Remote agricultural field monitoring.
- Moisture-based irrigation support.
- Educational and experimental soil-analysis systems.
- Soil data logging and comparison over time.

IX. CURRENT PROGRESS AND FUTURE WORK

The project plan includes literature survey, problem statement, objectives, system architecture and methodology. Hardware implementation is to be started. Future work includes sensor interfacing, STM32 firmware development, RS485 Modbus communication, ESP8266 IoT connectivity, dashboard integration, fertilizer recommendation, calibration and complete testing.

- Complete hardware assembly and sensor interfacing.
- Develop and test STM32 firmware.
- Verify RS485 Modbus communication.
- Connect ESP8266 to the selected IoT platform.
- Develop the monitoring dashboard.
- Validate fertilizer recommendation logic.
- Perform calibration and field testing.

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X. ADVANTAGES

- Multiple soil parameters in one system.
- Remote IoT monitoring.
- Local and cloud-based display.
- Support for data-driven fertilizer decisions.
- Embedded processing using STM32.
- Scope for precision agriculture.

XI. LIMITATIONS

- Sensors require calibration and validation.
- Wireless monitoring depends on network availability.
- Recommendation depends on decision rules and crop information.
- Field conditions influence measurements.
- Final performance requires practical hardware testing.

XII. CONCLUSION

IoT-based soil monitoring provides a practical approach for collecting important soil parameters such as NPK, pH and moisture. The proposed architecture combines sensors, STM32F103C8T6 processing, RS485 Modbus communication, ESP8266 wireless connectivity and an IoT dashboard to support real-time monitoring. The integration can provide useful information for fertilizer decision support. Reliable calibration, communication, field testing and crop-specific recommendation logic are essential for dependable operation.

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