Integrating IoT and ML for Precision Agriculture

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***Abstract*—Precision agriculture and sustainable crop management techniques are the results of the industry's rapid transformation due to Internet of Things (IoT) technology. This study examines the ways in which “Internet of Things (IoT)” technology is transforming agriculture, with a focus on precision agriculture and sustainable crop management strategies. In order to improve crop monitoring and management and enable farmers to make decisions that are well-informed, the study investigates the importance and scope of utilizing sensors, Internet of Things devices, and data analytics. Real-time data collection on crop health, temperature, humidity, and soil moisture helps farmers allocate resources more effectively and generate less waste. The key components of IoT-based precision agriculture, including sensor technologies that data collection, analytics, and decision support systems, are covered in comprehensive detail. The study focuses on the advantages of IoT use in agriculture, emphasizing how technology has the potential to revolutionize farming practices for greater efficiency and sustainability. Additionally, the system integrates desktop Application like Tkinter- farmers access to remote irrigation control, crop recommendations, and real-time notifications, enhancing the usability and accessibility of farm management. This Project analyses requirement of selection of Crop based on NPK parameter (Dataset), Temperature, Humidity, Rainfall, and send to the server and further data processed takes place and required output will be given by system.**

***Index Terms*— “Internet of Things (IoT Sensors)”, “Machine Learning”, Precision Agriculture, Support vector machine, Smart Farming**

1. INTRODUCTION

Precision agriculture (PA) is a contemporary farming management concept that maximizes the management of crops at the field level by utilizing technology. Utilizing data from several sources was crucial in PA because it enables growers to make informed decisions based on real-time track data about their land and crops. With its underlying goal of maximizing crop yields, minimizing environmental effect, and conserving funds through precision water, fertilizer, and pesticide operations, PA is significant. Farmers may improve the precision of their operations, forecast crop performance, and spot problems before they become serious by combining lot and machine learning. This will make conventional agriculture a more effective and sustainable activity.Using a series of machine learning models that are the focus of all the research above, including "Support Vector Machines" (SVM), "Decision Tree," "Extra Trees," and "Random Forest," this project will try to offer a solution-oriented path forward towards empowering the Indian farmer to construct an integrated crop and soil advisory system [5]. It takes into account all the critical agronomic parameters like "nitrogen," "phosphorus," "potassium level" [NPK], soil pH, temperature, humidity, and climate change, and anticipates what kinds of crops can be grown based on that environmental condition [2]. The Random Forest model was described as being quite effective, despite being especially well-suited for recommendatory scenarios for choosing the ideal crop and congenial soil type. The selection of the corresponding model was based on their interaction super-sensitivity with very large, convoluted data sets, generally with high dimensionality, as stated in agriculture. In the learning phase, it builds a significant amount of decision trees. Ultimately, the most popular area is provided in the final projection, providing us the maximum accuracy and reliability. The significance of machine learning in agriculture and the potential impact it can have on the output of models. It gives users with an option to complement standard farming methods, consequently benefiting resource utilization, maximizing yield, and ensuring more. Integrating Internet of Things (IoT) and Machine Learning (ML) technologies is transforming precision agriculture by enabling real-time monitoring, data-driven decision-making, and resource optimization. These advancements aim to address challenges such as increasing food demand, resource inefficiency, and environmental sustainability in modern farming. It gives consumers the chance to supplement conventional farming methods, which improves resource use, maximizes productivity, and ensures more sustainable practices [3]. to provide examples of data from the current crop selection machine learning models. The document does not specifically address the main research question or hypothesis that this study is attempting to answer. But according to the data presented, the study's primary goals and focus seem to be: offering a solution-focused strategy to enable farmers to build an effective crop and soil advising system. Give advice on the ideal soil types to maximize agricultural output.

2. LITERATURE REVIEW

The systematic review by Mughele et al. (2024) analyzes the application of the “Internet of Things (IoT)”, big data analytics, and machine learning in precision agriculture (PA) for increasing food production in response to increasing global demands. With estimates projecting a 70% boost in food production by 2050, PA utilizes high-end sensor technologies for optimizing resource management, tackling issues such as climate change and urbanization. The research emphasizes the need for real-time decision-making support systems and geospatial data management and highlights barriers as data transmission infrastructure. Infrastructure development, education, funding, and public-private partnerships are suggested for Nigeria to promote PA adoption and sustainability.

2.1. Roles Of Iot, Big Data And Machine Learning In Precision Agriculture: A Systematic Review

The overview starts with the contemporary situation of precision agriculture, with emphasis placed on the use of IoT-based sensors. These sensors help track real-time information on the soil status, weather, and plant health. This information is immense, and this is where Big Data comes in: it takes in the data and analyses it to create actionable information for farmers. Machine Learning algorithms are then utilized to make predictions on crop growth, identify diseases at early stages, and streamline the allocation of resources such as water and fertilizer [6]. A major observation is that IoT devices enable farmers to receive accurate, timely information, resulting in informed “decision-making”. Contribute in making sense of intricate agricultural systems, while Machine Learning models enhance predictions for yields and pest infestations. Some difficulties have been pointed out in the paper, including the expensive cost of technology, poor infrastructure, and lack of technical skills among farmers.

2.2. A Case Study of Soil Parameters for Efficient Crop Recommendation using ML and IoT

The paper discusses the integration of “machine learning (ML)” and “Internet of Things (IoT)” technologies to improve crop recommendation systems in agriculture. By using IoT sensors to collect real-time soil parameters (such as “NPK”, pH, and moisture) and analyzing this data with ML models, the system provides farmers with data-driven crop recommendations tailored to their specific soil and environmental conditions. The proposed framework aims to increase agricultural efficiency, sustainability, and profitability by enabling better crop selection, resource management, and adaptation to climate change. The system is designed to be user understandable, scalable, and secure, supporting real-time decision-making for farmers.

2.3. A systematic literature review of machine learning applications in IoT

A network of linked smart objects with capabilities that work together to create an ecosystem and provide customers with smart services is known as the (IoT). Through the environment, the IoT is improving people's lives in a number of ways. Facilities and services are provided by the different applications that operate in the Internet of Things ecosystem. Making decisions quickly for effective management is Among the most crucial services provided by IoT apps. The potential of IoT systems has recently been successfully increased by the application of machine learning (ML) techniques [8]. The literature on the incorporation of machine learning techniques in the Internet of Things is systematically reviewed in this work. solving basic system operating issues such data aggregation, routing, clustering, big data, and security Recent advancements in precision agriculture highlight the transformative role of integrating "Internet of Things (IoT) and Machine Learning (ML) technologies". Numerous studies have demonstrated the effectiveness of using IoT-based sensors for collecting real-time data on soil health, environmental conditions, and crop status. For example, systems that combine IoT with ML algorithms like "Random Forest", "SVM", and "Logistic Regression" have shown improved accuracy in crop and fertilizer recommendations. Robotic and drone-based solutions have further been explored to detect and manage plant diseases efficiently, minimizing the use of chemicals while improving yield. However, challenges such as data inconsistency, computational limitations in rural environments, and the lack of scalable, cost-effective deployments persist. To address these gaps, recent efforts focus on deploying lightweight ML models on edge devices (TinyML), ensuring accessibility and real-time decision-making even in resource-constrained settings.

Sr. No	Title	Summary	Research Gap & Technical Challenges
1	Adaptive AI in Precision Agriculture	Explores real-time data-driven AI to optimize crop management using IoT and ML. Shows impact on yield and sustainability.	High implementation costs, technical complexity, and lack of rural infrastructure hinder adoption. Need accessible, robust AI tailored to rural conditions.
2	A Case Study of Soil Parameters for Efficient Crop Recommendation Using ML and IoT	Integrates IoT sensors and LLMs to analysed soil parameters and recommend crops. Uses real-time data to guide farmers.	Limited generalizability due to local data constraints. Sensor accuracy and connectivity issues are technical hurdles in rural areas.
3	A Qualitative Review of Smart Farming in ASEAN	Reviews smart farming adoption across ASEAN. Highlights policy, economic, and tech-readiness factors.	Regional disparities and poor digital infrastructure slow tech uptake. There's a lack of unified policy and training support for smallholders.
4	Crop and Fertilizer Recommendations with Agriculture Waste Integration	Uses soil sensors and ML to provide fertilizer/crop suggestions and turns waste into economic value.	Lack of frameworks combining aggrotech and agri-business. Real-time data integration and sustainable waste management need enhancement.
5	Design and Development of Smart Farming using ML and IoT in India	Builds a smart greenhouse model using IoT sensors and ML to recommend crops and automate farming.	Technical integration is strong but lacks scalability. Challenges include standardization, cost, and climatic adaptability across India.
6	Enhancing Predictive Accuracy with Machine Learning and IoT Integration in Energy	This paper explores the integration of IoT and ML technologies for enhancing the predictive accuracy of energy consumption forecasts. It focuses on using real-time data from IoT sensors combined with regression and classification ML models. The study highlights the importance of data preprocessing, feature engineering, and model evaluation for optimal energy prediction.	One significant challenge lies in the variability and incompleteness of IoT sensor data, which can hinder model accuracy. Handling large datasets in real-time also demands high computational resources. The study addresses these by using data cleaning, outlier detection, and edge computing solutions. Further research is needed in model generalization across diverse energy systems and improving low-power on-device ML processing.

Table1: Literature Review Table

The Combination of the "Internet of Things" (IoT) in Precision Agriculture (PA) has converted traditional farming practices by Getting data that is current available, automated "decision-making", and resource optimization. Several studies highlight the role of IoT-based sensors, wireless networks, and "machine learning" (ML) algorithms in improving crop monitoring, soil management, irrigation efficiency, and pest detection. Researchers emphasize that remote sensing technologies, including UAVs and GPS-based monitoring systems, facilitate precise field analysis, enhancing productivity while minimizing environmental impact [12]. Furthermore, Big Data analytics and artificial intelligence (AI) techniques, such as "Support Vector Machines (SVMs)", "deep learning", and predictive modelling, are increasingly being employed to analyze complex agricultural datasets. Studies suggest that IoT-enabled systems significantly contribute to yield prediction, disease detection, and decision support systems (DSS). However, existing literature also highlights critical challenges, including data security risks, interoperability issues among IoT devices, and high implementation costs. Despite these limitations, recent advancements in AI-driven analytics, blockchain for data security, and cloud-based IoT architectures indicate promising future developments in PA Agricultural robots are a special part of the evolution of digital agriculture. Fifty percent of farmers in India are small-scale farmers. By automating several farming chores and procedures, agricultural robot and drone technology has completely transformed the agricultural sector[8]. The integration of these technologies in agriculture has become more effective and efficient with the introduction of the Internet of Things (IoT) and developments in image processing and machine learning (ML).

3. PROPOSED SYSTEM / METHODOLOGY

System Architecture:

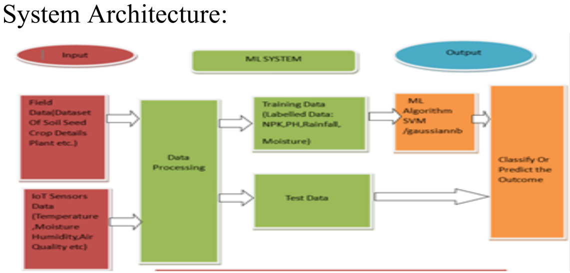


Fig 1: system Architectures

It considers all the critical agronomic parameters like "nitrogen", "phosphorus", "potassium level" [NPK], soil pH temperature, humidity, and Climate change and predicts what types of crops can be grown based on that environmental condition.

The accuracy and applicability of agricultural analysis are increased by holistic data integration, which combines conventional field data with inputs from IoT sensors to produce a multi-dimensional dataset that records both static and dynamic environmental variables. This integrated strategy highlights how crucial it is to combine real-time monitoring with on-ground measurements for thorough agricultural management. The importance of data preprocessing The necessity of normalization, adjusting, and converting unprocessed sensor and field data into formats that may be used is highlighted by the addition of a specific data processing step. Model performance and prediction reliability are directly impacted by effective preprocessing, which is essential to ensuring that the ML algorithms receive high-quality inputs. The system project focus on crop recommendation using machine learning model that are Gaussian NB, SVM and produce result based on text data that are collected from Kaggle dataset and other filed data and classifier and regression techniques are used to predict output.

3.1 DATA ACQUISITION

Fig 2: Sensor-Based Data Acquisition in Precision Agriculture

For data-driven decision-making, the suggested precision agriculture system uses a multi-sensor method to gather environmental and soil-related data. In order to provide information about the levels of air pollution that could affect plant health, the MQ135 gas sensor is utilized to detect hazardous gases and air quality metrics. The ambient temperature is measured by the temperature sensor (such as the DHT11 or DS18B20), which is essential for pest model forecasting and crop growth cycles. Because it can detect the water levels in the root zone and prescribe or automate watering schedules, the soil moisture sensor is essential for irrigation management. Crop placement optimization and photosynthesis depend on sunshine exposure, which is tracked by light sensors (such LDRs or photodiodes). Humidity sensors track the air and are usually coupled with temperature modules. Usually utilized alongside temperature modules, humidity sensors track air's moisture levels, which have an impact on crop disease susceptibility and transpiration rates.

The three essential nutrients needed for plant growth—"nitrogen (N), phosphorus (P), and potassium (K)"—are measured by the NPK sensor. The system can identify nutrient deficits and recommend the proper usage of fertilizer by gathering data from these sensors. Every sensor connects to an IoT device, such as an Arduino or ESP8266, or microcontroller. Data is sent to ML models for real-time processing, which produces practical suggestions for environmental control, fertilization, and irrigation.

3.2 DATA PREPROCESSING

The quality of the data collected by IoT sensors had a significant effect on the accuracy of "Machine Learning (ML)" predictions in precision agriculture. Due to environmental influences, transmission failures, or sensor malfunctions, raw data gathered from a variety of sensors including MQ135, temperature, humidity, soil moisture, light intensity, and NPK, frequently has noise, inconsistencies, or missing values because of transmission faults, environmental influences, or sensor failures.

3.3 ML MODELS

Sr. No	ML Algorithm Implemented	Accuracy in %
1	Light-GBM Model accuracy score:	0.989
2	"Decision Tree Model" accuracy score:	0.9848
3	"Random Forest Model" accuracy score:	0.9917
4	"Logistic Regression Model" accuracy score:	0.9435
5	Support Vector Machine	0.9575
6	Gaussian-NB	0.9918

In this project build ML model Is SVM and Gaussian NB whis is showing accuracy that shows in table with precise output system will more reliable on agro data, The quality of the data collected by IoT sensors have a significant impact on the prediction accuracy of Machine Learning (ML) predictions in precision agriculture. Due to environmental influences, transmission failures, or sensor malfunctions, raw data gathered from a variety of sensor.

3.4 IMPLEMENTATION TOOLS

The crop recommendation framework is realized through a mix of hardware and software devices. Arduino/ESP32 microcontrollers are employed to connect environmental and soil sensors to acquire real-time data. Sensor information is sent over Wi-Fi or LoRa modules to a cloud server or edge device. At the software level, Python is utilized for data preprocessing and model implementation using packages such as Scikit-learn, Pandas, and NumPy. A web-based user interface is developed using a Flask framework or Django, whereas IoT data visualization and cloud storage can be done using ThingSpeak or Firebase. The whole system provides real-time, smart crop recommendation based on combined IoT and ML

3.5 TECHNOLOGICAL COMPONENTS

3.5.1 IoT Sensors:

Soil Sensors:

- Soil Moisture Sensors: (Dielectric sensors) Measure volumetric water content, crucial for precise irrigation.
- pH Sensors: Determine soil acidity/alkalinity for optimal nutrient uptake.
- Nutrient Sensors: (Electrochemical sensors) Measure levels of nitrogen, phosphorus, potassium (NPK), and other essential nutrients to guide fertilizer application.
- Electrical Conductivity (EC) Sensors: Indicate salinity levels in the soil.
- Soil Temperature Sensors: Help understand microbial activity and seed germination conditions.

3.5.2 *Wireless Networks:*

Numerous benefits come from integrating WSN applications in agriculture, including autonomous agricultural machinery, fertilizer optimization, crop monitoring using UAVs, irrigation control, and monitoring of health of the crop. With the ultimate goal of improving a long-term sustainable farming production in the agricultural sector, these technological developments work together to propel agricultural automation. Important elements that are essential to guaranteeing the production of food worldwide include land assessment, crop predictions, and protection of crops. Real-time field status monitoring and effective agricultural field management are made possible by wireless sensors and mobile networks.

Furthermore, technology enables farmers to make precise yield maps and collect vital data, enabling precision agriculture and the production of premium products at a reasonable price with WSNs.

3.5.3 Machine Learning:

Naive Bayes model:

Naive Bayes was chosen because of its effectiveness and ease of use in managing classification issues including several input features, which makes it a good fit for agricultural applications where crop selection can be determined by probabilistic results. Conditional probabilities are used in this model, which is perfect for situations when the independence assumption is roughly true and computation speed is crucial for prompt recommendations.

Support Vector Machine:

The main applications of the robust and adaptable "Support Vector Machine (SVM)" supervised machine learning technique are in classification and regression. The fundamental principle underlying SVMs is to identify the "best" border or "hyperplane" that divides several classes of data points in a given feature space. It works especially well in situations when data needs to be divided into multiple classes.

3.5.4 Cloud Platforms

Thing-speak Platform*:*

The main functions of Thing-Speak, a cloud platform created by MathWorks, the company behind MATLAB, are: Gather Data: Get information from the internet about Internet of Things devices (microcontrollers, sensors, etc.).Store Data: The cloud's "channels" are where this stream data is stored.

Visualize Data: Without requiring much code, create both historical and real-time
data visualizations (charts, graphs).

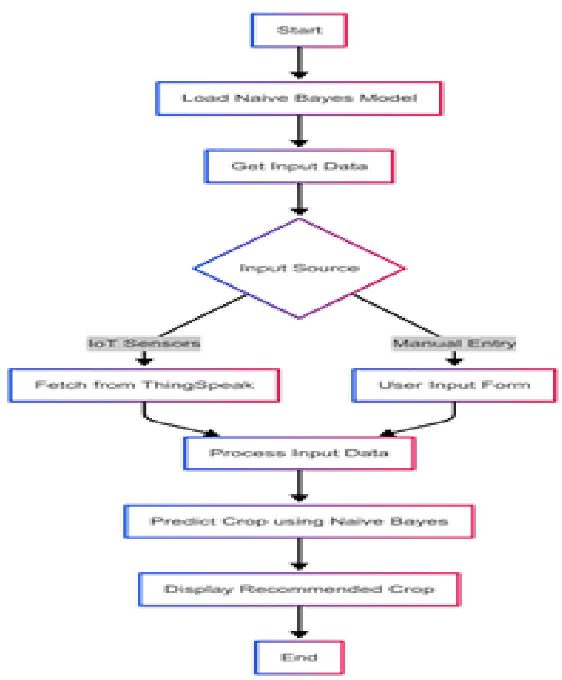
Analyze Data: Use the platform's MATLAB code to

enable more thorough
data analysis. Let users set up alerts and take action in response to specific data situations It links gadgets that gather data to user-friendly cloud-based analysis.

Things-peak result for Project Analysis

Fig 3: Result1

3.6. Flowchart



- Several data input sources, include manual input and Internet of Things sensors
- Data from the ThingSpeak platform is included for improved IoT analytics.
- Data readiness is ensured by the pre-prediction data processing stage.
- Using processed data, Naive Bayes was used to forecast the perfect crop.
- Crop suggestions displayed intuitively for knowledge that can be put to use streamlined process from data entry to output that is suitable for automation in agriculture

3.7. FUTURE DIRECTIONS AND OPPORTUNITIES

- Integrating drone imagery and satellite data
- Use of deep learning (CNN/LSTM)
- Blockchain for secure data logging
- Farmer-friendly UI/UX mobile app

3.8. RESULTS AND DISCUSSION

Hardware Image:

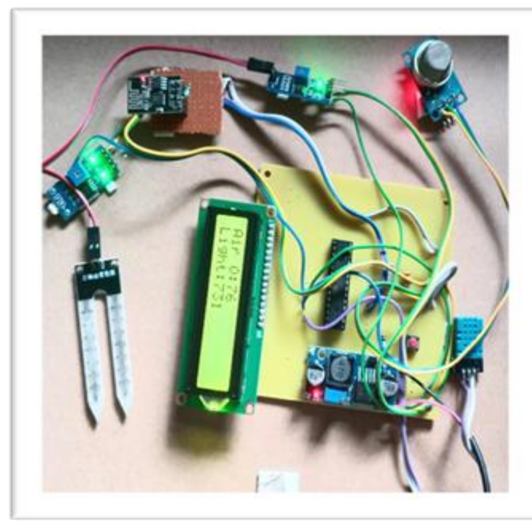


Fig 4: Hardware Image

Model performance:

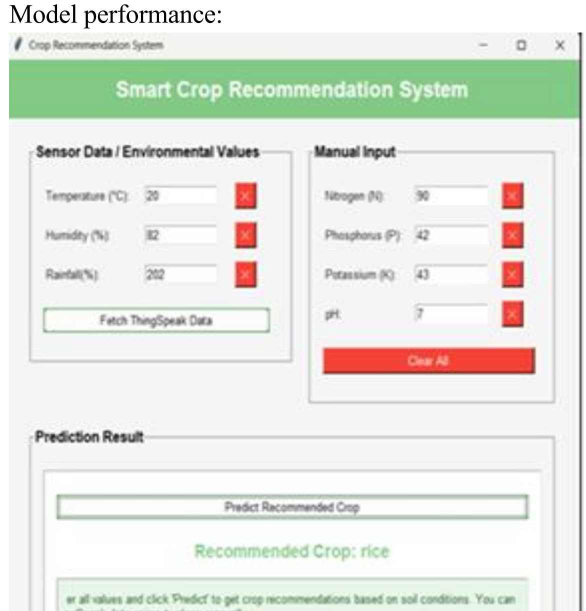


Fig 4: Front View

4. ML PERFORMANCES AND RESULTS

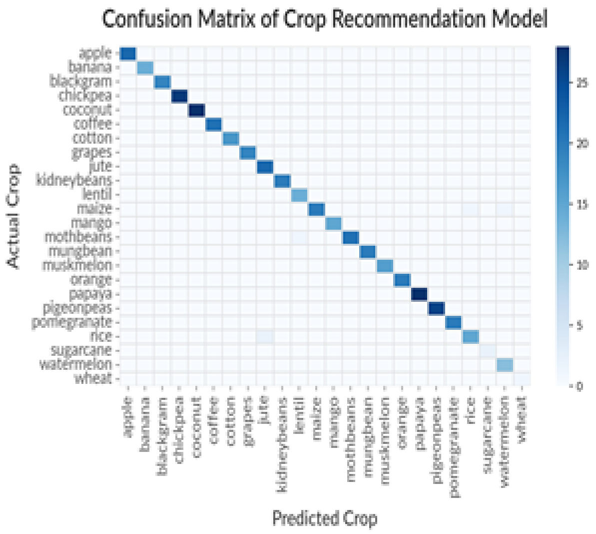


Fig 6: Confusion Metrix for Crop Recommendation Model

As can be seen, the dataset contains a broad variety of crops, with others occurring more than others. In this distribution lies significance in learning the balance of the dataset as well as preventing the model from tilting towards more common crops. Second, we will look at the feature distributions and proceed with model evaluation to see how the crop recommendation system performs

5. CONCLUSION

In order to solve the challenges with agriculture, particularly in India, smart farming is crucial. It improves irrigation and water management. An IoT and machine learning system informs farmers about the weather and provides the best crop and irrigation recommendations to increase yields. Therefore, instead of using traditional methods, smart irrigation with machine learning advice educates farmers, saves money, and makes data-driven judgments. This solves a massive issue that affects millions of people in a scalable way. We recommend ideals and evaluation parameters for evaluating the smart farming system's performance. Crop yield, dependability, along with resource efficiency are benchmarks. Temperature, humidity, rainfall, and the kind and stage of crop production are all variables that change in test conditions.

All things considered, the proposed IoT-based intelligent agriculture model makes use of sensors, cloud computing, decision support tools, and IoT devices to guarantee effective agricultural management. Some of the major technologies that are essential to the effort are machine learning, cloud platforms, wireless sensor networks, and Internet of Things devices. The framework's effectiveness in raising agricultural production and sustainability is demonstrated by its use in practice. The innovative technology transforms traditional farming methods by leveraging cloud analytics, machine learning, and the Internet of Things.

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