# INTELLIGENT SMART AGRICULTURE MONITORING SYSTEM USING IOT AND MACHINE LEARNING

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***Abstract:-*** This paper presents an Internet of Things IoT based smart agriculture monitoring system integrated with Machine Learning (ML) to make real time crop monitoring and intelligent descision making. The proposed system employs an ESP32 microcontroller interfaced with multiple sensors, including DHT22 for temperature and humidity, soil moisture , ph, MQ135 air quality, Light Dependent Resistor (LDR), flame, tilt, and rain sensors, to continuously monitor agricultural field conditions.Sensor data is processed using Embedded C programming and transmitted via Wi-Fi to a Python-based application for storage, analysis, and real-time visualization. A Random Forest Classifier is utilized to analyze environmental parameters and predict crop health by classifying field conditions into Good, Fair, and Poor categories. The system further provides irrigation recommendations, risk assessment, and real-time Telegram notifications to assist farmers in timely decision-making. A relay-controlled water pump enables automatic irrigation based on soil moisture levels, minimizing water wastage and reducing manual intervention. The proposed system enhances crop productivity, optimizes resource utilization, and promotes sustainable farming through intelligent data-driven monitoring. Its modular architecture also supports future expansion with additional sensors and automation features for precision agriculture.

***Keywords****: Internet of Things, Smart Agriculture, ESP32, Machine Learning, Random Forest Classifier, Crop Health Prediction, Precision Agriculture.*

## 1. INTRODUCTION

In order to maintain global food security and promote economic growth, agriculture is essential. However, in order to keep an eye on crop and soil conditions, conventional farming methods mostly rely on farmers' experience and manual observation. The demand for agricultural output is predicted to rise as the world's population approaches 9.7 billion by 2050, despite obstacles such soil degradation, water scarcity, climate change, and dwindling arable land. These difficulties have sped up the adoption of agriculture, where cutting-edge technologies are used to boost agricultural output, optimize resource use, and encourage sustainable farming methods. The advent of Internet of Things (IoT) technology in agriculture can be considered a breakthrough as it enables constant monitoring of environmental and soil parameters via interconnected sensors and wireless communication. IoT based solutions deliver instant feedback on vital agricultural factors like temperature, humidity, moisture content of the soil, and rainfall. Continuous monitoring allows farmers to identify changes in field conditions at an early stage and make timely decisions for effective crop management. Moreover, the combination of Machine Learning (ML) with IoT technology improves the ability of the agriculture system by converting sensor data into predictions and intelligent insights.

To address the above issues, this research work will come up with a system named “IoT Smart Agriculture Monitoring system” using Machine Learning algorithms for predicting the crop health intelligently and irrigation control. The proposed system uses an ESP32 microcontroller interfaced with different environmental sensors in order to get the field data. The gathered data from sensors will be processed using Embedded C programming and then sent via Wi-Fi to Python application for storage and analysis. Before the process of training, the gathered dataset will be pre-processed using Standard Scaler to normalize the sensor values. In this paper, I will utilize three Machine Learning classifiers: Decision Tree (DT), Linear Support Vector Classifier (Linear SVC), and Random Forest (RF) in order to analyze the agricultural dataset. The Decision Tree algorithm will serve as a baseline model for crop health classification, and the Linear SVC will classify environmental conditions. Decision Tree is an understandable method that serves as a baseline model for classification of crops health. The other classifier Linear SVC efficiently conducts linear classification of environment. The Random Forest classifier, composed of many decision trees, has demonstrated high prediction accuracy; hence it has been used as the best classifier for classifying the health of crops as either Good, Fair, or Poor. The model also offers irrigation suggestions, conducts risk assessment, and issues Telegram alerts. Moreover, in order to minimize water wastage, when the soil moisture becomes lower than the preset threshold, a relay controlled water pump irrigates the field automatically.

This sensor data is analyzed by means of Embedded C programming and sent via Wi-Fi to a Python program where the data is stored, visualized, and then processed by a Random Forest classifier to predict the status of the crop. The predictions are made by classification of the field condition into Good, Fair, and Poor conditions while recommending irrigation, risk assessment, and sending Telegram notifications in real time. Additionally, the system incorporates a relay module that controls an automatic water pump and makes it possible to irrigate the field automatically without wasting unnecessary amounts of water and decreasing manual intervention.Therefore, the suggested IoT enabled Smart Agriculture Monitoring System combines IoT and machine learning technologies in one inexpensive and scalable solution

## 2. LITERATURE REVIEW

The integration of Internet of Things (IoT) and Machine Learning technologies has transformed modern agriculture through real-time monitoring, intelligent decision making, and effective resource management. Researchers have been concentrating on creating an effective solution for smart agriculture systems based on sensors, embedded devices, and algorithms which will increase crop production and minimize the efforts and resources.Many researchers have suggested agricultural monitoring systems based on IoT in which they have collected various environmental data like temperature, humidity, soil moisture, rainfall, etc. using wireless sensor networks. This system provides real-time data to farmers through the cloud or web application to monitor field conditions. The use of microcontrollers like ESP32 has made these systems more economical and scalable because of their built-in Wi-Fi capabilities, multiple GPIO interfaces, and low power consumption. However, these systems only rely on monitoring of sensors' data and do not offer any intelligent predictions or decision support.

Different kinds of algorithms have been used including Descision Trees, SVM, Artificial Neural Network and Random Forest Classifiers for purposes like predicting crop health, crop disease identification, irrigation schedule and estimating yields. Among the methods applied for crop prediction and management, Random Forest has proved to be very accurate in prediction due to its effectiveness of handling non-linear relationship, reduces overfitting and analyzing different environmental parameters simultaneously. Past research work has found that integration of machine learning with IoT sensor network enhances prediction and proactive agricultural management.

## 3. EXISTING METHODOLOGY

In traditional farming methods, the process of monitoring the condition of the crops relies entirely on personal observation and expertise of the farmers. Farmers conduct frequent inspections of their farms and assess the condition of the crops, soil, and other environmental factors including temperature, moisture levels in the soil, humidity, and the rate at which the plants are growing. In most cases, irrigation is conducted based on a set schedule regardless of the moisture level in the soil. This means that degradation.

A few agricultural monitoring systems that are available use automation using sensors and microcontrollers to measure environmental conditions. But the limitation of these agricultural monitoring systems is that they are able to measure only a small number of parameters and do not incorporate multiple environmental factors for their analysis. The stored data in most systems is stored locally and cannot be accessed remotely. In addition, these systems do not have intelligent decision-making capabilities, predictive crop health analysis, automated irrigation management, and real-time alerts regarding any abnormal environmental conditions.Therefore, these agricultural monitoring systems need substantial human involvement, slow response time to changing environmental conditions, Water management and effective utilization of agricultural resources. The above-listed challenges illustrate the need for a comprehensive smart agriculture monitoring solution based on IoT.

## 4. PROPOSED METHODOLOGY

The suggested system combines Internet of Things (IoT) with Machine Learning (ML) technologies to implement real-time monitoring and intelligent decision making in smart agriculture. The IoT sensors will monitor environment parameters in real time with the help of an ESP32 microcontroller. Sensor readings will be transmitted to the Python server for further processing and storage in the database and analysis with the help of the Random Forest classifier. Based on the prediction about the state of crops and soil, the system will generate irrigation suggestions and send real-time notifications to farmers via Telegram.Hardware includes ESP32 microcontroller connected to DHT22 sensor (temperature and humidity), capacitive soil moisture sensor, pH soil acidity sensor, MQ135 air quality sensor, LDR light intensity sensor, as well as safety sensors (flame, rain, and tilt). A relay module manages a 12 V DC water pump and starts irrigation automatically when the soil moisture level drops below the pre-defined threshold.

ESP32 microcontroller collects sensor data at fixed intervals and sends them to the server through Wi-Fi connection. The server saves the data in a CSV dataset, which is further used for data analysis and ML model training. Prior to training, the datasetis pre-processed by handling missing values and applying feature scaling to improve prediction performance. The overall architecture of the proposed systemA Random Forest classifier is used to predict crop health by employing the environmental parameters including temperature, humidity, soil moisture, pH, air quality, and intensity of light. Crop health is classified into three categories that include Good, Fair, and Poor. With the help of predicted output, it can be determined whether there is need for irrigation and also potential risk factors. Model trained is saved and used again for prediction.

The collected agricultural data set was split into 70% for training and 30% for testing purposes.Decision Tree, Linear SVC, and Random Forest classifiers were trained using the train dataset and evaluated using the testing dataset. Among the compared models, the Random Forest **classifier** demonstrated the best prediction performance and was selected as final modelfor crop health prediction due to its higher accuracy, robustness, and ability to handle complex environmental data. An automated irrigation system is used to ensure effective water management. The relay module turns on the water pump automatically when the moisture level in the soil drops below the specified limit.

| **Machine Learning Model** | **Accuracy (%)** | **Precision (%)** | **Advantages** | **Role in the Project** |
|---|---|---|---|---|
| Random Forest | **94.65** | **99.65** | High accuracy, reduces overfitting, handles nonlinear relationships, robust against noise. | Crop health prediction and final intelligent decision-making model |
| Decision Tree | **96.00** | **100.00** | Simple to understand, fast training, easy implementation. | Crop health classification model used for comparison |
| **StandardScaler** *(Preprocessing)* | **95.80** | **95.81** | Improves model convergence and ensures features have equal importance. | Normalized sensor values before training the Machine Learning models to improve prediction performance. |
| Linear Support Vector Classifier(Linear ) | **96.50** | **96.41** | Good performance for small and medium-sized datasets, efficient classification. | Used to classify crop health by separating different classes using a linear decision boundary and compared with other models. |

Table 1. Performance Comparision of Machine Learning Modelsused in the Proposed system

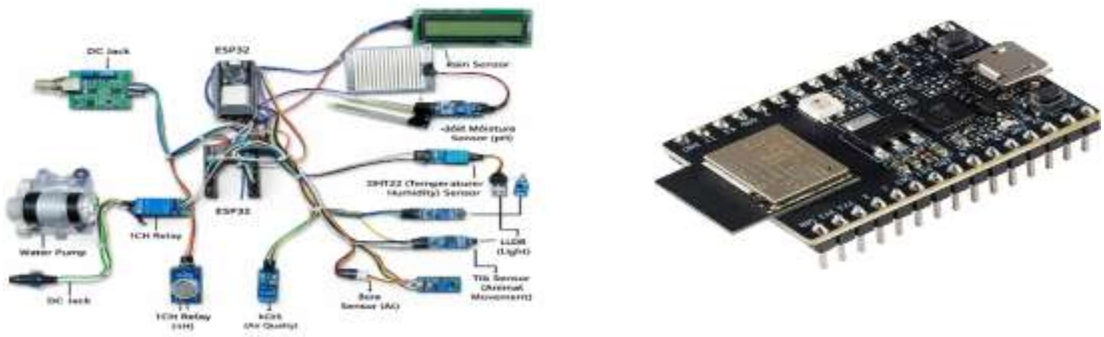


Fig. 1. Hardware implementation of the proposed ESP32-based IoT for smart agricultural monitoring system.

Moreover, the abnormal conditions, like fire, rainfall, and animal intrusion, are constantly monitored with the help of dedicated sensors. If any of the abnormal events are detected, instant alert messages will be conveyed to the farmer via the Telegram application. The entire process flow for this system consists of continuous cycles in which the sensor information is gathered by ESP32 and then sent to the Python server, where the Random Forest model processes the information and then displays it on the monitoring dashboard while also managing irrigation and alerts

## 5. RESULTS

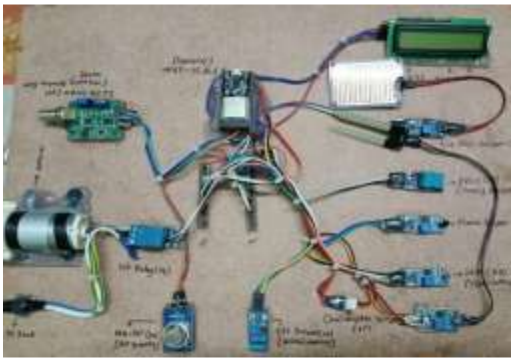

Fig.2. Hardware Kit .


Fig.3. LCD display output.

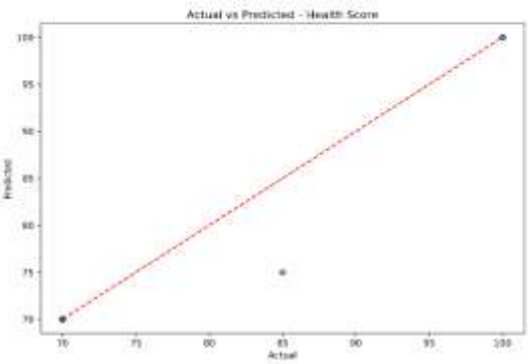


Fig.4. Actual vs Predicted health Score .

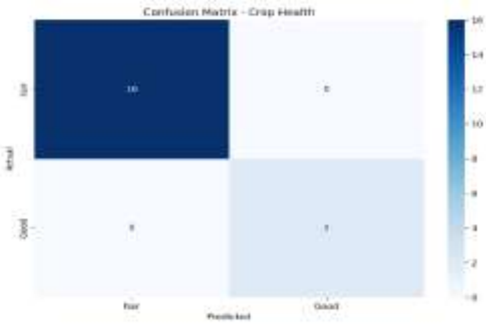


Fig.5. Confusion Matrix for crop health classification.

The confusion matrix and predictions graph show the efficiency of the Machine Learning algorithm. Moreover, the Telegram notification system worked effectively to notify about the abnormal environmental factors, and the relay irrigation system worked automatically to operate the water pump if Soil moisture content was found to be below the predetermined level.

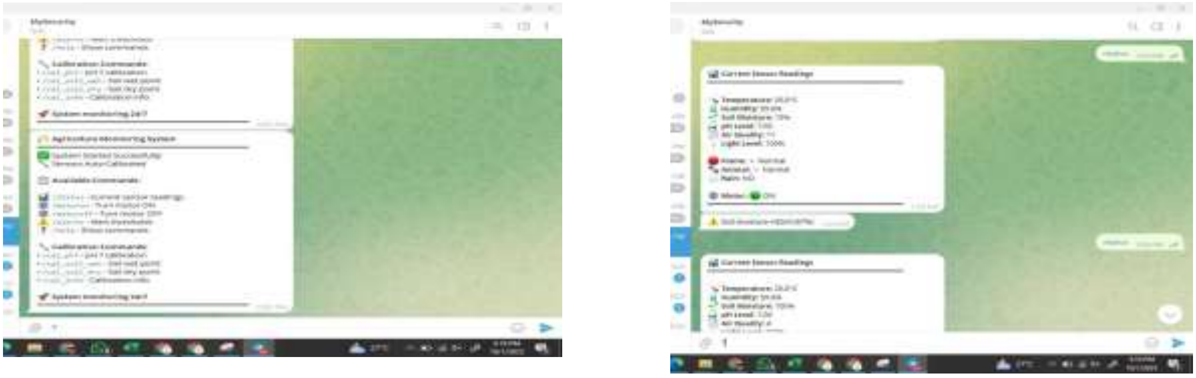

Fig.6. Telegram alerts notifications.


Fig.7. Web dashboard displaying data collected by sensors and prediction of crop health.

The proposed IoT based Smart Agriculture Monitoring System was successfully implemented and tested under various environmental conditions. The ESP32 kept on collecting sensor data and transmitting the same to the Python program using Wi-Fi connectivity. The Random Forest model was successful in predicting the state of the crops based on environmental factors while displaying sensor readings on the LCD screen.

## FUTURE WORK

Improvements to the system in the future will include use of cloud computing for remote access and agricultural application on a wide scale. Deep learning and advanced machine learning algorithms could be employed to help predict plant condition, yields, and disease. Two-way communications between the server and ESP32 would facilitate automation of irrigation processes. Also, weather prediction and mobile applications could be integrated into the system for better performance.

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