

Leafy: A Sustainable IoT Solution for Improving Plant Health & Monitoring in Small-Scale Agriculture

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Abstract— Small-scale farmers often struggle with monitoring crop health due to expensive and complex agricultural technologies. Existing solutions lack real-time data collection and are difficult to use, making it hard for farmers to respond quickly to environmental changes and crop diseases. This paper presents Leafy, an affordable Internet of Things (IoT) system designed specifically for small farms. Leafy uses low-cost sensors to monitor soil moisture, temperature, humidity, and light levels, along with a camera module to capture crop images for disease detection. The collected data is sent wirelessly to a mobile app that shows real-time information, stores historical data, and uses AI models from Hugging Face to predict plant diseases. The system is designed to be easy to use, affordable, and scalable for farmers with limited technical knowledge. Initial testing shows that Leafy can help improve crop management and support sustainable farming practices. (Abstract)

Keywords—*IOT in Agriculture, smart farming, Crop Disease Detection, Environmental Monitoring, Small-Scale Farming (key words)*

I. INTRODUCTION

Agriculture remains a fundamental sector in many developing countries, yet small-scale farmers often lack access to advanced technologies that can improve crop health and yield. Traditional farming methods, while practical, are limited in their ability to provide timely insights into environmental conditions or early signs of plant disease. This gap leaves farmers vulnerable to issues such as inconsistent soil moisture, temperature stress, and undetected pest infestations, all of which can significantly affect productivity. To address these challenges, *Leafy* introduces a compact, cost-effective device that integrates Internet of Things (IoT) sensors and image-based disease detection, paired with a mobile application. Designed specifically for small-scale farming, Leafy enables real-time environmental monitoring, historical data analysis, and intelligent diagnostics, helping farmers make informed decisions with minimal technical overhead.

II. OBJECTIVES

Leafy is specifically designed for small-scale farmers with limited technical background, ensuring that the system is easy to deploy, operate, and maintain without specialized training.

- **Plug-and-play setup:** All sensors are precalibrated and integrated into a compact unit, allowing quick and hassle-free installation in the field. The device requires minimal wiring and configuration, making it accessible even to users with no prior experience in electronics or IoT. (Figure 1) (Figure 2)
- **Intuitive mobile app:** Developed using the React-native framework, the Leafy app offers a clean and responsive user interface. Real time environmental data such as soil moisture, temperature, humidity, and light intensity are presented in a visual dashboard (Figure 3), enabling quick understanding at a glance.
- **Multi crop monitoring:** Users can add and manage multiple crops through the app interface. When a new crop is added, the system stores ideal environmental conditions for that specific crop in the database. Alerts and recommendations are then dynamically adjusted based on the unique requirements of each plant, enabling personalized and effective monitoring.
- **Automated alerts:** The system generates notifications when environmental parameters fall outside optimal thresholds for example, when soil moisture drops too low or if a potential disease is detected through image analysis. These alerts are delivered in simple, easy to understand language, helping farmers take timely action without needing to interpret raw data.
- **AI-powered disease analysis:** The app includes an advanced feature that analyzes crop health by processing photos and videos captured by the device. Using pretrained AI models from Hugging Face's state of the art repositories, the system can identify and classify common crop diseases without the need for custom model training. This approach leverages transfer learning and robust image recognition capabilities, enabling accurate and efficient disease detection while reducing development time and resource requirements.

Figure 1: Leafy Hardware Sketch

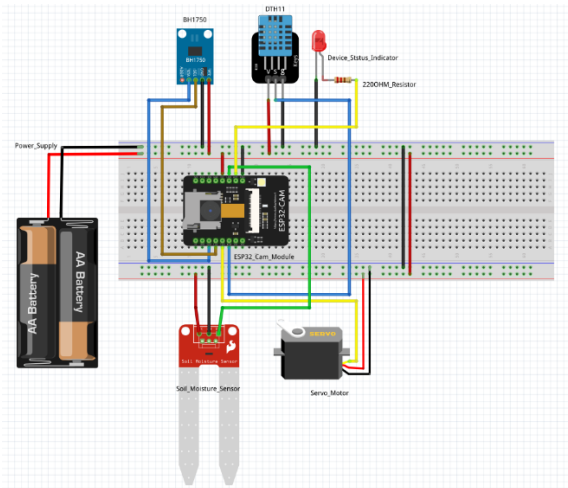
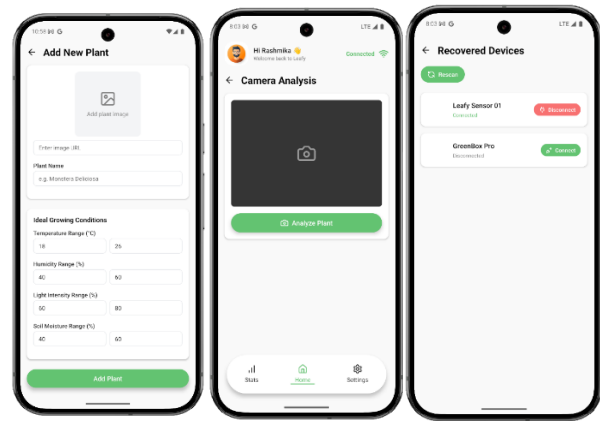
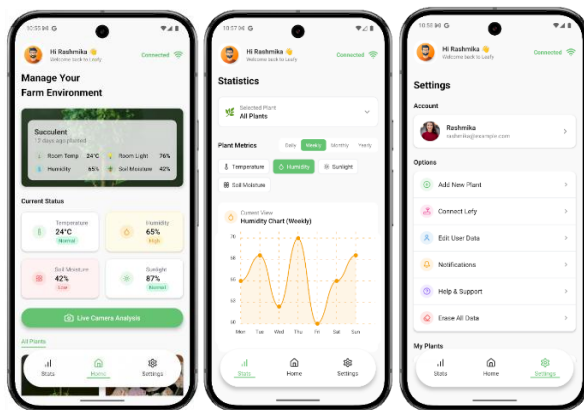


Figure 2: Complete Device Prototype



Figure 3: Leafy Mobile App Interface



III. HARDWARE COMPONENTS

The Leafy system integrates a carefully selected set of hardware components to ensure affordability, scalability, and reliability in real-world farm environments. Each component was chosen to meet the specific needs of small-scale farming with a focus on low cost, low power consumption, and ease of integration. (Figure 1)

-ESP32 Camera Module: This microcontroller was selected due to its built-in Wi-Fi and Bluetooth capabilities, enabling both wireless communication and remote access for real-time monitoring. Its integrated camera support allows for real-time image and video capture essential for disease detection and crop monitoring. The module features expandable memory via SD card slot for local image storage, ensuring data retention even in areas with poor connectivity. Its low power consumption and multiple sleep modes make it ideal for battery operation, while its compact design and cost-effectiveness ensure suitability for field deployment. The ESP32's versatility extends to supporting image streaming, facial recognition capabilities, and seamless integration with IoT platforms for comprehensive agricultural monitoring systems.

-Soil Moisture Sensor (Capacitive Type): Unlike resistive sensors, capacitive moisture sensors demonstrate superior durability and accuracy due to their resistance to corrosion in wet environments. This technology ensures stable long-term performance, making them more reliable over extended periods of field use. These sensors are essential for effective irrigation management and continuous plant health monitoring, providing critical data for optimizing water usage in agricultural applications.

-DHT11 Sensor (Temperature and Humidity): These sensors were chosen for their simplicity, low cost, and acceptable accuracy levels suitable for agricultural applications. They provide dual functionality by measuring both temperature and humidity through a single digital output, simplifying system integration. Their easy integration with microcontrollers and extensive support in software libraries make them ideal for monitoring microclimate variations that directly affect plant growth and disease susceptibility.

-BH1750 Light Sensor: The BH1750 digital light intensity sensor was selected over simpler alternatives like LDRs due to its superior precision and direct digital lux output capabilities, eliminating the need for analog-to-digital conversion or complex calculations. It offers high accuracy with a sensitivity range of 1–65,535 lux and features an I2C interface for seamless integration. Its spectral response closely mimics the human eye, making it more precise and user-friendly than photodiodes or LDRs. This makes it ideal for monitoring sunlight exposure levels critical to crop health and photosynthesis optimization.

Power Supply and Battery Backup: To ensure uninterrupted operation in remote or unstable power environments common in agricultural settings, the device supports battery-powered operation with optional solar charging capabilities. This design enhances the system's reliability for continuous monitoring while enabling deployment in off-grid areas where traditional power sources are unavailable, ensuring consistent data collection for effective crop management.

Leafy measures key parameters with the following units and optimal ranges:

(Table 1)

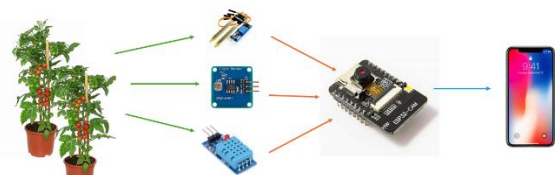
Parameter	Unit	Optimal Range	Sensor Used
Soil Moisture	%	40–80% (varies by crop)	Capacitive Soil Moisture Sensor
Temperature	°C	18–30°C (crop-specific)	DHT22
Humidity	%	50–70%	DHT22
Light Intensity	lux	10,000–50,000 lux	BH1750

IV. DEVICE ARCHITECTURE AND DATA FLOW

The hardware setup (Figure 01) uses a breadboard for prototyping with carefully planned pin connections to ensure reliable communication between all components. The DHT11 sensor connects through a digital GPIO pin for simple data collection, while the BH1750 sensor uses the I2C communication protocol through SCL and SDA lines for efficient data transfer. The capacitive soil moisture sensor connects to an analog input pin, allowing continuous monitoring of soil water levels. The servo motor is connected to a PWM-capable pin, providing precise control for environmental responses or user commands. The LED status indicator serves as a clear diagnostic tool with specific patterns: steady light indicates successful network connection, flashing every one second shows the device is ready to connect but not yet connected to the network, and rapid flashing every 0.1 seconds signals hardware faults or system errors. All components share a common power supply, ensuring coordinated operation and maintaining the low power consumption necessary for reliable performance in remote, battery-powered field conditions.

The data collection process in the Leafy system starts with all sensors gathering environmental information at the same time. The ESP32-CAM collects readings from each sensor at set intervals, processes the raw data, and formats it for wireless transmission. At the same time, the built-in camera captures plant images or videos based on scheduled timing or user requests. These complete data packages, containing both environmental measurements and visual information, are sent wirelessly to the mobile application using HTTP communication methods. Once received, the mobile app displays current data for immediate viewing and saves historical information in a database for tracking trends over time. The captured images are processed by pre-trained AI models accessed through *Hugging Face APIs*, which analyze the images and provide crop health assessments and disease detection results. The system automatically monitors for problems, sending immediate alerts to users when environmental readings go beyond safe limits or when AI analysis detects potential disease issues. This complete data flow ensures farmers receive accurate and timely information for making informed decisions with minimal technical complexity. (Figure 04)

Figure 04 : Data Flow



V. LEAFY MOBILE APPLICATION

Application Overview

The Leafy-Farm-Monitoring-App is a specialized React Native Android application designed to bridge the gap between modern IoT technology and practical agricultural management. This mobile solution enables farmers and agricultural technologists to monitor their field devices in real-time, capturing and displaying environmental data as it transmits from connected sensors. The application transforms complex sensor measurements into accessible, actionable information that supports precision farming decisions and environmental monitoring practices. By providing instant access to critical field data through an intuitive mobile interface, the app empowers users to respond quickly to changing agricultural conditions and optimize their farming operations.

Technical Implementation and Core Functionality

Built on React Native's cross-platform framework, the application utilizes a unified JavaScript/TypeScript codebase optimized for Android devices, incorporating native components and potentially enhanced UI libraries like React Native Paper for professional interface design. The technical architecture supports multiple communication protocols, primarily Wi-Fi-based REST API and WebSocket connections, enabling seamless data transmission from cloud-connected IoT devices directly to the mobile application. Core functionality centers on real-time data

capture, instantly processing environmental metrics including temperature, humidity, soil moisture, and light intensity as they arrive from field sensors. The system features comprehensive device connectivity management with intuitive pairing interfaces, secure user authentication through services like Firebase, and intelligent alerting mechanisms that provide immediate notifications when sensor readings exceed critical thresholds. Data handling capabilities include parsing, validation, and immediate visualization of incoming information, with optional cloud integration for persistent storage and enhanced notification services.

User Experience and Interface Design

The application's user interface prioritizes simplicity and functionality through clean, distraction-free layouts that focus attention on essential agricultural data. The responsive design ensures optimal performance across various Android screen sizes and orientations, while real-time feedback mechanisms provide instant visual updates through intuitive color-coded indicators green for normal conditions and red for alerts. The user experience revolves around three core screens: a Device Connection interface for IoT discovery and pairing, a comprehensive Dashboard displaying real-time sensor data through interactive cards and graphs, and a Settings screen for profile management and notification preferences. Supporting components include specialized data visualization cards, interactive charts for historical analysis, and prominent status indicators that communicate device connectivity through recognizable icons and colored badges. Accessibility considerations encompass adequate color contrast, readable typography, and touch-friendly elements designed for practical field use, ensuring the application remains functional and intuitive even in challenging outdoor agricultural environments.

VI. CONCLUSION

This research presents Leafy as a practical IoT solution that helps small-scale farmers monitor their crops more effectively. The system successfully combines affordable sensors, camera-based disease detection, and an easy-to-use mobile app to provide farmers with important information about their crops without requiring technical expertise.

The main achievements of this work include creating a low-cost device that is reliable and accurate while remaining affordable for small farmers. The system is designed for easy setup and use, and it uses existing AI models to detect plant diseases without needing expensive equipment or specialized knowledge. The mobile app presents complex data in a simple, visual way that helps farmers understand their crop conditions and respond quickly to problems.

Testing shows that Leafy can significantly improve how farmers manage their crops by providing real-time monitoring that was not available to small farms before. The system can monitor different types of crops and adjust alerts based on each plant's specific needs, making it useful for various farming situations.

Future improvements could include adding more sensors to measure things like soil pH and nutrients, making the system work faster for urgent decisions, and adding features that can predict problems before they happen. Solar charging and satellite connections could also make the system work better in remote areas with limited power and internet access.

Leafy represents an important step in making advanced farming technology available to small farmers. By combining low cost, ease of use, and powerful features, Leafy can help improve farming practices and food security in developing areas, ultimately supporting the lives of millions of small-scale farmers around the world.

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