

IoT-Based Smart Irrigation and Soil Nutrient Management System Based Upon Crops

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Abstract

The rise of the Internet of Things (IoT) has introduced new possibilities in the field of agriculture, especially in optimizing irrigation and managing soil nutrients. This paper presents an IoT-based Smart Irrigation and Soil Nutrient Management System tailored to specific crop requirements. The proposed system automates irrigation processes and monitors real-time nutrient levels in the soil using multiple sensors. It reduces water wastage, improves crop productivity, and minimizes the need for manual labor, making it a sustainable and cost-effective solution for modern agriculture. The system integrates soil moisture detection, nutrient analysis, and cloud-based monitoring to achieve intelligent and precise farming.

Keywords: IoT, Smart Irrigation, Soil Nutrient Monitoring, Precision Agriculture, Automation, Crop-based System

1.Introduction

In recent years, the agricultural sector has been facing numerous challenges, including inefficient water usage, over-dependence on chemical fertilizers, and lack of real-time data for crop management. Traditional irrigation systems are often time-consuming, labor-intensive, and do not take into account real-time soil and environmental conditions. The incorporation of IoT into agriculture introduces the concept of smart farming, where automation and sensor data play a crucial role. This paper introduces an IoT-based system that not only automates the irrigation process but also monitors soil nutrients such as Nitrogen, Phosphorus, and Potassium (NPK) essential for crop growth. This crop-based system aims to provide an intelligent solution that supports sustainable agriculture through efficient water use, improved soil management, and increased productivity.

2.Objectives

The primary goals of this project are structured to transform traditional irrigation practices into a smart, data-driven model using IoT.

- To develop a smart irrigation system using IoT that automatically irrigates the field based on real-time soil moisture levels and specific crop requirements. This ensures that water is applied only when necessary, reducing waste and enhancing efficiency.
- To incorporate NPK sensors into the system to monitor the essential soil nutrients—Nitrogen, Phosphorus, and Potassium. By continuously analyzing these levels, the system ensures the soil remains fertile and balanced for optimal crop yield.
- To alert farmers about nutrient deficiencies and soil moisture conditions through a user-friendly mobile application. Real-time alerts allow timely intervention, such as adding fertilizers or initiating irrigation.
- To reduce manual labor and promote automation, making it easier for farmers to manage irrigation and soil health without constant field supervision. The system functions independently, providing consistent performance regardless of external human input.
- To provide a scalable and cost-effective solution that can be tailored to various crops and adapted to different geographical regions and soil conditions. The modular nature of the system allows it to be used on small farms as well as large agricultural setups, ensuring flexibility and broader impact.

3. Literature Review

Many existing systems have attempted to address irrigation automation using moisture sensors, but these systems often lack nutrient management features. Studies show that most farmers apply fertilizers without knowing the current soil composition, leading to nutrient imbalances and environmental degradation. A review of smart irrigation systems shows that systems such as Arduino-based auto irrigation models do work efficiently, but still require manual inspection for soil health. Our system overcomes this limitation by integrating real-time NPK monitoring with a crop-specific model. Research papers such as those by Patil & Kale (2016) and Kumar et al. (2019) emphasize the importance of integrating multiple parameters for effective crop management, which forms the basis for our project development.

4. Methodology

The methodology adopted involves hardware and software integration for real-time data acquisition and processing. The system begins by detecting environmental and soil parameters using sensors. These values are fed into the ESP32 microcontroller which processes the data using threshold values pre-defined for different crops. If soil moisture is below the threshold, the microcontroller activates a relay which turns on the water pump. Nutrient data is evaluated and if any deficiencies are detected, a notification is sent to the farmer via the Blynk app. Data from the sensors is uploaded to the ThingSpeak platform to visualize trends and track performance over time. The entire system is powered by either a battery or a solar power unit, ensuring continuous operation even in remote areas.

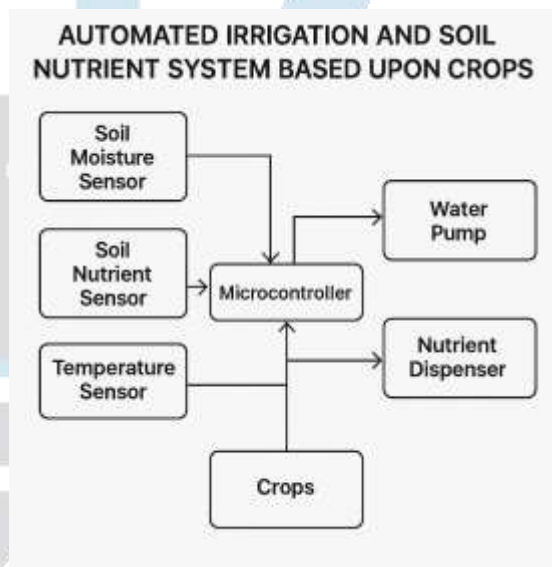
5. System Architecture

The system architecture integrates multiple hardware and software components to create a seamless and intelligent irrigation and nutrient management solution:

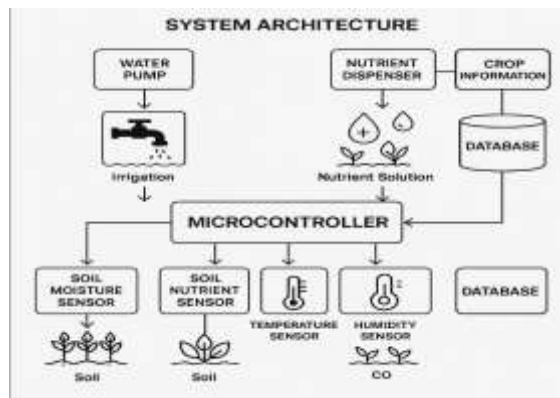
- **Soil Moisture Sensor (YL-69):** Measures the volumetric water content in the soil to determine dryness levels. It provides analog signals indicating moisture status, which are used to decide when irrigation is needed.
- **NPK Sensor:** Detects the presence and concentration of key macro-nutrients (Nitrogen, Phosphorus, and Potassium) in the

soil. These readings help determine soil fertility and prompt nutrient recommendations.

- **DHT11 Sensor:** Collects real-time environmental data, including temperature and humidity, to support accurate irrigation timing based on ambient conditions.
- **Microcontroller Unit (ESP32/Arduino UNO):** Serves as the central control unit that gathers sensor data, processes it against predefined thresholds for each crop, and sends control signals to actuators.
- **Relay Module and Solenoid Valve:** Act as switch controls for the water pump. When soil moisture is below the threshold, the relay triggers the valve and pump to initiate watering.



- **LCD Display (optional):** Displays live readings of moisture, temperature, and nutrient levels, offering local visibility of the system's performance.
- **Water Pump:** Pumps water to the crops as per control instructions from the microcontroller. It ensures timely and sufficient irrigation.
- **Solar Power Supply:** Provides an eco-friendly and reliable power source, particularly useful in remote or off-grid farming locations.



6. Components Used

Soil Moisture Sensor (YL-69): This sensor is designed to measure the volumetric water content in the soil. It uses electrical conductivity between two probes to detect moisture levels. When the soil is dry, conductivity decreases, indicating low moisture. The analog value is read by the microcontroller, which compares it to a threshold value set based on crop requirements. If the value falls below the threshold, it triggers irrigation. This sensor plays a pivotal role in conserving water by preventing unnecessary watering.

NPK Soil Sensor: The NPK sensor is a vital tool for precision agriculture, capable of detecting the concentration of Nitrogen (N), Phosphorus (P), and Potassium (K)—the three essential macronutrients required by crops. By inserting the probe into the soil, it provides real-time quantitative data which helps evaluate soil fertility. These readings help the system or farmer decide whether fertilization is needed, thus avoiding over-fertilization, improving yield, and preserving the environment.

DHT11 Sensor (Temperature and Humidity): This sensor collects environmental data such as temperature (in °C) and humidity (in %RH). It uses a thermistor and a capacitive humidity sensor for measurement. Ambient temperature and humidity influence plant transpiration rates and soil evaporation, making this data useful in fine-tuning irrigation schedules for better efficiency.

Microcontroller (ESP32 / Arduino UNO): The ESP32 or Arduino UNO acts as the brain of the system. It receives analog and digital input from various sensors, processes the data using predefined thresholds or algorithms, and outputs control signals to actuators. The ESP32 is preferred due to its built-in Wi-Fi and Bluetooth capabilities, higher processing power, and support for real-time cloud connectivity.

Relay Module & Solenoid Valve: The relay module works as an electrically operated switch, allowing the microcontroller to control high-voltage components like water pumps. It opens or closes the circuit based

on sensor input. The solenoid valve is connected in the water line and operates using the relay signal. When the valve is opened, it allows water to flow to the crops; when closed, it stops the flow, enabling automated irrigation.

Water Pump (DC/AC Submersible): The water pump facilitates the movement of water from a reservoir or underground source to the irrigation pipes. It is activated via the relay when the soil moisture level drops below the set threshold. The type and capacity of the pump can be selected based on the field size and irrigation needs.

LCD Module : An LCD display is optionally included to provide real-time on-site display of critical parameters such as soil moisture percentage, ambient temperature, humidity, and NPK levels. This feature benefits users who prefer or require local visual feedback without relying solely on cloud access.

7. Software Tools

- **Arduino IDE:** The Arduino Integrated Development Environment (IDE) is a cross-platform application used to write, compile, and upload code to microcontroller boards like the Arduino UNO or ESP32. It supports C/C++ and offers libraries and tools that simplify sensor interfacing, hardware control, and debugging, making it suitable for IoT prototyping and implementation.
- **Embedded C/C++:** These are the core programming languages used to control embedded systems. In this project, they enable communication between the microcontroller and sensors, handle logical decisions (such as when to irrigate), and ensure accurate timing and data acquisition processes. They offer low-level access to hardware features for optimal system performance.

8. Results and Discussion

Field tests were conducted for multiple crop types including paddy, maize, and tomato. The system efficiently managed irrigation and significantly reduced water usage by more than 30%. The NPK sensor helped maintain soil health by alerting the user about missing nutrients, enabling the farmer to add only the required fertilizer. Data was successfully transmitted to the Blynk app, and users could track temperature, humidity, moisture, and nutrient levels. The combination of automation and monitoring

made the system not only efficient but also easy to use, especially for farmers with limited technical knowledge.

9. Advantages

- Intelligent decision-making based on real-time data.
- Supports precision farming by adapting to specific crop needs.
- Significantly reduces water and fertilizer wastage.
- Remote access allows monitoring from anywhere.
- Low maintenance and cost-effective.
- Solar-powered option ensures energy sustainability.

10. Future Scope

The current version of the system can be further enhanced by integrating weather forecast APIs to make smarter irrigation decisions. Artificial Intelligence (AI) and Machine Learning (ML) can be used to predict irrigation cycles and detect disease symptoms. Image processing-based pest detection, multi-crop support, and multilingual user interfaces can also be incorporated to expand usability and adoption.

11. Conclusion

This paper presents a comprehensive IoT-based solution to address the critical issues in irrigation and soil health management. By using sensors and automation technologies, the system ensures that water and nutrients are supplied efficiently and as per crop needs. The proposed model offers a promising solution for sustainable and precision farming practices. It is suitable for deployment in rural areas and can be scaled for large farmlands. Through intelligent decision-making and minimal manual intervention, this system sets the foundation for the future of smart agriculture in India.

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