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IoT-Based Leaf Disease Detection Through Color Change Using ESP32-CAM and TCS3200 with Telegram Alerts

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ABSTRACT

2 Improving crop health and agricultural productivity requires early detection of plant diseases. Frequently, one of the earliest obvious signs of plant stress or disease is leaf discoloration, especially yellowing. This study introduces an Internet of Things (IoT)-based system that uses an ESP32-CAM module and a TCS3200 color sensor to detect disease-induced changes in leaf color in real time. Using preset thresholds, the TCS3200 sensor continuously analyzes the RGB values of leaves to identify yellowing. A secondary ESP32-CAM module receives a signal upon detection and uses it to take a picture of the afflicted leaf. HTTPS requests are then used to send the captured image and a notification to a specified Telegram chat. The suggested system lessens the need for ongoing manual supervision in agricultural settings by providing an affordable, automated solution for remote plant health monitoring and early disease detection. The system's ability to identify color variations and provide timely alerts is demonstrated by experimental results. By providing visual confirmation in addition to sensor data, the combination of color-based sensing and image capture improves the accuracy of disease detection. Farmers, agronomists, or automated systems can minimize crop damage by acting promptly thanks to this dual-layer verification. The system is appropriate for smart farming applications in both open fields and greenhouse settings because it is scalable, energy-efficient, and adaptable to different plant types. This study supports the creation of proactive plant health management systems and advances precision agriculture by utilizing the Internet of Things and real-time communication via Telegram

Keywords [Plant Health Monitoring, ESP32-CAM, TCS3200, Telegram Bot, Color Sensing, Leaf Disease Detection, Precision Agriculture, Image Capture, and Real-Time Notification] .

I. INTRODUCTION

To meet the rising food demands of a growing population, global agricultural production must expand quickly. Crops, however, are susceptible to a number of diseases that can seriously impair quality and yield. For efficient management, crop loss reduction, and pesticide use reduction, early detection of these diseases is essential. Leaf discoloration, especially yellowing, is frequently one of the first obvious signs of plant disease and can be brought on by pathogen attacks or environmental stress.

Plant disease detection has historically depended on manual inspection, which is labor-intensive and time-consuming. Automation of plant health monitoring has become possible thanks to recent developments in sensor and Internet of Things (IoT) technologies. Early disease indicators can be found and treated more quickly by employing sensors to identify physical changes in plant traits, such as leaf color. The TCS3200 color sensor and ESP32-CAM modules are combined in this study's innovative IoT-based system to identify disease-related changes in leaf color. By measuring the RGB values of the leaf surface, the TCS3200 sensor makes it possible to identify yellowing patterns linked to plant disease and stress. When the system notices such changes, it notifies a Telegram bot and sends it a picture of the impacted leaf. This method offers a cost-effective, automated, and real-time way to monitor the health of plants remotely. The objective of this research is to create a system that can identify changes in leaf color and enable prompt communication with agronomists and Rent/lease services, weather forecasting, payment solutions, and credit accessibility are the four main elements that form the foundation of the application. These features help farmers cut expenses, streamline operations, and guarantee smooth financial transactions by addressing some of their most urgent and immediate issues. The application establishes the groundwork for a more comprehensive agricultural ecosystem by concentrating on these elements.

farmers, allowing for prompt mitigation of crop damage. This work adds to the expanding field of precision agriculture and demonstrates how technology has the potential to completely transform crop management by utilizing IoT and Telegram for real-time notifications.

II. LITERATURE SURVEY

There has been a lot of interest in the monitoring and detection of plant diseases, and many studies have looked into different early detection techniques and technologies. Plant disease detection has historically mainly depended on agricultural specialists' visual inspection, but this approach is time-consuming and prone to human error. Researchers are increasingly using automated solutions that make use of cutting-edge sensor technologies and machine learning to overcome these constraints.

Color sensing is one of the most widely used sensor technologies for plant monitoring. The use of color sensors to identify alterations in leaf color brought on by illness or environmental stress has been investigated in a number of studies. For example, Tuch et al. (2016) employed color analysis to identify plant chlorophyll degradation, a typical sign of a number of plant diseases. Because it can measure RGB values and is reasonably priced, the TCS3200 color sensor in particular has been widely used in applications similar to this one. Sharma et al. (2018) showed how well TCS3200 distinguishes various colors linked to plant health, allowing for the early identification of diseases like rust and blight.
Significant advancements have also been made in IoT-based plant health monitoring. Plants can be continuously and remotely monitored thanks to the integration of IoT devices with environmental sensors. The use of IoT systems to monitor different environmental factors like temperature, humidity, and light—all of which have an impact on plant growth and health—was investigated in studies like those by Khan et al. (2020) and Patel et al. (2019). However, these systems frequently lack the specificity required to identify diseases early on. In order to increase the accuracy of disease detection, recent developments have combined sensor data with image processing. For instance, Lin et al. (2021) demonstrated the potential of visual data in plant health by using computer vision techniques in conjunction with IoT sensors to classify plant diseases from drone-captured leaf images.

Additionally, a number of Internet of Things applications have used Telegram bots to provide real-time notifications. Telegram's wide user base, API accessibility, and ease of use make it the perfect platform for agricultural alert systems. Telegram bots were used in a study by Nguyen et al. (2022) to notify users of environmental changes in greenhouse settings, demonstrating how this platform could improve agricultural decision-making.
Despite significant advancements, there is still a gap in the integration of visual confirmation and real-time disease detection. The majority of existing systems concentrate on either image processing or color sensing, but very few integrate both into a straightforward, automated, and reasonably priced system. By creating a system that employs color-based detection using the TCS3200 sensor and visual confirmation using the ESP32-CAM module, as well as sending alerts and images via Telegram to facilitate prompt intervention, this research seeks to close that gap.

Proposed Method

A TCS3200 color sensor and two ESP32-CAM modules are integrated in a multi-step procedure to create the suggested system for identifying leaf diseases based on color changes. The architecture of the system is made to recognize possible disease-related yellowing, detect color changes in leaves, take a picture of the afflicted leaf, and notify users via Telegram. The methodology is broken down step-by-step below.:
Overview of System Design
There are two main components to the system:
The RGB values of the leaf are read by the ESP32-1 (Color Detection) module, which is attached to the TCS3200 color sensor. It signals the second ESP32 to start taking pictures if the RGB values show yellowing.
ESP32-2 (Image Capture & Notification): This module uses the onboard camera to take a picture of the leaf and then uses a bot to send the picture and a notification to a specified Telegram chat bot.

1.Color Detection using TCS3200
Detecting variations in leaf color is the system's initial step. The TCS3200 color sensor measures the amount of red, green, and blue light reflected from the leaf using a collection of photodiodes. Each color component's corresponding frequency is output by the sensor and processed by the ESP32-1 module.

RGB Calculation: The RGB values are determined by the ESP32-1 by reading the TCS3200's output. Each color component's intensity is ascertained using the frequency output of the sensor.

Threshold-Based Detection: The system has preset thresholds for RGB values that match the color yellow, which is indicative of possible illness. The second ESP32-CAM receives a signal to trigger if the RGB values are in the yellow range.

2.Capturing and Sending Images
When the first ESP32 notices yellowing, it signals ESP32-2 (through a digital pin) to use the onboard ESP32-CAM module to take a picture of the leaf. After that, the picture is processed and ready to be sent.

Wi-Fi Connection: ESP32-2 uses pre-configured credentials to connect to the internet via Wi-Fi. This guarantees that the Telegram bot can receive data remotely from the system.

Image Capture: A picture of the leaf is taken by the ESP32-CAM. By adjusting the camera settings, image clarity can be changed based on the lighting and the position of the leaf.

3.Monitoring and Alerts in Real Time

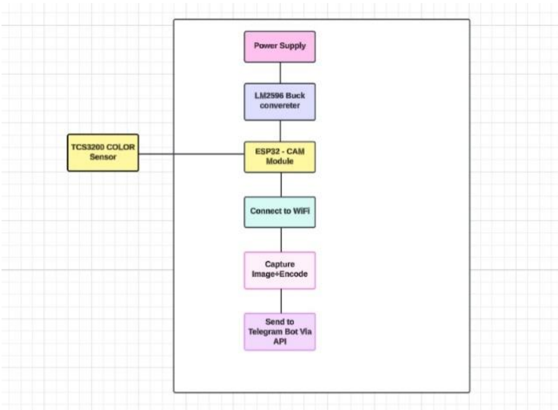
The leaves are continuously monitored for color changes by the real-time system. The ESP32-1 instructs the ESP32-2 to take and transmit the picture if yellowing is detected. The user is informed through Telegram notifications, which enable prompt remedial action.

4.Diagram of the System Flow

The system's operation is depicted in the flow diagram below:
Step 1: The TCS3200 detects the leaf's RGB values.
Step 2: The ESP32-1 analyzes the data and looks for the yellow (disease) indicator.
Step 3: ESP32-1 notifies ESP32-2 if yellow is detected.
Step 4: The ESP32-2 establishes a Wi-Fi connection, takes a picture, and transmits it to the Telegram bot.

III. PROPOSED METHOD

BLOCK DIAGRAM:



Workflow:

The suggested system uses a TCS3200 color sensor and two ESP32-CAM modules in a sequential workflow to identify possible leaf diseases based on discoloration. The steps listed below outline how the system functions in its entirety:

Steps:

1.Configuration and Initialization

The TCS3200 color sensor is linked to the ESP32-1, which continuously checks the leaf's RGB values.
The Telegram bot token and chat ID for message delivery are pre-programmed into the ESP32-2, which is set up to connect to a Wi-Fi network.

2. ESP32-1 Color Detection

By using its array of photodiodes to detect red, green, and blue components, the TCS3200 sensor determines the color of the leaf.
The ESP32-1 converts the frequency output from the sensor into RGB values.
The detected color is compared to predetermined thresholds for yellowing, a potential disease symptom, by the system.

3:.Signal Trigger

ESP32-1 serves as a digital trigger for ESP32-2 by setting GPIO pin 16 to HIGH if yellow is detected.
The ESP32-1 scans continuously if no yellowing is found.

4. ESP32-2 Image Capturing

The ESP32-2 initializes the onboard camera upon receiving the signal.
The impacted leaf is photographed using the ideal focus and brightness settings.

5.Telegram Notification The ESP32-2 connects to the Telegram Bot API over HTTPS.
The user receives the captured image via Telegram along with a pre-written alert message (for example, "⚠ Leaf Color Change Detected – Possible Disease").
This enables remote visual verification of the plant's health by farmers or agricultural specialists.

6. Reset the system

The ESP32-2 goes back to standby mode after sending the image, anticipating the subsequent trigger.
ESP32-1 keeps an eye out for additional variations in leaf color.

IV. Results and Discussions

The developed system's capacity to identify changes in leaf color that could be signs of possible plant diseases was validated through practical testing. One TCS3200 color sensor and two ESP32-CAM modules made up the configuration. While the second ESP32 was configured to take a picture and send it to a Telegram account when triggered, the first ESP32 module interfaced with the color sensor to continuously monitor the RGB values of a leaf surface.

Several leaf samples with different conditions—from fully and partially yellowed leaves to healthy green leaves—were examined during the experiment. The ESP32-1 module converted the color frequencies that the sensor precisely recorded into RGB values. These numbers were contrasted with a predetermined yellow coloration threshold. A digital HIGH signal was sent to the second ESP32 module when the RGB values crossed the threshold in cases of yellowing, which is frequently an early sign of a disease or nutrient deficiency.

This signal caused the ESP32-2 to initialize the camera module, take a picture of the afflicted leaf, and successfully send it to the user via the Telegram bot. This transmission usually happened 3–5 seconds after color detection, demonstrating the system's ability to notify users and indicate diseases almost instantly. The quality of the Telegram-received images was adequate to visually detect discoloration and evaluate the health of the plant. A high degree of specificity in the detection logic was demonstrated by the fact that brown, dried leaves and healthy green leaves did not cause the system to activate because their color values were outside the detection range.

The system's performance demonstrates a number of benefits. It combines the usefulness of image-based confirmation with the ease of use of color-based detection. Due to its low resource requirements and lack of external servers, this setup is far more economical and energy-efficient than conventional manual monitoring or high-computation image classification systems. Small-scale farmers without access to advanced disease detection equipment will find it especially useful.

Nevertheless, certain restrictions were also noted. The system's reliance on yellow coloring restricts its ability to detect diseases that do not initially manifest with noticeable color changes, and its color detection accuracy may vary in changing lighting conditions. Furthermore, even though the system verifies discoloration, it is unable to identify the disease type, which may necessitate additional AI model integration or outside diagnostics. Notwithstanding these drawbacks, the system presents a viable basis for automated, scalable, and reasonably priced disease warning systems that can be implemented in isolated or resource-constrained agricultural settings.

The findings show that the suggested system is a dependable, real-time way to identify early indicators of leaf discoloration and send out alerts via Telegram. This system has the potential to develop into a comprehensive plant health monitoring tool with additional improvements, such as disease classification models and lighting normalization.

Future Outcomes

The present system establishes the foundation for an inexpensive, real-time plant monitoring system that focuses on the early identification of disease-related leaf discoloration. Its accuracy, intelligence, and usability can all be greatly increased in the future with a few improvements. Using machine learning algorithms to categorize various leaf diseases from the photos taken is one of the most promising approaches. A lightweight neural network model can be trained on labeled leaf disease datasets to diagnose specific conditions like leaf blight, chlorosis, or nutrient deficiencies, going beyond the simple detection of yellowing.

Expanding the system to accommodate multi-spectral color detection is another potential improvement. The system could detect stress patterns in plants that are not visible to the human eye by integrating extra sensors like ultraviolet (UV) or near-infrared (NIR) detectors, providing an even earlier and more accurate diagnosis. This would increase the solution's resilience and dependability in a variety of plant species and environmental circumstances.

Cloud integration can also help the project by enabling the creation of a centralized dashboard that allows farmers or agricultural specialists to concurrently monitor the health of plants from several farms. To anticipate disease outbreaks and take preventative action, trend analysis can be carried out with the aid of data logging. Additionally, adding GPS modules can enable disease reports to be geotagged, which aids in the development of intelligent agricultural maps for local disease monitoring.

Future versions of the system could include a mobile app interface for improved user management and interaction in terms of accessibility. This would create a feedback loop that improves the model's performance over time by enabling users to view image logs, modify detection thresholds, receive real-time alerts, and even report back observations.

All things considered, the suggested system has a great deal of potential to grow into an intelligent, AI-powered precision agriculture tool that gives farmers timely, useful insights, lowering crop losses and raising total yield.

V. Conclusion

In this study, an economical and effective Internet of Things-based system was created to identify early plant disease symptoms by analyzing changes in leaf color, with a particular emphasis on yellow discoloration. With the help of two ESP32-CAM modules and the TCS3200 color sensor, the system was able to detect color changes in real time and send out alerts via Telegram. It also took pictures for visual confirmation. With this method, farmers can remotely check on the health of their crops and take prompt action to stop diseases from spreading.

The findings show that the suggested system's affordability, ease of use, and scalability make it useful for actual agricultural applications in addition to being accurate at identifying leaf yellowing. Although the system's primary function at the moment is to identify yellow as a general disease indicator, it offers a solid basis for future developments like disease classification, AI integration, and cloud-based analytics.

This system fills a significant void in easily accessible plant health diagnostics by providing users with automated, real-time monitoring and notifications. It has great potential to support intelligent and sustainable farming methods with further development and integration of cutting-edge technologies, particularly for small and medium-sized farmers operating in environments with limited resources.

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