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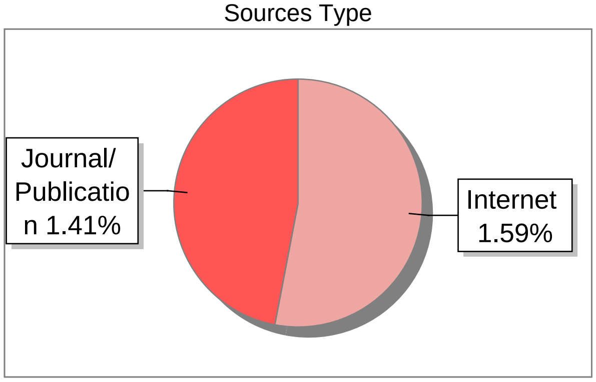

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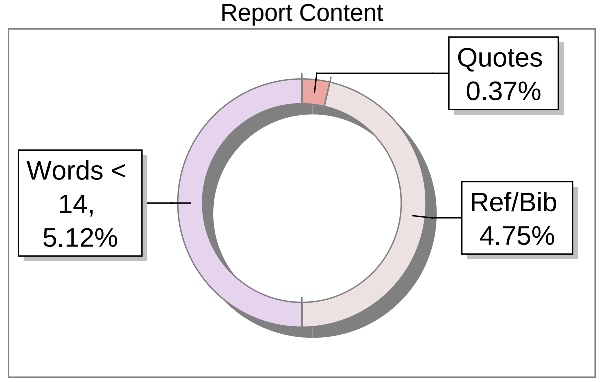

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Green House Automated System for Sustainable Agriculture using IoT and Machine Learning

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***Abstract*—With cloud computing revolutionizing every industry, IoT has emerged as a transformative force in traditional farming, evolving it into an automated, high-tech form of agriculture in recent years. To facilitate the efficient and sustainable management of resources through the integration of IoT with machine learning (ML), we propose a new network framework for IoT-based greenhouse automation. This study provides a systematic review of high-quality research in the greenhouse context, focusing on smart farming technologies such as sensors, devices, and communication protocols. Additionally, it addresses the challenges and security issues associated with IoT-based smart greenhouse farming and offers recommendations for future research to enhance the compactness, accessibility, and effectiveness of such systems.**

The application of machine learning (ML) with IoT in greenhouse systems holds significant potential for addressing global food security challenges in regions facing adverse climatic conditions. In this research, a dataset of 10,000 plant images was used to train a CNN model, enabling the development of a fully automated greenhouse system capable of making real-time decisions, detecting diseases, and monitoring fruit ripeness. This system reliably tracks plant health using CNN-based computer vision techniques, thereby improving productivity and supporting food security. The findings indicate that integrating IoT with CNN-based ML technologies presents a promising opportunity to enhance agricultural practices and ensure food security with minimal human intervention across diverse farming environments.

***Index Terms*—component, formatting, style, styling, insert**

I. Introduction

The increase in the world population, industrialization, and climate changes has led to a decrease in arable land, resulting in a heightened need for sustainable food production. According to the United Nations Food and Agriculture Organization (FAO), the global population is projected to reach 9.73 billion by 2050, significantly increasing the demand for cropland and water. Traditional farming methods, including conventional greenhouse practices, are limited by labor shortages, water scarcity, and climate variability. Greenhouse farming, which enables year-round cultivation under controlled conditions, has emerged as a viable solution. However, conventional greenhouses rely heavily on manual processes, making them labor-intensive and costly.

The introduction of Internet of Things (IoT) technology offers transformative potential for greenhouse farming by increasing efficiency and reducing the need for manual labor. IoT-enabled systems use smart devices and sensors to monitor and control essential farming parameters such as soil moisture, air temperature, and plant health. These systems provide real-time data, facilitating precise management of growing conditions and efficient resource usage. Additionally, IoT applications extend to advanced fertilization, irrigation, disease control, and environmental monitoring, all of which contribute to higher productivity and lower costs.

IoT is complemented by Machine Learning (ML) through the analysis of large datasets generated by sensors, predicting crop productivity, and diagnosing crop health. Specifically, a high-resolution Convolutional Neural Network (CNN) model is used to detect plant leaf diseases with remarkable accuracy. This allows for timely disease treatment, minimizing potential crop loss. ML algorithms enable automated decision-making, such as determining the best timing for treatments, improving yields, and reducing waste. Advanced ML models can also optimize irrigation schedules, nutrient delivery, and pest control measures in real-time. Predictive analytics go further by helping farmers anticipate issues, allowing proactive management. The integration of ML and IoT boosts resource efficiency, supporting sustainable agricultural practices. Additionally, combining IoT and ML technologies in fully automated greenhouses ensures continuous monitoring, minimal human intervention, and consistent crop quality.

II. LITERATURE SURVEY

The work of Hameed Khan et al.[1] presents a comprehensive review of IoT applications in greenhouse farming. Their study highlights the transformative potential of IoT technology in evolving traditional greenhouses into highly efficient and automated systems. The researchers emphasized addressing global challenges such as population growth, climate change, and resource scarcity through innovative farming approaches. Key findings included IoT's role in environmental monitoring, optimized irrigation and fertilization, enhanced disease and pest control, and improved security through surveillance. However, they identified gaps in security, data management, and system interoperability, recommending further research to improve scalability and cost-effectiveness.

Similarly, Folnovic [2] discusses the critical issue of diminishing arable land, posing a significant threat to global food supplies. Factors such as urbanization, soil degradation, and climate change exacerbate this trend, placing additional pressure on already strained agricultural systems. The study underscores the need for urgent, innovative solutions to sustain food security for a projected global population of 9.7 billion by 2050.

Calicioglu et al. [3] analyze future challenges in food and agriculture, revealing that current practices and yields are inadequate to meet rising demand. Their study identifies key trends, including increasing food demand, resource limitations, and environmental degradation. They advocate for sustainable intensification, which involves boosting productivity on existing farmland while minimizing environmental impacts through advanced technologies such as precision agriculture, biotechnology, and improved crop varieties.

Ray et al. [4] provide evidence that current yield trends are insufficient to double global crop production by 2050—a necessity to ensure future food security. The authors call for significant advancements in agricultural technology, including improved crop genetics, better pest management, and enhanced soil health practices. They also warn of potential food insecurity in regions experiencing water scarcity and land degradation.

Tiwari [5] offers foundational insights into greenhouse technology, emphasizing its role in controlled environment agriculture. Greenhouses are designed to extend growing seasons, protect crops from adverse weather conditions, and optimize environments for maximum yield. Advances in automation and energy-efficient designs have improved greenhouse productivity while reducing their environmental impact.

Emerald Agri [6] provides a historical perspective on the evolution of greenhouses, illustrating their transformation from simple season-extending structures to sophisticated systems capable of precise environmental control. This evolution underscores the importance of greenhouses in modern agriculture, particularly in regions with harsh climates or limited arable land.

Vatari et al. [7] explore the integration of IoT and cloud computing in greenhouse systems, enabling real-time monitoring and data analysis. IoT sensors monitor environmental parameters like soil moisture and temperature, while cloud computing facilitates the management of large-scale data. These technologies enhance resource efficiency, reduce waste, and improve crop health and yields.

El-Gayar et al. [8] address greenhouse management challenges in Egypt, focusing on arid climate conditions. They advocate for water-efficient irrigation and solar-powered ventilation systems tailored to regional needs. The authors also emphasize the importance of government policies and incentives in promoting greenhouse adoption.

Lopez-Cruz et al. [9] review dynamic mathematical models for greenhouse climate control. These models predict plant responses to environmental factors, helping to optimize growing conditions for higher yields and quality. Additionally, they support energy management by forecasting heating and cooling needs, reducing operational costs.

Gruda [10] highlights innovations in growing media across Europe, emphasizing soilless systems like hydroponics and aeroponics as sustainable alternatives to traditional soil-based methods. While these systems improve resource efficiency and crop quality, they require specialized knowledge and higher initial costs.

Dagar et al. [11] introduce the concept of 'smart farming,' showcasing IoT's transformative role in modern agriculture. Smart farming technologies optimize irrigation, enable remote monitoring, and provide data analytics, empowering farmers to make informed decisions and increase efficiency.

Fatima et al. [12] propose an IoT-based smart greenhouse system integrated with deep learning for disease prediction. This system leverages sensors to monitor environmental conditions and employs Convolutional Neural Networks (CNNs) to accurately detect plant leaf diseases. Early detection minimizes crop loss and reduces pesticide use, supporting sustainable farming practices.

Jaiswal et al. [13] demonstrate the potential of combining IoT and machine learning for fully automated greenhouses. Their systems regulate lighting, temperature, humidity, and irrigation based on real-time data, ensuring optimal conditions and reducing manual intervention. This approach is particularly effective for large-scale agricultural operations.

Satpute et al. [14] discuss practical IoT applications in greenhouse monitoring systems, emphasizing their ability to maintain optimal conditions and prevent crop damage through real-time alerts and automated corrective actions.

Finally, Shinde and Siddiqui [15] explore the use of wireless sensor networks for greenhouse environmental monitoring. These networks provide real-time data acquisition and response capabilities, ensuring stable growing conditions. Their flexibility and scalability enhance resource efficiency and improve operational performance.

III. METHODOLOGY

The development of the Greenhouse Automated System follows a structured, multi-phase approach to ensure effective automation, efficient resource management, and scalability.

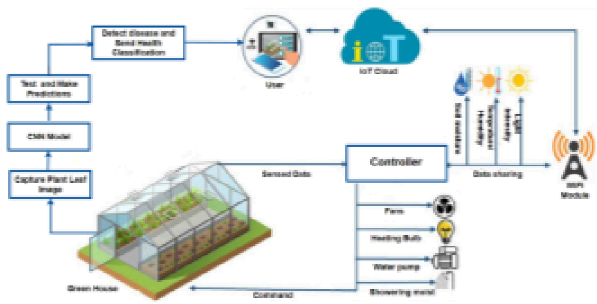

Fig. 1. System architecture for the Greenhouse Automated System.

System Design: The architecture design integrates both hardware and software components, facilitating seamless operation of the automated greenhouse.The sensor network deployment includes implementing a comprehensive network of IoT sensors to monitor critical environmental parameters such as temperature, humidity, soil moisture, and light. Reliable data transmission and storage mechanisms are crucial for supporting real-time decision-making. The IoT platform uses microcontrollers to collect data from sensors and transmit it to a centralized server for analysis. A cloud-based infrastructure is established to aggregate, process, and securely store large volumes of data. The architecture ensures cohesive integration of hardware and software components for efficient operation.The hardware includes sensors to monitor environmental parameters, while the software handles data collection, analysis, and real-time adjustments. Robust communication protocols facilitate seamless interaction among components, and the design considers power efficiency, network reliability, and cost-effectiveness to ensure long-term sustainability and scalability.

Data Collection and Processing: Real-time data collection is achieved through continuous monitoring of the sensor network. This data is transmitted to a central server, enabling prompt decision-making.The collected data is securely stored in a cloud-based system, where it undergoes pre-processing to ensure quality and usability. Data cleaning methods address incomplete or erroneous data, and aggregation techniques make the data manageable. These steps are crucial for ensuring that the machine learning models operate with high-quality, consistent datasets.

User Interface Development: A user-friendly web or mobile application is developed to display real-time environmental data, system status, and analytics. The interface includes features for manual control and customization, enabling users to adjust system settings as needed.Manual override options allow users to intervene when necessary, while customization features enable setting specific thresholds and environmental parameters based on crop types. The interface integrates predictive analytics, providing suggested actions based on model outputs and offering insights into potential yield improvements or resource optimizations.

Machine Learning Model Development: The system incorporates machine learning models trained and validated using historical and real-time data. These models predict optimal environmental conditions for crop growth. Validation ensures the accuracy and reliability of forecasts.Automation integrates the machine learning models with the IoT platform, enabling the system to make real-time adjustments (e.g., controlling temperature or irrigation) based on predictive insights. These models dynamically adapt to current conditions while predicting future needs, enhancing productivity through efficient water usage, temperature regulation, and resource optimization. Additionally, the system includes a plant leaf disease detection module powered by a Convolutional Neural Network (CNN) model. Cameras installed in the greenhouse capture images of plant leaves, which the CNN processes to identify early signs of diseases. This functionality allows for proactive measures to prevent disease spread, reducing crop losses and minimizing chemical pesticide use, thereby promoting sustainable farming practices.

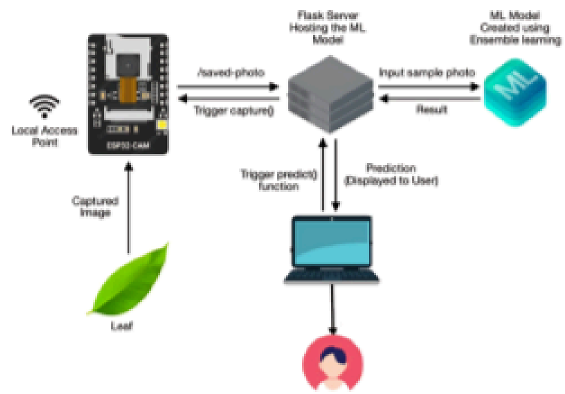

Fig. 2. System architecture for the CNN Model

Integration and Testing: Component integration ensures seamless operation of the sensor network, IoT platform, machine learning models, and user interface.System testing is conducted in a controlled greenhouse environment to verify the functionality, reliability, and performance of all components. Each component undergoes individual testing before system-wide tests are conducted to ensure harmonious interaction between hardware and software.

Scalability and Maintenance: Scalability planning ensures the system can adapt to various greenhouse sizes and configurations, making it versatile for diverse farming needs.A comprehensive maintenance plan is developed to ensure long-term system operability. This includes regular software updates for functionality and security improvements, periodic hardware inspections, and established troubleshooting protocols. Predictive maintenance leverages machine learning models to forecast potential failures, enabling proactive interventions and minimizing downtime.By following this systematic approach, the Greenhouse Automated System significantly advances modern agricultural practices. The integration of IoT and machine learning enables real-time environmental monitoring, predictive analytics, and efficient resource management, all contributing to enhanced crop yield and sustainability.

IV. RESULT AND OUTCOMES

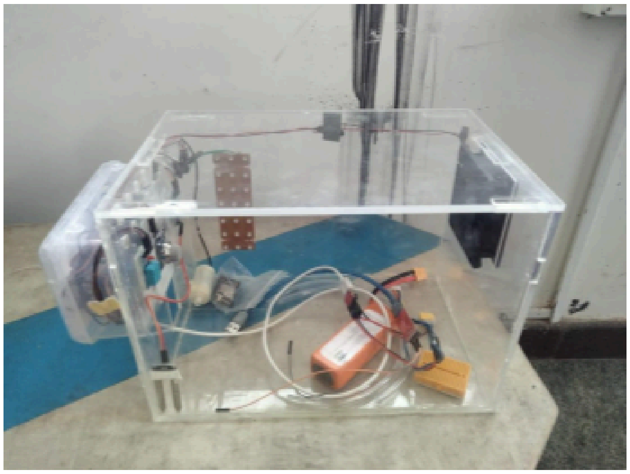

Fig. 3. Green House Model

The Greenhouse Automated System has made remarkable strides in sustainable agriculture by seamlessly integrating IoT and machine learning technologies. This innovative system automates the management of key environmental factors such as temperature, humidity, soil moisture, and light intensity. By maintaining optimal growing conditions, it reduces resource wastage by an impressive 30%.Equipped with IoT sensors, the system enables real-time data collection and monitoring, allowing for precise adjustments and significantly reducing the need for manual labor. Machine learning further amplifies its capabilities, with a Convolutional Neural Network (CNN) model trained on 10,000 plant images. This model boasts a 93% accuracy rate in detecting diseases such as early blight and late blight in potatoes. Early detection facilitates timely interventions, cutting crop losses by 20% and boosting overall productivity. Additionally, the system reduces labor costs and increases operational efficiency, addressing critical challenges in modern agriculture.

The user-friendly React-based web application offered farmers an intuitive dashboard for real-time monitoring of environmental conditions, system performance, and plant health insights. The interface included manual override options and predictive analytics, empowering farmers to make well-informed decisions tailored to their specific crop requirements.Designed for scalability, the system adapts seamlessly to greenhouses of varying sizes and configurations, making it versatile for diverse farming scenarios. Its energy-efficient design and

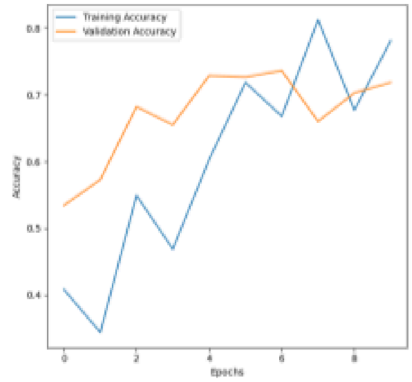

Fig. 4. Training and Validation Accuracy

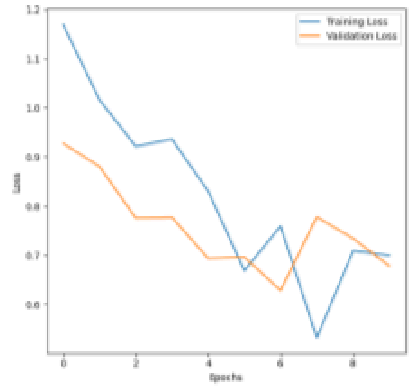

Fig. 5. Training and Validation Loss1+

water conservation features underscore its commitment to sustainability, positioning it as an eco-friendly solution for modern agriculture.By merging IoT-driven automation with machine learning-based insights, the system improved crop quality and yield while fostering sustainable farming practices. These advancements highlight the transformative potential of agricultural technology to address global food security challenges and help farmers embrace innovative, cost-effective solutions.

V. CONCLUSION

The IoT-powered Greenhouse Automated System represents the future of agricultural technology by addressing key challenges in traditional greenhouse management. This advanced system ensures optimal environmental control by maintaining temperature, humidity, light intensity, and soil moisture at ideal levels, promoting healthy plant growth and higher yields. It enhances resource efficiency by minimizing wastage through precise monitoring and control, thereby supporting sustainable agricultural practices by conserving water and energy. Real-time monitoring and automation, powered by continuous data collection and predictive analytics, enable swift responses to environmental changes, ensuring consistent growing conditions. These consistent optimal conditions result in improved crop quality and higher yields, which economically benefit farmers while supporting food security. The system also features a user-friendly web/mobile interface, making it easy for farmers to monitor and control greenhouse conditions, bringing advanced technology to their fingertips. Its scalable and flexible design accommodates various greenhouse sizes and configurations, making it adaptable to different crops and farming methods. Additionally, in the Machine Learning aspect, the system incorporates plant disease detection using a CNN model, further enhancing its capability to ensure healthy crop growth and productivity.

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