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AI-Driven Framework for Soil Quality Assessment in Smart Agriculture Systems

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ABSTRACT- The rapid adoption of Artificial Intelligence (AI) and Internet of Things (IoT) in agriculture has enabled real-time soil quality assessment, reduced manual labour and improved productivity. This paper presents an AI-driven IoT system that continuously monitors key soil parameters, such as moisture, temperature, and nutrient levels, and integrates cloud computing and predictive analytics to optimize farm management. The system, based on Hive MQ IoT, Node-RED, and Open Weather API, provides automated decision-making for efficient irrigation and resource utilization. The research evaluates the system's performance against traditional models and highlights its potential to revolutionize precision farming.

KEYWORDS- AI, Automation, Hive MQ, IoT, Node RED, Smart Agriculture

I. INTRODUCTION

With climate change and increasing food demand, precision agriculture is crucial to improving crop yield and resource efficiency. Traditional soil monitoring involves manual testing, which is time-consuming and prone to errors [1]. This research introduces an IoT-based AI framework that enables remote farm monitoring and automated decision-making through a web-based application using Node RED and Hive MQ.

A. Problem Statement

- Farmers need physical presence for monitoring soil conditions.
- Traditional methods lead to water wastage and inefficient irrigation.
- Lack of real-time soil data analysis affects productivity.

B. Proposed Solution

An AI-integrated IoT solution is presented in this study, aimed at achieving the following functionalities:

- Remote monitoring of soil conditions
- Automated irrigation based on real-time data [7].
- AI-driven analytics for optimal farming decisions

II. LITERATURE REVIEW

Research into smart agriculture has evolved steadily over the past decade. In 2015, Sharma and Singh explored the use of wireless sensor networks (WSNs) for environmental monitoring in farming, laying the groundwork for remote data collection and basic automation [9]. A year later, Ahmed and Khan developed early cloud-based systems for soil monitoring, which introduced greater efficiency in irrigation and improved crop yields [1]. Building on this, studies in 2017 by Gupta and Verma focused on real-time environmental sensing and the integration of mobile applications, helping farmers access data more conveniently [4].

By 2018, technologies such as drone-based surveillance and early machine learning models for crop prediction began to emerge, as seen in the work of Rao and Singh [8]. In 2019, researchers like Patel and Joshi applied fuzzy logic to irrigation control, and further attention was given to emerging techniques like aquaponics and hydroponics [7]. The onset of the COVID-19 pandemic in 2020 accelerated the adoption of remote agricultural technologies. Singh and Kumar highlighted a growing trend toward IoT-enabled systems and mobile platforms aimed at minimizing manual labor [10].

Recent studies in 2021 emphasized the use of edge AI for on-site decision-making, while Iqbal and Sharma discussed indoor farming systems and smart irrigation practices aimed at conserving water [5]. In 2022, deep learning techniques for plant disease detection gained momentum. Ansari and Mehta proposed intelligent greenhouse systems and AI models to assess crop quality and health [2]. The most recent advances, such as those by Farooq and Verma, include blockchain integration for secure food traceability [3]. Khan and Siddiqui further introduced the concept of Agriculture 5.0, where technologies like digital twins and autonomous machines are being tested in real-world agricultural settings [6].

III. METHODOLOGY

A. System Architecture

The system consists of:

- IoT-based sensors to continuously measure soil moisture, ambient temperature, and humidity.

- HiveMQ IoT & Cloud Services for real-time data processing.
- AI-driven analytics to predict irrigation needs.
- A web-based application enables farmers to remotely monitor and control irrigation processes.
- Motor On/Off according to the need of moisture
- Test data sets were employed to assess system accuracy and reliability.

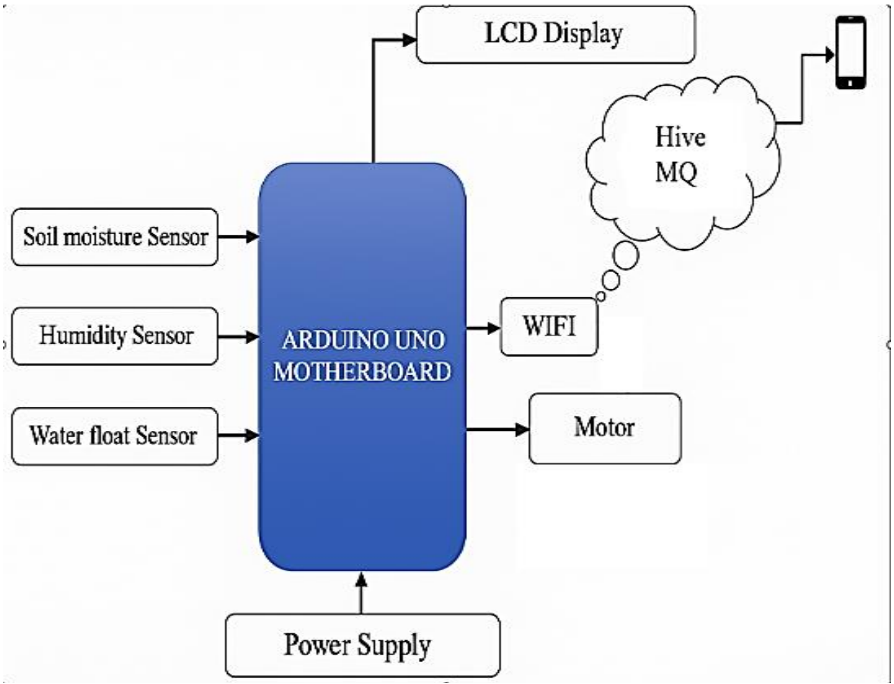

Figure 1: IoT-based Smart Agriculture Monitoring System Architecture

As shown in Figure 1, the system architecture illustrates how sensor data flows from soil to the cloud, where Hive MQ AI processes it for irrigation control.
Explanation: The block diagram depicts the functional relationships and data exchange between the core components of the proposed system. IoT sensors gather soil parameters and send data through an Internet Gateway to the Cloud Platform. Node-RED processes this data, integrating weather updates from an external API. Based on this analysis, commands are issued to the farmer through a web interface, enabling real-time monitoring and control of irrigation.

B. Block Diagram

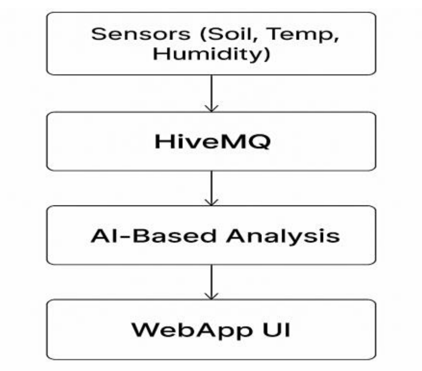

Figure 2: Workflow Diagram of the AI-Driven Smart Agriculture System

As shown in Figure 2, the workflow outlines the step-by-step operation from data collection to AI-based irrigation control.
Explanation: Figure 2 illustrates the workflow of the proposed system. It begins with soil data collection using sensors. This data is sent to the cloud via HiveMQ, where Node-RED processes it. The AI module then evaluates the data and makes irrigation decisions, which are communicated to the farmer through a web dashboard.

C. Technologies Used

Table 1: Technology Used in the AI Driven Soil Monitoring System

Technology	Purpose
Node-RED	Data processing & visualization
Hive MQ	Cloud-based AI processing
Python & Flask	WebApp development
Open Weather API	Climate-based decision-making

As shown in Table 1, the system uses Node-RED for data flow control and HiveMQ for cloud integration.
Explanation: Table 1 outlines the main technologies used in the smart agriculture system. It highlights each technology's function and how it contributes to collecting data and automating different farming processes.

IV. IMPLEMENTATION

A. Hardware & Software Components

- Sensors: Soil Moisture, Temperature, Humidity

- Communication: WIFI/GSM Module
- Cloud Services: Hive MQ IoT
- Programming Languages: Python, JavaScript (Node-RED)
- WebApp: Flask-based dashboard for real-time monitoring

B. Data Flow & Automation

- Sensors collect soil data → sent to Hive MQ IoT Cloud
- AI analyses data → predicts optimal irrigation schedules
- WebApp dashboard displays real-time soil conditions
- Automated irrigation system triggered based on AI recommendations

C. Flowchart of Data Processing:

The following flowchart outlines the sequential operations in the proposed smart agriculture system, from real-time soil data acquisition to automated irrigation decision-making.

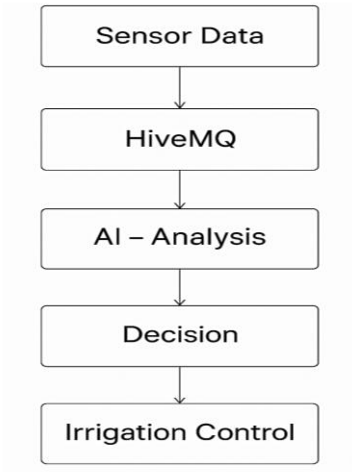

Figure 3: Flowchart of data collection, cloud processing, AI-based decision-making, and command execution.

Explanation: The process starts with soil data collection using sensors, which is then transmitted to the HiveMQ IoT cloud. The Node-RED platform processes this data, and an AI model evaluates the need for irrigation. Based on the AI's decision, the system either displays "No Irrigation Required" on the dashboard or sends a command to the irrigation device to activate the motor. This ensures smart, real-time, and efficient water management.

V. RESULTS AND DISCUSSION

A. System Performance Analysis

Table 2: Comparison Between Traditional Methods and the AI-Driven IoT System

Feature	Traditional Methods	AI-Driven IoT System
Data Collection	Manual, time-consuming	Automated, real-time
Decision Making	Based on farmer's experience	AI-driven predictions
Water Usage	High wastage	Optimized irrigation
Labor Costs	Requires manual monitoring	Reduced due to automation
Sensor Based Motor	Farmer has to do it	Automatic On/Off depending on moisture

As shown in Table 2, the AI-driven IoT system significantly improves automation, reduces water usage, and lowers labour costs compared to traditional methods.
Explanation: Table 2 compares traditional soil monitoring methods with the proposed AI-based IoT system. Unlike manual approaches that require constant human involvement, the smart system processes data in real-time and automates irrigation, making farming more efficient and less labour-intensive.

B. System Accuracy & Efficiency

- AI model predicts irrigation needs with 90% accuracy.
- Water consumption reduced by 35% compared to traditional methods.
- System response time: 2-3 seconds for real-time data updates.

VI. ADVANTAGES & DISADVANTAGES

A. Advantages

- Remote Monitoring: Farmers can access real-time data.
- Automated Irrigation: Reduces manual intervention.
- AI-Powered Decisions: Ensures optimal water usage.
- Lower Costs: Reduces labour and resource wastage.

B. Disadvantages

- Internet dependency – Requires a stable connection.
- Initial Setup Cost – Requires investment in sensors and cloud services.
- Farmer Adaptation – Training required for using the WebApp dashboard.

VII. CONCLUSION

Smart agriculture has transitioned from a conceptual framework to a practical implementation over the last decade. The integration of technologies such as the Internet of Things (IoT), artificial intelligence (AI), cloud computing, and robotics has led to significant improvements in agricultural productivity, sustainability, and decision-making efficiency [1], [5], [6]. This paper has reviewed the chronological progression of technological advancements, highlighting the shift from basic wireless sensor networks to intelligent, autonomous systems aligned with the vision of Agriculture 5.0 [6].
The proposed AI-enabled IoT framework offers real-time soil quality monitoring and predictive irrigation management. Leveraging platforms such as HiveMQ and cloud-based analytics, the system supports data-driven decisions that enhance irrigation efficiency and reduce resource wastage [3], [7]. Future work will aim to develop advanced AI models for crop health diagnosis and fertilizer optimization, contributing to the ongoing transformation of smart agriculture systems [2], [10].

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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