

AgroSense: A Real-Time Smart Irrigation Monitoring System Using IoT and Machine Learning

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Abstract - *AgroSense* is an intelligent irrigation monitoring device designed to help farmers make faster, more informed irrigation decisions. The system collects real-time data such as temperature, humidity, electric conductivity, and soil moisture using a field-deployed network of sensors. The data are transferred to a server, where a decision tree-based machine learning algorithm determines whether or not irrigation is required. Users can then access the insights using a mobile and web application, which allows them to view historical data in charts, monitor current conditions, and get timely irrigation warnings. *AgroSense*, developed utilizing cutting-edge technology and with a focus on simplicity and sustainability, is intended to reduce water waste and enable more informed farming via smart automation.

Key Words: Smart Irrigation, IoT Sensors, Machine Learning, Flutter, Real-time Data, Web and Mobile Application, Precision Agriculture, Decision trees, Flask, PostgreSQL, LH-SLTHPECR sensor, USR-W610.

1.INTRODUCTION

In most countries, especially developing ones like India where the vast majority of people depend on agriculture for their livelihood, it continues to be the foundation of both economic stability and food security. Technology has advanced in other fields, but agriculture has lagged behind in adopting new solutions, primarily due to ignorance and resource constraints. Water management stands out as one of the most pressing issues facing farmers these days. It is more important than ever to control water use in agriculture because of the rising strain that climate change is placing on freshwater resources and the unpredictable weather patterns it produces. Traditional irrigation techniques, including hand watering or schedule-based systems, frequently lead to either excessive or insufficient irrigation, which negatively impacts crop productivity and health. Conventional approaches typically overlook time-sensitive aspects including temperature, humidity, and soil moisture, which results in water waste and, in some cases, crop damage. These inefficiencies may have significant socioeconomic repercussions in regions with limited water supplies. This calls for a more intelligent, data-driven approach to irrigation—one that reduces waste

without compromising output and enables farmers to make better decisions.

1.1 Motivation

Mismanagement of agricultural water is still a major problem, with common consequences such as crop loss, low yields, and long-term environmental damage. Farmers continue to use conventional irrigation techniques, which may result in excessive or insufficient usage of water since they do not take into consideration the actual soil or weather conditions. This not only wastes valuable resources but also has an impact on farm productivity and profitability. According to research, smart irrigation systems based on the Internet of Things can reduce water consumption by up to 40% while maintaining or even increasing crop yields. *AgroSense*, our solution, uses a sensor-driven, real-time decision-support system to solve these issues. *AgroSense* uses machine learning to provide precise irrigation recommendations by taking temperature, soil moisture, and other environmental factors into account. In addition to improving water efficiency and enabling sustainable agriculture, this technology gives farmers practical insights.

1.2 Objective

This study seeks to develop and deploy a smart irrigation system that utilizes the potential of IoT and machine learning to optimize water management in agriculture. The primary objective is to create a system that is capable of providing precise and timely irrigation suggestions based on real-time soil data received from IoT-based sensors. One of the most significant goals is assessing the efficiency of a decision tree algorithm in interpreting this sensor data and making irrigation decisions. Another significant goal is the creation of an easy-to-use mobile application that enables farmers to see important soil parameters and obtain irrigation recommendations in an intuitive and user-friendly manner. In general, this research adds to the emerging body of precision agriculture by offering a real-world and effective solution to maximize water use and enhance crop yields through smart automation.

1.3 Scope

The goal of this project is to develop a smart irrigation system that uses machine learning and real-time soil monitoring to optimize agricultural water management. Using an LH-SLTHPHECR sensor, the system keeps an eye on four crucial soil parameters: temperature, pH, humidity, and electrical conductivity. A Flask-based backend receives the data wirelessly via a USB-W610 Wi-Fi module, processes it, and stores it in a PostgreSQL database. The sensor values are processed using a decision tree algorithm to determine whether irrigation is necessary. A Flutter-based smartphone application that displays historical patterns, real-time sensor values, and intelligent irrigation recommendations is how users interact with the system. The scope of this effort is limited to system creation and initial testing; automated control functions and extensive field deployment may be added in the future.

2. UNDERSTANDING PRECISION AGRICULTURE

Precision agriculture is a cutting-edge farming method that uses location-specific, real-time data that is immediately gathered from the field to inform agricultural decisions. This approach allows for the customized administration of inputs like water, fertilizer, and pesticides based on the unique needs of each location rather than employing standard procedures throughout a farm. This focused strategy minimizes environmental damage, cuts waste, and increases crop yield and quality. By keeping an eye on environmental variables, crop health, and soil conditions, technologies like GPS, GIS, and different field sensors are essential. The fundamental tenet of precision agriculture is to apply the appropriate input at the appropriate time, location, and quantity. Some advanced models also highlight a fifth element—executing these tasks in the most effective and responsible way.

2.1 The Role of Internet of Things (IoT) Devices in Modern Agriculture, Focusing on Sensor Technologies for Soil Monitoring

Internet of Things (IoT) has revolutionized farming in the current era by uniting a collection of intelligent devices and systems. In this case, IoT connects different elements such as sensors, agricultural machinery, and controllers so that tasks are automated and there is real-time feedback on essential factors such as soil health, weather, and crop status. This connection allows farmers to make well-educated, data-driven decisions, leading to improved yields and greener farming practices. Among the core applications of IoT in agriculture is the use of sensor technologies to monitor soil properties continuously. In this project, the LH-SLTHPHECR sensor has been utilized—a multifunctional multi-parameter device that can monitor soil temperature, pH, humidity (moisture), and electrical

conductivity. The sensor sends data using the USB-W610 Wi-Fi module, which provides uninterrupted transmission of data to linked systems. In contrast to traditional manual sampling, IoT sensors offer continuous streams of data, which are essential in applying machine learning models used to optimize agriculture and improve decision-making.

2.2 Application of Machine Learning Algorithms, Specifically Decision Trees, in Agricultural Decision-Making, Particularly for Irrigation Management

Machine learning has emerged as a robust tool in precision farming, providing advanced techniques to model intricate agricultural data and make forecasts that can optimize resource management and improve decision-making. Of the many machine learning algorithms, decision trees are notable for their interpretability and robust classification performance, and hence are especially suitable for use in applications such as irrigation management. A decision tree is a tree structure in which every internal node is a soil parameter, every branch is the result of that parameter, and every leaf node is a decision. For irrigation management, leaf nodes would generally be whether or not to irrigate. The algorithm operates by continuously dividing the data according to input feature values to produce balanced subsets that relate to a given outcome. Decision trees have a number of benefits for farm use, such as their capacity to process both categorical and numerical data without the need for extensive data preparation

3. RELATED WORK

3.1 Literature Survey

Various research studies have explored the convergence of IoT and machine learning to improve irrigation efficiency and foster agricultural sustainability. Mohammad Hussain Seyar et al. [1] designed a precision irrigation system that integrates neural networks, fuzzy logic, and IoT sensors, facilitating real-time monitoring of soil moisture and smart water delivery in greenhouse and open-field implementations. Their application showed substantial reductions in water loss and increased crop yield. Also, Ban Alomar and Azmi Alazzam [2] used a Mamdani-type fuzzy logic controller in their IoT-based irrigation model, controlling water flow based on pre-defined fuzzy rules associated with soil temperature and moisture. Efficiency of the system was confirmed through MATLAB simulations.

J.N. Kaggwa and A. Telukdarie [3] introduced an ML-aided IoT irrigation system optimized for crops including beans and potatoes. Their method reduced overwatering by turning on irrigation only when soil moisture fell below a

certain level, lowering the cost of operations and increasing the accuracy of irrigation. Swapnali B. Pawar et al. [4] came up with a low-cost implementation using IoT and Raspberry Pi and automated irrigation depending on crop-based moisture requirements in order to save labor and water. In a more general context, Ravesa Akhter and Shabir Ahmad Sof [5] discussed the use of IoT, data analytics, and ML in precision agriculture, proposing a predictive model for detecting apple disease while describing the challenges of integrating technology into conventional farming practices.

Additional developments are Revanth Kondaveti et al. [6], who integrated rainfall forecasting and motor optimization with Romyan's method in a smart irrigation scheme for rural water and energy efficiency. R.N. Kirtana et al. [7] suggested a Zigbee-based, solar-powered irrigation system that makes use of ETcrop modeling and machine learning to forecast crop water requirements, thus improving sustainability. Khaled Obaideen et al. [8] presented a meta-analysis presenting the effect of IoT-based smart irrigation on UN Sustainable Development Goals, focusing on enhanced water resource management and environmental gains. J. Karpagam et al. [9] proposed a sensor-driven automated irrigation system using microcontrollers, enabling real-time crop monitoring and autonomous water management to eliminate labor and ensure sustainable agriculture. Finally, Kiran Kumar Gopathoti et al. [10] utilized a logistic regression-based model with IoT sensors and past irrigation data to develop a smart scheduling system that facilitates effective water usage and enhanced agricultural productivity.

4. PROPOSED MODEL

4.1 System architecture

The idea is made up of a number of clever parts that work together to create an intelligent irrigation system that displays data in real time. The main component of the arrangement is the LH-SLTHPHECR sensor, which keeps an eye on important soil characteristics like conductivity, temperature, pH, and humidity. A Flask-based backend server receives the readings wirelessly via theUSR-W610 Wi-Fi module. A consistent record of soil conditions is created over time by the Flask server, which handles all processing and stores the data in a PostgreSQL database.

The Flask backend uses an integrated decision tree machine learning algorithm to assess this data and decide whether irrigation is necessary. The system's front end, a Flutter mobile application, then conveys the information to users. The application's straightforward, user-friendly interface with graphs and summaries shows real-time sensor readings, trends, and recommendations for intelligent irrigation.

Together, these elements create a closed-loop system that includes data gathering, analysis, and application. As a result, producers or end users may monitor soil health and make data-driven, more educated decisions about when and how to irrigate to boost crop health and conserve resources in a beautiful and efficient process.

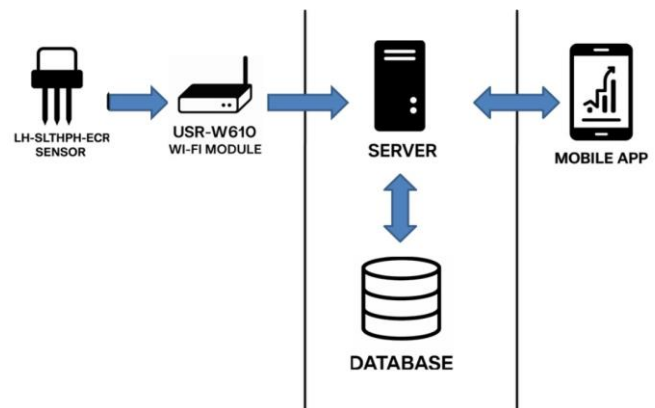


Fig 1: System architecture

4.2 Data flow

The flow of data in this system begins with the LH-SLTHPHECR sensor, which continuously monitors major soil parameters such as temperature, pH, humidity, and conductivity. This raw data gets transmitted wirelessly to the backend via theUSR-W610 Wi-Fi module, typically employing a protocol like RS485 to TCP/IP. After receiving the data from the Flask backend, it gets processed and validated and then saved in a PostgreSQL database. A decision tree algorithm, implemented in the backend, subsequently processes this data to produce irrigation suggestions. Concurrently, a Flutter mobile application on the user's device interacts with the backend by making API requests to fetch both real-time sensor readings and the most recent suggestion. The Flask server returns by extracting the data requested from the database and the output of the machine learning model and relaying it back to the app. The app shows this information in a straightforward, visual way—displaying live soil information, past patterns in graphs, and personalized irrigation recommendations. The smooth, bidirectional flow of data keeps the user continuously informed with precise, intelligent insights to make improved irrigation decisions.

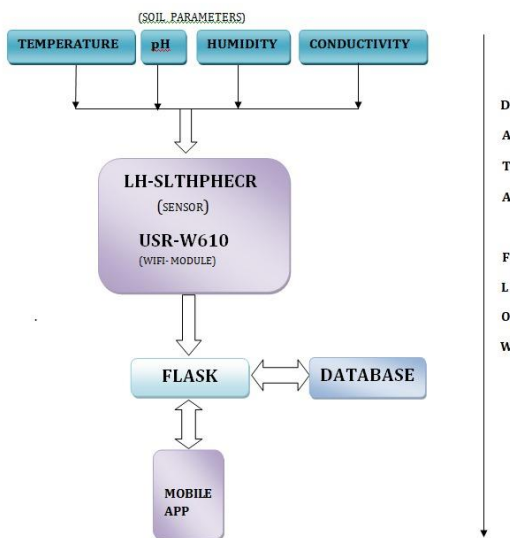


Fig 2: Data flow

5. IMPLEMENTATION

5.1 Backend Development using Flask

The smart irrigation system's backend was implemented using the Flask framework due to its versatility and lightweight nature. Flask is a microframework that works well for developing targeted web apps and RESTful APIs that efficiently connect to databases and IoT devices. Because of its simplicity, we were able to quickly set up API endpoints to control real-time data exchange between the Flutter mobile app, PostgreSQL database, and USR-W610 Wi-Fi module.

Additionally, Flask has session management and user authentication built in, enabling safe access and focused user interactions. As the main server, it handles user sessions, reacts to incoming sensor data, and starts the appropriate reactions.

Libraries like psycopg2 were used to manage the PostgreSQL integration, allowing for smooth data retrieval and storage. In order for the system to offer real-time irrigation recommendations based on real-time sensor information, the Decision Tree machine learning algorithm was also integrated into Flask.

All things considered, Flask provided a strong and efficient backend that enabled the hardware, database, mobile application, and machine learning model to guarantee smooth system integration.

5.2 Mobile Application Development with Flutter

Because the Flutter framework is cross-platform, a single codebase was used for development on both the iOS and Android platforms, allowing for a broad user base.

This allowed for the development of the mobile application. The direct interface for users to engage with the smart irrigation system is the smartphone application. The smartphone application displays real-time sensor measurements through an easy-to-use user interface. The application's graphical depiction of the historical trends of each soil parameter is among its most crucial features. The application uses charting libraries to graph time series plots by retrieving data from the PostgreSQL database using the Flask backend. This allows users to observe the evolution of soil conditions over time. HTTP requests are used to communicate between the Flask backend and the Flutter application. In order to obtain current sensor data, historical data for charting, and irrigation recommendations, the application sends calls to certain API endpoints on the backend. The requested data is returned formatted by the backend.

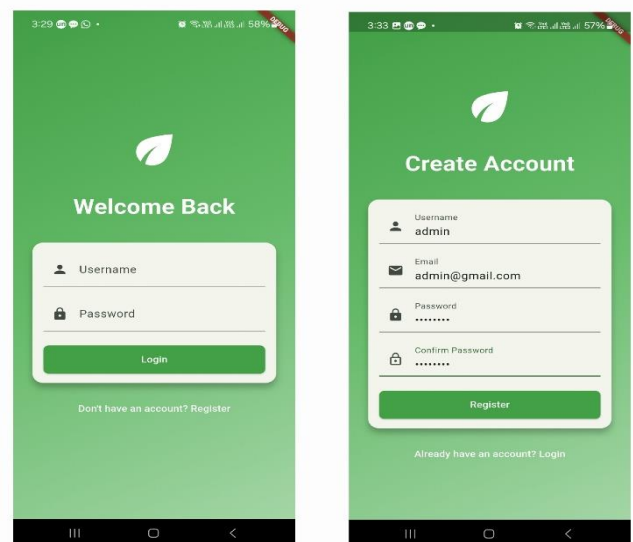


Fig 3: Login page

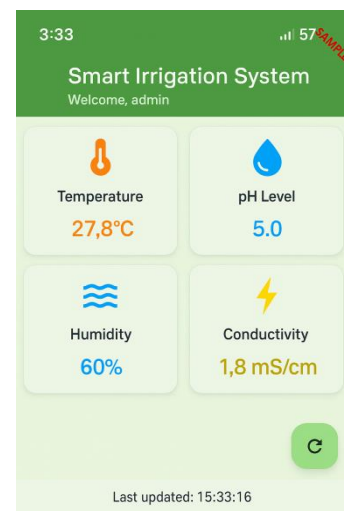


Fig 4: Sensor data Display in app

5.3 Implementation of the Decision Tree Machine Learning Algorithm

In the Flask backend of the intelligent irrigation system, a Decision Tree machine learning algorithm was used to make smart and data-based irrigation recommendations. The model operates on a straightforward binary response—either suggesting irrigation or not—based on a range of soil parameters. These parameters were scrutinized using a dataset constructed from past agronomic records that associate certain combinations of conditions with optimal irrigation action on particular crops.

In training, the dataset was split into training and test sets so that the model can be trained without overfitting. The Decision Tree was trained to identify patterns and relationships between the inputs of soil data and the resultant irrigation decision. The tree structure consists of decision nodes that check particular soil characteristics, such as moisture or temperature, with the results branching to a recommendation at the leaves of the tree.

The thresholds and decision rules were not pre-specified; rather, they were learned from the data in training. This improves the system to be flexible and adaptable to many different soil conditions. For evaluating the effectiveness of the model, common evaluation metrics such as accuracy, precision, recall, and F1-score were employed. The above metrics validated the reliability of the model and its appropriateness over other machine learning methods to this application.



Fig 5: Irrigation notification

5.4 PostgreSQL Database Design and Management

PostgreSQL was named as the database result for the smart irrigation system because of its high scalability, trustability, and superior time-series data operation capabilities. As an important object-relational database operation system, PostgreSQL is well-suited for storing structured detector data particularly when powered by extensions similar as TimescaleDB, designed to give effective running of temporal data.

Two key tables live in the database design one reserved for storing the credentials of druggies securely, and another reserved for logging detector measures of soil temperature, humidity (moisture), pH, and conductivity, each with a timestamp. The timestamp is either an indicator or a primary key so that queries can be queried snappily and efficiently over a certain time range, a demand that's imperative for examining trends and producing data visualizations.

The Flask backend interacts with PostgreSQL to add new detector records transferred by the USR-W610 Wi-Fi module. This operation is performed with the help of database libraries similar as SQLAlchemy and psycopg2, which make SQL commands for performing data operations similar as insertions and queries more manageable.

When druggies pierce the mobile app to view literal detector data, the backend fetches affiliated data from the database as per the chosen time window. For maintaining performance as data increases, timestamp indexing was done to allow effective and fast data reclamation so that the system remains responsive indeed with large data sets.

5.5 Integration of lh-slthphec Sensor and USR-W610 Wifi Module

Both the LH-SLTHPHECR sensor and the USR-W610 Wi-Fi module are used in this intelligent irrigation system to collect data as well as transmit data wirelessly. The sensor measures vital soil parameters and transmits the same through a serial interface on the Modbus RTU protocol. The sensor is connected to the USR-W610 module, which is configured to receive this serial data through a specified port.

To send the data, the USR-W610 will be used as a Wi-Fi client and connect to a local wireless network with an internet connection. The module then processes the sensor readings, encoding the data into network packets, usually in the MQTT protocol, and sends the packets to the Flask backend server via the server's IP address and port number.

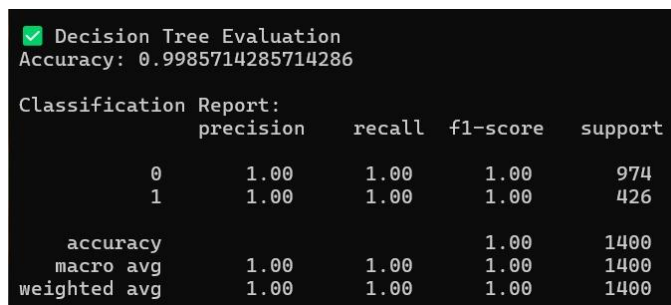
This configuration ensures that real-time soil information is accurately communicated from the field to the backend system, allowing responsive and smart irrigation control.

6. RESULTS

Data on soil parameter trends gathered by the LH-SLTHPHECR sensor and saved in the PostgreSQL database were presented in an intuitive manner by the Flutter-based mobile application. In order to understand how temperature, pH, moisture (humidity), and conductivity varied over time, users could simply see line graphs that displayed historical values of these parameters. Farmers were able to make better judgments about crop management and irrigation by learning more about soil behavior and how it responds to agricultural and environmental factors thanks to these graphical insights.

With precision, recall, and an F1-score of 0.99 (99%), the decision tree model used in the irrigation suggestion system was incredibly precise. These results demonstrate how well the model can process soil data and offer trustworthy suggestions regarding when irrigation is necessary.

Overall, by facilitating the convergence of IoT and machine learning to better manage water resources, this research contributes to the dynamic future of smart farming. This approach offers a comprehensive view of soil health, unlike methods that solely track soil moisture. By putting real-time data and practical suggestions at the farmer's fingertips, the intuitive mobile app improves the system's usefulness.



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Decision Tree Evaluation
Accuracy: 0.9985714285714286

Classification Report:
      precision    recall  f1-score   support

0         1.00         1.00         1.00         974
1         1.00         1.00         1.00         426

accuracy         1.00         1400
macro avg        1.00         1.00         1.00         1400
weighted avg     1.00         1.00         1.00         1400
    
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Fig 6: ML model Evaluation

7. CONCLUSION

In order to support more intelligent agricultural methods, this study was able to present AgroSense, a real-time smart irrigation monitoring system that uses IoT and machine learning. The system incorporates a PostgreSQL database for storing time-series and structured data, a Flask backend for handling data and executing machine learning algorithms, a USB-W610 Wi-Fi module for optimal wireless communication, the LH-SLTHPHECR sensor for detailed soil data collection, and a Flutter

mobile application that presents the data in an intuitive, user-friendly format.

These technologies work together to provide a complete and useful precision farming solution. Based on actual soil conditions, the decision tree model proved to be a very successful tool for accurately recommending irrigation.

The system's main value is in facilitating sustainable water use by providing farmers with dependable, data-based information. Future improvements could include the addition of more environmental factors (like crop or weather), autonomous irrigation system control, research into sophisticated machine learning algorithms, and additional testing in various agricultural environments to confirm performance and adaptability in a range of circumstances.

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