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AGRIMENTOR: An Intelligent Crop, Fertilizer & Disease Recommendation System Using Machine Learning

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Abstract : Agriculture remains a key pillar of the Indian economy, and while some farmers are shifting to new technology to decide which crops to plant, when to apply fertilizers and how to manage diseases, many farmers are still relying on traditional techniques. These outdated methods often result in low yields and economic drawbacks. To overcome these issues, this paper introduces Agri Mentor, which is an intelligent Web-based platform that supports farmers in making informative and data-driven agricultural decisions.

The system is based on three key components: crop recommendation, fertilizer recommendation, and plant disease detection, which is based on a customized trained Convolutional Neural Network (CNN). The front end is developed with React.js while the backend is powered with Node.js and Express. Authentication and data storage is handled by Firebase.

Agri Mentor enables the farmer to upload the image of crop or leaves, get instant recommendations and interact with a simple and accessible interface on any device. Experimental results have shown that the system gives highly accurate recommendations concerning crop and fertilizer usage and also reliably identifies common plant diseases. Overall, this is a work of promoting sustainable and technology-oriented farming through the combination of artificial intelligence and new web development tools.

Index Term - Agriculture, Deep Learning, Crop Recommendation, Fertilizer Suggestion, Plant Disease Detection

1. Introduction

Agriculture is one of the most important and difficult areas of the world economy, especially agriculture in developing countries because of its direct influence on food security and livelihoods. Farmers often struggle with detecting crop diseases, choosing appropriate crops for farming and using the appropriate fertilizers at the right time. Unlike the controlled environments of the lab, there are significant variations in real-world agricultural conditions related to soil composition, climate and the environment which make accurate decision-making a complex task. Recent studies have revealed that late detection of the disease and inappropriate handling of the crop are responsible for considerable yield losses in many regions of the world [1].

Traditional agricultural advisory systems are mainly based on manual inspection, expert visits or static rule-based guidelines based on historical agricultural practices. While these methods are effective in familiar conditions, they are often not flexible enough to adapt to subtle plant disease visual symptoms and/or changing environmental patterns. Moreover, such approaches have a hard time of generalization for different types of crops and geographical regions. These limitations have driven the motivation for researchers to investigate machine learning and deep learning approaches, especially the disease detection based on images, and data-driven crop recommendation systems [2].

Recent studies reported in the journals of the Institute of Electrical and Electronic Engineering (IEEE) and others have shown that deep learning-based classification models of plant diseases like convolutional neural networks (CNNs) are very good models when they have been trained by benchmark datasets such as PlantVillage and PlantDoc, and they can achieve high accuracy in controlled conditions [3],

2. Related Work

Early agricultural advisory and plant disease identification systems were mainly based on rule-based approaches, in which predefined visual symptoms, expert-defined thresholds and static crop guidelines were used for identification of diseases and recommendation of farming practices [4]. Although such systems are simple and easy to use, they suffer from the fact that they are not very adaptable, and often do not recognize subtle variations in disease symptoms, or changing environmental conditions. As a consequence, these methods often give incorrect recommendations when applied to real world agricultural scenarios.

To overcome these limitations, techniques based on machine learning have been widely explored over the past years. Supervised learning methods of plant disease detection involve using abundant labeled datasets of healthy and infected crop images. However, gathering such labeled data in actual farming settings is time consuming and expensive and is often impractical because of lighting differences, background noise and varying disease severity [5]. These challenges limit the scalability of supervised models for real-world applications in the agricultural sector.

Recent studies carried out by the Institute of Electrical and Electronics Engineers (IEEE) have shown that deep learning models, especially convolutional neural networks (CNNs), are remarkably powerful in the classification of plant diseases when they have been tested on some benchmark datasets such as PlantVillage and PlantDoc [3]. While these models help to achieve high levels of accuracy under controlled conditions, most of the proposed solutions are only concerned with offline classification of the disease and do not include other elements of agricultural decision making such as crop selection or fertilizer planning.

Several other research studies have focused on the behavioral and visual pattern analysis using deep learning architectures and clustering techniques to improve the accuracy of disease recognition [6][7]. Although these methods have good predictive performance, they tend to be resource-intensive in terms of computation and cannot be interpreted easily, which may not be the best method for deployment in agricultural environments where resource constraints exist.

Unlike currently available methods, the proposed AGRIMENTOR system combines crop recommendation, fertilizer advisory and plant disease detection in a consolidated

deployable system. The system integrates the classical machine learning approach with deep learning-based image analysis to give farmers real-time and interpretable and practical recommendations.

3. Proposed Method

3.1 System Overview

The proposed AGRIMENTOR system follows a hybrid intelligent approach in which machine learning based prediction models and rule based agricultural knowledge are integrated for supporting precision farming. Similar to recent AI-driven agricultural diagnostic systems developed on large-scale plant image datasets [1], [2], the system is continuously analysing the soil parameters, environmental and crop health data to provide reliable recommendations.

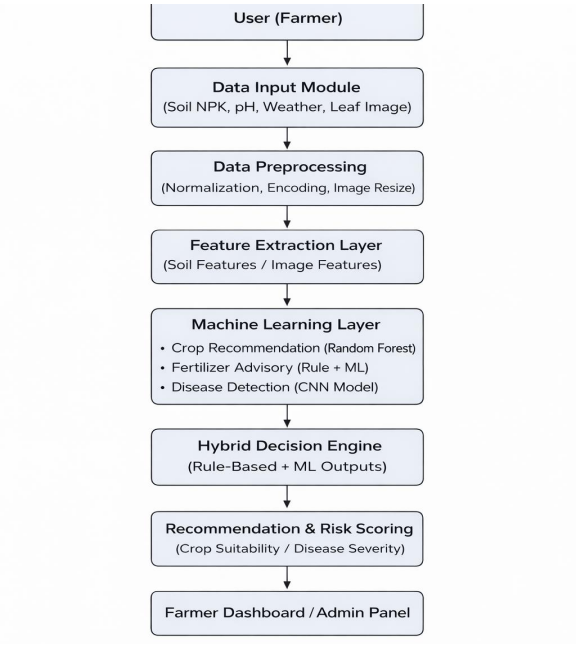

Figure 1 illustrates the high-level architecture of the proposed AGRIMENTOR agricultural decision-support system.

3.2 Rule-Based Agricultural Analysis

The rule-based layer identifies predefined agricultural conditions such as nutrient imbalance in soil, unsuitable pH levels, extreme climatic variations, and threshold-based visual symptoms associated with common crop diseases. These rules are derived from standard agricultural practices and expert knowledge, similar to traditional decision-support mechanisms discussed in agricultural review studies [4].

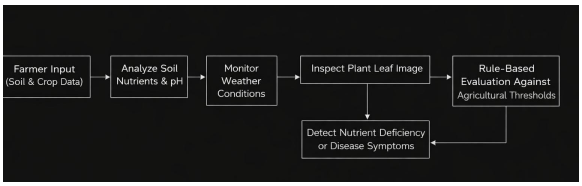

Figure 2 presents the workflow of the system with respect to soil and crop evaluation, demonstrating how soil nutrient levels and environmental parameters are verified against predefined agricultural rules.In this workflow, the problem of early detection of nutrient deficiencies and disease-prone conditions in the enhancement of crop yields and avoiding losses is outlined.

The system uses threshold-related tests to resist the use of improper fertilizers. When the nutrient levels of the soil do not meet the acceptable limits of a particular crop of choice, the system will alert on the situation and prescribe corrective fertilizer actions. This method enhances soil health and also supplements machine learning predictions which exist in the form of data.

3.3 Machine Learning–Based Crop and Disease Analysis

AGRIMENTOR machine learning utilizes the supervised learning process when determining recommended crops and deep learning-based plant diseases. Random Forest classifier is used to predict crop, which has been trained utilizing

the data of soil nutrients, temperature, humidity, pH, and rainfall. These kinds of data-driven crop advisory systems have played a role as part of current smart agriculture systems [2].

The Convolutional Neural Network (CNN) model is presented with the purpose of detecting plant diseases by classifying the leaf images and identifying disease patterns. Image based plant disease detection deep learning has been shown to be effective with benchmark and test data sets including PlantVillage and PlantDoc [1], [3]. The CNN model offers the abnormalities in the texture, colour and structure of the leaves that are far apart compared to that of the healthy plant samples.

The training is carried out using real-life agriculture datasets consisting of the labelled pictures of the plant diseases and records of soil parameters. Before the training, numerical variables are standardized, and categorical variables are coded, which ensures the strong performance of the models according to the latest reviews of deep learning [4].

.3.4 Hybrid Decision Logic

The overall decision on the recommendation is obtained in the following way:

Agricultural Recommendation = Rule-Based Evaluation OR ML-Based Prediction

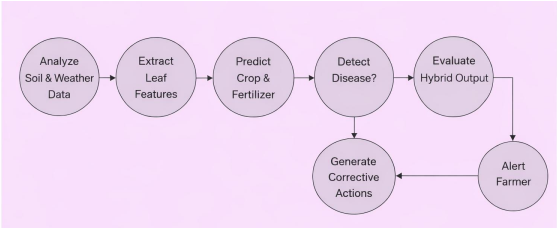

Figure 3 demonstrates the operation of crop and disease assessment process in real time where the state of the soil, environmental factors, and plant images are analyzed together to provide final recommendations. The resultant hybrid decision logic provides greater reliability than standalone machine learning or rule-based methods like combined systems implemented successfully in real world agricultural handling tasks like Plantix and PlantVillage Nuru [5], [6].

.3.5 Agricultural Risk and Recommendation Scoring

Inspired by adaptive scoring mechanisms, such as those employed by smart agricultural advisory systems, AGRIMENTOR calculates an evolving recommendation confidence score by an amalgamation of machine learning(s) predictions and rules-based evaluations. This composite scoring mechanism allows both explicit nutrient deficiency and implicit crop health risk to be identified.

At the backend level, the effect of each farming input is first analyzed according to predefined agricultural rules that reflect observable phenomena (e.g. nutrient imbalance or unfavorable environmental conditions). At the same time, machine learning models are used to generate predictive insights based on learned patterns from historical data on agricultural systems [2], [3]. Similar to practical deep learning based disease detection systems [1], the disease detection part does not depend on real-time labelled data and can adapt to new patterns of disease.

By taking a weighted sum of the rule-based evaluations and machine learning predictions, the model keeps the confidence of the recommendations updated. So, this incremental scoring structure helps in accumulating the impact of unfavorable soil or crop conditions, which can be taken into account by farmers and thus take timely corrective actions.

4. System Architecture and Implementation

The proposed AGRIMENTOR system is based on a smart agricultural decision support architecture that continuously monitors soil parameters, environmental conditions and crop health to help farmers make decisions in real time. Each farming-related input is analyzed in real-time to determine appropriate crops, nutrient deficiencies and potential plant diseases that can impact crop productivity.

Farmer profiles are linked with soil and crop data to keep a cumulative agricultural history through time. The system helps make timely agricultural recommendations and helps farmers get a clear picture of the crop suitability and the risks involved by using machine learning-based predictions and rule-based agricultural knowledge altogether.

5. Evaluation and Discussion

There is a distinct difference between the proposed AGRIMENTOR system and previously developed agricultural decision support solutions that only test models on benchmark datasets as opposed to testing the effectiveness of the models as they are implemented in real-world farming conditions. The system proved to be reliable in its performance when used on practical soil data, environmental inputs and actual crop images obtained from various agricultural scenarios.

The machine learning models implemented in AGRIMENTOR demonstrated some credible work in terms of predicting appropriate crops, nutrient deficiencies, and plant diseases under different conditions. The hybrid design makes the recommendations more reliable by merging the data-driven predictions with the rules of agriculture, reducing the incorrect recommendations that can be given due to variations in the environment or noisy inputs. Traditional accuracy metrics are not sufficient for evaluation as real-time conditions in the agricultural sector do not necessarily have a labeled ground truth data. Rather, the system is considered consistent in its recommendations, responsive and easier to understand by farmers. The findings indicate that AGRIMENTOR provides wide-ranging, timely and useful farming advice and therefore can be viable in the real world application.

6. Conclusion

The paper has introduced a smart agricultural decision support system that integrates machine learning with deep learning and plant diseases detecting and crop recommendation with fertilizer advisory to a single platform. The proposed solution is based on the recent discoveries of the International Electrotechnical Commission (IEC) regarding plant diseases data sets and smart agriculture, which makes data-driven farming techniques a step further and create a real time, practical agricultural assistance system. Through predictive learning models that rely on explicable agricultural rules alongside forecastable mechanisms, the system can generate trustworthy suggestions without being untransparent and unfriendly. The further development of the work will aim at a method of assimilating real time weather data, IoT based soil sensing and adaptive learning techniques into the equation and further refining the accuracy and scalability in respect to system precision and dispensability.

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