SMART AGRI: IoT-BASED AUTOMATED IRRIGATION AND AI-DRIVEN CROP HEALTH ADVISORY SYSTEM

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Keywords:

Precision Agriculture, IoT, Raspberry Pi, Automated Irrigation, LangChain, LLM, GPT-4o, Crop Disease Detection, Nutrient Deficiency, Pest Detection, Soil Moisture, Web Dashboard.

Introduction:

Modern agriculture faces growing challenges of water scarcity, indiscriminate pesticide use, and crop losses due to undiagnosed plant diseases and nutrient deficiencies. Farmers, especially smallholders, often rely on guesswork to decide when to irrigate or what treatment to apply, resulting in resource wastage and poor yields. This project proposes a smart agriculture system that combines a multi-sensor IoT network built on Raspberry Pi Zero W nodes with a LangChain-powered AI advisory pipeline. The IoT layer continuously monitors soil moisture, temperature, humidity, rainfall, and insect sound activity to automate irrigation via solenoid valves and relay modules. The AI layer accepts plant images uploaded by the farmer through a web dashboard and fuses them with live sensor context to diagnose whether a crop is suffering from nutritional deficiency, pest infestation, or environmental stress, then prescribes the correct fertilizer or pesticide with dosage guidance. The system replaces manual judgment with data-driven, real-time decision support accessible through a browser-based interface.

Objectives:

1. To automate irrigation by monitoring soil moisture, temperature, humidity, soil temperature, and rainfall using Raspberry Pi Zero W sensor nodes, actuating solenoid valves via relay based on configurable thresholds and time-of-day schedules.
2. To provide a manual override option on the web dashboard, allowing the farmer to start or stop irrigation at will, independent of automated rules.
3. To build a LangChain AI pipeline that combines plant images uploaded by the farmer with live sensor readings and uses a vision-capable LLM (GPT-4o) to diagnose nutritional deficiencies and insect infestations, prescribing the correct fertilizer or pesticide with dosage guidance.

4. To deliver all features through a responsive web dashboard displaying live sensor readings, historical trends, irrigation controls, and AI advisory reports, with data persisted in PostgreSQL (POC) and a migration path to Firebase for production deployment.

Methodology:

The system is implemented in five integrated layers:

(1) Sensor Node Setup – Each node uses a Raspberry Pi Zero W connected to a capacitive soil moisture sensor, DHT22 (temperature and humidity), DS18B20 soil temperature sensor, raindrop sensor, and a microphone/sound sensor for insect activity detection. Nodes are deployed across field sections.

(2) Data Acquisition and Communication – The Pi reads all sensors at fixed intervals, timestamps the readings, and transmits JSON payloads over Wi-Fi using HTTP/MQTT protocols to a backend server. Data is stored in PostgreSQL for the POC phase, with Firebase Firestore as the production target.

(3) Automated Irrigation Control – The irrigation engine evaluates soil moisture, temperature, humidity, and rainfall to actuate solenoid valves via relay modules. A time-of-day scheduler allows farmers to set preferred watering windows. A manual override button on the web dashboard lets the farmer trigger or stop irrigation instantly.

(4) LangChain AI Crop Health Advisory – The farmer uploads plant images through the web dashboard. A LangChain pipeline constructs a multimodal prompt combining the image(s) with live sensor readings (soil moisture, temperature, humidity, sound intensity) and sends it to GPT-4o. The LLM diagnoses nutritional deficiencies (N, P, K, Fe, Mg), pest or insect infestation (cross-validated with elevated sound sensor readings), and environmental stress. It returns a structured advisory with probable diagnosis, confidence level, recommended fertilizer or pesticide, dosage, and application schedule.

(5) Web Dashboard – A responsive browser-based interface displays live sensor data with configurable alert thresholds, historical trend charts, irrigation schedule settings with manual override, and the AI advisory panel. All advisory reports are stored against the corresponding sensor snapshot for traceability.

Result and Conclusion:

In conclusion, the proposed system successfully integrates IoT-based environmental sensing with an LLM-powered crop health advisory pipeline to address two critical pain points in modern farming: inefficient irrigation and misdiagnosed crop conditions. The automated irrigation module, driven by real-time soil moisture, temperature, humidity, and rainfall data from Raspberry Pi Zero W nodes, is expected to reduce water usage by triggering watering only when required and suppressing it during precipitation. The manual override feature ensures the farmer retains full control. The LangChain AI advisory pipeline, combining farmer-uploaded plant images with live sensor context and processed through GPT-4o, is expected to accurately differentiate between nutritional deficiencies and pest infestations—conditions that are visually similar and routinely confused—and prescribe the appropriate fertilizer or pesticide with dosage. The web dashboard consolidates sensor monitoring, irrigation control, and AI advisories into a single interface accessible without technical expertise. Overall, the system demonstrates that affordable, scalable precision agriculture is achievable through the convergence of IoT and generative AI, contributing to reduced chemical use, improved crop yield, and data-driven farming practices.

References:

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Future Scope:

The future scope of this project includes:

1. Integration of drone-based aerial imaging to enable field-wide crop health scanning, allowing the LangChain AI pipeline to process multiple field zones simultaneously rather than relying solely on farmer-uploaded images.
2. Transition to a fine-tuned, open-source vision LLM (e.g., LLaVA or Gemma) deployed on-device or on a local edge server to eliminate cloud API dependency, reduce operational costs, and ensure functionality in low-connectivity rural environments.
3. Extension of the platform to support multi-crop, multi-farm management with role-based access for agricultural extension officers, enabling aggregated analytics, regional pest outbreak alerts, and government advisory integration at scale.