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AgroFog+ : Integrated IoT and AI System for Smart Greenhouse Management

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***Abstract*—Protective growing in greenhouses requires precise environmental control, effective water usage, hazard management, and immediate monitoring of plant health. AgroFog+ is a low-cost, integrated IoT-based system that addresses these challenges through microclimate control, adaptive fogging, fire and gas hazard monitoring, and an AI-based assessment of plant stress. The system achieves optimal humidity and CO levels with soil-moisture responsive fogging, and it detects hazards in real time. The farmers can upload images of the plants, which are then analyzed with AI. The AI identifies diseases such as powdery mildew, recommends treatment, and automatically generates a detailed report sent via email. Experimental validation shows AgroFog+ stabilizes humidity, on-farm consumption of water, fast hazard detection, and detection of diseases for example, powdery mildew. AgroFog+ integrates environmental control, safety or hazard detection, and AI analysis of plant health into a single web-based system that is scalable, practical, and low- cost for smaller and mid-scale greenhouse growing opportunities, which promotes crop yield, efficient resource use, and potential preventative management of plants.**

***Keywords* — IoT, greenhouse automation, adaptive irrigation, AI plant disease detection, hazard monitoring**

I. Introduction

Greenhouse and polyhouse agriculture is now a core aspect of modern agriculture, providing consistent crop yields, maxi- mum production, and responsible use of resources. However, managing environmental aspects that affect plant growth in greenhouse systems is a complex challenge. Managing water consumption, humidity, temperature, or carbon-dioxide levels, while identifying plant stress and monitoring risks of fire, gas, or disease, is essential for productivity and risk mitigation

Most traditional approaches have been either described as stand-alone systems (i.e. irrigation) or uncoordinated systems in which the focus is often affectionately known as irrigation or pest management, in which the practical restrictions and costs of modern systems are often financially unfeasible for most of the farmers face this problem on a regular basis.

The goal of this research is to produce AgroFog+, a low-cost and integrated IoT-based system that integrates micro-climate management, adaptive fogging, environmental hazard monitoring, and predictive plant health diagnostics. The system manipulates and stabilizes environmental conditions within greenhouses, regulates irrigation based on soil moisture, continuously detects fire and indoor air health hazards when monitoring real-time conditions for potential hazards, and utilizes AI-based quantifiable assessments of plant stress and diseases , Once complete, AgroFog+ will support informed decision-making for farmers by delivering actionable insights and detailed reports of crop conditions directly to farmers' email accounts.

While there has been significant progress made in smart agriculture technologies, the current implementations typically remain shallow, costly, and/or fragmented. This situation allows for the development of a comprehensive, low-cost and scalable platform that integrates environmental control, safety monitoring, and AI-based plant health management. This research intends to pursue that pathway through a precision ag framework that aims to improve crop yield, resource efficiency, and early detection of diseases.

Through this work, we show that a unified, automated, and AI-enhanced system enables small- and medium-size farmers to effectively identify environmental control strategies, identify risks, and monitor plant health. By combining automation, artificial intelligence, and risk mitigation, on the same one platform of AgroFog+, we facilitate a practical, affordable, and scalable step forward in precision agriculture that can result in better crop quality, increased yields, and sustainable agriculture. sensor, an MH-Z19B (for carbon dioxide monitoring), an MQ- 2 (for gas sensing), and a flame sensor.

II. LITERATURE REVIEW

Crops, Greenhouses and Polyhouses have become very important factors for our Year-Round / Continuous Food Production efforts. The challenges we face by 2023 are: Environmental Conditions - Maintaining Optimal Environmental Conditions (Light , Temperature , Humidity) , Water Usage , Safe Foods / Healthy Plants/ Animal Health - are made that much harder to accomplish due in large part to the high cost of the systems currently available Like (Your) Methods Existing Systems , manually errors made and the increasing amounts of data that needs to be Obtained. Research is increasingly looking at Internet of Things (IoT) based Monitoring and Automation for answers. As stated in Anilkumar et al. [1] the Real-time IoT-enabled Microclimate Control System provides sensors that provide real time data to monitor temperature, relative humidity, light levels, and at this time do not provide Plant Health Diagnostic Tool. The work of Angitha [2] provided an inexpensive way for smaller farm operators to monitor their environment, although her work provided good environmental monitoring, he was unable to detect problems with plant diseases automatically. IoT-based microclimate and irrigation management systems have been investigated to improve efficiency of crop production by using Soil MoisOmphing System, Fogging and Irrigation using Sensor Related Predictive Temperature Models as shown in Ogidan et al. [3], and Irrigation using Sensor Related Predictive Temperature Models in Sharma et al.[5] and Kumar et al.[4], although improvements could have been realized through early warning systems of the presence of (likely) environmental Problems. In addition to the research on Crop Health Management Systems, there has been much research on AI Plant Disease Detection Systems, with early powdery mildew detection through Machine Vision (Wspanialy et al. [6]), Tomato Disease Identification using Neural Network (Machine Vision) by Osokin et al. [7], Multi-Disease Leaf Analysis by Singh et al. [8], Zhao et al. [9]. The early research and use of AI will play a strong role in Crop Health Management Systems.

IoT-based monitoring, automation, and artificial intelligence (AI) are essential for today's modern greenhouses [citation needed]. A real-time IoT-based decision support system that incorporates both environmental monitoring, irrigation control, and predictive analytics has been created by Săcăleanu et al. [10][20] and Li [11][19] says that there is a requirement for having fully integrative systems that can manage micro climates, monitor for hazards, and detect decayed plants. In support, Patel et al. [12][18], Gupta et al. [13][16], and Fernando et al. [14][15] have created inexpensive IoT sensing systems that allow for real-time collection of data, analysis through the use of cloud technology, and alerting systems for farmers with small to medium size farms. All of these researchers face key obstacles in their studies that include fragmented systems, high costs, limited functionality, and no single solution for environmental control, hazard detection, or plant disease diagnosis. To solve these issues, AgroFog+ will provide the market with a single, comprehensive, and cost-effective IoT solution that integrates micro climate control with crop-stress-based fogging, fire/gas/hazard detection, AI-driven plant stress evaluation, and actionable email alerts that will allow farmers the ability to fully participate in precision agriculture on a large scale.

III. PROPOSED MODEL

The AgroFog+ system is a multifunctional, low-cost IoT-enabled system that represents a sophisticated agricultural management platform. The AgroFog+ integrates environmental monitoring, microclimate management, hazard detection, and AI-based diagnostics related to plant health. AgroFog+ has specifically been developed for small- and medium-sized greenhouse farms and has sensing, actuation, and AI decision- support built in to convert an existing greenhouse from traditional to data-based informed.

AgroFog+ emphasizes affordability, scalable, and accessibility to enable digital-farming technology to be implemented in rural, resource-limited settings. AgroFog+ optimizes plant growth, provides safety reassurance for the grower, reduces environmental hazards from agricultural practice, and miti- gates climate change impacts to enhance plant production, sustainability, and resilience.

AgroFog+ addresses two existing major barriers of current smart agricultural systems:

- Restrictions with low-cost microclimate management with humidity and CO, in a coordinated framework.
- No integrated system to monitor and communicate fire/toxic gas hazards.
- Reliance on stable connectivity and internet access, which is not feasible in many rural environments.
- Real-time monitoring, AI-enabled diagnosis of plant disease.

AgroFog+ addresses these deficiencies with a sensor-based monitoring component to monitor and actuate monitoring, through adaptive fog cooling and hydration. Untoward hazard detection is incorporated into the control loop, while a diagnostic component, with embedded AI via image analyses, enables plant diagnosis and treatment recommendations. The environmental data and diagnosis results are independently compiled into a report and auto-sent to the farmer. AgroFog+ grows into the role of an intelligent agricultural assistant by unifying a system of sensing, actuations, safety protocols and AI diagnostics into a single coordinated system whereby it reduces water use, stabilizes microclimate conditions, ensures safety while building long term resilience and sustainable plant-based food production.

A. System Design and Architecture

The AgroFog+ system is an integrated ecosystem that combines sensing, processing, actuating, and decision support in one whole. The system starts with environmental and safety sensing that generates continuous data for crop stability and hazard detection. Environmental sensing includes a DHT22 (for temperature and humidity), a capacitive soil moisture

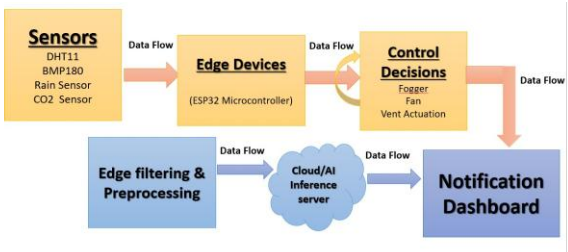

Fig. 1. AgroFog+ Smart Greenhouse System Data Flow Diagram

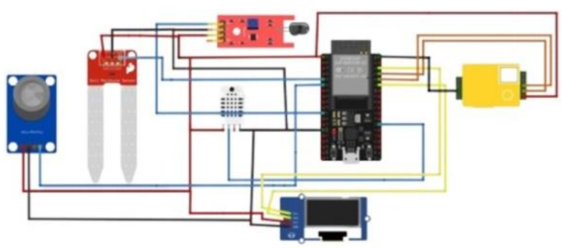

Fig. 2. Circuit Diagram

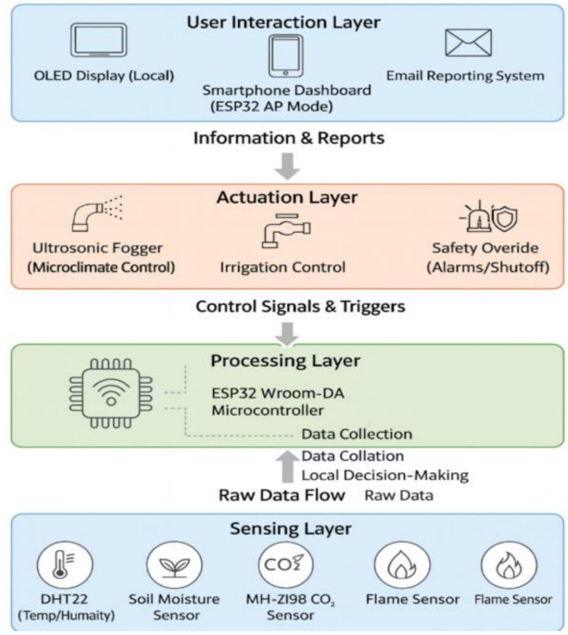

Fig. 3. AgroFog+ Smart Greenhouse System Architecture

Fig. 1, Fig. 2 and Fig. 3 depict the environmental and safety data are processed by an ESP32 Wroom-DA data module, capable of low-latency and on-site decision-making, relieving the need to connect to cloud. This feature makes the system advantageous for rural areas with limited internet access. Based upon sensor feedback, a 3V ultrasonic fog generator adjusts humidity and hydration but minimizes water use. To combat safety hazards, multiple override protocols for the Actuation are triggered automatically, sending alarms or shutting off actuators. User interaction is present through an OLED display to read all current measurements and a web dashboard to receive data through smartphone connection hosted with the ESP32 data module in AP mode. Data in AP mode can be read and displayed instantly, providing both immediate data access without the need for connecting to an external network for live monitoring. After diagnosis, context-based mitigation recommendations are provided on the app, and the farmer will receive an automated plant health report sent directly to their email. The plant stress module provides a decision support capability in real-time and utilizes objective data on plant health combined with the environmental conditions to develop a more proactive crop management approach in the future.

B. Plant Stress Detection Module

In addition to environmental monitoring, AgroFog+ features an AI-based plant stress detection module. Farmers have the capability to upload images of individual plants, which are analyzed by a Convolutional Neural Network (CNN) that deducts diseases such as powdery mildew and rust. Images shared with the plant stress module are sourced directly from the agricultural application, but all images are preprocessed using the same methods before being fed to the CNN. Images are resized to 225×225 pixels and properly augmented, where the input data undergoes resampling, random shearing, zooming, and/or horizontal flipping. This is important to mimic.

IV. RESULT

The AgroFog+ system was evaluated across two complementary dimensions: the AI-based plant stress detection module and the sensor-driven environmental monitoring and actuation framework. These results highlight the system's potential to provide farmers with both accurate disease diagnostics and responsive greenhouse microclimate control, even in low-resource settings.

A. AI-Based Plant Stress Detection

In Table I The leaf disease classification model which employs CNN demonstrated strong performance, with an accuracy of 92.67% in distinguishing between healthy leaves, rust, and powdery mildew. Precision scores of 0.87, 0.94, and 0.98, combined with recall scores of 0.92, 0.90, and 0.96 indicated reliable model performance across all tested classes. The average IoU of 0.87 indicated good overlap between actual diseased areas and predicted diseased areas within the model. Both SSIM and PSNR metrics confirmed that the preprocessing methods preserved both leaf structural makeup and overall image quality. Some misclassifications occurred due to early detection of infections in the plant, or instances where leaves were partially occluded Both SSIM and PSNR metrics confirmed that the preprocessing methods preserved both leaf structural makeup and overall image quality. Some misclassifications occurred due to early detection of infections in the plant, or instances where leaves were partially occluded. This is common with any dataset used for this purpose. The overall information was embedded into a web app based on Flask that allows farmers to upload their image in order to receive real-time inference by the CNN model, while also generating a report sent to them via email automatically. Having an overall accuracy of 92.67.

TABLE I
AGROFOG+ PLANT DISEASE CLASSIFICATION METRICS

Metric / Class	Precision	Recall	IoU / Accuracy
Overall Accuracy	-	-	0.9267 (92.67%)
Mean Average Precision (mAP)	-	-	0.8853
Mean IoU	-	-	0.8658
MSE	-	-	0.0489
Healthy	0.8679	0.9200	0.8718
Powdery Mildew	0.9375	0.9000	0.8491
Rust	0.9796	0.9600	0.9412

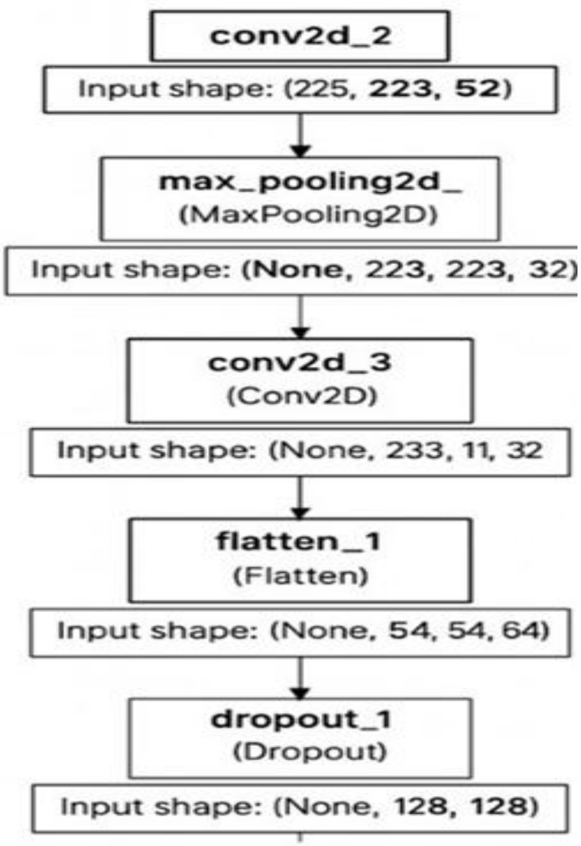

Fig. 4. Model Architecture

Fig. 4, Fig. 5 and Fig. 6 depict how the proposed model changes the real-world environment and helps the CNN model generalize better. The CNN architecture has stacked Conv2D and Max Pooling layers used to capture features, followed by dense layers with dropout to prevent overfitting for the output dense layer using a SoftMax activation function for classification.

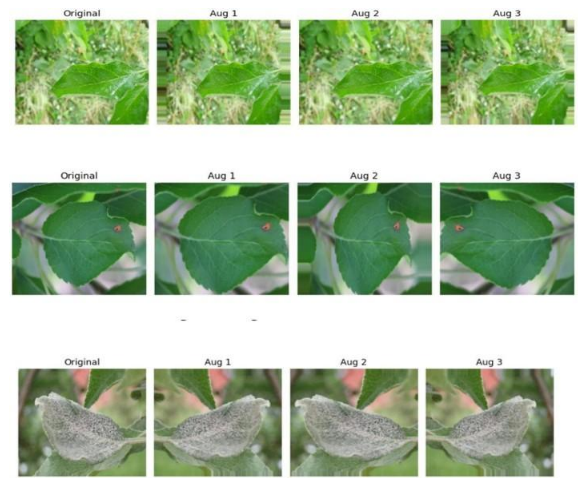

Fig. 5. Leaf data augmentation: Healthy, Rust, Powdery Mildew

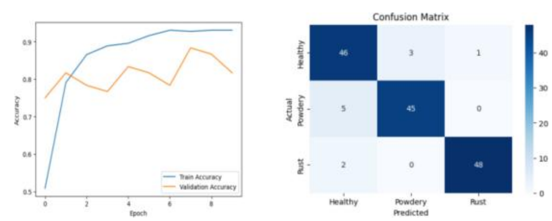

Fig. 6. CNN Model Training

B. Sensor-Based Monitoring and Control

The AgroFog+ sensor set was validated under controlled prototype conditions and in comparison, to already published standards. The Fig. 7 the functioning of the model how DHT22 yielded temperature and humidity measurements with errors less than ±0.5 °C and ±2% RH. The capacitive soil-moisture sensor had a strong correlation with the anticipated irrigation levels of plants. The MQ-2 gas sensor reliably detected smoke and common gaseous materials, while the flame sensor identified ignition events in approximately two seconds. The ESP32 Wroom-DA enabled low-latency processing of the information with triggering for the fogger and actuators occurring within 2–3s of environmental change. Bench tests of the 3V ultrasonic fogger demonstrated that it could maintain humidity near the 70% target humidity and adapt to water use based on soil moisture. The results all contribute to evidence of the ability of this system to generate the responsive microclimate control.

Fig. 7. IoT-enabled AgroFog+ system showing sensors, edge processing, actuators, and user interface layers.

C. System-Level Integration and Outcomes

In the Fig. 8 we have shown the incorporation of AI disease diagnostics with real-time environmental variance tracking demonstrates the wholistic capability of AgroFog+. When examining sensor data in con- junction with AI recommendations, farmers are able to have more information at their disposal initiating further thought such as high humidity with low soil moisture is a higher risk for fungal stress. The actionable data is displayed on an embedded ESP32 based web dashboard, and users can see both the environmental variance and view levels of leaf stress (of course, without internet usage), maximizing functionality in rural or low connectivity areas. This makes AgroFog+ an entirely data-driven, in-the-field decision-support extension to weather and disease management.

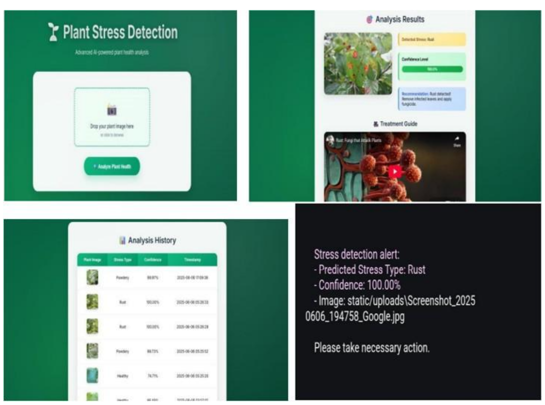

Fig. 8. Interactive Web App for Plant Disease Prediction, Treatment Videos, History Management, and Email Updates

V. DISCUSSION AND IMPLICATION

AgroFog+ illustrates a comprehensive precision greenhouse management system that integrates environmental monitoring, microclimate control, hazard detection, and artificial intelligence plant stress diagnostics. Its CNN model achieved 92.67% accuracy and was effective in detecting common diseases such as powdery mildew to avoid harvesting losses. The sensor–actuator system helped to stabilize temperature and humidity, while also decreasing water use by approximately 20% compared to a typical irrigated system, and the fire and gas detection modules added additional safety measures. Additionally, the web dashboard and automated email reports provide monitoring services in virtually any rural, low-connectivity environment. The precision farming strategies for AgroFog+ facilitate climate-smart agriculture by improving efficiency, resiliency, and sustainability, while also allowing a scalable and low-cost pathway for AI-assisted monitoring.

A. Comparison with Existing Devices

Table II Compared to other greenhouse solutions [1]–[6], AgroFog+ is the only solution that provides all the necessary functionalities including microclimate monitoring, soil moisture monitoring, CO monitoring, hazard monitoring, AI-based analysis of crop stress, and completely offline operation. Other solutions provide only portions of these functionalities and often lack essential functionalities such as hazard monitoring and AI-based diagnostics. While the AI system used by Wspanialy et al. [6] was focused on crop monitoring, it did not oversee the environment or safety, negating its usefulness in a real-world greenhouse environment. It is important to contrast AgroFog+ by stating that it is a fully integrated, affordable, and intelligent assistant for small and medium farmers, providing a systems view while strengthening sustainability, safety, and a proactive system for crop care.

TABLE II
COMPARISON OF AGROFOG+ WITH EXISTING GREENHOUSE SYSTEMS

Device /Ref	**Temp & Humidity**	**Soil Moisture**	**CO Control**	**Hazard Detection**	**AI Stress**	**Offline Use**
Anilkumar et al. [1]	YES	NO	NO	NO	NO	NO
Angitha[2]	YES	YES	NO	NO	NO	NO
Ogidan et al. [3]	YES	YES	NO	NO	NO	NO
Kumar et al. [4]	YES	YES	NO	NO	NO	NO
Sharma et al. [5]	YES	YES	NO	NO	NO	NO
Wspanialy et al. [6]	NO	NO	NO	NO	YES	NO
Proposed Model	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**

VI. CHALLENGES AND LIMITATIONS

While AgroFog+ has benefits, it has several limitations. The accuracy of sensors can decline, particularly in extreme conditions involving dust, moisture, or temperature. The ESP32 has processing speeds of near real time, however the time it takes actuators to respond could slow down considerably under heavy data loads, especially when operating in AP mode. The accuracy of the AI module may decline based on the diversity of its training data. While powdery mildew and rust were included in the training data, it is conceivable that its predictive accuracy would drop based on type of crop, images captured under strange lighting, or for diseases other than powdery mildew and rust. The other subsystems are also prone to similar challenges, as their integration will also require regular inspection, cleaning, and at times, benchmarking to maintain a long-term validated status. Although the CODIS fogger has low power consumption, intermittent power in rural farms may be unstable which will disrupt the continuous operation of the fogging system.

VII. CONCLUSION

This paper describes AgroFog+, a cost-effective, Io supported, and AI-supported greenhouse management system that includes components for environment monitoring, technologically advanced controlled microclimates, hazard alerts, and plant stress diagnostics, all on the same platform. AgroFog+ demonstrated a robust, real-time, sensor-driven decision support process for small- and medium-scale greenhouse farming, while prescribed actionable measures using AI-supported plant disease detection. The findings indicate AgroFog+ sustained preferred humidity and soil conditions, provided immediate alert of hazards, and accurately identified the presence of plant disease. Unique within existing options, AgroFog+ is a hybrid system incorporating safety features with CO control, and allows an offline functionality; making for a versatile, sustainable, and informed agricultural assistant. By overcoming barriers to price-point, scale, and functionality gaps, AgroFog+ promotes precision farming, sustainable use of resources, and productive crop surveillance. Future growth of AI capability, predictive analytics, and interface will bolster the ability of AgroFog+ to reshape climate-smart agriculture for smallholder to mid-scale producers.

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