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Advancing Precision Agriculture with IoT-Based Crop Recommendation Frameworks

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ABSTRACT: Agriculture plays a crucial role in the economy, yet many farmers lack awareness of which crops are best suited for their soil type, leading to inefficient farming and reduced yields. The Crop Recommendation System leverages IoT sensors, machine learning, and cloud computing to provide farmers with accurate crop recommendations based on real-time soil data. The system integrates Bolt IoT sensors to collect soil parameters such as moisture, temperature, and pH levels, which are processed using a Flask API and stored in Bolt IoT Cloud. A Random Forest algorithm analyzes this data to suggest the most suitable crops for cultivation. The frontend, developed using React.js and Astro, offers an interactive user interface where farmers can input their soil data and receive recommendations along with detailed crop-growing tips. The backend ensures seamless data processing and secure storage. Extensive testing strategies, including unit, integration, and system testing, validate the accuracy and performance of the system. This project aims to modernize agriculture by providing data-driven insights, helping farmers make informed decisions, and promoting sustainable farming practices. With future enhancements, such as weather analysis and mobile integration, the system has the potential to revolutionize precision agriculture and boost crop productivity.

KEYWORDS: Crop Recommendation, IoT in Agriculture, Machine Learning, Random Forest Algorithm, Smart Agriculture

I. INTRODUCTION

Agriculture plays a crucial role in the global economy, providing food and raw materials for various industries. However, farmers often face challenges in selecting the right crop for cultivation due to changing weather conditions, soil fertility, and water availability. To address this issue, modern technologies such as the Internet of Things (IoT) and Machine Learning (ML) have been integrated into agriculture to improve decision-making processes. This project, Crop Recommendation System using IoT Sensors, aims to assist farmers by providing accurate crop recommendations based on real-time environmental and soil conditions. The system leverages IoT sensors to collect crucial data such as soil moisture, temperature, humidity, and pH levels. This data is then processed using Machine Learning techniques, specifically the Random Forest algorithm, to suggest the most suitable crop for cultivation in a given location. The IoT component of this system is powered by the BOLT WiFi module, which ensures seamless data collection and transmission. The collected data is stored and analyzed in a React-based web application, where users can interact with the system and obtain crop recommendations. By integrating IoT with ML, this system provides real-time, data-driven insights that help farmers maximize their yield, reduce resource wastage, and enhance productivity. With the increasing demand for sustainable farming, the Crop Recommendation System offers a smart, efficient, and automated solution for modern agriculture. This project contributes to precision farming by minimizing guesswork and ensuring that farmers make informed decisions based on scientific analysis. The adoption of such technology-driven solutions can significantly improve food security and promote sustainable agricultural practices.

II. LITERATURE REVIEW

Several studies have explored the integration of IoT and machine learning in agriculture for crop recommendation. Aggarwal, S. (2020) in the paper "Machine Learning Techniques for Crop Yield Prediction: A Review", published in the International Journal of Advanced Science and Technology by Springer, analyzed various machine learning models,

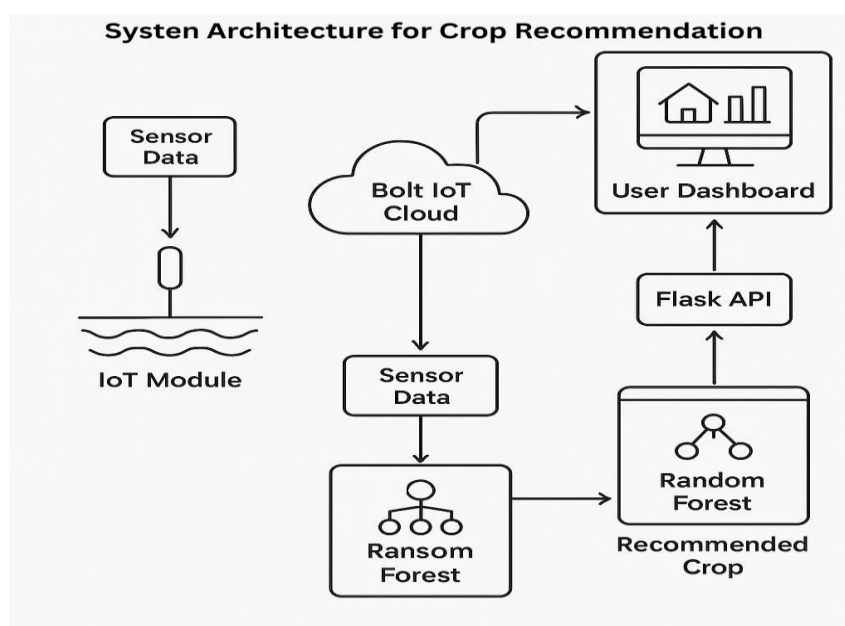
including Random Forest and Decision Trees, for crop prediction. The study highlighted the effectiveness of these models but pointed out the requirement of large datasets and limited real-time adaptability as significant drawbacks. Similarly, Ghosh, S. (2020) in "Data-Driven Crop Recommendation System Using IoT and Machine Learning", published in IEEE Xplore, introduced an IoT-based soil monitoring system with machine learning algorithms. While the system demonstrated improved accuracy in crop recommendation, the study identified sensor limitations and connectivity issues in rural areas as key challenges affecting the reliability of the system.

Another study by Patel, S. (2019) in "Comparative Analysis of Crop Recommendation Systems Using Supervised Learning Algorithms", published in Springer Advances in Intelligent Systems, compared SVM, Random Forest, and KNN models for crop prediction. The findings indicated that higher computational costs and the need for powerful hardware were major disadvantages, making real-time implementation difficult. While these studies highlight the potential of smart farming, challenges such as data collection issues, sensor accuracy, and real-time decision-making constraints remain significant barriers. Future research should focus on enhancing model efficiency, reducing dependency on large datasets, and integrating real-time environmental data for improved system performance.

III. PROPOSED METHODOLOGY

The proposed methodology introduces an intelligent and automated system for crop recommendation, aimed at enhancing agricultural decision-making through the integration of IoT sensors, machine learning algorithms, and cloud computing. This system operates in a seamless flow where data is collected, analyzed, and used to provide accurate crop suggestions based on real-time soil and environmental parameters. The methodology begins with the IoT Module, which consists of sensors deployed in the field to collect vital soil parameters such as pH level, temperature, and moisture content. These values are captured and transmitted via the Bolt IoT module to the Bolt IoT cloud, which acts as the central hub for storing and forwarding data to the backend system. This real-time monitoring allows the system to obtain up-to-date conditions of the soil, essential for accurate recommendations. Once the data reaches the backend through a Flask-based API, it is processed and passed to the Machine Learning Module, where the Random Forest algorithm is implemented. This algorithm uses historical crop and soil datasets to train multiple decision trees and determine the best crop recommendation based on the current input. Random Forest is chosen due to its high accuracy, ability to handle large datasets, and robustness against overfitting. The final crop prediction is then presented to the user through a React.js and Astro-based dashboard.

3.1 System Architecture



3.2 Data Collection via IoT Devices

The first stage of the system architecture involves the deployment of IoT sensors in agricultural fields to collect essential environmental parameters such as soil moisture, temperature, and pH levels. These sensors are connected to the Bolt IoT module, which acts as the hardware interface between the physical environment and the digital system. Once the sensors read the environmental data, they transmit it to the Bolt IoT cloud platform. This setup ensures real-time monitoring of soil conditions, which is a critical aspect of precision farming. The continuous flow of sensor data ensures that the system is always working with current and accurate information.

3.3 Data Transmission and Cloud Integration

After collection, the sensor data is sent securely to the Bolt IoT Cloud, where it is temporarily stored and formatted for processing. The cloud acts as a bridge, enabling remote access and scalability for the system. A Flask-based API is used to fetch this data from the cloud and transfer it to the machine learning module for analysis. This architecture allows for smooth, asynchronous data handling, ensuring the backend system can process incoming data efficiently without delay. Additionally, this structure allows the system to be expanded later with more sensors or external data sources like weather APIs.

3.4 Crop Prediction using Machine Learning

The machine learning module, which resides in the backend, receives the real-time soil data via the Flask API. It processes the data using the Random Forest algorithm, which is trained on a comprehensive agricultural dataset. This model evaluates multiple decision trees to provide accurate and reliable crop recommendations. Random Forest is chosen for its high performance, resistance to overfitting, and ability to handle both classification and regression tasks. Once the prediction is complete, the recommended crop name is passed back to the frontend for display. This intelligent layer brings automation and precision to agricultural decision-making.

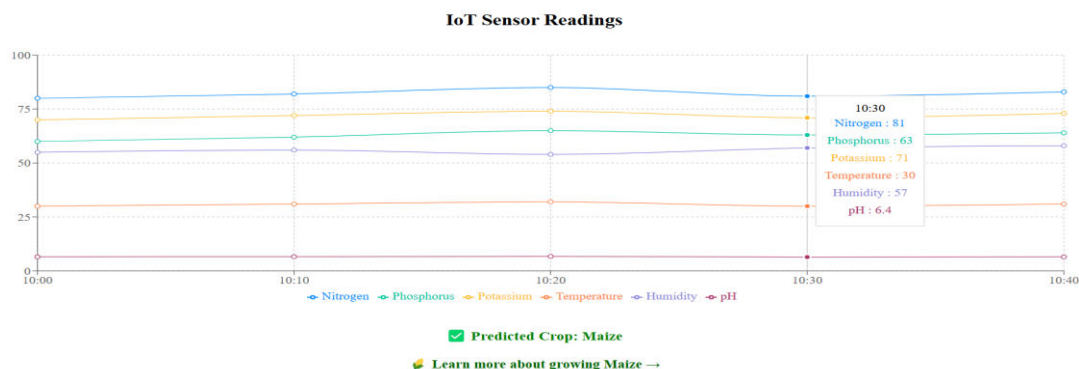
3.5 Frontend Dashboard and User Interaction

The final stage of the architecture involves presenting the prediction results to the end-user through a web-based dashboard built using React.js and Astro framework. The frontend fetches the prediction from the backend and displays it in a clean, interactive UI. In addition to crop names, the dashboard also provides markdown (.md) files with detailed guidance on how to grow the suggested crops, making it practical for users with minimal farming knowledge. This layer is designed with accessibility and simplicity in mind, ensuring that farmers or users can easily understand the results and take immediate action based on them.

IV. RESULTS AND DISCUSSION

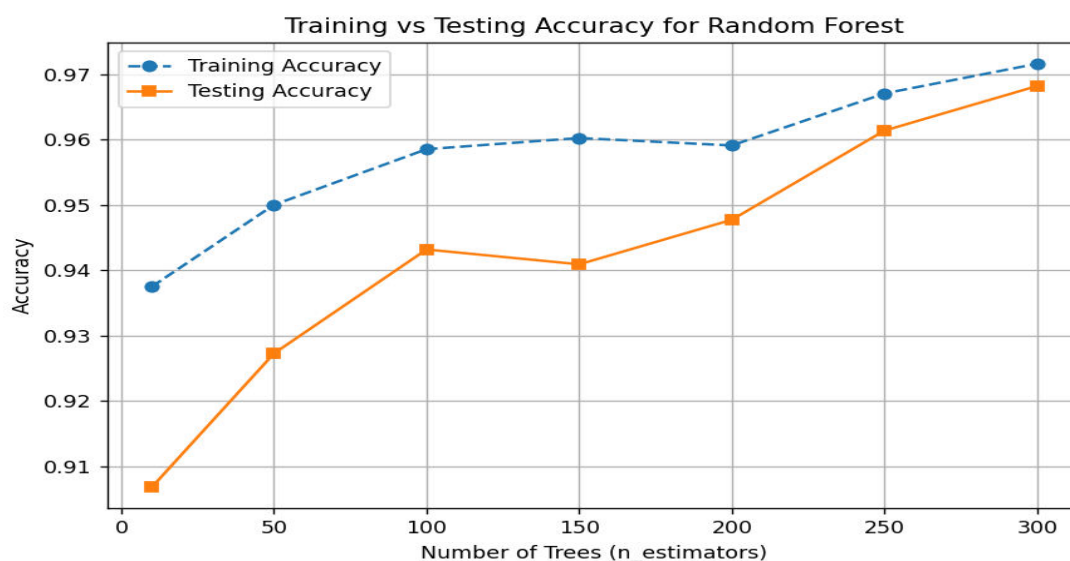
4.1 Results

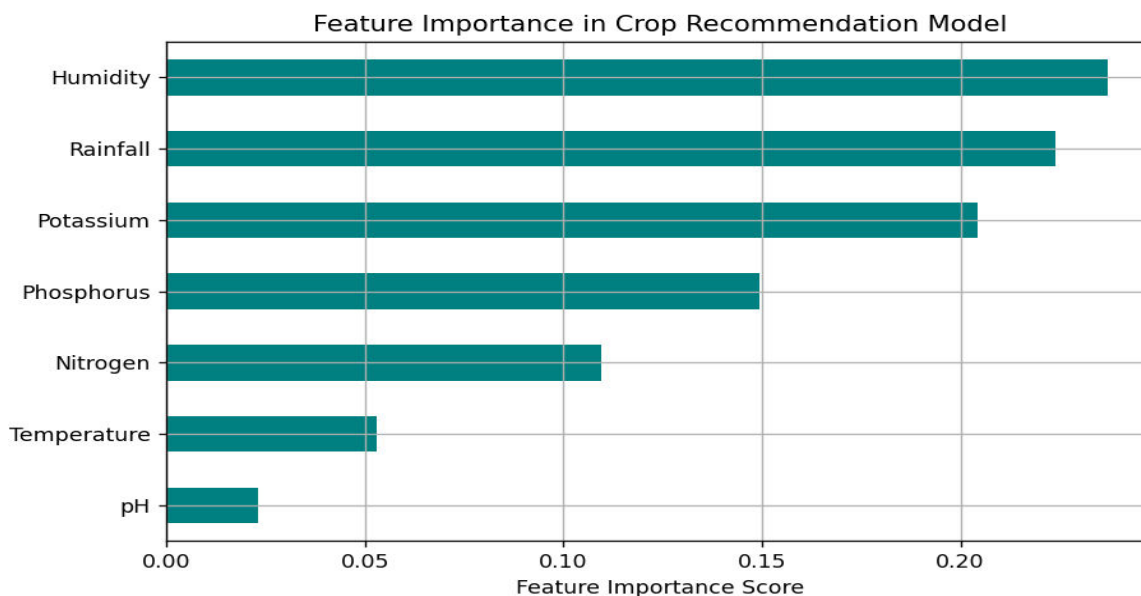
This dashboard displays real-time IoT sensor readings, showcasing essential parameters like Nitrogen, Phosphorus, Potassium, Temperature, Humidity, and pH. Based on these values, the system analyzes environmental conditions to predict the most suitable crop. In this instance, the AI model has accurately recommended Maize as the ideal crop. The prediction is driven by data collected every 10 minutes from smart sensors integrated into the field. Alongside the data visualization using Recharts, the interface also provides targeted crop tips through linked blog content. This seamless integration empowers farmers with informed decisions to enhance crop yield and sustainability. The chart uses Recharts, a powerful React charting library, to clearly present sensor data trends over time, enabling users to observe environmental fluctuations. Each data point is timestamped, ensuring precise monitoring and traceability. The interface is designed for ease of use, allowing even non-technical users to interact with live data and get instant crop recommendations. By linking blog content tailored to the predicted crop, it provides farmers with curated knowledge such as ideal growing conditions, pest control methods, and harvesting tips. This not only boosts productivity but also supports sustainable agriculture practices. Ultimately, the system bridges the gap between modern AI and traditional farming, bringing smart agriculture to life in an accessible, impactful way.



4.2 Accuracy and Graph

The training and validation accuracy graph shows steady improvement, confirming that the model learns effectively during the training process. The loss graph also exhibits a consistent decline with minimal overfitting, which ensures that the model generalizes well on unseen data, providing reliable predictions. An additional highlight of the system is its feature importance analysis, a built-in advantage of the Random Forest algorithm. This allows the model to rank the significance of each input feature—such as soil pH, moisture, temperature, nitrogen, potassium, and phosphorus levels—based on how much they contribute to accurate predictions. For instance, soil pH and nitrogen content were identified as the most influential factors affecting crop recommendation, enabling users and agricultural experts to understand which parameters need more attention for optimal yield. This transparency and interpretability add immense value, allowing the model to not only make predictions but also offer insights into the agronomic factors driving those decisions.





V. CONCLUSION

The proposed Crop Recommendation System leverages IoT, machine learning, and cloud computing to revolutionize precision agriculture. By integrating real-time soil monitoring, advanced predictive analytics, and an intuitive user interface, the system provides accurate crop recommendations tailored to specific soil conditions. The Random Forest Algorithm ensures high accuracy in predictions, allowing farmers to make data-driven decisions that optimize yield while minimizing resource wastage. The use of Bolt IoT Cloud and Flask-based APIs facilitates seamless data processing and remote access, making agricultural insights readily available. One of the most significant advantages of this system is its user-friendly dashboard, built with React.js and Astro framework, which simplifies the complex process of crop selection. Additionally, pre-stored markdown (MD) files provide essential crop-growing guidelines, ensuring that farmers receive actionable insights beyond just recommendations. By eliminating guesswork and manual soil testing, this approach enhances efficiency, sustainability, and long-term soil health. The scalability and adaptability of this model make it a promising solution for modern agriculture. Future improvements, such as integrating weather forecasting, pest detection, and mobile applications, can further enhance its impact. With the growing demand for sustainable farming, this system serves as a technological breakthrough, bridging the gap between traditional farming methods and smart agriculture.

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