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Agro Monitoring System with AI For Rice Growth Analysis Using WSN

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Abstract: This project, "Agro Monitoring System with AI for Rice Growth Analysis Using WSN," sets out to make rice farming smarter by tracking and analysing crop conditions automatically. It brings together wireless sensor networks with IoT and AI techniques to work around the shortcomings of traditional farming. An ESP32 reads air temperature, relative humidity, soil water content and ambient light from its sensors and sends the readings wirelessly to a cloud platform. Rice growth is tracked with Growing Degree Days (GDD) and Cumulative Growing Degree Days (CGDD), while a Random Forest model predicts the current growth stage and estimates how long the crop will take to reach the next one. An ESP32-CAM also photographs rice leaves, and a Convolutional Neural Network examines those images to spot and classify likely diseases. Everything is shown on an easy-to-use dashboard, so farmers can keep an eye on crop health, catch diseases early and make better-informed decisions for efficient, sustainable rice cultivation.

Keywords: ESP32 microcontroller, DHT22 sensor, BH1750 light sensor, relay module, ESP32-CAM, OLED display, DC-DC converter, jumper wires, PCB board

I. INTRODUCTION

Rice is one of the world's most important food crops, and agriculture as a whole is central to keeping people fed. How well rice grows depends heavily on its surroundings: air temperature, moisture in the air and ground, and the amount of sunlight all matter. Traditionally, farmers have had to check their crops by hand. That takes a lot of time, and it can mean growth problems and diseases are noticed late. A smart monitoring system can give farmers timely information about what is happening in the field and help them decide what to do next.

The Intelligent Agro Monitoring System with AI for Rice Growth Analysis Using WSN that we propose pairs wireless sensor networks with IoT and AI techniques for smarter rice cultivation. An ESP32 microcontroller reads sensors that track air temperature, relative humidity, soil water content and ambient light. That data is sent wirelessly to a monitoring dashboard, so users can watch field conditions in real time.

To follow how the crop is developing, the system uses Growing Degree Days and Cumulative Growing Degree Days. A Random Forest model is meant to predict the crop's growth stage, and an ESP32-CAM takes pictures of rice leaves so a Convolutional Neural Network can look for signs of disease. The dashboard brings together the sensor readings, the camera images and whatever analysis results are available. Solar-assisted power is also part of the design to keep the system running.

By combining environmental monitoring, growth-stage analysis and disease detection, we hope to help farmers keep a closer watch on their rice crops, spot problems sooner and manage their fields with more confidence.

II. PROBLEM STATEMENT

Traditional farming often has no real-time monitoring and no intelligent analysis of environmental conditions or rice growth. Checking crops by hand can delay the discovery of diseases and growth problems, which leads to wasted resources and poor crop management. What is needed is an intelligent agro-monitoring system built on WSN, IoT and AI. It should monitor environmental parameters, analyse rice growth using GDD/CGDD, predict growth stages and detect rice diseases from crop images. By delivering timely information through a cloud-based dashboard, the system can support better decisions and more efficient rice cultivation.

III. OBJECTIVES

- To build an IoT-based system that tracks air temperature, humidity, ambient light and soil water content live.
- To classify rice growth stages with a Random Forest model using the relevant input data.
- To capture rice crop images with an ESP32-CAM for image-based analysis.
- To control a grow light based on sensor readings.

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- To develop a web dashboard that displays sensor values and crop detection results.

IV. LITERATURE REVIEW

A. Cao-hoang and Duy: Cloud-Linked Field Monitoring (2017)

Tien Cao-hoang and Can Nguyen Duy proposed an agricultural environment monitoring system built on Wireless Sensor Networks. Sensors linked to Arduino and ESP8266 modules track temperature, humidity, light intensity and air pressure. Readings travel wirelessly to a Raspberry Pi, which keeps them in IBM's Watson IoT cloud, so farmers can see up-to-the-minute field conditions in a browser-based app. That gives farmers an effortless view of their surroundings and backs the wider move toward smart agriculture. [1]

B. Cabaccan et al.: Raspberry Pi Sensor Nodes (2017)

Carlo N. Cabaccan and co-authors built a sensor network that watches farm conditions, with Raspberry Pi boards as its nodes. Using sensors such as the DHT22 and TSL2561, it measures temperature, humidity and light intensity, and sends the data over Wi-Fi to a central system. A MATLAB-based graphical interface shows the environmental information in real time. The system helps farmers keep tabs on growing conditions and manage their farming activities more effectively. [2]

C. Aquino et al.: ESP32 Mesh for a Small Farm (2021)

Aulivier Gilchrist Q. Aquino and co-authors put forward a farm-monitoring setup based on ESP32 boards, with sensors for soil wetness, air temperature, humidity and sunlight. The sensor nodes talk to each other over the ESP-WIFI-MESH protocol and forward readings to a central unit, and the readings can be viewed remotely through a web server. Solar-powered batteries keep the system running continuously. The study shows how ESP32 boards and wireless sensor networks can be put to work for efficient agricultural monitoring. [3]

D. Mulik and Patil: Camera-Based Crop Disease Watch (2023)

Vinod Mulik and Vinod Patil studied how networks of visual sensors might be applied to watching crops and spotting plant diseases. They describe how cameras and sensors can gather both crop images and environmental information, which helps farmers spot diseases early and keep an eye on plant health. The paper also looks at technologies such as Wi-Fi, ZigBee, LoRa and Raspberry Pi for agricultural use, and argues that visual sensor networks are valuable for better crop monitoring and smart farming. [4]

E. Mowla and Mowla: IoT and WSN in Smart Farming (2023)

M. D. Najmul Mowla and Neazmul Mowla looked at how IoT platforms and sensor networks serve smart agriculture. Their paper covers how sensors monitor soil moisture, temperature, humidity and other environmental conditions, and it reviews wireless technologies such as Wi-Fi, ZigBee, LoRaWAN and Sigfox. These technologies help farmers watch their fields and use resources efficiently. They go on to describe how AI and machine learning can sharpen farming practice and enable precision agriculture. [5]

F. Trigka and Dritsas: A Broad WSN Overview (2025)

Maria Trigka and Elias Dritsas gave a detailed overview of Wireless Sensor Networks and their uses in many fields, including smart agriculture. They explain how sensor nodes collect and transmit data wirelessly and discuss communication protocols, routing methods and energy-saving techniques. They also describe how artificial intelligence can make sensor networks and data processing more efficient. The study helps show why WSN technology matters for real-time monitoring and smart agricultural applications. [6]

G. Khaliq, Khan and Jan: AI Advice for Soil and Crops (2025)

Ayesha Khaliq, Atif Khan and Salman Jan proposed an AI-based smart agriculture system built on IoT sensors. It collects soil information such as moisture, temperature, pH and nutrient levels, and uses different AI models to suggest irrigation, recommend crops and predict fertilizer needs. Weather data is also used to improve farm planning, and a chatbot helps farmers understand the recommendations easily. The study shows how AI and IoT together can improve farming decisions, raise productivity and support sustainable agriculture. [7]

V. COMPARATIVE ANALYSIS

Table I summarises the representative studies by year, technology or method, main contribution and limitation.

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TABLE I. COMPARATIVE ANALYSIS OF AGRICULTURAL MONITORING STUDIES

Ref.	Year	Technology / Method	Contribution	Limitation
[1]	2017	Arduino, ESP8266, MQTT	Real-time environmental monitoring	No rice growth prediction
[2]	2017	Raspberry Pi, sensors	Agricultural environmental monitoring	No specific crop monitoring
[3]	2021	ESP32, multiple sensors, Wi-Fi mesh	Monitors soil moisture and temperature	No AI-based rice growth prediction
[4]	2023	WSN, cameras	Crop image monitoring	No rice growth prediction
[5]	2023	IoT, WSN	Supports better farm monitoring	No rice-specific analysis
[6]	2025	WSN protocols	Improves sensor communication	No crop monitoring
[7]	2025	IoT, AI	Gives crop and fertilizer recommendations	No image-based rice growth analysis

Most of the existing work focuses on environmental monitoring, crop disease detection or smart agriculture in general. Some papers rely on sensors for data collection, while others use cameras and AI. None of them, however, unite all of these capabilities in a single rice growth analysis system.

VI. RESEARCH GAP

Existing research mostly deals with agricultural monitoring, wireless sensor networks, crop disease detection and smart farming. Many of these systems only log field data like air temperature, humidity, soil water content and illumination, and they say little about the different growth stages of rice plants. A few studies do use cameras to watch crops, but they don't combine image analysis with environmental sensor data to give a complete picture of rice growth.

Farmers also need a simple way to see sensor readings and crop analysis in one place. To address these gaps, our project combines the ESP32, ESP32-CAM, environmental sensors and a Random Forest model to monitor rice field conditions, capture plant images and analyse rice growth stages. We have also developed a web-based dashboard that displays the sensor readings and AI analysis results, making it easier for farmers to follow how their rice is growing.

VII. PROPOSED SYSTEM ARCHITECTURE

The proposed Intelligent Agro-Monitoring System is built from a power supply, sensor monitoring, image capture, data processing, growth prediction and automatic control units. A 7–12 V DC supply feeds a 5 V regulator, which powers the ESP32 and ESP32-CAM modules. The ESP32 is the main controller, and it takes readings from a DHT22 (temperature and humidity), a BH1750 (light) and a capacitive soil probe. A Random Forest machine learning model then works on these readings to predict the rice growth stage. The ESP32-CAM takes pictures of the rice plants to look for possible signs of disease. Two relay modules control a 12 V DC water pump and a grow light. An SH1106 OLED display shows the sensor readings, and the web-based dashboard presents the monitoring and analysis results. Altogether, the system makes it easier for farmers to track rice growth and manage field conditions.

The functional flow is as follows:

- Power supply → 5 V regulator → ESP32 → sensor data collection → Random Forest model → rice growth prediction.
- ESP32-CAM → image capture → disease identification→ web dashboard.
- ESP32 → Relay Module 1 → water pump (planned for the future).
- ESP32 → Relay Module 2 → grow light.
- ESP32 → SH1106 OLED display → sensor readings.

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VIII. HARDWARE CONFIGURATION

TABLE II. HARDWARE CONFIGURATION

Component	Specification	Function
ESP32	Wi-Fi and Bluetooth	Main controller
ESP32-CAM	OV2640 camera	Captures rice plant images
DHT22	Temperature and humidity sensor	Measures temperature and humidity
BH1750	Digital light sensor	Measures light intensity
Soil moisture sensor	Moisture level	Measures soil moisture
DC-DC converter	5 V regulator	Provides regulated 5 V supply
Relay Module 1	Channel 1	Controls water pump
Relay Module 2	Channel 2	Controls grow light
OLED display	SH1106, 1.3-inch, 128×64	Displays sensor readings
PCB board	Circuit board	Connects electronic components

IX. SOFTWARE CONFIGURATION

Random Forest Model Implementation and Training

We implemented the Random Forest algorithm in Python using the Scikit-learn library to predict the growth stage of rice plants. The model uses four environmental inputs: air temperature, humidity, soil water content and light level. The DHT22, the soil probe and the BH1750 attached to the ESP32 supply these values.

A. Library Installation

We installed the Python packages we needed through pip. They are:

- Scikit-learn: to build and train the Random Forest model.
- Pandas: to load and process the agricultural dataset.
- NumPy: for numerical calculations and data operations.

B. Dataset Preparation

The agricultural dataset was collected and stored in CSV format. It holds four input columns (air temperature, humidity, soil water content and light level), and the rice growth stage is the label the model learns to predict. The data was organised and prepared before being used to train the model.

C. Model Training

The dataset is split 80% for training and 20% for testing. The Random Forest Classifier is configured with 100 decision trees. During training, the model learns how environmental parameters relate to the different rice growth stages, and it is then tested on the remaining data to evaluate how well it predicts.

D. Growth Stage Prediction

Once trained, the Random Forest model takes in the environmental sensor readings and predicts the matching rice growth stage. The predictions are sent to the web-based dashboard for display, helping farmers follow their crop's growth conditions and understand how it is developing.

X. METHODOLOGY

1. The ESP32, ESP32-CAM, DHT22, BH1750, capacitive soil moisture sensor, SH1106 OLED display and two relay modules are connected.
2. A DC power supply is connected to a voltage regulator to give the system the power it needs.
3. The DHT22 measures the temperature and humidity of the agricultural environment.
4. The BH1750 measures the light intensity in the rice field.
5. The soil probe reports how wet the soil is.
6. The ESP32 gathers whatever each attached sensor reports and prepares it for processing.
7. The readings are passed to the trained Random Forest model, which predicts the rice growth stage.

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8. The ESP32-CAM captures images of the rice plants for visual monitoring and possible disease identification.
9. Two relay modules connected to the ESP32 control the attached electrical loads.
10. The SH1106 OLED shows the collected environmental sensor readings.
11. Sensor values, growth-stage predictions and possible disease identification results appear on a web-based dashboard.
12. The system helps farmers monitor rice growth and environmental conditions with less manual effort.

XI. IMPLEMENTATION

The proposed system is built around an ESP32 microcontroller, an ESP32-CAM, a DHT22 sensor, a BH1750 light sensor, a soil moisture sensor and an SH1106 OLED display. These components are integrated to collect environmental data from the rice field. The DHT22 measures temperature and humidity, the BH1750 records how bright it is and the soil probe follows moisture in the ground. The ESP32 processes the readings and shows them on the OLED display.

The ESP32-CAM captures images of the rice crop for image-based analysis. A trained Random Forest model classifies rice growth stages from the available trained dataset and input features. We also developed a Wi-Fi-enabled web dashboard that displays live field readings (temperature, humidity, brightness and soil wetness) together with the predicted growth stage.

Two relay modules are included, one to control the grow light and one to leave room for water pump automation later. At present, the grow light is controlled using predefined light intensity thresholds. Water pump automation, driven by soil moisture readings, is planned as a future enhancement.

XII. TEST RESULTS

The system successfully tracks air temperature, humidity, ambient light and soil water content live. The ESP32-CAM captures images of the rice crop, and the Random Forest model handles growth-stage classification. The readings and the predicted stage show up on both the web dashboard and the OLED display.

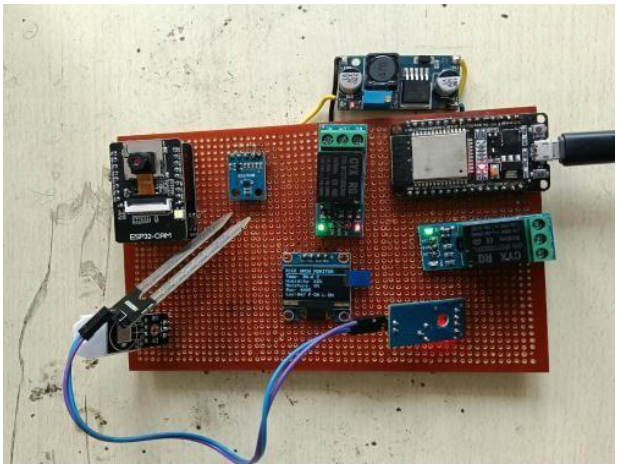


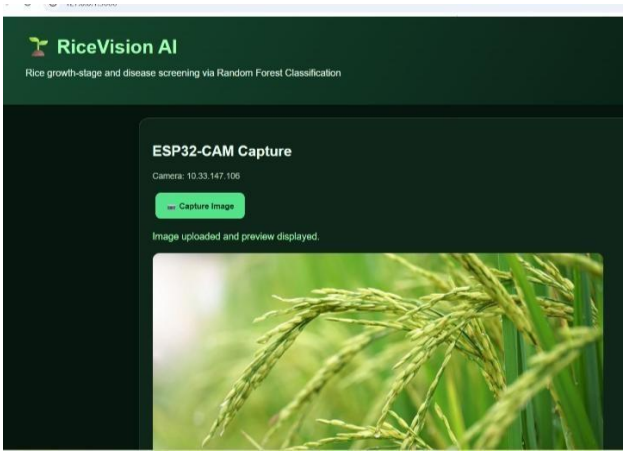
Fig. 1. The system hardware.

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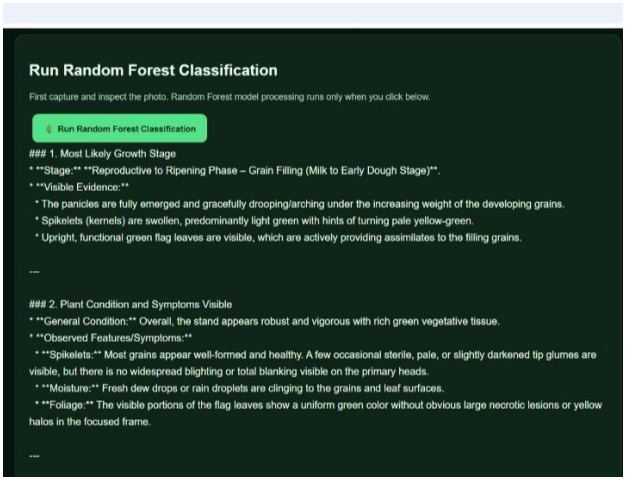


Fig. 2. Crop growth stage result.

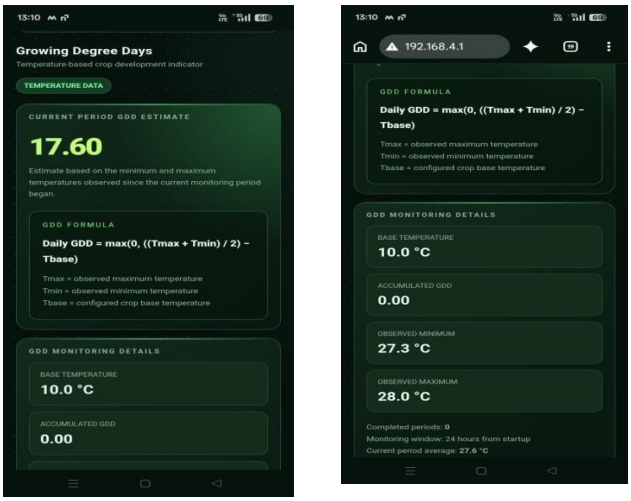


Fig. 3. GDD calculation.

XIII. ADVANTAGES

- Real-time monitoring of environmental parameters.
- Automatic grow-light control based on light intensity.
- Rice growth-stage classification using a Random Forest model.
- Wireless data monitoring through a web dashboard.



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- Less manual effort needed for crop monitoring.
- An IoT-based approach to smart agriculture.

XIV. LIMITATIONS

- A Wi-Fi link is required for web-based monitoring.
- How accurate the classification is depends on how good the training data is.
- Environmental conditions can influence the sensor readings.
- Water pump automation has not been built yet and is left for later work.
- The system must be powered continuously to work properly.

XV. FUTURE SCOPE

The system can be taken further in several ways. Automatic irrigation could be added, using a water pump driven by soil moisture levels. Stronger ML models could make growth-stage classification more accurate, and additional sensors could track other soil and environmental parameters. A mobile app could give farmers remote monitoring and notifications, and solar power could be introduced to cut energy consumption and support operation in the field. Together, these improvements could make monitoring more accurate, reduce manual effort and support efficient, sustainable smart agriculture.

XVI. CONCLUSION

This paper presented an effective approach to smart agriculture. The system uses IoT technology to monitor key environmental parameters — temperature, humidity, light intensity and soil moisture — in real time. The ESP32-CAM captures images of the rice crop, while the Random Forest model classifies the growth stage. Sensor data and classification results are shown through a Wi-Fi-enabled web dashboard and the OLED display.
The grow light is switched automatically through relay modules based on predefined light intensity thresholds. The system cuts down on manual monitoring and gives useful insight into crop growth conditions. Overall, this work illustrates how pairing IoT, machine learning and sensor networks can strengthen crop monitoring and smart farming.

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