EKITI STATE UNIVERSITY

Journal of Engineering, Technology and Innovation
Volume 4, Issue. 1 (March, 2025) pp. 13-20

Design of an IoT-Based Control System for Intelligent Power Management of a Greenhouse

Abiodun Michael Adebimpe[a]*, Daniel Chukunebikpe Uguru-Okorie[a], Joseph Yakubu Oricha[b], Adetoye Ayokunle Aribisala[a], Kehinde Oluwafemi Olusuyi[b], Shereefdeen Oladapo Sanni[b] and Gideon Oreoluwa Olorunmojo[a]

[a]*Department of Mechatronics Engineering, Federal University, Oye-Ekiti, Ekiti State, Nigeria.*

[b]*Department of Electrical and Electronic Engineering, Federal University, Oye-Ekiti, Nigeria*

Abstract

Greenhouses are crucial elements of contemporary farming methods that enable the year-round production of crops under carefully regulated climatic conditions. Conventional manual control of greenhouse parameters and power management are laborious and inefficient. Therefore, this study designs a control system for intelligent power management of a greenhouse, implement the proposed design and evaluate the performance of the system. The system comprises the current sensor, temperature and humidity sensor, soil moisture sensor, Light Dependent Resistor (LDR) for monitoring the temperature, humidity, soil moisture and light intensity. As the central control unit, the ESP32 microcontroller processes data from various sensors and makes decisions in real time to modify the greenhouse's operations, including the watering, lighting and cooling systems that are necessary for the sustainability and growth of the plants. Using the Internet of Things, real-time remote monitoring and control was incorporated to enable users to modify environmental parameters without physically present in the greenhouse. The study outcomes revealed that the temperature was effectively kept between 23°C and 27°C, the humidity level was maintained between 65% and 80% and the soil moisture content maintained between 60% and 80% which are ideal for growing tomatoes in greenhouse. Result further shows that the farmer can monitor and modify environmental parameters within the distance of 35 to 40 meters away from the greenhouse and the greenhouse's optimal energy utilization was achieved as a result of components' operation as needed. The applied control system could give tomatoes nursery plants a steady and regulated environment resulting in more consistent and healthy growth.

Keywords: *Control System, Greenhouse, Power Management, Algorithm, Intelligent, Internet of Things.*

* Corresponding author. Tel.: +2348062470796
E-mail: abiodun.adebimpe@fuoye.edu.ng

1. Introduction

Crops are cultivated in greenhouses, which are frames of inflated structures covered in a transparent substance, under carefully regulated climatic conditions. They are crucial elements of contemporary farming methods, enabling the year-round production of crops in controlled settings regardless of the outside weather [1], [2]. In addition to providing opportunities to optimize growing conditions for increased productivity and crop quality, they also offer controlled climate conditions, efficient water usage, optimized space, crop diversity and specialization, nutrient management, season extension and crop rotation, technology integration, and protection from unfavourable weather, pests and diseases [3]. Compared to the traditional field farming approach, intelligent greenhouses yield greater harvests [4]. The management of climatic elements that impact crop output in order to cultivate crops in the most favourable environment has been identified as the reason for the improved yield [5]. Presently, the world's population growth, urbanization, depletion of arable land and climate extremes pose a serious challenge to the agriculture industry. Growing crops in greenhouses could offer creative solutions for sustainable agriculture, which is needed to mitigate these issues [6]. However, effective resource management, of which energy is a crucial component, is necessary for the sustainable running of greenhouses [7]. Energy usage in greenhouses includes, among other things, ventilation, lighting, heating and cooling systems. Both the environmental effect and operating expenses are greatly increased by these systems. Since energy costs are the second-highest operational cost for greenhouse production in cold climates after labour, [8] and [9] posited that the higher energy costs associated with greenhouse production are a significant problem. As a result, efficient energy management in the greenhouse is necessary. Effective greenhouse management requires intricate decision-making to strike a balance between the best growing conditions for plants and the utilization of resources like energy and water [10] - [12]. In the meantime, advanced greenhouse automation systems have been developed in this area through developments in sensor technology, artificial intelligence [13] and data analytics. In-depth information about greenhouse conditions can be obtained using wireless sensor networks that are outfitted with sensors for temperature, humidity, soil moisture and light intensity [14], [15]. In order to optimize energy consumption and maximize crop output, machine learning algorithms, such as neural networks and fuzzy logic controllers, may evaluate sensor data and modify equipment operation in real-time [16], [17]. A robust and flexible control system for greenhouses is produced by combining the Internet of Things (IoT) with microcontrollers [18]. The microcontroller processes the continuous stream of precise data from IoT sensors to maximize growing conditions. Automated systems carry out the microcontroller's decisions thereby continuously enhancing the outcomes. In the contemporary context of climate change and food security, this synergy is essential because it enables more effective resource management, higher productivity and improved adaptation to changing conditions [19]. There is still a need for a straightforward yet all-inclusive intelligent power management system designed especially for greenhouse operations, even with the advancements in greenhouse automation technology. Current solutions frequently concentrate on certain elements or don't integrate with larger greenhouse management systems [20]. In order to resolve the issues of cost-effectiveness, sustainability, and energy efficiency in greenhouse operations, there is an urgent need for research and innovation in this field. Conventional power management systems for greenhouses frequently depend on manual control or simple automation, both of which are ineffective and incapable of adjusting to changing environmental conditions [21], [22]. Manual techniques are time-consuming and prone to human error, which results in energy waste and less-than-ideal resource use. The inability of simple automation systems, such as timers or thermostats, to optimize energy use based on real-time data [23], [24] results in inefficiencies and higher expenses. Advanced sensor technologies, control algorithms and data analytics provide a more flexible solution to these constraints. By optimizing energy use and guaranteeing ideal growing conditions, these technologies allow for real-time monitoring and decision-making. The creation of intelligent power management systems for greenhouses ought to be promoted in view of the aforementioned.

Most of the existing work on the power management of greenhouse did not consider all the factors that contribute to the overall improvement of the greenhouse. Therefore, this work designs a control system for intelligent power management of a greenhouse with due consideration of all the factors that improve greenhouse productivity, implement the proposed design using both software and hardware prototype adaptable to the research farm of the faculty of agriculture, Federal University, Oye-Ekiti and evaluate the performance of the system.

Considerable progress has been made in optimizing greenhouse energy consumption. An intelligent Internet of Things-based system for monitoring and controlling greenhouse temperature was designed in the research efforts by [25]. In order to monitor the greenhouse environment and generate the appropriate reference temperature that was delivered to a temperature regulating block, a Petri Nets (PN) model was employed. Furthermore, the PN model tracked the greenhouse's energy usage and gave the right signal for the necessary modification as needed. To regulate the greenhouse's temperature, a wireless sensor network continuously measures the outside temperature and compares it with readings kept in the system's backend database. Meanwhile, other factors that improve greenhouse productivity and power usage, such as irrigation and humidity, were not taken into account in this study. In order to automate and improve agricultural productivity, research by [26] investigated the integration of information technology with greenhouse climate management. According to the study, these systems are essential for controlling the seasons, shielding crops from harsh weather and guaranteeing ideal growing circumstances. In order to satisfy certain plant development requirements, the researchers also created a complete control system for intelligent greenhouses using Mitsubishi PLC and MCGS. To maintain optimal environmental conditions, the system used a standard PID control method with sensors and control devices. The study demonstrated how well sophisticated control systems work to maximize greenhouse management and raise agricultural yields. [27] worked on integrating intelligent control, artificial intelligence (AI) and the Internet of Things (IoT) into the greenhouse system. Through the examination of real-time environmental data, their study suggested a monitoring and control system intended to improve greenhouse operations. The design of the system makes use of AI and IoT to streamline greenhouse management procedures, guaranteeing effective regulation of temperature, humidity and other crucial parameters. The study illustrated how intelligent technologies could greatly increase agricultural practices' efficiency. Despite the fact that the outcome of their study produced a good control system for sustainable greenhouse management, combining the technologies involved may be capital intensive thereby making it unaffordable for the rural farmers.

This work advances knowledge by the development of control algorithm, adaptable to FUOYE research farm, to optimize energy usage and enhance operational efficiency of a greenhouse through the integration of real-time data on environmental conditions and plant requirements for sustainable agriculture.

2. Methodology

The methodology adopted in this work includes the design description that gives details of the components used and their functions, the design calculation that shows the values and ratings of key components and design implementation that shows the layout and construction of the prototype.

A. Design Description

Modular components and a flexible feedback loop algorithm, an ingenious automation solution that ensures stability and efficiency and enables dynamic modifications depending on changes in environmental conditions were employed in the design of the intelligent greenhouse system. The system comprises the current sensor, temperature and humidity sensor, soil moisture sensor, Light Dependent Resistor (LDR) for monitoring the temperature, humidity, soil moisture and light intensity. As the central control unit, the ESP32 microcontroller processes data from various sensors and makes decisions in real time to modify the greenhouse's operations, including the watering, lighting and cooling systems that are necessary for the sustainability and growth of the plants. It is set up to effectively control these devices, guaranteeing that the greenhouse keeps the ideal growing circumstances for plants while using the least amount of energy. A 4-channel relay module is also integrated into the system to regulate the lightbulb, water pump, and DC fan in response to detected conditions. The real-time data on the system status and ambient conditions is shown on a digital Liquid Crystal Display (LCD). Additionally, the design includes wireless connectivity, which shows how the Internet of Things (IoT) may be used practically by allowing remote control and monitoring via a web interface. The microprocessor, sensors and actuators work together to create a responsive and adaptable system that improves greenhouse management productivity and efficiency. The block diagram of the greenhouse and the control components is shown in Fig. 1. The microcontroller, as illustrated in Fig. 1, is an inexpensive microcontroller that has built-in Bluetooth and Wi-Fi, which makes it perfect for

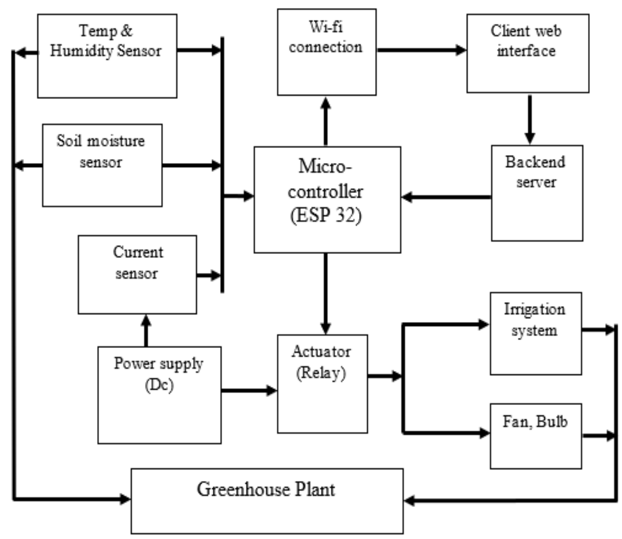

Fig. 1: Block diagram of the greenhouse and control components

Internet of Things applications. In order to interface with sensors, relays and actuators, it features a number of general-purpose input/output (GPIO) pins, analog-to-digital converter channels and pulse-width modulation outputs. Its dual-core processing power guarantees effective management of real-time communication and data processing. It provides smooth cloud service integration for remote greenhouse management and monitoring. Reliable measurements of both temperature and humidity are provided by the DHT11 sensor, which is crucial for keeping an eye on and managing the greenhouse environment. It functions within a temperature range of 0 to 50°C and a humidity range of 20% to 90%. The water content of the soil is determined via the attached soil moisture sensor. The resistance between the two probes, which is dependent on the moisture content of the soil, is measured by this device. Utilized for ventilation, the DC fan aids in controlling the greenhouse's temperature and air flow. The greenhouse's artificial light source is a DC lamp. In order to guarantee that the plants receive constant illumination, it is triggered when the light-dependent resistor sensor detects inadequate natural light. In order to prolong the sunshine hours for photosynthesis, this is essential. The greenhouse's watering system makes use of the DC water pump. It is triggered when the soil moisture sensor senses that the soil is dry. The microcontroller communicates with fans, pumps and lightbulbs through the 4-channel relay module. Because the module can switch DC loads, it can be used in a variety of greenhouse applications. The current sensor keeps track of how much electricity is being utilized by the different components in the greenhouse. It gives the microcontroller real-time data, which aids in assessing the energy efficiency of the system. The system makes judgments to minimize waste and optimize power usage by monitoring current usage. Fig. 2 displays the control system's circuit diagram.

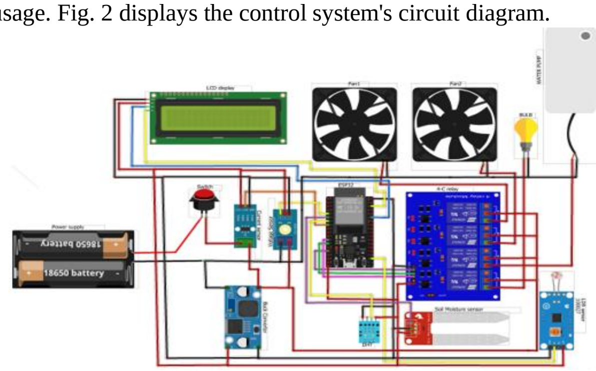

Fig. 2: Greenhouse control system circuit diagram

B. Design Calculations

The power requirement of the greenhouse and control components was calculated using equation 1;

$$P = IV \quad (1)$$

where; I = Current and V = Voltage.

The breakdown of the system power requirement is shown in Table 1.

Table 1: Greenhouse control power requirement

Device	Operating voltage (V)	Current (I)	Power (I x V)
Light bulb	12	1.75	21
DC cooling fan	12	0.3	3.6
DC water pump	12	0.3	3.6
DC outlet fan	12	0.45	5.4
Buck converter	12	5	60
Total power drawn from the main power supply			= 93.6 W
ESP32 Microcontroller	5	0.25	1.25
Relay	5	0.3	1.5
LCD	5	0.02	0.1
Current sensor	5	0.012	0.06
DHT sensor	5	0.0003	0.0015
LDR sensor	5	0.05	0.25
Soil moisture sensor	5	0.005	0.025
Total power drawn from the buck converter			= 3.2 W

From Table 1, the total power consumption of the system is 93.6 W. This informed the choice of a 100 W main power adapter with voltage and current ratings of 12 V and 8.3 A respectively. Therefore, the main power adapter supplies the components with 12 V rating directly while the buck converter steps down the 12 V input from the main power adapter to 5 V output and supplies the 5 V-rated components. The soil moisture content as a percentage of the sensor's readings was computed using the range of dry and humid soil required for plant growth [28];

$$\text{Soil moisture} = \frac{\text{Volume of water}}{\text{Volume of soil}} \times 100$$

Therefore, the maximum sensor reading of 4095 corresponds to 100% dry soil, sensor readings between 365 and 600 corresponds to humid soil while sensor readings of the range 605 – 1000 corresponds to dry soil. Using linear interpolation within the range of humid (365) and dry (1000) with the sensor reading (Sr), the percentage of soil moisture content was computed using equation 2;

$$\text{Soil moisture (\%)} = \frac{1000 - S_r}{1000 - 370} \times 100 \quad (2)$$

C. Design Implementation

A 30-litre storage container of dimension 450mm x 350mm x height 260mm was used as the framework of the greenhouse. On the external part of the storage container, shown in Fig. 3, the system power supply, a box which contains the control system components and the two fans were attached using a hot glue to ensure firmness.

Fig. 3: Assembled components

The components of the irrigation system were fixed to the outer surface of the top of the container and the lighting bulb connected to the inner top surface. The temperature, humidity and soil moisture sensors were kept in the container. The completed prototype of the greenhouse with the control components is shown in Fig. 4.

Fig. 4: Constructed prototype

The algorithm written for the control of the greenhouse's parameters is as follows;

Step 1: Start.

Step 2: Initialize the microcontroller and connected sensors.

Step 3: Read sensor data for plant environmental parameters.

Step 4: Analyze the data to determine the greenhouse condition.

Step 5: If the temperature exceeds 300C: activate the cooling fan.

Step 6: If the soil moisture is below 10%: turn on the water pump to irrigate the plants.

Step 7: If light intensity is low or below 50%: turn on the lighting bulb.

Step 8: Continuously monitor the conditions and adjust the devices accordingly.

Step 9: Send real-time data to the user via Wi-Fi for remote monitoring and control.

Step 10: Repeat the process in a loop for continuous operation.

Step 11: End.

The microcontroller hosts a web server that allows it to connect to a local server via a web interface. It can send and receive data across a network by connecting to a Wi-Fi network. The microcontroller continuously gathers sensor data, which includes temperature, humidity, soil moisture and light levels. The data is shown in real-time on the web interface, and the user can adjust the parameters remotely. The microcontroller's corresponding GPIO pins are triggered when a control command is provided, enabling functions like turning devices on and off. For effective greenhouse management, the microcontroller serves as both a controller and a data collector, facilitating smooth communication between the user, sensors, and actuators.

In order to test the responsiveness and efficiency of the greenhouse, tomatoes were planted and the growth was monitored.

3. Results and Discussion

The control of the parameters of the greenhouse was actualized in a number of steps shown in the flow chart of Fig. 5. The microcontroller loads the stored software during system initialization, turning on all the sensors and linked devices. The greenhouse's parameters are continuously monitored by environmental sensors, which include light, temperature, humidity and soil moisture sensors. These sensors provide real-time data to the microcontroller, which processes it using preset thresholds and control algorithms depicted in Fig. 5. The microcontroller uses the linked relays to transmit a signal to turn on the cooling system (fan) if the temperature rises beyond the predetermined threshold of 30^{o}C. This threshold was set because temperature above 30^{o}C is not favourable for the growth and wellbeing of tomatoes.

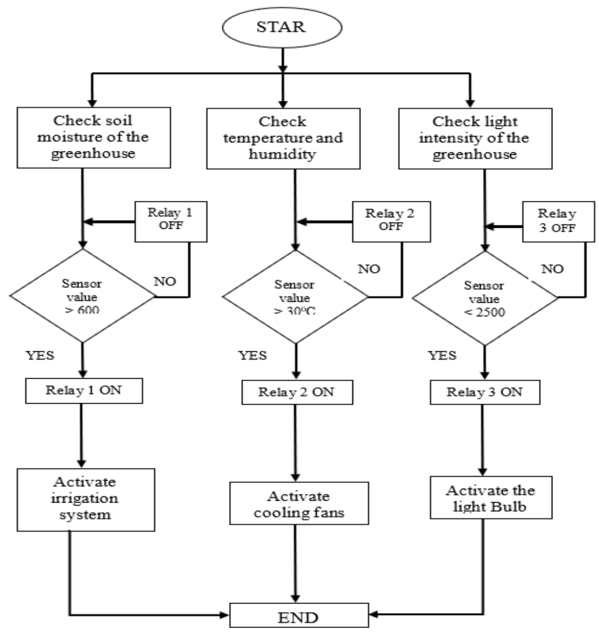

Fig. 5: Greenhouse control system flow diagram

Similarly, the microcontroller activates the water pump to start the irrigation system if the soil moisture levels fall below the predetermined range. The light intensity is managed by controlling the lighting system to ensure the plants receive sufficient light based on day-night cycles. Every activity is recorded, and the system shows real-time information on an LCD screen, such as the state of the linked devices and the surrounding environment. The system stays inactive and continuously monitors and updates sensor data when no changes are required. The temperature was effectively kept between 23°C and 27°C, which is ideal for growing tomatoes in both greenhouse and natural planting systems. Additionally, the humidity level was maintained between 65% and 80% to maintain a favourable environment for the growth of healthy plants while preventing the establishment of mold or other infections. As seen in Figures 6a and 6b, the soil moisture sensor inserted into the loamy soil successfully activated the irrigation system when necessary, keeping the soil moist and not waterlogged and preventing the root from rotting. This is in accordance with the ideal soil moisture content for tomato growth, which is between 60% and 80% [29].

(a) Before irrigation (b) After irrigation

Fig. 6: Irrigation system implementation

In order to make sure the tomatoes plant received enough light for photosynthesis, the light sensor tracked the amount of natural light and sent signals to turn on the light bulb when needed, taking into account the light intensity ideal for tomato growth, which is between 600 and 1000 µmol/m²/s. This was especially helpful in the early morning and late evening when there was not enough natural light, as seen in Fig. 7. Real-time remote monitoring and control were made possible by the web interface's integration, giving users the freedom to modify

Fig. 7: Lighting system implementation

environmental parameters without physically being in the greenhouse. Even when the user is within a certain distance of the greenhouse, this feature has shown to be extremely helpful in keeping constant growing conditions. After testing, it was found that the Wi-Fi network worked well within 35 to 40 meters of the greenhouse. Communication and reception can deteriorate if the farmer is out of range. As seen in Fig. 8, the greenhouse's temperature, humidity, soil moisture content, light intensity and load consumption were all shown on the web interface.

Fig. 8: Web interface performance evaluation

Fig. 9 displays the current sensor's measurements, which were used to calculate the current used by each part of the greenhouse's control system.

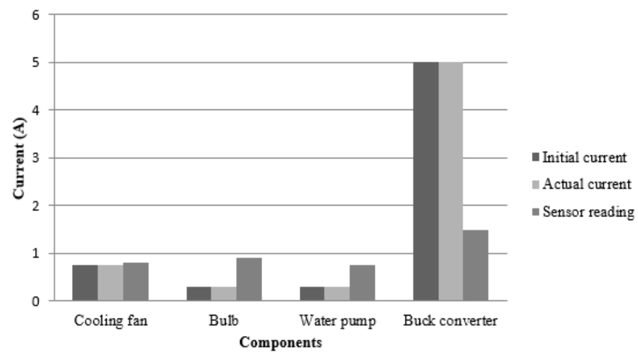

Fig. 9: Graphical representation of control components' current

The sensor data from Fig. 9 show that the components of the control system were able to operate as needed and the drawn current was less than their rated values. This accounts for the greenhouse's optimal energy utilization achieved through a system automation that allows components' operation when the need arises. In terms of energy preservation, this is an improvement over the greenhouses where the light is permanently on regardless of the light intensity of the greenhouse. The implemented design of the control system for the greenhouse proved that it could give tomato nursery plants a steady, regulated environment, resulting in more consistent and healthy growth. Utilizing this technology in plant nurseries can optimize the use of resources like water and electricity while drastically reducing the labour required for manual monitoring and control.

4. Conclusion

Design and implementation of a control system for intelligent power management of a greenhouse was carried out in this work. The system comprises the current sensor, temperature and humidity sensor, soil moisture sensor, Light Dependent Resistor (LDR) for monitoring the temperature, humidity, soil moisture and light intensity. As the central control unit, the ESP32 microcontroller processes data from various sensors and makes decisions in real time to modify the greenhouse's operations, including the watering, lighting and cooling systems that are necessary for the sustainability and growth of the plants. Using the Internet of Things, real-time remote monitoring and control was incorporated to enable users to modify environmental parameters without physically present in the greenhouse. The study outcomes revealed that the temperature was effectively kept between 23°C and 27°C, the humidity level was maintained between 65% and 80% and the soil moisture content maintained between 60% and 80% which are ideal for growing tomatoes in greenhouse. Moreover, the farmer can monitor and modify environmental parameters within the distance of 35 to 40 meters away from the greenhouse and the greenhouse's optimal energy utilization was achieved by system automation that allows components' operation when the need arises. The applied control system could give tomatoes nursery plants a steady and regulated environment resulting in more consistent and healthy growth. Meanwhile, future work may consider integration of solar energy as alternative power source and improvement of the network range beyond 40 meters to enhance the efficiency of the greenhouse.

References

[1] Nemali, K. (2022). "History of Controlled Environment Horticulture: Greenhouses", HORTSCIENCE, vol. 57, no.2, pp. 239 – 246.

[2] Farvardin, M., Taki, M., Gorjian, S., Shabani, E. and Julio C. Sosa-Savedra, J. C. (2024). "Assessing the Physical and Environmental Aspects of Greenhouse Cultivation: A Comprehensive Review of Conventional and Hydroponic Methods", Sustainability, 16, 1273, pp. 1 – 34.

[3] Karanisa, T., Achour, Y., Ouammi, A. and Sayadi, S. (2022). "Smart Greenhouses as the Path Towards Precision Agriculture in the Food Energy and Water Nexus: Case Study of Qatar", Environment Systems and Decisions, 42, pp. 521–546.

[4] Mourik, S. V., Tol, R. V. D., Linker, R., Reyes-Lastiri, D., Kootstra, G., Koerkamp, P. G. and Henten, E. J. (2021). "Introductory Overview: Systems and Control Methods for Operational Management Support in Agricultural Production Systems", Environmental Modelling and Software, 139, 105031, pp. 1 – 15.

[5] Singh, N., Sharma, A. K., Sarkar, I., Prabhu, S. and Chadaga, K. (2024). "IoT-based Greenhouse Technologies for Enhanced Crop Production: A Comprehensive Study of Monitoring, Control, and Communication Techniques", Systems Science & Control Engineering, vol. 12, no.1, pp. 1 – 14.

[6] Castro, R. P., Dinho da Silva, P. and Pires, L.C.C. (2024). "Advances in Solutions to Improve the Energy Performance of Agricultural Greenhouses: A Comprehensive Review. Appl. Sci., 14, 6158, 1 – 59.

[7] Jamshidi, F., Ghiasi, M., Mehrandezh, M., Wang, Z. and Paranjape, R. (2024). "Optimizing Energy Consumption in Agricultural Greenhouses: A Smart Energy Management Approach", Smart Cities, 7, pp. 859–879.

[8] Ahamed, M. S., Guo, H. and Tanino, K. (2019). "Energy Saving Techniques for Reducing the Heating Cost of Conventional Greenhouses", Biosystems Engineering, 178, pp. 9 – 33.

[9] Maraveas, C., Karavas, C. S., Loukatos, D., Bartzanas, T., Arvanitis, K.G. and Symeonaki, E. (2023). "Agricultural Greenhouses: Resource Management Technologies and Perspectives for Zero Greenhouse Gas Emissions", Agriculture, 13, 1464, pp. 1 – 46.

[10] Ghiasi, M., Wang, Z., Mehrandezh, M. and Paranjape, R. (2024). "A Systematic Review of Optimal and Practical Methods in Design, Construction, Control, Energy Management and Operation of Smart Greenhouses", IEEE Access, vol. 12, pp. 2830 – 2853.

[11] Volosciuc, C., Bogdan, R., Blajovan, B., Stângaciu, C. and Marcu, M. (2022). "GreenLab, an IoT-Based Small-Scale Smart Greenhouse", Future Internet, 16, 195, May 2024, pp. 1 – 19.

[12] Soussi, M., Chaibi, M.T., Buchholz, M. and Saghrouni, Z. "Comprehensive Review on Climate Control and Cooling Systems in Greenhouses under Hot and Arid Conditions", Agronomy, 12, 626, pp. 1 – 31.

[13] Chen, Q. and Hu, X. (2022). "Design of Intelligent Control System for Agricultural Greenhouses Based on Adaptive Improved Genetic Algorithm for Multi-Energy Supply System", Energy Reports, 8, pp. 12126–12138.

[14] Touhami, A., Benahmed, K., Parra, L., Bounaama, F. and Lloret, J. (2020). "An Intelligent Monitoring of Greenhouse Using Wireless Sensor Networks", Smart Structures and Systems, vol. 26, no. 1, pp. 117-134.

[15] Riahi, J., Vergura, S., Mezghani, D. and Mami, A. (2020). "Intelligent Control of the Microclimate of an Agricultural Greenhouse Powered by a Supporting PV System", Applied Sciences, 10, 1350, pp. 1 – 20.

[16] Badji, A., Benseddik, A., Bensaha, H., Boukhelifa, A. and Hasrane, I. (2022). "Design, Technology, and Management of Greenhouse: A review", Journal of Cleaner Production, 373, 133753.

[17] Ojo, M. O. and Zahid, A. (2022). "Deep Learning in Controlled Environment Agriculture: A Review of Recent Advancements, Challenges and Prospects", Sensors, 22, 7965, pp. 1 - 43.

[18] Hosny, K. M., El-Hady, W. M. and Farid M. Samy, F. M. (2025). "Technologies, Protocols, and applications of Internet of Things in greenhouse Farming: A survey of recent advances", Information Processing in Agriculture, vol. 12, no 1, pp. 91-111.

[19] Platero-Horcajadas, M., Pardo-Pina, S., Cámara-Zapata, J. M., Brenes-Carranza, J. A. and Ferrández, F. J. (2024). "Enhancing Greenhouse Efficiency: Integrating IoT and Reinforcement Learning for Optimized Climate Control", Sensors, 24, 8109, pp. 1 – 24.

[20] Martinez, R. (2022). "Intelligent Control Strategies for Greenhouse Power Management: A Systematic Review", Computers and Electronics in Agriculture, vol. 28, no. 1, pp. 75-92.

[21] Maraveas, C., Karavas, C.-S., Loukatos, D., Bartzanas, T., Arvanitis, K. G. and Symeonaki, E. (2023). Agricultural Greenhouses: Resource Management Technologies and Perspectives for Zero Greenhouse Gas Emissions. Agriculture, vol. 13, no. 7, 1464.

[22] Hoque, M. J., Ahmed, M. R. and Hannan, S. (2020). "An Automated Greenhouse Monitoring and Controlling System using Sensors and Solar Power", European Journal of Engineering and Technology Research, vol. 5, no. 4, pp. 510 – 515.

[23] Huynh, H. X, Tran, L. N. and Duong-Trung, N. (2023). "Smart greenhouse construction and irrigation control system for optimal Brassica Juncea development", PLoS ONE, e0292971, vol. 18, no. 10, pp. 1 – 46.

[24] Sapounas, A., Katsoulas, N., Slager. B., Bezemer, R. and Lelieveld, C. (2020). "Design, Control, and Performance Aspects of Semi-Closed Greenhouses", Agronomy, 10, 1739, pp. 1 – 22.

[25] Subahi, A. F. and Bouazza, K. E. "An Intelligent IoT-Based System Design for Controlling and Monitoring Greenhouse Temperature", IEEE Access, vol. 8, July 2020, pp. 125488 – 125500.

[26] Huang, M. (2023). "Design of Intelligent Greenhouse Control System Based on MCGS and PLC", Journal of Physics Conference Series, 2510, 012022, pp. 1 – 9.

[27] Lee, M. H., Yao, M. H., Kow, P. Y., Kuo, B. J. and Chang, F. J. (2024). "An Artificial Intelligence-Powered Environmental Control System for Resilient and Efficient Greenhouse Farming", Sustainability, 16, 10958, pp. 1 - 18.

[28] Basterrechea, D. A., Rocher, J., Parra, M., Parra, L., Marin, J.F., Mauri, P.V. and Lloret, J. (2021). "Design and Calibration of Moisture Sensor Based on Electromagnetic Field Measurement for Irrigation Monitoring", Chemosensors, 9, 251, pp. 1 – 32.

[29] Nurhasanah, R., Savina, L., Nata, Z. M. and Zulkhair, I. (2021)." Design and Implementation of IoT Based Automated Tomato Watering System Using ESP8266", in 5th International Conference on Computing and Applied Informatics, Journal of Physics: Conference Series, 012041, pp. 1 – 8.