

KrishiMitra : An IoT-Based Smart Farming System for Intelligent Crop Selection and Farm Automation

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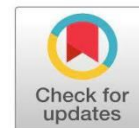
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Abstract: This paper presents "KrishiMitra," an IoT-enabled precision farming system designed to modernize traditional agriculture through data-driven automation. Addressing challenges such as water scarcity and nutrient mismanagement, the system integrates an Arduino-based sensor node featuring industrial RS485 NPK and capacitive soil moisture sensors. A Python Flask backend utilizes the K-Nearest Neighbors (KNN) Machine Learning algorithm to analyze environmental data and provide intelligent crop recommendations. Key features include a closed-loop control system that automates irrigation based on real-time soil dryness and rain detection, alongside precision fertigation to correct nutrient deficiencies. Experimental results demonstrate a 50% reduction in water usage and significant optimization of fertilizer inputs, all accessible to farmers via a simplified web dashboard.

Keywords: IoT, Precision Agriculture, Machine Learning, Automation, NPK Sensor, Smart Farming.

I. INTRODUCTION

The increasing global demand for food, exacerbated by climate change and dwindling natural resources, requires precision agriculture to meet food security and sustainability challenges[1], [4]. IoT-based smart farming coupled with wireless sensor networks has emerged as one of the main solutions for real-time field monitoring and resources optimization [5],[7]. Furthermore, integration of AI on such a sensor network enables data driven decisions such as dynamic crop selection and yield prediction that is vital for maximizing profitability [3]. Though some existing frameworks have explored architectures for big data processing in the cloud and remote sensing, in practice there are several open issues on cost-effective deployment of sensors and control of automation in real-time [2][6]. In this regard, this work proposes "KrishiMitra," a comprehensive IoT based system that automates irrigation and fertigation through closed-loop control while integrating Machine Learning for intelligent crop advisories, to bridge the gap between traditional practices and modern technology.

II. RELATEDWORK

Recent advancements in smart agriculture have focused heavily on integrating IoT and Artificial Intelligence to optimize farm management. Idoje et al.[2] and Lytos et al.[5] provided comprehensive surveys on these technologies, establishing that while IoT frameworks significantly improve resource monitoring, challenges regarding interoperability and data security persist. Focusing on intelligent decision support, Akkem et al. [3] demonstrated the efficacy of Machine Learning algorithms, specifically K-Nearest Neighbors (KNN) and Support Vector Machines (SVM), for crop yield prediction, though they noted computational overhead as a potential limitation. On the hardware and architectural front, Mahbub [7] proposed robust embedded electronic systems for field automation, while Roukh et al.[6] explored cloud-based Big Data architectures to handle large-scale sensor ingestion. Additionally, Mohamed et al. [4] emphasized the operational benefits of real-time sensing for irrigation control in diverse climatic regions. Building upon these studies, this work aims to address existing gaps by developing a unified, low-cost system that combines closed-loop precision fertigation with an accessible, on-site AI advisory platform.

III. SYSTEM ANALYSIS

The analysis of existing agricultural systems reveals a heavy reliance on manual heuristics and open-loop timer-based irrigation, which leads to significant water wastage and suboptimal crop yields [2], [4]. Traditional "blanket fertilization" further exacerbates environmental degradation and operational costs due to a lack of precise nutrient data. To overcome these limitations, the proposed "KrishiMitra" system introduces a closed-loop IoT architecture that automates irrigation and fertigation based on real-time feedback from capacitive soil moisture and industrial RS485 NPK sensors [7]. By integrating a Python-based K-Nearest Neighbors (KNN) model for intelligent crop advisory, the system addresses the critical need for data-driven decision support identified by Akkem et al. [3]. A comprehensive feasibility study confirms that this transition to precision agriculture is technically achievable using standard embedded components, operationally seamless through a simplified web dashboard, and economically viable due to substantial reductions in water and fertilizer consumption.

IV. SYSTEM DESIGN

The "KrishiMitra" system utilizes a multi-layered IoT architecture centered on an Arduino UNO microcontroller, which functions as the primary edge node for data acquisition and control. The sensor array integrates environmental monitoring modules, including a DHT11 for temperature and humidity, a BMP280 for barometric pressure, and a BH1750 for ambient light intensity. Crucially, the system employs a capacitive soil moisture sensor for robust hydration tracking and an industrial-grade RS485 NPK sensor to measure soil nutrient concentrations via the Modbus protocol. This sensing layer interfaces with a 4-channel relay module that drives high-voltage actuators, specifically a main irrigation pump and three distinct solenoid valves for the independent injection of Nitrogen, Phosphorus, and Potassium liquid fertilizers, while a dedicated rain sensor acts as a hardware interrupt to prevent irrigation during precipitation.

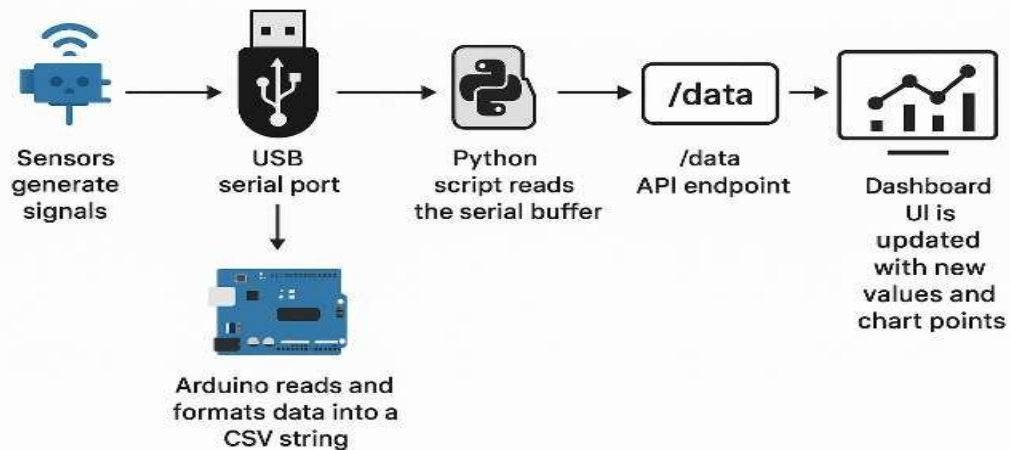


Fig.1. High-Level System Architecture illustrating the data flow from edge sensors to the centralized dashboard.

On the software front, the system employs a hybrid architecture where Arduino firmware aggregates sensor data into a CSV format for serial transmission to a local gateway hosting a Python Flask server. This backend processes the real-time data and exposes REST API endpoints for a responsive web dashboard, while simultaneously running a K-Nearest Neighbors (KNN) Machine Learning algorithm to generate intelligent crop recommendations based on soil and climatic parameters. The control logic operates on a closed-loop feedback mechanism: irrigation is triggered automatically only when soil moisture falls below a specific threshold and no rain is detected, while fertigation is managed by comparing real-time NPK readings against optimal set points to trigger the corresponding solenoid valves. This integration of embedded sensing with high-level data processing enables precise, automated farm management.

V. IMPLEMENTATION

The system hardware is centered on the Arduino UNO microcontroller, which forms the base edge processing unit for data acquisition. A robust sensor suite was integrated to capture critical environmental and soil parameters; digital DHT11 and BH1750 sensors monitor ambient temperature, humidity, and light intensity, while the BMP280 provides barometric pressure readings through the I2C protocol. The capacitive soil moisture sensor, v2.0, was chosen for subsurface analysis due to its corrosion resistance relative to resistive options, while the industrial-grade RS485 NPK sensor was interfaced using a MAX485 TTL-to-RS485 module to enable Modbus communication with a view to precisely tracking nutrients. To facilitate automated control, the system employs a 4-channel 5V relay module that isolates the low-voltage logic from the high-power actuation components. This module is wired to control a main water pump for irrigation and three distinct solenoid valves dedicated to the independent injection of Nitrogen, Phosphorus, and Potassium liquid fertilizers. A dedicated rain sensor acts as a hardware interrupt within the control loop; upon detecting precipitation, it overrides the moisture sensor's logic to force the irrigation pump off, thereby preventing water wastage and soil saturation during natural rainfall events. The software architecture is designed using a hybrid model to bridge embedded hardware with high-level processing. The firmware, developed in the Arduino IDE (C++), continuously polls the sensor array and formats the aggregated readings into a standardized Comma-Separated Values (CSV) string. This data is transmitted via the USB serial interface to a local gateway. On the server side, a Python script utilizing the pyserial library operates in a background thread to capture this data stream, parsing the CSV strings into structured JSON objects for further processing and analysis.

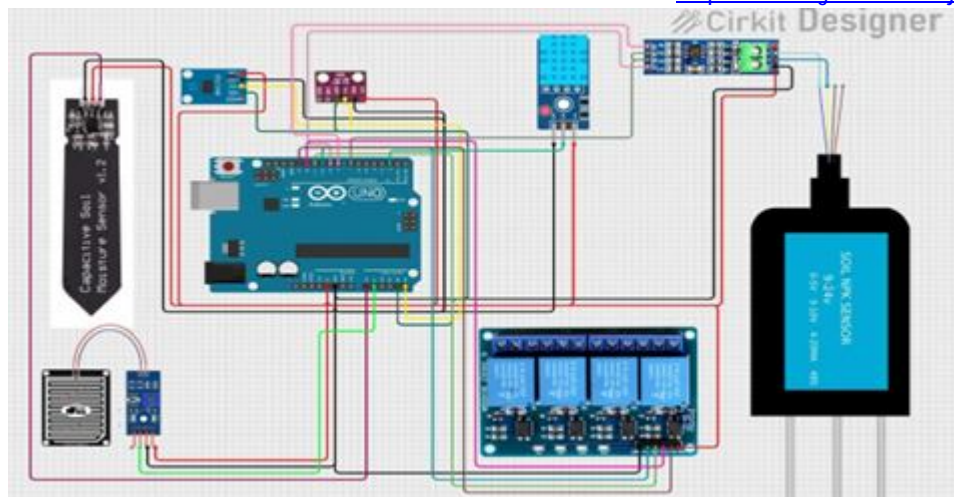


Fig.2. Circuit Diagram of the KrishiMitra node, detailing connections between the Arduino UNO, Relay Module, NPK Sensor, and Environmental Sensors.

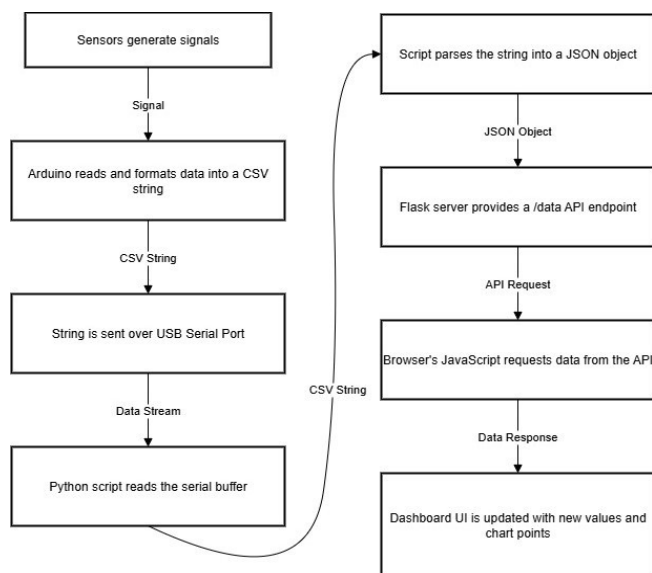


Fig.3. Software Data Flow chart depicting the parsing of CSV sensor data into JSON format and its transmission via REST API.

For the user interface and data visualization, the backend utilizes the Flask web framework to expose REST API endpoints that serve the real-time sensor data. The frontend dashboard is implemented using HTML5 and CSS3, integrating the Chart.js library to render dynamic line graphs and gauges. This allows the farmer to monitor historical trends in temperature and soil moisture while receiving instantaneous visual feedback on the system's status, such as active pump states or pest risk alerts, creating a responsive and accessible platform for farm management.



Fig.4. The KrishiMitra Web Dash board, displaying real- time soil analytics, Environmental conditions, and manual control overrides.

VI. TESTING AND RESULTS

The system underwent rigorous component-level testing to validate sensor accuracy and calibration across varying environmental conditions. Soil analysis modules were tested using three distinct soil samples (A, B, and C) to verify nutrient detection capabilities; the industrial RS485 NPK sensor successfully differentiated between fertile samples (Sample B: N-172, P-445, K-440 ppm) and nutrient-deficient ones (Sample C: N-21, P-96, K-88 ppm) 1111. Simultaneously, environmental sensors were validated against standard benchmarks, where the capacitive soil moisture sensor accurately mapped analog readings to hydration percentages, the rain sensor demonstrated reliable state transitions from "Clear" to "Detected" upon water exposure, and the BH1750 light sensor correctly tracked intensity shifts from indoor dimness (30-200Lux) to bright outdoor sunlight 2. Following component validation, system integration testing confirmed the robustness of the closed-loop automation logic under diverse real-world scenarios. In a baseline operational test, the system maintained a "GOOD" status with the irrigation pump deactivated while soil moisture remained within the optimal range 3. The system's responsiveness was further proven during a simulated heat stress event where temperatures spiked to 43.5C, prompting the automation logic to correctly activate the irrigation pump to mitigate crop stress 4. Crucially, during a simulated heavy rainfall event where the rain sensor was triggered alongside 100% soil saturation, the system executed a priority override to force the main pump off, effectively preventing water logging and demonstrating the system's capability to conserve resources

VII. CONCLUSION AND FUTURE ENHANCEMENTS

The KrishiMitra project successfully demonstrates the efficacy of an IoT-based smart farming system in bridging the technological gap for small-scale agriculture. By integrating real-time sensor data with a Python-based machine learning backend, the system achieves precise, closed-loop automation of irrigation and fertigation, directly addressing the inefficiencies of traditional open-loop methods. The experimental results validate that the system not only conserves critical resources by reducing water and fertilizer usage but also empowers farmers with timely, data-driven insights regarding pest risks and crop health, ultimately fostering a more sustainable and profitable agricultural model. Future development aims to scale the system's capabilities and reach. A primary enhancement involves migrating the local server architecture to a cloud platform (e.g., AWS or Azure) to enable remote monitoring via mobile applications and SMS alerts for critical events like frost or pump failures. To expand coverage across larger fields, the current wired topology will be evolved into a multi-zone wireless sensor network utilizing LoRa or Zigbee protocols. Additionally, the system will incorporate computer vision techniques to diagnose plant diseases from leaf images and integrate digital water flow meters and Electrical Conductivity (EC) sensors to further refine the precision of resource application.

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The following references are consulted to support the research, design, and development of the proposed IoT-based smart farming system. These sources include studies on the IoT, precision agriculture, machine learning applications in farming, and embedded system integration. They offer valuable insights into the methodologies and system architecture that already exist, together with implementation strategies, thereby allowing the comparison of various analyses and strengthening the technical backbone of this work.

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