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IOT-Based Smart Irrigation System

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Abstract— This paper presents the design and implementation of a low-cost IoT-based Smart Irrigation System aimed at improving water management and crop productivity. The system monitors key soil parameters such as moisture content and nutrient levels (NPK) using appropriate sensors. An ESP32 microcontroller processes sensor data and controls irrigation automatically. When soil moisture falls below a predefined threshold, the system activates a water pump through a relay module, ensuring efficient and timely irrigation. Real-time monitoring is provided through a mobile application using Wi-Fi connectivity via a mobile hotspot, enabling remote access to soil data and alerts. The system is cost-effective, easy to deploy, and suitable for small-scale farmers and academic purposes. It promotes water conservation, reduced labor, and sustainable agricultural practices.

The proposed system integrates soil sensors, microcontroller-based logic, relay actuation, and IoT connectivity to deliver a complete smart irrigation solution suitable for Indian agricultural conditions.

Keywords— *IoT; Smart Irrigation; ESP32; Soil Moisture; NPK; Automation; Mobile Application.*

I. INTRODUCTION

Agriculture plays a vital role in the economy, especially in developing countries where a large population depends on farming for livelihood. Efficient water use and proper soil nutrient management are critical factors that directly affect crop yield and sustainability. Traditional irrigation methods rely heavily on manual observation and experience, often leading to over-irrigation, water wastage, and improper fertilizer application.

With the advancement of Internet of Things (IoT) technology, smart agriculture systems have gained significant importance by enabling real-time monitoring and automation. A smart irrigation system allows farmers to monitor soil conditions such as moisture level and nutrient content without frequent field visits, saving time and labor while improving crop productivity and resource utilization.

The proposed project focuses on developing a low-cost IoT-based smart irrigation system that monitors soil moisture and NPK (Nitrogen, Phosphorus, Potassium) levels using an ESP32 microcontroller. The system transmits real-time data and alerts to a mobile application through Wi-Fi via a mobile hotspot. Automatic control of the water pump based on soil moisture enhances irrigation efficiency.

II. LITERATURE REVIEW

1. A Review of Irrigation Engineering: Principles, Processes, Procedures, Design, and Management — Vijay P. Singh and Qiong Su. This reference details classical irrigation methods including surface, furrow, and sprinkler systems. The primary limitation is these systems are engineered for water delivery but disconnected from real-time soil water requirements. Eisenhauer et al. note that traditional fixed-schedule approaches fail to account for localized soil variations, leading to significant inefficiency.

2. A Review of Principles of Soil and Plant Water Relations — M.B. Kirkham. Kirkham explains soil water potential and volumetric water content, clarifying that plant health depends on actual moisture available at roots rather than watering schedule. This establishes the fundamental need for a sensor-based measurement system, which this project directly implements.

3. A Review of The Emergence of Precision and Automated Agriculture — D. Kent Shannon and David E. Clay. Shannon and Clay define precision agriculture as a

data-driven approach for site-specific management, moving beyond treating entire fields as uniform blocks. Sensors and actuators are identified as fundamental components — a principle directly embodied by this project.

4. A Review of Automated Irrigation: A Practical Guide — Dinesh Pappan. Pappan traces the evolution from ancient canals to modern IoT-enabled irrigation, discussing automation, precision scheduling, and sensors for sustainable water management. The work provides direct technical precedent for microcontroller-based sensor reading and pump control.

III. PROBLEM STATEMENT

Farmers in India face challenges including improper irrigation scheduling, lack of real-time soil information, and inefficient fertilizer usage. Conventional irrigation depends on manual soil inspection, which is time-consuming, labor-intensive, and inaccurate. Excessive irrigation leads to water wastage, while insufficient irrigation hampers crop growth. Improper knowledge of soil nutrient levels results in poor yield and soil degradation.

Existing advanced soil monitoring systems are expensive and unaffordable for small-scale farmers. There is a clear need for a low-cost, simple, and reliable system that can continuously monitor soil conditions and provide timely notifications. The problem is to design and implement a cost-effective smart irrigation system that can:

- Monitor soil moisture for efficient water usage
- Detect soil nutrient (NPK) status automatically
- Provide real-time notifications through a mobile application
- Automatically control irrigation based on soil requirements

IV. OBJECTIVES

1. IoT-based smart irrigation system with ESP32 as central controller.

2. Control water pump and monitor soil data from mobile application.

3. Drive DC water pump using relay module triggered by soil moisture readings.

4. Provide real-time NPK and moisture alerts via mobile hotspot.

5. Use a 5V/12V power supply with appropriate voltage regulation.

6. Integrate soil sensors and ESP32 for data capture and web-server dashboard.

V. PROPOSED SYSTEM

A. System Architecture / Workflow

The overall system architecture is shown in Fig. 1. Data flows from the soil sensors (moisture and NPK) to the ESP32 microcontroller, which makes automated decisions and pushes readings to the user's mobile application via Wi-Fi. When moisture falls below threshold, the ESP32 triggers the relay module which activates the DC water pump, delivering water to the crop area.

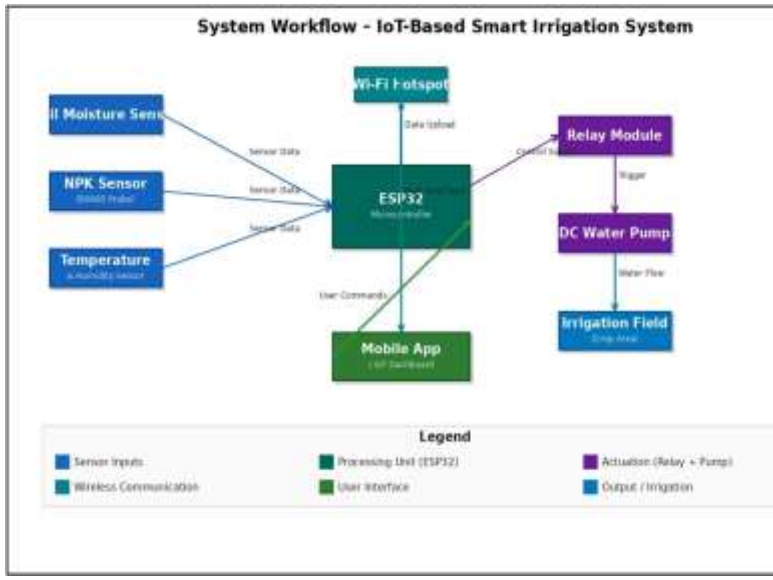

Fig. 1: System Architecture – IoT Smart Irrigation Workflow Diagram

B. NPK Sensor Module

The NPK sensor module (Fig. 2) is an RS485/UART-based stainless-steel probe that measures Nitrogen (N), Phosphorus (P), and Potassium (K) levels in soil. It outputs readings in mg/kg and operates on 5V DC drawing less than 20 mA. An RS485-to-TTL converter connects it to the ESP32 serial port, making it practical for low-cost agricultural deployment.

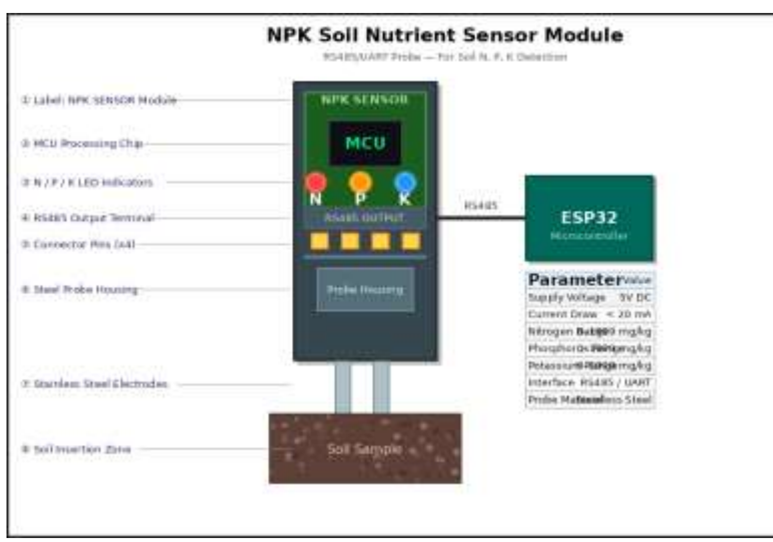

Fig. 2: NPK Soil Nutrient Sensor Module with RS485-ESP32 Interface

C. Block Diagram Overview

The system comprises five integrated modules: (1) Soil Moisture Sensor, (2) NPK Sensor Module, (3) ESP32 Microcontroller as central processing unit, (4) Relay-controlled DC Water Pump for actuation, and (5) Wi-Fi-connected Mobile Application for remote monitoring. The ESP32 processes sensor readings, triggers actuation, and simultaneously pushes telemetry to the user's mobile device.

D. Methodology

Soil Moisture Sensing: A capacitive soil moisture sensor inserted near plant roots continuously transmits analog/digital readings to the ESP32.

NPK Detection: Soil nutrient levels are estimated using the RS485-based probe sensor which interfaces with the ESP32 via a serial converter.

Control Logic: The ESP32 compares sensor values against predefined thresholds. When moisture drops below threshold, it activates the relay to energize the DC water pump. When moisture is restored, the pump is deactivated, preventing over-irrigation.

Wireless Communication: The ESP32 connects to the internet via Wi-Fi through a smartphone mobile hotspot. Sensor readings and pump status are transmitted to a mobile application or IoT dashboard for remote monitoring.

VI. SOFTWARE ARCHITECTURE

There are several software architecture types used in this embedded system:

Simple Control Loop: The software has a main loop calling subroutines that manage soil moisture sampling, NPK estimation, relay control, and Wi-Fi data transmission independently.

Interrupt-Controlled System: Timer-based interrupts trigger sensor reads at regular intervals. Serial-port controller events handle data from the NPK module, ensuring low-latency response. This brings the system close to a multitasking kernel with discrete processes.

Cooperative Multitasking: A non-preemptive multitasking approach where each task — sensor reading, pump control, and network transmission — yields control when idle. This ensures real-time responsiveness without requiring a full RTOS operating system.

Mobile Application / Web Dashboard: A lightweight web server hosted on the ESP32 provides a browser-accessible dashboard where users can view live sensor values, pump status, and notification alerts remotely from a smartphone.

VII. FIELD WORK

Field work was designed considering Indian agricultural practices, where farms are typically small, irrigation methods are traditional, and resources are limited. Soil samples were collected from nearby agricultural land, gardens, and experimental plots to test the system under realistic conditions.

Sensors were placed at appropriate depths to measure moisture levels near plant roots. Multiple tests were conducted by varying soil moisture conditions to observe system response. The pump's automatic ON/OFF operation based on soil readings was monitored carefully.

Special emphasis was placed on ease of installation, as farmers may lack access to advanced technical support. The system was tested using a mobile hotspot commonly available on rural smartphones. Field observations confirmed the system operates effectively under real Indian agricultural conditions, offering a practical and affordable irrigation solution.

VIII. TESTING

Complete integration of the ESP32, soil moisture sensor, NPK sensor module, relay, and DC water pump was tested together under controlled conditions. The system successfully performed real-time soil monitoring and automated pump control simultaneously.

Tests were conducted under varying soil moisture conditions. The pump activated correctly when moisture dropped below threshold and deactivated when the required level was restored, confirming correct operation of the automated mechanism.

Final testing confirmed successful operation of the IoT smart irrigation system including mobile application data reception and alert notification delivery.

IX. RESULTS & DISCUSSION

The Smart Irrigation System was successfully designed and tested. The ESP32 microcontroller integrated with soil moisture and NPK sensors, relay module, and DC water pump functioned as a complete automated irrigation solution.

The system reduced unnecessary water usage and minimized manual irrigation effort. Real-time data transmission to the mobile application was achieved over Wi-Fi, enabling remote monitoring of soil conditions. The NPK measurement provided approximate values suitable for academic purposes; higher precision can be achieved with electrochemical sensors in future work.

Overall, the system demonstrated good performance in automation, cost-effectiveness, and ease of use, establishing its suitability for small farms and educational applications.

X. CONCLUSION

Integrating features of all hardware components has been successfully developed in this project. Presence of every module has been reasoned out and placed carefully, thus contributing to the best working of the unit. Using highly accessible components with IoT technology, the project has been successfully implemented and tested.

The proposed IoT-based smart irrigation system provides an effective and economical solution for modern irrigation management. By automating irrigation based on real-time soil moisture and NPK nutrient data, the system significantly reduces water wastage and improves irrigation efficiency without constant manual supervision.

The project demonstrates that smart irrigation systems built on accessible microcontroller platforms can play a vital role in promoting sustainable agriculture, improving crop productivity, and conserving water resources for future generations.

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