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Smart Irrigation System Using AI

Mr. Rohit Chandrashekhar Iyer[1], Anjali Gadpayle[2], Sonali Kore[3], Ayushi Kharwade[4], Janvi Dakhale[5]

[1]Priyadarshini College of Engineering Department of Electronics and Communication Engineering, Nagpur, Maharashtra, India
iyerrohit@gmail.com
[2]Priyadarshini College of Engineering Department of Electronics and Communication Engineering, Nagpur, Maharashtra, India
anjaligadpyle913@gmail.com
[3]Priyadarshini College of Engineering Department of Electronics and Communication Engineering, Nagpur, Maharashtra, India
sonalidadukore@gmail.com
[4]Priyadarshini College of Engineering Department of Electronics and Communication Engineering, Nagpur, Maharashtra, India
kharwadeayushi@gmail.com
[5]Priyadarshini College of Engineering Department of Electronics and Communication Engineering, Nagpur, Maharashtra, India
jdakhale@gmail.com

ABSTRACT

Efficient water utilization and soil nutrient management are essential for improving agricultural productivity and promoting sustainable farming practices. This paper presents an AI-driven smart irrigation and soil health monitoring system that continuously monitors soil moisture and essential macronutrients, including nitrogen, phosphorus, and potassium (NPK). The proposed system integrates an NPK soil sensor with an ESP32 microcontroller through the MAX485 RS485 communication interface. The built-in Wi-Fi capability of the ESP32 enables real-time transmission and remote monitoring of sensor data. A machine learning model analyzes the collected soil parameters to determine irrigation requirements and estimate an appropriate watering duration. The measured parameters are displayed in real time using an OLED display, while a relay-controlled 12 V water pump automatically performs irrigation when required. Historical sensor data can also be stored to support long-term soil-condition analysis and crop-specific nutrient-management recommendations. By integrating IoT connectivity, multi-parameter soil sensing, and machine learning, the proposed system aims to reduce water wastage, optimize irrigation and nutrient management, and provide farmers with useful data-driven insights for precision agriculture.

Keywords: Smart Irrigation, Soil Health Monitoring, Internet of Things (IoT), Precision Agriculture, ESP32, Machine Learning; NPK Sensor, Automated Irrigation.

1. Introduction

Agriculture depends on careful management of water and soil nutrients to support healthy crop growth and maintain productivity. However, irrigation decisions are often based on fixed schedules or manual observation, which may not reflect actual field conditions. As a result, crops can receive too much or too little water, while farmers may lack timely information about soil nutrient status. Improving irrigation efficiency is particularly important because agriculture accounts for a large share of global freshwater withdrawals.

Recent advances in the Internet of Things (IoT), low-cost sensors, and artificial intelligence have made it possible to monitor agricultural conditions more continuously and make data-informed decisions. Soil-moisture sensors can indicate the water available in the root zone, while NPK sensors provide estimates of the soil's nitrogen, phosphorus, and potassium levels. When these measurements are collected over time and considered in relation to the selected crop, they can help identify changing soil conditions and inform irrigation and nutrient-management decisions.

This research proposes an AI-based smart irrigation and soil health monitoring system that integrates soil-moisture and NPK sensing with an ESP32 microcontroller. Sensor readings are transmitted for analysis through IoT connectivity, where an AI/ML system evaluates the measured parameters according to the selected crop. Based on this analysis, the system determines whether irrigation is required and estimates a suitable irrigation duration. The ESP32 then controls a 12 V water pump through a relay, allowing irrigation to be initiated automatically when the system identifies a need.

The system also provides information to users through an OLED display and a web-based dashboard. This combination of local and remote monitoring is intended to help users observe current soil conditions and irrigation activity. By retaining historical sensor data, the system can also support the tracking of soil conditions over time and provide a basis for crop-specific recommendations.

Research into IoT-based irrigation similarly uses real-time sensor data and machine-learning methods to support irrigation scheduling and improve water-use management.

The proposed system aims to reduce avoidable water use, improve the consistency of irrigation decisions, and make soil-condition information more accessible. Its integration of sensing, automated pump control, and AI-based analysis offers a practical framework for precision agriculture. The system is intended to support—not replace—agronomic judgment, since sensor readings and recommendations should be interpreted in the context of crop requirements and local growing conditions.

2. Aim and Objectives

2.1 Aim

The main aim of the proposed system is to develop an intelligent agricultural system that automatically monitors soil conditions and controls irrigation according to AI-based analysis while providing information about soil nutrient conditions.

2.2 Objectives

The major objectives of the proposed system are:

1. To continuously measure soil moisture.
2. To measure nitrogen, phosphorus, and potassium using an NPK sensor.
3. To interface the NPK sensor with the ESP32 using MAX485 RS485 communication.
4. To process sensor data using the ESP32.
5. To transmit sensor information through Wi-Fi.
6. To analyze soil parameters using a machine-learning model.
7. To determine whether irrigation is required.
8. To estimate suitable irrigation duration.
9. To display soil parameters using an OLED display.
10. To automatically control a 12V water pump using a relay.
11. To store historical sensor information.
12. Toprovide crop-specific nutrient-management recommendations.

3. Proposed System

The proposed hardware includes an ESP32 development board, capacitive soil-moisture sensor, NPK soil sensor, MAX485 RS485 interface, OLED display, relay module, 12 V DC pump, and an appropriate power supply.

The NPK sensor communicates with the ESP32 through the MAX485 module using RS485 and Modbus RTU. The moisture sensor supplies an analog signal read by the ESP32's ADC. The ESP32 collects the measurements and sends them over Wi-Fi to a Python application. That application evaluates the readings using a trained model and returns a prediction to the controller. The ESP32 then updates the display and, when appropriate, switches the pump through the relay.

Data flow: Soil sensors → ESP32 → Wi-Fi → Python AI/ML application → irrigation and soil-status prediction → ESP32 → relay → pump.

A web dashboard can display current moisture and NPK values, crop selection, soil and nutrient classifications, irrigation recommendation, pump status, and historical trends.

4. SYSTEM METHEDOLOGY

4.1 Sensor acquisition and calibration

The capacitive moisture sensor produces an analog reading. Its raw output should be calibrated using dry-soil and wet-soil reference measurements, then mapped to an approximate moisture percentage. Calibration may need to be repeated for different soil types.

The NPK sensor provides nitrogen, phosphorus, and potassium readings over RS485. The exact measurement range, units, and accuracy depend on the sensor model. Readings should be checked against suitable reference measurements before being used to train or evaluate a prediction model.

4.2 Data communication

The ESP32 packages sensor readings with crop type and a timestamp, then transmits the record over Wi-Fi. The presentation proposes Google Sheets and an Apps Script endpoint as a simple prototype data pathway, with Python retrieving the measurements and writing predictions back. A production implementation should also account for communication failures, stale data, access control, and safe pump behavior when the network or prediction service is unavailable.

4.3 Machine-learning process

The proposed model inputs are soil moisture, nitrogen, phosphorus, potassium, and crop type. The outputs may include:

- Soil condition, such as dry, normal, or wet.
- Whether irrigation is required.
- Recommended irrigation duration.
- Nutrient classifications, such as low, normal, or high.
- An overall soil-health status.

A Random Forest classifier is suggested for categorical predictions, while a separate regression model could estimate irrigation duration. These are proposed choices, not validated results. A dataset should be collected across relevant soils, crops, and growth stages, with labels based on experimentally verified decisions or reliable agricultural guidance. Training and evaluation data should be kept separate, and model performance should be assessed on previously unseen observations.

4.4 Pump control and feedback

When the model recommends irrigation, the ESP32 activates the relay and runs the pump for the recommended duration. After watering, the system measures soil moisture again to assess the change. If the soil remains below the desired condition, the controller may initiate another limited irrigation cycle. The controller should enforce a maximum run time and provide a manual override to reduce the risk of unintended pumping.

4.5 Nutrient guidance

The system compares NPK readings with crop-specific reference ranges and reports whether each nutrient appears low, normal, or high. These outputs should be treated as preliminary nutrient-management guidance. Fertilizer decisions require context such as soil type, crop variety, growth stage, and locally appropriate recommendations; sensor readings alone should not be treated as a substitute for professional soil analysis.

5. AI and Machine-Learning Module

The AI/ML module processes ESP32 sensor readings in Python to generate irrigation and soil-health recommendations. Inputs include calibrated soil moisture, nitrogen, phosphorus, potassium, and crop type. Outputs include soil status, irrigation need and duration, nutrient status, and overall soil health.

Sensor data are checked, calibrated, and labeled using verified agricultural guidance or experimentally confirmed decisions. A Random Forest classifier can predict soil status and irrigation need, while a regression model can estimate irrigation duration. Models should be tested on unseen data; report performance metrics only after evaluation.

During operation, predictions are returned to the ESP32. If irrigation is needed, it activates the relay and pump for the recommended duration; afterward, moisture is measured again. Results are shown on the OLED and dashboard. Because predictions depend on sensor accuracy and representative training data, the system requires validation under intended conditions.

Process flow: Sensor readings → data validation → trained models → recommendations → ESP32 display and pump control → post-irrigation measurement.

6. Hardware and Software

Components	**Proposed role**
ESP32	Reads sensors, communicates over Wi-Fi, updates the display, and controls the relay

Components	**Proposed role**
Capacitive moisture sensor	Measures soil moisture through an analog output
NPK soil sensor	Measures nitrogen, phosphorus, and potassium; communicates over RS485/Modbus
MAX485 module	Interfaces the ESP32 UART with the RS485 sensor
OLED display	Shows measurements and system status locally
Relay module	Switches the separate pump supply under ESP32 control
12 V DC water pump	Delivers water to the crop area
Python application	Processes data, runs the model, and supports a dashboard
Data platform	Stores sensor history and exchanges predictions with the controller

7. Limitations and Future Work

The design depends on sensor calibration and the quality of its training data. Low-cost NPK sensors may not provide laboratory-level analysis, and readings may vary with soil composition and operating conditions. A model may also perform poorly when used on crops, soils, or environmental conditions not represented in its training data. The system should therefore be considered a prototype and decision-support aid, not a replacement for professional soil testing.

Future work could add soil pH, temperature, electrical conductivity, weather, rainfall, and crop-stage information. Multiple sensor nodes could support irrigation by field zone, while long-range communication such as LoRa could be considered where Wi-Fi is unavailable. Field trials should compare the system with a specified irrigation baseline and document sensor calibration, model performance, water use, and crop outcomes.

8. Conclusion

This paper describes the design of an AI-assisted irrigation and soil-health monitoring system integrating an ESP32, soil-moisture and NPK sensing, IoT communication, machine-learning decision support, and automatic pump control. The proposed feedback loop uses sensor readings to inform irrigation and checks soil moisture after watering. A dashboard and OLED display provide visibility into system operation. The design's effectiveness remains to be demonstrated through calibrated measurements, representative data, and controlled field evaluation.

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References

1. G. Singh et al., Machine Learning based Soil Moisture Prediction for Internet of Things based Smart Irrigation System, ISPCC, 2019.
2. K. A. Gujar and S. Jagtap, Intelligent Irrigation System for Agriculture using loT and Machine Learning, ICACITE, 2022.
3. Dattatraya et al., Conventional to Modern Methods of Soil NPK Sensing: A Review, IEEE Sensors Journal, 2024.
4. B. Cheruvu et al., Smart Farming System using NPK Sensor, ICACCS, 2023.
5. R. M. C. Kota et al., ML Assisted Smart Watering System with lot for Cloud-Based Precision Agriculture, TENSYMP, 2024.
6. Atalla, S., Tarapiah, S., Gawanmeh, A., Daradkeh, M., Mukhtar, H., Himeur, Y., Mansoor, W., Hashim, K. F. B., & Daadoo, M. (2023). IoT-enabled precision agriculture: Developing an ecosystem for optimized crop management. Information, 14(4), 205. *https://doi.org/10.3390/info14040205*
7. Bouni, M., Hssina, B., Douzi, K., & Douzi, S. (2024). Integrated iot approaches for crop recommendation and yield-prediction using machine-learning. IoT, 5(4), 634–649. *https://doi.org/10.3390/iot5040028*
8. Dafonte, J., González, M. Á., Comesaña, E., Teijeiro, M. T., & Cancela, J. J. (2024). Soil water status monitoring system with proximal low-cost sensors and LoRa technology for smart water irrigation in woody crops. Sensors, 24(24), 8104. *https://doi.org/10.3390/s24248104*
9. Del-Coco, M., Leo, M., & Carcagnì, P. (2024). Machine learning for smart irrigation in agriculture: How far along are we? Information, 15(6), 306. *https://doi.org/10.3390/info15060306*

10. Lloret, J., Sendra, S., Garcia, L., & Jimenez, J. M. (2021). A wireless sensor network deployment for soil moisture monitoring in precision agriculture. Sensors, 21(21), 7243. *https://doi.org/10.3390/s21217243*

11. 1Mohiuddin, M., Islam, M. S., & Shanjida, S. (2024). Internet of things (IoT)-based smart agriculture irrigation and monitoring system using Ubidots server. ECSA-11, 99. *https://doi.org/10.3390/ecsa-11-20528*

12. Muthuramalingam, R., Rathnam Velu, R., Baskar, H., & Vellan Saminathan, M. H. (2024). An IoT-based smart irrigation system. Engineering Proceedings, 66(1), 13. *https://doi.org/10.3390/engproc2024066013*

13. Nsoh, B., Katimbo, A., Guo, H., Heeren, D. M., Nakabuye, H. N., Qiao, X., Ge, Y., Rudnick, D. R., Wanyama, J., Bwambale, E., & Kiraga, S. (2024). Internet of things-based automated solutions utilizing machine learning for smart and real-time irrigation management: A review. Sensors, 24(23), 7480. *https://doi.org/10.3390/s24237480*

14. Pereira, G. P., Chaari, M. Z., & Daroge, F. (2023). IoT-enabled smart drip irrigation system using ESP32. IoT, 4(3), 221–243. *https://doi.org/10.3390/iot4030012*

15. Zhang, Y., Wang, X., Jin, L., Ni, J., Zhu, Y., Cao, W., & Jiang, X. (2025). Research and development of an IoT smart irrigation system for farmland based on LoRa and edge computing. Agronomy, 15(2), 366. *https://doi.org/10.3390/agronomy15020366*