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A Comprehensive Study on Improving Green House Farming Efficiency and Productivity with IoT

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ABSTRACT—

The Internet of Things (IoT) has the potential to revolutionize greenhouse farming by providing real-time data and insights on the greenhouse environment, which can be used to optimize the growing conditions and improve crop yields. This study discusses about an intelligent IoT-based system design for controlling and monitoring greenhouse farming. The system consists of sensors, protocols, a cloud, a controller, and a user interface. The sensors collect data on the greenhouse environment, such as temperature, humidity, light levels, CO2 levels, and soil moisture. The protocols involve in transferring data from the detectors to the cloud and further to the user. The cloud stores the data and processes it using machine learning algorithms (e.g., Decision Trees, SVM, Random Forests, or Adaboost), to generate insights and recommendations for improving the greenhouse environment. The controller receives the insights and recommendations from the cloud and uses them to control the greenhouse environment, such as by opening and closing vents, adjusting the fans, or turning on the heaters. The user interface allows the farmer to monitor the greenhouse environment and control the controller. By amalgamating real-time data, advanced analytics, cloud technology, and automated control, this intelligent system presents a holistic solution for optimizing resource utilization, enhancing crop yields, and fostering sustainable agricultural practices. This study contributes significantly to the ongoing discourse on smart agriculture and underscores the potential of IoT to reshape the future of farming.

Keywords—Internet of Things; Greenhouse Farming; cloud; machine learning algorithms; controller; user interface;

Introduction

Amid the ever-evolving landscape of agriculture, the marriage between technology and traditional farming practices has emerged as a transformative force, particularly evident in the realm of greenhouse cultivation. The integration of the Internet of Things (IoT) stands as a beacon of innovation, offering a promising avenue to revolutionize and elevate the efficiency and productivity of greenhouse farming. Greenhouses, renowned for their controlled environment, present a dynamic platform for cultivating crops year-round, shielded from external climatic fluctuations. However, optimizing the diverse variables that impact crop growth within these environments poses a complex challenge, necessitating a fine balance of factors like temperature, humidity, light exposure, and soil conditions. This exploration delves into the world of greenhouse farming, delving into the challenges, innovations, and potential transformations brought forth by technology, highlighting how advancements such as the Internet of Things (IoT) and automated control systems are reshaping the landscape of farming within these controlled environments.

The Internet of Things (IoT), a network interconnecting physical objects embedded with sensors, software, and network connectivity, holds the promise of transformative impact across diverse industries, particularly within agriculture. Greenhouse farming, a method centre-ed on controlled environmental conditions, stands as a focal point for IoT innovation. This method enables year-round crop cultivation, independent of external weather variations, and extends the potential for cultivation in regions unsuitable for traditional farming, such as deserts or extreme climates. However, the meticulous regulation of environmental factors like temperature, humidity, and light within these enclosures remains a labour-intensive challenge.

This study delves into the potential of IoT technology to revolutionize greenhouse farming by leveraging automation and data-driven solutions. IoT-based systems, equipped with sensors, have the capability to streamline tasks, optimize resource usage, and offer predictive insights. By automating adjustments in response to real-time data, these systems not only alleviate the labour-intensive aspects of monitoring but also ensure precise resource allocation. Moreover, these systems can enhance operational efficiency by automating the regulation of environmental conditions such as moisture levels and nutrients, leading to optimal crop growth and reduced resource wastage.

Additionally, the integration of IoT empowers greenhouse environments to become energy-efficient through the controlled application of heating, cooling, and lighting, thereby contributing to sustainable agricultural practices. Such systems can create crop-specific microenvironments tailored to the unique needs of various plants, optimizing growth and yield. Remote monitoring and control offer farmers the flexibility to oversee and regulate the greenhouse environment from afar, ensuring timely responses to changing conditions. Moreover, the data-rich environment facilitated by IoT systems allows for data-driven decision-making, utilizing machine learning to derive insights, forecast patterns, and preempt potential issues, thereby enabling informed and proactive agricultural management strategies

In essence, the integration of machine learning within IoT systems transforms the greenhouse from a manually monitored environment into a self-regulating, intelligent ecosystem. This not only reduces the labor burden on farmers but also augments their decision-making capabilities by providing data-driven, informed insights. Ultimately, this amalgamation sets the stage for a future where precision, efficiency, and sustainability become the cornerstones of greenhouse farming practices.

Methodology

Basic System Outline

An indoor intelligent agriculture system comprises several interdependent elements, harmoniously working together to create an environment ideal for plant growth within indoor settings. The setup shown in figure.1 incorporates a range of critical components, each playing a vital role in maintaining and optimizing the indoor farming ecosystem.

Data sensing devices: Sensors are strategically positioned throughout the indoor space to constantly monitor crucial environmental factors. These sensors continuously track essential variables such as temperature, humidity, light intensity, and gas levels. Their primary function is to collect real-time data crucial for plant health and growth.

Microcontrollers: They act as the system's decision-making core. They receive, process, and analyze the data streamed in from the sensors. These microcontrollers interpret the received data, apply predefined algorithms or logical instructions, and make decisions based on the analysis. They then communicate directives to the actuators, orchestrating subsequent actions for the system.

Actuators: They are responsible for executing the physical adjustments within the indoor environment. Guided by the microcontrollers, actuators regulate various environmental elements such as lighting, irrigation systems, or ventilation. Their role is to maintain and fine-tune the indoor conditions necessary for healthy plant growth.

Communication modules: These are protocols that serves as the conduit for seamless connectivity within the system. These modules establish the network for data flow, enabling communication between the sensors, microcontrollers, actuators, and other components. Their efficient operation ensures smooth transmission of information.

Cloud Service Layer: The cloud service layer serves as the central hub for data storage, processing, and analysis. It receives and stores the vast amounts of data collected by the sensors. It processes this data, deriving insights and trends which are accessible to users for informed decision-making.

User Interaction Layer: The user interaction layer, usually presented through web-based dashboards or mobile applications, provides users with access to real-time and historical data. This interface enables users to monitor the system's status, view analytics, and sometimes interact or provide input to the system.

This elaborate design supports a comprehensive and interconnected system that effectively manages and optimizes the indoor environment, fostering a conducive space for healthy plant growth.

Data Sensing Devices

In the architecture of an indoor intelligent agriculture system, sensors play a pivotal role in monitoring crucial environmental factors necessary for plant growth. Temperature sensors, such as the DS18B20 and LM35, precisely measure ambient temperature. These devices ensure that the indoor environment maintains the ideal thermal conditions necessary for optimal plant growth. Humidity sensors like the DHT11 or HIH6130 are integrated to monitor moisture content in the air, vital for

regulating the humidity levels to favour healthy plants. Light sensors such as the BH1750 or TSL2561 meticulously manage light intensity and duration, ensuring the photosynthesis process is well supported. Gas sensors, including MQ series sensors for CO_2 and O_2, help maintain the right air quality levels essential for the plants' respiration. Soil moisture sensors like the capacitive soil moisture sensor monitor and control the hydration of the soil, guaranteeing plants receive adequate water. Finally, pH sensors like the SEN0161 pH sensor ensure the growth medium's acidity or alkalinity is within the optimal range, facilitating proper nutrient absorption. This assortment of sensors, each playing a critical role, collectively maintains an environment ideal for fostering robust and healthy plant growth within the indoor agriculture system.

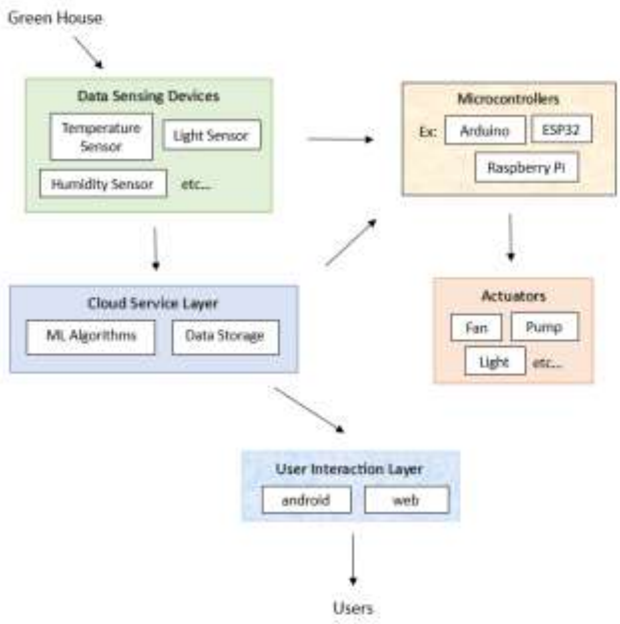

Fig.1. Data Flow in the system

Microcontrollers

In the context of greenhouse farming and IoT, popular microcontroller platforms include Arduino, Raspberry Pi, ESP32, and Particle Photon. These platforms provide the necessary computational power to manage and control sensors, actuators, and other devices in the greenhouse. They can execute programs to collect data from sensors, process that data, and send commands to actuators for environmental control.

Arduino

Arduino is a popular open-source microcontroller platform that consists of a simple hardware board and a user-friendly software development environment. It's designed for hobbyists, makers, and professionals alike. Arduino boards are known for their ease of use and versatility. They come in various models and are commonly used in projects ranging from simple LED control to complex robotics and IoT applications.

Raspberry Pi

Unlike Arduino, Raspberry Pi is a full-fledged single-board computer. It's more powerful than microcontrollers like Arduino and is capable of running a complete operating system, such as Linux. Raspberry Pi has significantly more computational capacity and memory, allowing it to handle more complex tasks and run various applications. It's used for a wide range of applications, including IoT, home automation, media centers, and more.

ESP32

The ESP32 is a low-cost, low-power system-on-a-chip microcontroller with integrated Wi-Fi and Bluetooth capabilities. It's commonly used in IoT applications due to its wireless communication features. The ESP32 is suitable for applications that require connectivity and can be programmed using the Arduino IDE, making it relatively user-friendly.

Protocols

In the domain of greenhouse farming, several key protocols and technologies play essential roles in enabling seamless communication, data transfer and secure interactions among its various components. The survey describes the use of various protocols and technologies for different purposes within the smart farming system. Some of the protocols and technologies mentioned include MQTT, CoAP, GSM, WIFI and HTTPS.

MQTT and CoAP

MQTT (Message Queuing Telemetry Transport) and CoAP (Constrained Application Protocol) are pivotal due to their lightweight design, optimizing communication among the vast array of sensors, actuators, and devices interconnected within a greenhouse. The lightweight nature of these protocols minimizes the overhead associated with data exchange, conserving both bandwidth and power. This is particularly valuable in a greenhouse environment where resources might be scarce, allowing the devices to operate efficiently despite limited power and computational capabilities.

MQTT operates on a publish-subscribe messaging model, significantly reducing the need for continuous connections between devices. This allows devices to function intermittently, entering low-power states during inactive periods, consequently extending their lifespan.

CoAP, specifically tailored for resource-constrained IoT devices, focuses on simplifying communication processes. Its design prioritizes efficiency and energy savings, making it an ideal fit for environments with limited resources, such as greenhouses.

While MQTT and CoAP optimize resource usage and communication efficiency, HTTPS plays a pivotal role in ensuring secure communication. In greenhouse settings, where data on environmental conditions, crop health, and other vital metrics are exchanged, security is paramount. HTTPS provides a secure, encrypted channel for data transfer, safeguarding information from potential cyber threats.

TCP/IP

Now coming to TCP/IP in greenhouse IoT, it ensures reliable, end-to-end communication. TCP/IP's reliability and error-checking mechanisms ensure that data is accurately transmitted and received, a crucial factor in greenhouse automation where precision is key. The scalability of TCP/IP is also vital as greenhouse IoT networks expand, accommodating more devices and functionalities without compromising stability.

Additionally, TCP/IP allows for scalability. Greenhouse environments often expand as the IoT network grows to accommodate more sensors, devices, or functionalities. TCP/IP protocols can handle this expansion seamlessly, supporting the growing infrastructure without sacrificing stability or efficiency.

Http

As for HTTPS, its role in securing the exchange of sensitive data within the greenhouse environment cannot be overstated. By encrypting communication, HTTPS safeguards information from potential cyber threats, ensuring the integrity and confidentiality of vital data related to environmental conditions and plant health. This secure exchange of information is fundamental for making informed decisions regarding environmental controls and crop management.

Cloud Service Layer

The cloud service layer is the central component of an indoor intelligent agriculture system, designed to manage data and facilitate various crucial functions. At its core, this layer emphasizes data persistence, utilizing a MySQL database to securely store the extensive data accumulated from the sensors. This feature allows historical data to be preserved for future analysis and comparisons.

Periodically, the accumulated data in the MySQL database is formatted and archived into a Hadoop HDFS. This archival system ensures effective storage and subsequent analysis, offering insights based on historical data. Analysis services within this layer employ advanced techniques, such as machine learning algorithms (e.g., Decision Trees, SVM, Random Forests, or Adaboost), to interpret the gathered environmental data and predict plant growth. These machine learning (ML) algorithms play a pivotal role in processing and analysing the vast amount of data collected from sensors. These algorithms contribute to generating valuable insights for optimizing plant growth and overall system efficiency. Here are some common ML algorithms employed in this scenario:

Decision Trees

Decision trees are employed for classification tasks, making them suitable for determining the health and growth status of plants based on sensor data. These trees provide a clear decision-making structure, aiding in identifying patterns in the dataset.

ANFIS

Adaptive Neuro-Fuzzy Inference System combines fuzzy logic and neural networks to model complex relationships in agricultural data. It excels in handling uncertainties related to plant health and environmental conditions. ANFIS processes sensor data, predicting and optimizing plant growth and system performance. Its fuzzy logic accommodates imprecise variables, crucial in agriculture. Through training, ANFIS refines its parameters, adapting to changing conditions. It plays a key role in optimizing resource usage, such as irrigation scheduling, contributing to efficient crop management and sustainability.

Support Vector Machine (SVM)

SVM is utilized to classify and predict patterns in agricultural data. It excels in handling both linear and non-linear relationships between sensor data and plant growth parameters. SVM's ability to create optimal decision boundaries makes it valuable for tasks such as categorizing different plant growth states based on environmental conditions.

Random Forest

Random Forest is employed for its proficiency in handling large datasets with numerous variables. In indoor agriculture, it proves beneficial for analysing diverse sensor data simultaneously. By constructing multiple decision trees, Random Forest can predict plant growth outcomes, considering various environmental factors. Its ensemble learning approach enhances accuracy and robustness in the prediction process.

AdaBoost

AdaBoost, or Adaptive Boosting, is employed to improve the performance of other machine learning algorithms within the indoor agriculture system. By combining the strengths of multiple weak learners, AdaBoost enhances the overall predictive capability. In this context, it may be used to refine predictions made by SVM or Random Forest, contributing to more accurate and reliable insights into plant growth dynamics.

Multilayer Perceptron (MLP)

MLP, a type of artificial neural network, is employed to model complex relationships in sensor data. It consists of multiple layers of interconnected nodes, enabling it to capture intricate patterns. In indoor agriculture, MLP may be used for tasks such as predicting plant growth based on diverse environmental factors.

Kalman Filter Algorithm

The Kalman Filter algorithm is a crucial component in indoor intelligent agriculture systems, serving to refine sensor data by reducing noise and improving accuracy. It operates as a state estimator, continuously updating estimates based on sensor measurements. Applied to parameters like temperature and humidity, it enhances the reliability of data, contributing to more precise control of actuators and optimization of the indoor farming environment.

Additionally, the cloud service layer incorporates user-centric application services. These services include tools for data visualization, plant management, and live video streaming accessible through intuitive web and Android interfaces. These applications empower users to monitor real-time data, review historical records, manage devices, and observe live video feeds from the indoor farm.

This layer serves as the system's core by processing vast data sets from the sensors, transforming them into actionable insights. It is the hub for decision-making, enabling users to optimize plant growth and ensure the system's efficiency.

User Interaction Layer

The user interaction layer within an indoor intelligent agriculture system is a crucial component, serving as the bridge between users and the system's functionalities. It encompasses two primary interfaces: a web platform and an Android application. The web interface serves as a comprehensive dashboard accessible through a standard web browser. It allows users to securely log in and access real-time data from sensors, review historical records, manage connected devices, and monitor live video feeds from surveillance cameras within the indoor farm. The design prioritizes user-friendliness and an intuitive experience.

The Android application complements the web interface by providing a mobile platform for users. Through this app, users can securely log in, check real-time sensor data, browse historical records, manage devices, and view live video feeds from the indoor farm. It's designed for accessibility and convenience, catering to users who prefer engaging with the system via their mobile devices.

Both interfaces are aimed at providing a seamless and user-friendly experience, enabling users to effectively engage with the indoor intelligent agriculture system. This ensures easy access to vital data, device management, and live video feeds, regardless of their location or the device they're using.

Results and Analysis

In the domain of modern agriculture and greenhouse farming, microcontrollers stand as pivotal components, integrating seamlessly into the infrastructure and driving efficiency through intelligent, localized computation. The survey investigated the burgeoning role of microcontrollers within these systems, highlighting their significance in facilitating edge computing and on-device machine learning. These embedded systems, ranging from Arduino to Raspberry Pi, offer a robust platform for deploying lightweight machine learning models tailored for resource-constrained environments. They enable real-time analysis of sensor data, empowering immediate responses to changes in the greenhouse conditions, reducing latency and optimizing energy usage. Their adaptability and customization potential allow for tailored solutions, ensuring optimized plant growth and resource management. The integration of microcontrollers within greenhouse farming marks a significant stride in modern agriculture. Their capacity to drive edge computing and integrate machine learning locally elevates the intelligence of the IoT infrastructure within greenhouses, facilitating autonomous, data-driven decision-making, and fostering a more efficient and sustainable agricultural ecosystem. This integration provides an advanced framework, enhancing the intelligence of the Internet of Things (IoT) network and supporting autonomous, data-driven decision-making within greenhouse farming, ultimately fostering a more efficient and sustainable agricultural landscape.

Algorithms	Attributes	Accuracy	Sensitivity	Specificity	F-score	RMSE
SVM **MLP**	Pump	86.66 76.66	81.81 77.27	100 75	95.74 86.73	-
SVM **MLP**	Light	96.66 70	100 89.47	90.90 36.36	95.95 73.91	-
SVM **MLP**	Fan	90 83.33	94.11 82.35	84.61 84.61	89.88 86.41	-
Kalman Filter (with and without learning)	CO2	Improved (3.17% to 47.17%)	-	-	-	2.27 1.29
Kalman Filter (with and without learning)	Temperature	Improved (10% to 23.07%)	-	-	-	0.26 0.2
Kalman Filter (with and without learning)	Humidity	Improved (10% to 44%)	-	-	-	0.25 0.14

Table.1 Algorithm Results based on attributes or actuators

models and algorithms	ACCURACY	TIME CONSUMPTION	MEMORY	PRECISION	F1 SCORE	RECALL
ANFIS	91.2%	-	-	83%	81%	78%
svm	93.99%	2.53 sec	2.56MB	-	-	-
decision tree	96.22%	1.30 sec	2.78MB	-	-	-
random forest	96.88%	7.5 sec	2.9MB	-	-	-
adaboost	96.76%	70 sec	0.86MB	-	-	-

Table.2 Algorithm results for plant growth status

The study into machine learning algorithms in the context of greenhouse farming involved the examination of models designed to enhance crop yield and manage environmental conditions. Notably, as shown in below table the Decision Tree and Random Forest models demonstrated the highest accuracy at 96.88%, surpassing ANFIS (91.2%) and SVM (93.99%). However, Decision Tree executed faster, within 1.30 seconds, compared to the 7.5 seconds of the Random Forest model. In terms of resource consumption, SVM was notable, using 2.53 seconds for processing and 2.56MB of memory. Further analysis revealed that SVM and MLP models showed adaptability in attribute-specific tasks such as pump, lighting, and fan control, with varying accuracy, sensitivity, and specificity. The application of Kalman filters significantly improved the accuracy of CO_2, temperature, and humidity sensor data, augmenting precision for better control and monitoring from 3.17% to 47.17%, 10% to 23.07%, and 10% to 44%, respectively. These findings underscore the promising potential of machine learning in optimizing greenhouse farming, specifically in tailoring models to attribute-specific environmental conditions for more precise control and monitoring of greenhouse activities.

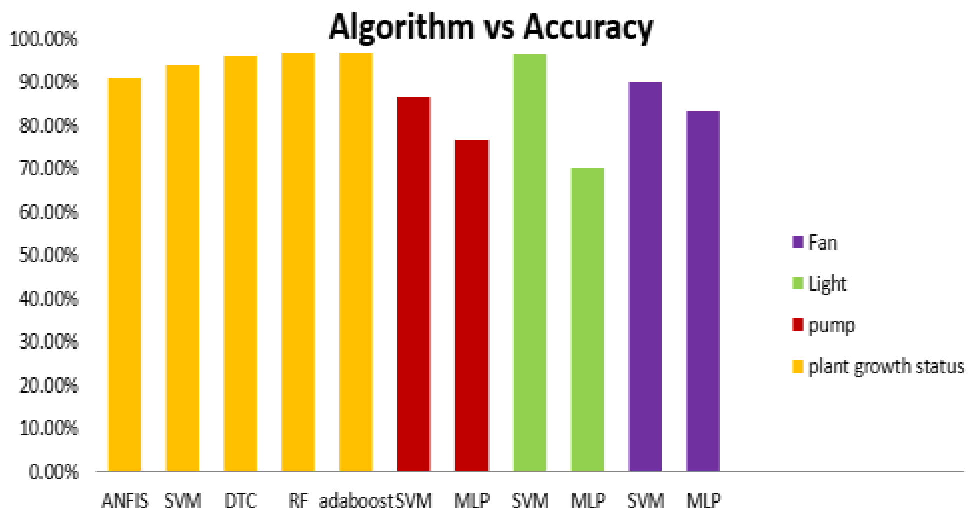

Fig.2. Graphical Representation of above ML Algorithms

This exploration presents a promising landscape for machine learning in greenhouse farming, advocating for the integration of these models with real-time monitoring and control systems. The Decision Tree and Random Forest models, showcasing superior accuracy and moderate resource usage, could be pivotal for swift decision-making in controlling diverse attributes within the greenhouse environment. Moreover, attribute-specific adaptations of SVM and MLP models present a tailored approach for efficient management of various actuators like pumps, lighting, and fans. The integration of Kalman Filters with learning mechanisms further bolsters the accuracy of sensor data, heralding a potential leap in the precision and control capabilities, thus accentuating the significance of these algorithms in greenhouse farming systems.

The survey also provides a comprehensive analysis of protocols and technologies within the domain of greenhouse farming, outlining their pivotal roles in optimizing smart farming systems. Among the highlighted technologies, MQTT and CoAP emerged as key facilitators, employing lightweight and resource-efficient designs to streamline communication among the extensive network of sensors and devices in greenhouses. Notably, these protocols significantly reduced the overhead in data exchange, conserving bandwidth and power, vital in resource-constrained environments. The study emphasized the criticality of HTTPS in ensuring secure data transfer, especially given the sensitive nature of information exchanged within greenhouse settings, such as environmental metrics and crop health. Additionally, TCP/IP's integral role was underscored for providing reliable end-to-end communication, safeguarding data integrity and enabling error-checking mechanisms. WiFi's significance was emphasized, enabling wireless connectivity among various IoT devices to gather crucial environmental data, allowing for remote monitoring and control. This section signifies the pivotal role these protocols and technologies play in modernizing and enhancing the efficiency of greenhouse farming by enabling secure, scalable, and robust systems for monitoring and controlling critical environmental parameters.

Conclusion

This research study investigates the revolutionary potential of IoT and machine learning in greenhouse farming through a thorough assessment. By combining these technologies, operations have been optimized and proactive greenhouse environment management is now possible thanks to predictive insights. All things considered, these results represent a paradigm change in agriculture, pointing to a future where sustainable development and optimum crop yields are possible in controlled agricultural contexts. We can build a complex system that integrates sensors, cloud infrastructure, and predictive analytics with these crucial data, combining IoT, machine learning, and reliable protocols to potentially control and monitor greenhouse settings dynamically. The results clearly imply that the productivity and efficiency of greenhouse farming might be greatly increased by integrating IoT, machine learning, and sophisticated protocols. Accurate decision-making models such as Random Forests and Decision Trees, along with data accuracy approaches like Kalman Filters, are leveraged by these technology integrations to provide more responsive and accurate control over greenhouse conditions. This could result in better crop yields, more efficient use of resources, and a more sustainable method of farming in regulated settings.

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