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Smart Farming - Precision Agriculture Using ML

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Abstract

Agriculture is the backbone of global food production, and with the rising population, the demand for sustainable farming solutions is more critical than ever. The Smart Farming Precision Agriculture project leverages Artificial Intelligence (AI), Machine Learning (ML), Internet of Things (IoT), and drones to tackle major agricultural challenges and optimize farming operations. This system integrates IoT sensors to enable real-time data collection on crucial factors such as soil health, weather conditions, temperature, and crop status. By analyzing this data, machine learning models provide accurate predictions on crop growth, disease risks, and yield estimation. Automated features like smart irrigation, pest detection, and nutrient monitoring help farmers make informed decisions, reducing resource wastage and improving efficiency. A key feature of the project is drone-based monitoring and spraying, which ensures precise pesticide and fertilizer application, minimizing environmental impact while maximizing productivity. Additionally, CCTV surveillance enables 24/7 field monitoring, enhancing security and protecting crops from external threats like wild animals or theft. The system also includes mobile app integration, allowing farmers to receive real-time alerts, crop recommendations, and remote irrigation control, making farm management more accessible and user-friendly. The proposed solution is cost-effective, eco-friendly, and focused on long-term sustainability and profitability. By incorporating AI-driven automation, it not only improves yield but also ensures better crop protection with minimal human intervention. This project empowers farmers with data-driven insights, enabling precision farming techniques that lead to higher productivity, reduced costs, and enhanced food security.

Keywords: *AI-Powered Agriculture; Crop Recommendation; Machine Learning; Precision Agriculture; Smart Farming.*

1. Introduction

Agriculture remains the backbone of India's economy, engaging nearly 60% of the nation's population. However, to enhance productivity and sustainability, the modernization of agricultural practices has become essential. Crop yield is influenced by various factors, including weather conditions, environmental changes, rainfall distribution, irrigation efficiency, and the use of fertilizers and pesticides. Essential soil nutrients such as nitrate (N), phosphate (P), and potassium (K) play a crucial role in plant growth and overall yield. With the global population rising and food demand increasing, smart farming and precision agriculture have emerged as vital solutions. These approaches optimize resource management, enhance crop productivity, and promote sustainable farming. The

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proposed system aims to tackle key agricultural challenges, such as resource mismanagement, pest control, and accurate crop prediction, through advanced data-driven decision-making techniques.
By leveraging IoT sensors and AI-driven analytics, farmers can monitor soil quality, moisture levels, climatic conditions, and wind patterns to make informed agricultural decisions. A mobile application serves as the central hub, providing real-time data access, automated irrigation control, and personalized crop recommendations. Additionally, integrating historical data with real-time inputs from IoT devices and drones allows for immediate action insights, ultimately fostering a more profitable, efficient, and sustainable farming system.

2. Literature Survey

Agriculture remains the backbone of India's economy, engaging nearly 60% of the nation's
A typical Machine Learning (ML) framework consists of a data acquisition mechanism, which may include IoT sensors, cameras, or other monitoring devices. The collected data undergoes preprocessing steps such as filtering and normalization, after which it is divided into training and validation sets. The training dataset, which is usually larger, is used to train an Artificial Neural Network (ANN) with specific hyperparameters, while the validation dataset is utilized to assess the model's performance through metrics like Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and R^2 score. If the accuracy does not meet the required standards, the hyperparameters are adjusted, and the training cycle is repeated [1]. The field of Smart Farming (SF) is closely related to Precision Agriculture and Farm Management Information Systems (FMIS). FMIS is a digital platform that collects, processes, and stores agricultural data, enabling farmers to make data-driven decisions for improved efficiency. The use of sensors in agriculture has significantly improved farm management by providing real-time data on soil moisture, temperature, humidity, and nutrient levels. Additionally, smart farming operations require a continuous internet connection for remote monitoring and decision-making. Many automated farming operations, such as seed distribution, fertilizer application, and pesticide spraying, rely on high-speed internet access to function optimally [2].

2.1 Role of Drones in Agriculture

Drones equipped with advanced sensors and digital imaging technologies provide farmers with detailed aerial insights about their fields. GPS-based mapping enhances land assessment accuracy, optimizing crop placement strategies and improving resource efficiency. In addition, drones facilitate precise pesticide and fertilizer spraying, reducing waste and improving application efficiency. Thermal drones further assist in irrigation management by detecting moisture variations across fields. They are also useful in livestock monitoring, helping farmers track cattle movement and prevent damage to crops [3].

2.2 IoT and Remote Monitoring Technologies

The MQTT communication protocol is widely used for remote agricultural monitoring, ensuring seamless data transmission between sensors and control systems. The following MQTT topics are commonly used in agricultural IoT networks:
Sensor/moisture—Transmits soil moisture levels.
Sensor/frequency—Reports the resonance frequency of the soil sensor. Sensor/delta frequency—Indicates changes in the sensor's resonance frequency over time [4]. Monitoring real-time crop conditions is crucial for agronomic decision support. Hyperspectral and LiDAR imaging techniques have been employed to analyze biophysical characteristics of crops, enabling early stress detection and yield forecasting. These methods allow healthy crops to be differentiated from diseased ones, improving agricultural management and productivity [5].

2.3 Trends in Precision Agriculture

The advancement of big data analytics, robotics, AI, and aerial imagery has significantly enhanced precision farming. The precision agriculture market, valued at USD 8.7 billion in 2022, is projected to grow to USD 21.4 billion by 2030, with a CAGR of 11.9%. This growth is fueled by rising food demand, increased profitability, and improved crop monitoring solutions. Traditional farming often applies uniform amounts of fertilizers and pesticides across fields, leading to inefficient resource utilization. In contrast, precision agriculture utilizes variable rate application (VRA) to optimize input distribution based on soil characteristics, reducing

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wastage and environmental impact [6].

2.4 Machine Learning in Smart Agriculture

Recent studies have explored ML and deep learning (DL) techniques for improving crop yield prediction and disease detection. Researchers have integrated U-Net for image segmentation and Convolutional Neural Networks (CNNs) for classification, enabling automated seed germination analysis. These AI-driven models enhance agricultural monitoring and farm management [7]. Soil nutrient sensors, particularly NPK sensors, have become essential tools for precision farming. Optical and wireless NPK sensors provide real-time nutrient analysis, helping farmers determine optimal fertilizer requirements. Fiber-optic-based NPK sensors have been developed to assess nitrogen (N), phosphorus (P), and potassium (K) concentrations, contributing to data-driven fertilization planning [8]. A real-time soil moisture monitoring system has been developed using IoT-enabled sensors. These sensors are tested under field conditions to ensure high accuracy. Data pre-processing is performed using the Savitzky-Golay filter, while Extreme Learning Machine (ELM) algorithms are applied for crop yield prediction [9].

2.5 Crop Yield Prediction and Soil Analysis

Machine learning algorithms play a crucial role in crop yield forecasting, utilizing soil, climate, and fertilizer data to enhance productivity predictions. Supervised classification algorithms help categorize yield levels, guiding farmers in making informed agricultural decisions. Soil properties are directly linked to geographic and climatic factors, influencing crop selection, seed germination, and land preparation. The prediction of soil characteristics, including moisture, pH, and nutrient levels, is essential for effective farm management. AI-based models integrate historical soil data with current climatic conditions to provide accurate yield forecasts [10].

2.6 AI and IoT in Precision Farming

Traditional farming methods operate on a reactive basis, where corrective actions are taken after visible signs of crop stress. However, AI-driven IoT solutions enable predictive farming, reducing risks and enhancing productivity. Excessive pesticide use in traditional farming not only increases operational costs but also damages the environment by contaminating soil and water sources. AI-powered IoT sensor networks continuously monitor soil moisture, crop health, and pest infestations, enabling data-driven interventions. These networks utilize Wireless Sensor Networks (WSN) to transmit data to cloud platforms, where AI-based algorithms analyze the data to optimize irrigation, fertilization, and pest control strategies [11]. The integration of edge computing with IoT further improves precision agriculture by filtering redundant data before transmission, reducing network congestion, and enhancing decision-making speed.

3. Proposed System

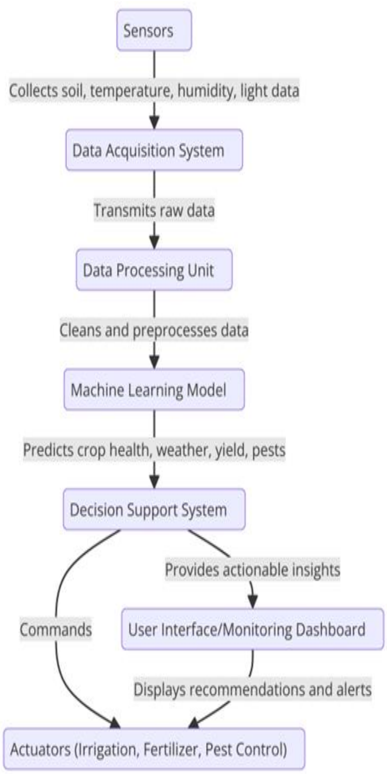

Figure 1 Workflow of Our Proposed System

The Smart Farming Precision Agriculture project will harmonize everything into one to integrate all the existing smart farming features into one mobile application. This will be a central controlling hub where, in real time and through a single interface, the farmer monitors and manages all aspects of his farm. The sequence of the proposed workflow is shown in Figure 1.

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Some of the characteristics that define the proposed system include:

3.1 Unified Monitoring of IoT:

All the IoT sensors (soil nutrients, moisture, temperature, weather conditions, etc.) will be combined into a single application. This will help the farmers view and analyze all the necessary data from one place.

3.2 Crop Recommendation

We are using the Crop_Recommendation.csv file from Kaggle for the training & testing of our machine learning model. The below steps are followed to train & test the model. In this project we have tested 8 machine learning algorithms on this dataset, which will be shown in Table 1 with their best hyperparameters, and we have achieved above 90% accuracy for Random Forest, Naive Bayes, KNN, Decision Tree, XGBoost & Gradient Boosting. Hyper- parameter tuning is performed on the random forest model to improve the accuracy of the proposed model. Then save the model in the pickle format, which will be used for making the top 5 best suitable crop predictions. The real-time data from the IOT sensors is fed to our ML model to provide accurate predictions. Table 1 shows Model Accuracy for Crop Recommendation.

Table 1 **Model Accuracy for Crop Recommendation**

Model	Train Accuracy	Test Accuracy	Best Hyperparameters
Random Forest	1	0.956	{'n_estimators': 100, 'max_depth': 10}
KNN	1	0.944	{'n_neighbors': 5, 'weights': 'distance'}
Naive Bayes	0.994	0.945	{'var_smoothing': 1e-09}
Decision Tree	1	0.946	{'max_leaf_nodes': 50, 'min_samples_split': 3}
Bagging	0.800	0.793	{'base_estimator_max_depth': 3, 'max_samples': 0.2}
AdaBoost	0.39	0.696	{'n_estimators': 1000, 'learning_rate': 0.01}
Gradient Boosting	1	0.92	{'n_estimators': 53, 'learning_rate': 0.25, 'max_depth': 2}
XGBoost	0.99	0.91	{'n_estimators': 150, 'learning_rate': 0.05, 'max_depth': 4}

3.3 Weed & Pest Identification

We are using the following datasets from Kaggle: plant-seedlings-dataset & pest-dataset. MobileNet and ResNet152V2 algorithms for training and validation of our deep learning model for accurate detection of pests and weeds in the farm. The accuracy of these models is more than 87%. In this work, we need to use a live video feed captured by a drone to detect weeds & pests simultaneously. Accuracy metrics of these models are shown in Figures 2 & 3.

3.1 Integrated Drone Monitoring

Drones are used to monitor crop conditions aerially, but then this data captured is taken straight into the app. Through the same app controlling irrigation and monitoring soil, real-time updates on crop health and field conditions can be accessed by farmers. It will have real-time sensor data, such as soil moisture and environmental factors, to be used for irrigation control using real-time sensors related to weather forecasts. This will enhance precision irrigation control; the model allows it to be monitored and adjusted directly from the mobile app to simplify water management. It combines complete data analysis and incorporates actual inputs from IoT devices, drone data, and even weather forecasts in a central system that might allow analysis to provide actionable insights for farmers. The farmer will receive crop predictions, pest alerts,

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and fertilizer recommendations all on the same platform.

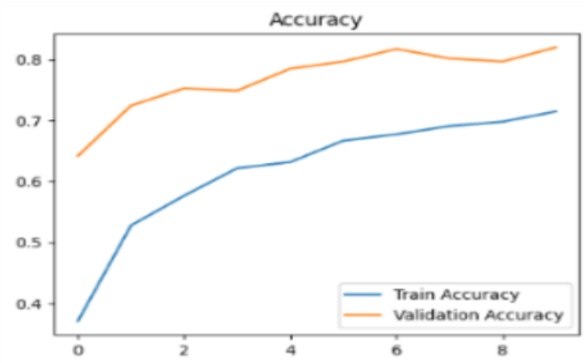

Figure 2 **Accuracy of MobileNet Model**

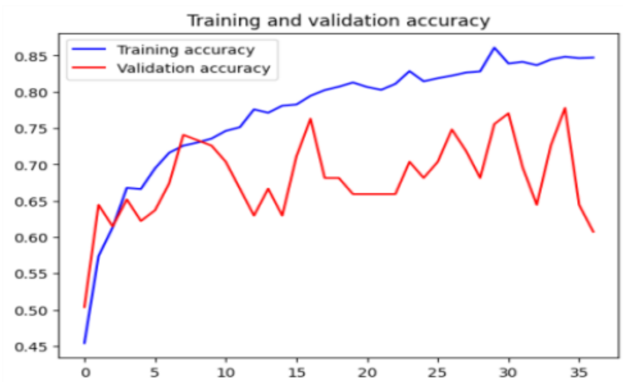

Figure 3 **Accuracy of ResNet152V2 Model**

3.2 All-in-One Mobile Application

The core feature of the proposed system is a mobile application, acting as the central control in the farming activities. There will be one app for the farmers about tracking soil conditions and weather forecasts, 24/7 CCTV surveillance, pest control, and irrigation control.

3.3 Regulating the irrigation system

Getting drone data and insights on crop health Receiving advice on crop management, pest control, and resource optimization. The application will send alerts to the farmers based on severe issues like weather conditions, infestation of pests, or short supply of water to the farmers using an app. This way, immediate action can be taken without verifying multiple systems.

3.4 Historical Data Storing:

The application will collect the historical data of the farm conditions, crop yield, and environmental changes, which will enable farmers to make data-driven decisions and predict future needs with greater accuracy.

4. Results and Discussion

4.1 Results

The developed precision agriculture system was evaluated through two key experiments. The first experiment focused on optimizing the model parameters, including data preprocessing techniques, feature selection, and the effectiveness of various machine learning models for crop prediction, disease detection, and nutrient recommendations. The second experiment involved deploying the trained models on real-world agricultural datasets to assess their generalization capability and effectiveness across different environmental conditions. The user inputs soil attributes such as electrical conductivity (Ec), sulfur (S), copper (Cu), iron (Fe), manganese (Mn), zinc (Zn), and boron (B). Upon submission, the system processes the data and ranks crops based on suitability percentages. As seen in figure 4, the dashboard suggests that potato (46.58%) and mulberry (45.75%) are the most suitable crops for the given soil composition. Other options include mango (4.58%), pomegranate (1.83%), and grapes (1.25%). The intuitive UI, developed using React + Vite, ensures seamless interaction, while FastAPI and Spring Boot efficiently process data and deliver real-time results. Figure 4 shows Best Crops Recommended.

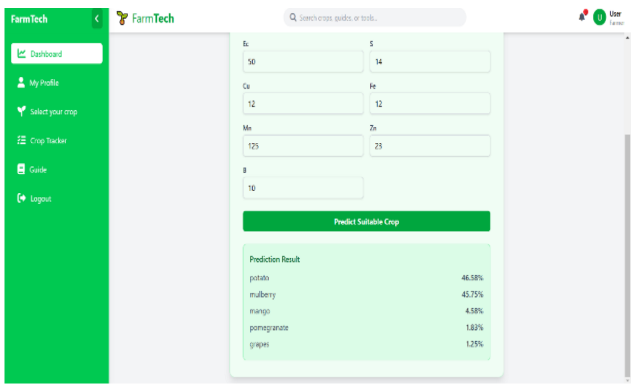

Figure 4 **Best Crops Recommended**

4.2 Discussion

The system was built as a progressive web application (PWA) using React + Vite for the frontend, Spring Boot for the backend, and FastAPI

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for integrating machine learning models. The dashboard shown in Figure 5 provides an intuitive interface displaying critical farming insights such as crop health (14%), weed presence (5%), and soil fertility index (85.2%). Additionally, the system integrates multiple AI-driven modules, including:

- Crop Predictor– Recommends optimal crops based on environmental and soil conditions.
- Weed Identification– Detects and classifies weeds to aid in precision weeding.
- Pest Identification– Analyzes crop health to detect potential pest threats.
- Crop Nutrient Requirements– Suggests the necessary nutrients for crop growth.
- Fertilizer Recommendation– Provides data-driven fertilizer suggestions.
- Maize Disease Prediction– Identifies potential maize-related diseases based on image and sensor inputs.
- Pest Control Recommendation– Suggests strategies for pest mitigation.

The system was evaluated for performance, accuracy, and real-time usability. Results indicate that AI-driven precision agriculture significantly improves decision-making for farmers, ensuring better crop yields, optimized resource usage, and enhanced sustainability. Future enhancements will focus on multilingual support to further expand accessibility and effectiveness for diverse agricultural communities. Figure 5 shows Dashboard [12].

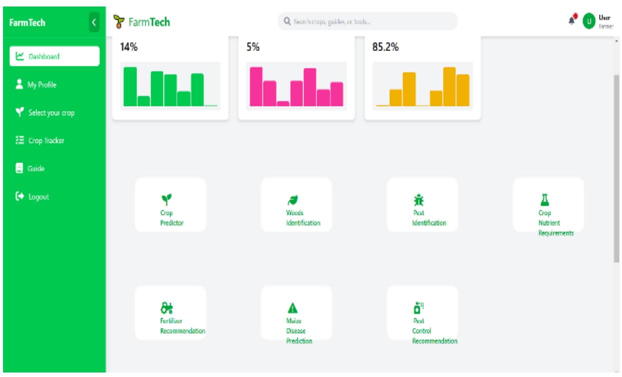

Figure 5 **Dashboard**

Conclusion

The Smart Farming Precision Agriculture project involves a wide solution towards the challenges of modern farming through the combination of existing technologies, such as IoT sensors and drones and precision irrigation systems, into one application for the mobile. The unified platform optimizes the usage of resources such as water, fertilizers, and pesticides. However, apart from this, it increases crop yield, reduces resource wastage, and provides support for sustainable farming practices. All the conditions of the soil along with the regulation of irrigation to crop recommendations can be seen in one window, which greatly enhances efficiency and profitability for the farmers. This brilliant solution for farming gives farmers access to advanced equipment while minimizing dependence on traditional and ineffective methods, all to guarantee satisfaction of demands for food since their needs are inevitably growing. This application is very useful for the farmers, and furthermore, not only all those, but we would like to display the selling price of the crop in the market that is grown and efficient ways to sell the yield in the market. So, this application would be an overall benefit for the farmers.

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