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Smart NPK Monitoring and Control System for Precision Agriculture

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***Abstract*— Precision agriculture is revolutionizing traditional farming by integrating advanced monitoring and control systems to optimize resource utilization and enhance crop productivity. This project, "Smart NPK Monitoring and Control System for Precision Agriculture," is designed to monitor and manage soil nutrients and moisture levels using an ESP32 microcontroller. The system incorporates an NPK sensor to measure nitrogen (N), phosphorus (P), and potassium (K) concentrations, along with a soil moisture sensor to assess hydration levels.**

I. INTRODUCTION

Agriculture plays a vital role in sustaining global food production, and optimizing soil fertility is essential for maximizing crop yield. Traditional farming methods often rely on manual soil analysis and fertilizer application, which can lead to inefficient resource utilization and environmental degradation. With the advancement of smart farming technologies, automated nutrient and moisture management systems are becoming essential for precision agriculture. This project, **"**Smart NPK Monitoring and Control System for Precision Agriculture**,"** aims to provide a cost- effective and scalable solution for monitoring and managing soil nutrients and moisture levels using an ESP32 microcontroller. The system integrates an NPK sensor to measure nitrogen (N), phosphorus (P), and potassium (K) levels in the soil, along with a moisture sensor to assess soil hydration.

II. LITERATURE SURVEY

N. V. S. Sai Teja et al. (2020**)** proposed a system titled “Soil Analysis for Fertilizer Prediction using IoT and Machine Learning”, which integrates soil monitoring with intelligent fertilizer recommendation techniques. The system uses various soil sensors to collect real-time data on soil properties such as moisture, temperature, and nutrient levels. This data is transmitted through an IoT network to a cloud-basedplatform, where machine learning algorithms analyze the input and predict the most suitable type and quantity of fertilizer needed. Their work highlights how the fusion of IoT with AI can lead to precise and data-driven agricultural decisions, improving productivity while reducing waste and environmental harm. The system also aims to reduce the dependency on traditional manual analysis by automating the process,. [1].

Sabiha Kousar et al. (2023)**,** in their study titled “Monitoring and Control System for Precision Agriculture Using Wireless Sensor Network*”*, developed a comprehensive system that leverages wireless sensor networks (WSNs) to monitor critical agricultural parameters such as soil moisture, temperature, humidity, and nutrient content. The proposed architecture enables real-time data acquisition and communication between sensor nodes and a centralized processing unit, facilitating timely agricultural interventions. The system supports automated irrigation and fertilizer scheduling based on the sensor data, aiming to optimize water and nutrient use. Their research emphasizes the scalability of WSNs in large agricultural fields and the role of wireless communication in reducing labor, enhancing crop yield, and supporting decision- making processes in precision agriculture. [2]

B. Priyanka et al. (2024**)**, in their paper titled *“*An Integrated Sensor Network for Precision Agriculture: Design, Implementation, and Performance Evaluation of a Multi- Parameter Soil and Weather Monitoring System*”*, presented the development of a robust and scalable sensor network capable of monitoring both soil and weather conditions in real-time. Their system integrates sensors for soil moisture, temperature, pH, ambient temperature, humidity, and light intensity, creating a comprehensive data profile for precision farming. The collected data is wirelessly transmitted to a central server, where it is processed and analyzed for actionable insights. The authors performed an extensive performance evaluation, demonstrating the system's reliability and accuracy in diverse field conditions. Their work illustrates the effectiveness of combining environmental and soil data to optimize irrigation and fertilization, thereby improving crop quality and conserving natural resources. [3]

S. U. Belgawmar et al. (2021**)**, in their work titled “IoT-Based Irrigation Monitoring and Control System”, introduced an intelligent irrigation framework designed to automate and optimize water usage in agricultural fields. The system employs various sensors to monitor soil moisture, temperature, and humidity, and uses an IoT-enabled microcontroller to analyze the data in real time. Based on predefined thresholds, the system activates irrigation mechanisms without the need for manual intervention. The authors highlighted the use of cloud platforms for data storage and mobile applications for remote access and control. This research underlines the potential of IoT in conserving water, reducing operational costs, and supporting sustainable agriculture. [4]

III. PROPOSED SYSTEM

This system provides continuous real-time monitoring of soil nutrients and moisture levels. It allows farmers to remotely access data and control fertilizer and water delivery through a user-friendly interface. The system is designed to be cost-effective, scalable, and easy to use, making it accessible to small and medium-scale farmers. It improves resource efficiency, reduces environmental impact, and enhances crop yield by enabling precise and timely nutrient management. The proposed system introduces a Smart NPK Monitoring and Control System for Precision Agriculture. This solution integrates:

ESP32 Microcontroller: ESP32 Microcontroller for Control and Communication The ESP32 is a powerful and versatile microcontroller that features built-in Wi- Fi and Bluetooth

NPK Sensor: NPK Sensor for Measuring Nitrogen, Phosphorus, and Potassium levels**.** The NPK sensor is specifically designed to detect the concentration of essential soil nutrients.

Soil Moisture Sensor: Soil Moisture Sensor for Monitoring Water Content. Helping to determine whether irrigation is necessary.

4-Channel Relay Module: The 4-channel relay module acts as a switch that can control high-power electrical components like water pumps, solenoid valves, or fertilizer dispensers.

TCP/UDP Communication Protocols: TCP/UDP Communication Protocols for Real-Time Data Transmission and Remote Access. To facilitate real- time data transmission, the system employs TCP and
UDP.METHODOLOGY

The flowchart represents the working process of a **Smart NPK Monitoring and Control System for Precision Agriculture**. The process begins with powering on the system, followed by initializing all connected sensors and devices. Once initialized, the system reads soil nutrient datathrough NPK sensors, which measure the levels of Nitrogen (N), Phosphorus (P), and Potassium (K) in the soil. This data is then transmitted to a microcontroller or IT device for further processing. The system analyzes the sensor data by comparing the current nutrient levels with predefined optimal thresholds. If the nutrient levels are found to be within the optimal range, the system proceeds to update the fertilizer control mechanism and dispenses nutrients as required. If the levels are not within range, it determines the necessary adjustments needed to bring them into balance. After updating the fertilizer control system, the system also updates a cloud platform or mobile application dashboard to allow for remote monitoring. Finally, the system waits for a defined time interval before restarting the cycle, ensuring continuous and automated soil nutrient management to support precision farming.

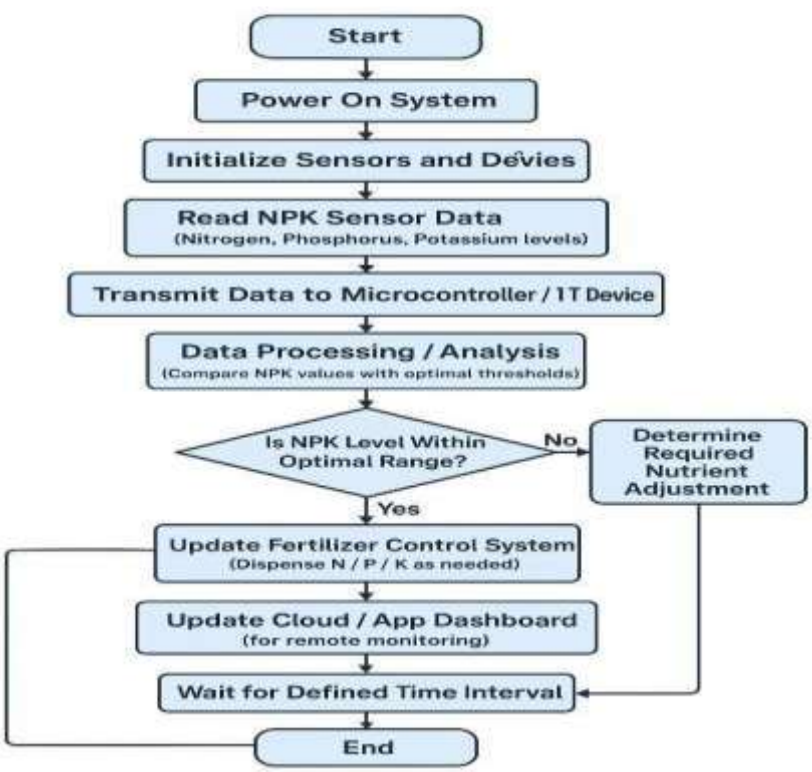

Fig 1: The flowchart represents the working process of a Smart NPK Monitoring and Control System for Precision Agriculture

A. ESP 32

ESP32 comes with an on-chip 32-bit microcontroller with integrated Wi-Fi + Bluetooth + BLE features that targets a wide range of applications. It is a series of low-power and low-cost developed by **Espressif Systems**. The **ESP32** is a powerful and versatile microcontroller developed by Espressif Systems, widely used in IoT (Internet of Things) applications due to its high performance, low power consumption, and integrated wireless connectivity.

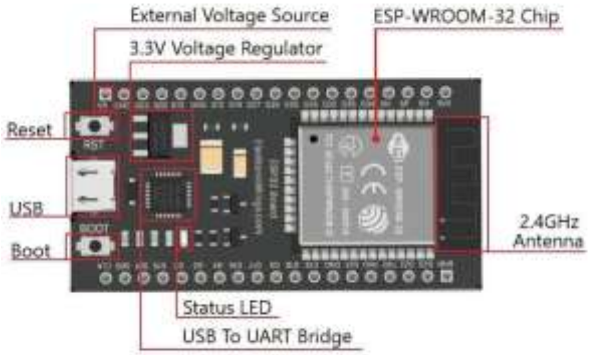

Fig 2: ESP 32 Board highlights

B. NPK SENSOR

The soil npk sensor is suitable for detecting the content of nitrogen, phosphorus, and potassium in the soil, and judging the fertility of the soil. thereby facilitating the systematic evaluation of the soil condition.

Fig 3: NPK Sensor

C. LCD DISPLAY

A liquid-crystal display (LCD) is a flat-panel display or other electronically modulated optical device that uses the light-modulating properties of liquid crystals. Liquid crystals do not emit light directly, instead using a backlight or reflector to produce images in color or monochrome. LCDs are available to display arbitrary images (as in a general-purpose computer display) or fixed images with low information content, which can be displayed or hidden, such as preset words, digits, and 7-segment displays, as in a digital clock.

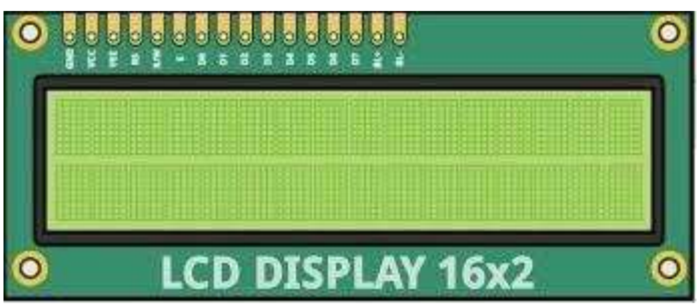

Fig 4: 16*2 LCD display

D. RELAY

A Relay is an electromechanical device that can be used to make or break an electrical connection. It consists of a flexible moving mechanical part which can be controlled electronically through an electromagnet, basically, a relay is just like a mechanical switch but you can control it with an electronic signal instead of manually turning it on or off. Again this **working principle of relay** fits only for the electromechanical relay.

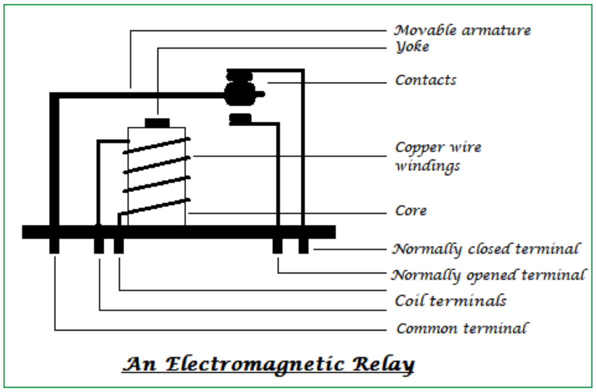

Fig 5: An electromagnetic relay

E. ARDUINO IDE

A program for Arduino may be written in any programming language for a compiler that produces binary machine code for the target processor. Atmel provides a development environment for their microcontrollers, AVR Studio and the newer Atmel Studio.The Arduino project provides the Arduino integrated development environment (IDE), which is a cross-platform application written in the programming language Java. It originated from the IDE for the languages Processing and Wiring. It includes a code editor with features such as text cutting and pasting, searching and replacing text, automatic indenting, brace matching, and syntax highlighting, and provides simple one-click mechanisms to compile and upload programs to an Arduino board. It also contains a message area, a text console, a toolbar with buttons for common functions and a hierarchy of operation menus.

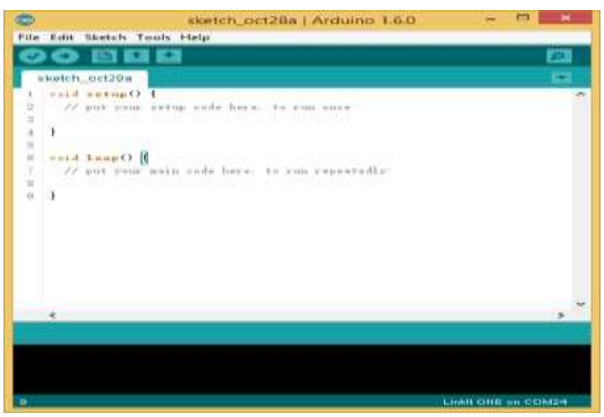

Fig 6: An Arduino Sketch

F. EMBEDDED C

When designing software for a smaller embedded system with the 8051, it is very common place to develop the entire product using assembly code. With many projects, this is a feasible approach since the amount of code that must be generated is typically less than 8 kilobytes and is relatively simple in nature. If a hardware engineer is tasked with designing both the hardware and the software, he or she will frequently be tempted to write the software in assembly language.

IV. RESULT AND DISCUSSION

The implementation of the **Smart NPK Monitoring and Control System for Precision Agriculture** successfully demonstrated the ability to automate soil nutrient monitoring and management using sensor technology and microcontroller-based control. The system was able to accurately measure the levels of Nitrogen (N), Phosphorus (P), and Potassium (K) in the soil in real time and compare them with predefined optimal thresholds. Based on the analysis, the system effectively determined the nutrient requirements

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and controlled the fertilizer dispensing mechanism accordingly. The system analyzes the sensor data by comparing the current nutrient levels with predefined optimal thresholds. The integration of the ESP32 microcontroller enabled seamless wireless communication with a cloud-based dashboard, allowing users to remotely monitor soil health and system performance. The use of time- based intervals ensured continuous monitoring and minimized manual intervention. Overall, the system enhances precision in fertilizer application, reduces nutrient wastage, supports sustainable farming practices, and offers a scalable solution for modern agriculture.

OVERVIEW OF NPK MONITORING AND CONTROL CONROL SYSTEM

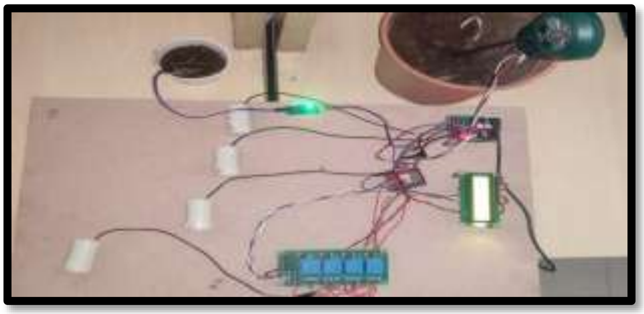

Fig 7: Model setup

The following figure shows the result of proposed system

Fig 8: Showing the NPK values

This image shows a mobile application functioning as a TCP Client, commonly used for communication over a TCP/IP network. The user has configured the app to connect to a specific target IP address, 192.168.196.203, and port 80, which is typically used for HTTP communication. After connecting, the app sends and receives data from a server or device, likely part of an IoT system used in smart agriculture. The data being received includes sensor readings such as Nitrogen (N) values, Phosphorus (P) values, Potassium (K) values, and Moisture levels. These values are displayed in real time, and the recurring message “Moist:4095” could indicate a sensor error, a default or saturated value, or the maximum reading from the moisture sensor. At one point, the message “Nitrogen Pump On” is displayed, indicating that the system has activated the nitrogen pump, possibly in response to low nitrogen readings. The letter “A” appears to be a command sent by the user to request data or trigger an action. At the bottom, there is a checkbox labeled “repeat A,” which, if selected, would continuously send the "A" command at intervals to maintain ongoing data collection or control.

Overall, this interface is part of a TCP-based communication setup used for monitoring and controlling NPK levels and moisture in precision agriculture systems.

CONCLUSION

The Smart NPK Monitoring and Control System is a cost-effective and efficient solution designed to enhance precision agriculture by optimizing soil nutrient levels and moisture management. By integrating ESP32, NPK and moisture sensors, a relay-controlled pump system, and TCP/UDP communication, this project enables real-time monitoring and remote control of soil conditions. This ensures that crops receive precisely the right amount of nutrients and water, leading to improved crop yield, soil fertility, and resource efficiency.While the system provides numerous advantages, including automation, reduced labor, and enhanced agricultural productivity, challenges such as sensor calibration, network dependency, and manual pH monitoring need to be addressed. Future enhancements, such as IoT-based cloud storage, AI-driven automation, and long-range communication protocols, can further improve the system's scalability and reliability.

Overall, this project demonstrates how smart farming technologies can contribute to sustainable agriculture, reducing resource wastage while increasing productivity. By leveraging technology for real-time soil monitoring and nutrient management, farmers can make data-driven decisions that promote efficient and environmentally friendly farming practices.

REFRENCES

[1] N. V. S. Sai Teja et al. (2020**)** proposed a system titled "Soil Analysis for Fertilizer Prediction using IoT and Machine Learning", which integrates soil monitoring with intelligent fertilizer recommendation techniques.

[2] Sabiha Kousar et al. (2023**),** in their study titled "Monitoring and Control System for Precision Agriculture Using Wireless Sensor Network", developed a comprehensive system that leverages wireless sensor networks (WSNs) to monitor critical agricultural parameters

[3] B. Priyanka et al. (2024**)**, in their paper titled "An Integrated Sensor Network for Precision Agriculture: Design, Implementation, and Performance Evaluation of a Multi-Parameter Soil and Weather Monitoring System", presented the development of a robust and scalable sensor network capable of monitoring both.

[4] U. Belgawmar et al. (2021**)**, in their work titled "IoT- Based Irrigation Monitoring and Control System", introduced an intelligent irrigation framework designed to automate and optimize water usage in agricultural fields.

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