v. 4, n. 27, 2024

Journal of
Engineering
Research

PROPOSAL FOR AN AEROPONIC SMART GREENHOUSE PROPOSAL FOR AN AEROPONIC SMART GREENHOUSE

Acceptance date: 28/11/2024
Submission date: 28/10/2024

Beatriz Eugenia Silva y Rodríguez García
Instituto Internacional de Aguascalientes
Tecnológico Nacional de México – Instituto Tecnológico de San Luis Potosí San Luis Potosí – San Luis Potosí
https://orcid.org/0000-0002-0905-932X

Jorge Norberto Mondragón Reyes
Instituto Internacional de Aguascalientes
Tecnológico Nacional de México – Instituto Tecnológico de Aguascalientes
Aguascalientes – Aguascalientes
http://orcid.org/0009-0006-2372-0942

Marco Antonio Hernández Vargas
Instituto Internacional de Aguascalientes
Tecnológico Nacional de México – Instituto Tecnológico de Aguascalientes
Aguascalientes – Aguascalientes
https://orcid.org/0000-0002-8146-9307

César Dunay Acevedo Arreola
Tecnológico Nacional de México, Instituto Tecnológico de Aguascalientes Instituto Internacional de Aguascalientes
Aguascalientes – México
https://orcid.org/0009-0001-9370-2997

All content in this magazine is licensed under a Creative Commons Attribution License. Attribution-Non-Commercial-Non-Derivatives 4.0 International (CC BY-NC-ND 4.0).

Abstract: Internet technologies encompass a wide range of tools and systems that enable communication, information sharing and global connectivity. The integration of the Internet of Things (IoT) and Artificial Intelligence (AI) in agriculture has revolutionized the way resources are managed and farming practices are optimized. Through the use of connected sensors, real-time monitoring systems and advanced data analytics, farmers can make informed decisions that improve the efficiency and sustainability of their crops. AI makes it possible to predict weather conditions, detect pests and diseases early, and automatically adjust irrigation and fertilization, which reduces resource waste and increases productivity. Together, these technologies not only improve profitability, but also contribute to food security and environmental protection. The objective of this research project is to manage the different physical variables such as temperature, humidity and luminosity involved in an aeroponic greenhouse through the use of Internet of Things and Fuzzy Logic. This proposal has been implemented in a low-cost greenhouse prototype where a bank of sensors managed through the open source automation platform Home Assistant (HA) has been placed. The aeroponic greenhouse can be controlled locally (Fog Computing) or from anywhere with an Internet connection via VPN (Cloud Computing). This type of proposal is intended to accelerate the growth process of the agricultural products placed inside the greenhouse. The implementation of this project will be in two phases. The first phase will consist of the construction of the aeroponic greenhouse along with the sensor bank, the central processing system, connectivity of the sensor bank to the Home Assistant platform and remote connectivity to the greenhouse. In the second phase, fuzzy logic will be implemented for the automatic management of the sensor bank and the control of ultraviolet light for the germination of different types of agricultural products. This proposal shows the results of the first phase of the project.
Keywords: Aeroponic greenhouse, Internet of Things, Artificial Intelligence, Fuzzy Logic, Sensor.

INTRODUCTION

Agronomy has evolved significantly in recent decades due to the growing need for sustainable solutions for food production, given population growth and climate change. Traditional approaches to agriculture have been complemented by technological innovations, such as precision agriculture, advanced irrigation systems and the use of new cultivation techniques, such as hydroponics and aeroponics (FAO, 2021).

A prominent trend is the use of sensors, drones, and mass data processing to improve crop efficiency and reduce natural resource use. These technologies allow for more detailed monitoring of soil conditions, weather, and plant health, which maximizes yields and minimizes environmental impact (Brady & Weil, 2019).

Vertical farming and soilless growing systems, such as aeroponics, are gaining ground in regions where land and water availability is limited. Aeroponics, in particular, has proven to be a promising technique for growing a wide variety of plants, especially in controlled environments such as greenhouses or urban facilities. This method optimizes water and nutrient use, making it a highly efficient option for the future of sustainable agriculture (Bailey- Serres et al., 2019).

Figure 1. Bustanica, the world's largest vertical farm (Source: www.xataka.com).

In Mexico, agronomy has also experienced significant advances, driven by the need to improve agricultural productivity and address climate and water resource challenges. Precision agriculture has begun to be implemented in several regions of the country with techniques such as aeroponics, although in its early stages of adoption, they have aroused interest in both academia and agricultural companies seeking to improve water use efficiency (Sánchez-Lizarraga & Carrillo-López, 2020).

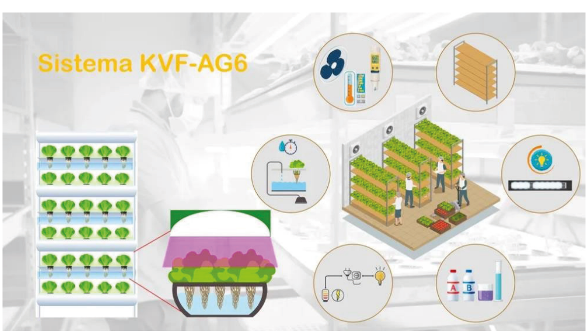


Figure 2. Karma Verde Fresh, an example of vertical agriculture in Mexico (Source: https://karmaverdefresh.com/).

The government and academic institutions have encouraged research and development in areas related to sustainable agriculture, and the Ministry of Agriculture and Rural Development (SADER) has promoted technological innovation projects in the agricultural sector, including soilless cultivation systems. The states with the greatest adoption of these techniques are those with scarce water or agricultural land, such as Baja California and Zacatecas, where aeroponic systems are being considered for high-value crops, such as vegetables and medicinal plants (Martínez & Pérez, 2021).

The proposed aeroponic greenhouse based on the Internet of Things (IoT), is a low-cost prototype that is composed of a sensor bank, a microcontroller and Home Assistant (HA) integrator platform. The sensor bank will be used to monitor the main physical variables of the greenhouse such as temperature, humidity and ambient brightness of the aeroponic environment. The main function of the microcontroller will be to monitor and process the above physical variables and send the result to the HA.

The HA will allow to display in a mobile application environment, the status of each of the sensors, actuators and remote access to the greenhouse.

THEORETICAL FRAMEWORK

Aeroponics is an advanced method of soilless cultivation in which plant roots are suspended in the air and sprayed with a nutrient-rich solution. This technique, which emerged as an evolution of hydroponics, has gained interest due to its ability to maximize water and nutrient use, reduce the space required for cultivation, and avoid problems associated with soil use (Kozai et al., 2020; Sharma et al., 2019; Lakhiar et al., 2018; Zhang & Ling, 2021).

Figure 3. Aeroponic cultivation towers (Source: www.agrohuerto.com)

The development of aeroponics has been driven by the need to find more sustainable agricultural solutions to the problems arising from climate change, water scarcity and loss of arable land. This technique is especially useful in controlled environments such as greenhouses and vertical farming systems, where the efficient use of resources is a priority.

One of the main advances of aeroponics is its ability to use up to 95% less water than traditional agricultural methods and its potential to increase the speed of plant growth, due to high oxygenation of the roots. In addition, aeroponic crops can produce food year-round regardless of weather conditions.

This makes them a viable option for production in urban areas and regions with unfavorable environmental conditions.

Despite its benefits, aeroponics faces challenges such as the high initial cost of the necessary infrastructure and equipment, as well as the need for specialized technical management to keep the systems running optimally. Interruption of the nutrient supply or spray system can cause rapid damage to plants, limiting mass adoption.

Advances in automation and monitoring have improved the viability of aeroponics, reducing reliance on manual management. However, the lack of standardization in technology and the poor dissemination of knowledge on the subject in some countries remain barriers to its global implementation (Medina & Gutiérrez, 2022).

On the other hand, the Internet of Things (IoT) has grown exponentially in the last decade, transforming the way we interact with the digital and physical world. IoT refers to the interconnection of everyday devices and objects through the internet, allowing them to collect, send and receive data without direct human intervention. Advances in sensors, wireless networks and processing technologies have facilitated this expansion (Atzori et al., 2020; Xu et al., 2019; Gubbi et al., 2021; Bello-Orgaz et al., 2021).

In agriculture, IoT has enabled remote crop monitoring, water use analysis and irrigation system automation, which optimizes crop yields in an environment where climate change and resource scarcity are growing problems. However, in Mexico, the main challenges remain the telecommunications infrastructure and the high cost of implementing IoT technologies compared to other countries.

On the other hand, Home Assistant (HA) is an open source automation platform designed to monitor, control and automate smart devices in a home. Since its launch in 2013, it has gained popularity for its flexibility, broad compatibility with a variety of devices and the ability to operate locally, without the need to rely on cloud services. This provides greater privacy and security, a concern growing in the field of the Internet of Things (IoT) (Schneider, 2020; Gaur et al., 2021; Guo et al., 2021).

With the objective of increasing plant growth speed, this research work focuses, in its first phase, on the implementation of a low-cost IoT-based aeroponic greenhouse.

MATERIALS AND METHODS

The design and implementation of the proposed smart greenhouse has been oriented, at first, towards the cultivation of radishes, without ruling out the possibility of adapting it to other crops by incorporating new sensors and actuators.

The growing cycle of radish depends on climatic conditions and can range from 20 to more than 70 days. Vegetative development takes place between 6 and 30º C. The optimum germination temperature is between 20 and 25ºC (SIAP, 2023).

Figure 4 shows the architecture of the intelligent greenhouse, indicating the scope of processing of the physical variables involved, the technological tools used and the communication protocols involved in data transmission.

On the far right of Figure 4, the bank of sensors and actuators managed by the ESP8266 microcontroller is shown. In this first version, the DHT22 sensors have been used to monitor the ambient temperature inside the greenhouse, the DHT11 sensor to monitor the humidity inside the aeroponic towers and the PS-006 solar panel to monitor the light intensity. Based on the values obtained by the above sensors, the greenhouse will be able to automatically manage the UV lamp (λ=385-400 nm), the air injector and extractor to maintain the inside temperature between 200 C and 250 C and the humidifiers of the tubes. The above temperature has been properly calibrated for radishes. The chosen UV lamp is activated in the absence of natural light.

The installation of Home Assistan on the Raspberry Pi 400 microcontroller as an operating platform, will allow both the management of the bank of sensors and actuators locally, as well as access to them from anywhere else on the Internet with a graphical interface to the user quite intuitive.

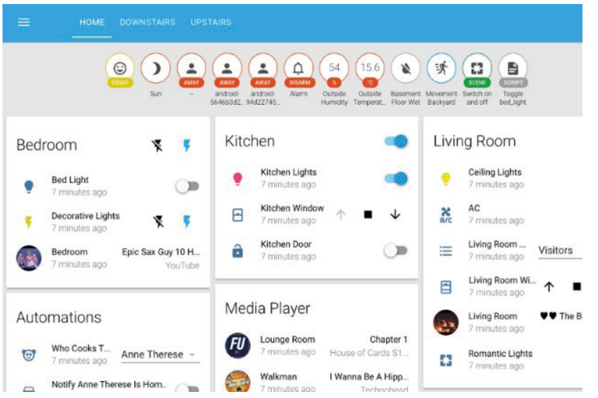


Figure 6. Example of a customized Home Assistant Graphical User Interface (GUI) (Source: https://magazine.odroid.com).

On the far left of Figure 4, the technologies that allow communication with the greenhouse from any other location are observed using the Home Assistant application on any end device such as a desktop computer, tablet or smartphone with Internet access. The Telegram application is used as a messaging service to send notifications about the greenhouse operation facilitating immediate and effective communication of any relevant event within the greenhouse and, finally, the Tail application is used to ensure secure communication via VPN with the Raspberry Pi 400 microcontroller (Tailscale Inc, 2024).

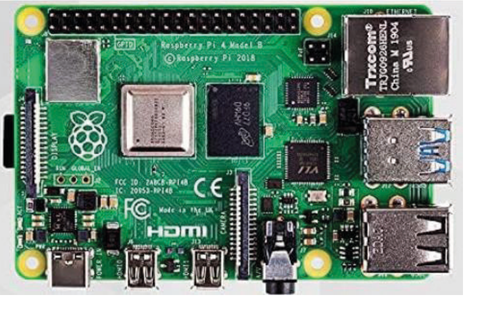


Figure 7. Raspberry Pi 4 microprocessor using HA as operating system.

Finally, by integrating Home Assistant with Google Drive, it will enable continuous backups of data generated by the greenhouse.

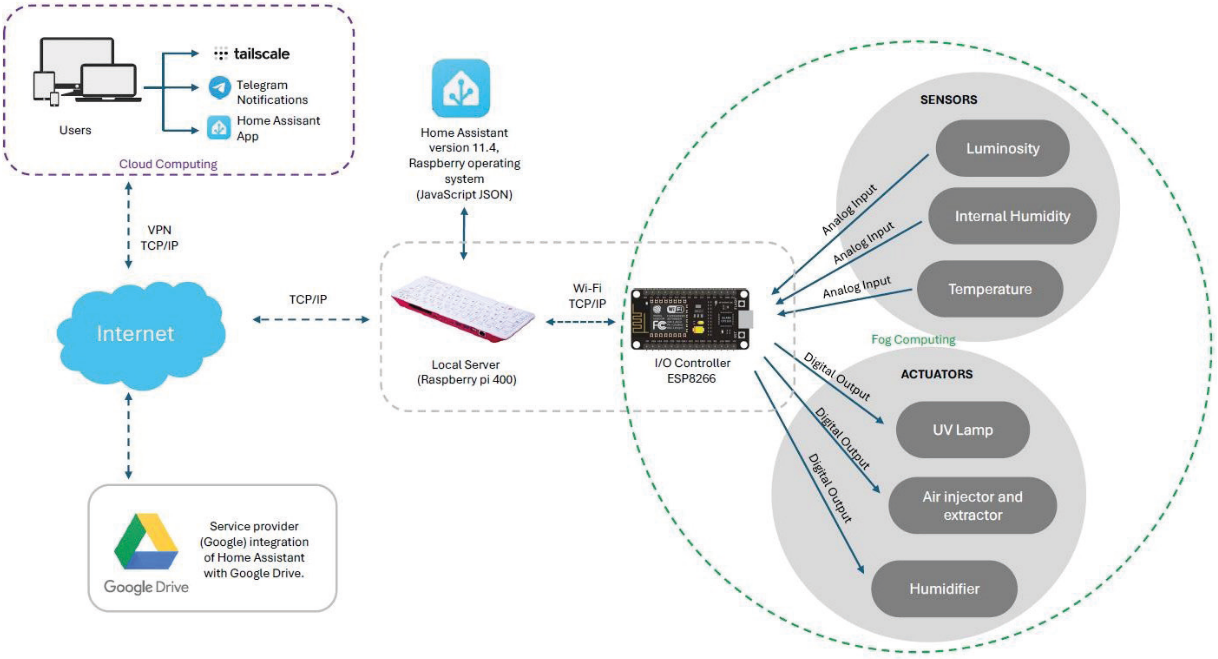
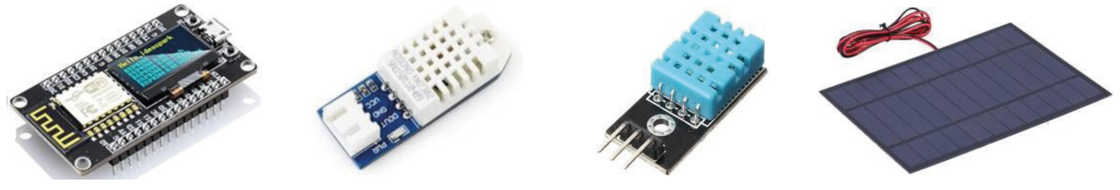


Figure 4. Architecture of the Smart Greenhouse based on Fuzzy Logic (Own design).



a) Micro ESP8266 b) DHT22 sensor. c) DHT11 sensor. d) Solar panel PS-006.

Figure 5. Microcontroller and sensor bank used in the first phase of the greenhouse.

a) Greenhouse Design. b) Implementation of the Greenhouse.

Figure 8. Design and implementation of the greenhouse model.

RESULTS AND DISCUSSION

Several phases have been planned for the implementation of this research project. In this first phase, the model was built with a wooden base, PVC aeroponic tubes and a polyethylene roof to allow the passage of natural light to the seedlings. Subsequently, the entire IoT system was installed, consisting of the DHT12 and DHT11 sensor bank, the solar panel, the fans (intractor and extractor), the ESP8266 microcontroller and the Raspberry Pi 4.

Now, Figure 9 shows the general electrical diagram of the Greenhouse derived from the connection of the sensors, actuators and microcontrollers.

For local or remote management of the greenhouse, the Home Assistant (HA) platform has been used as the user interface. The HA has the main feature of being an open source platform designed to control and manage smart devices in the home. Precisely because it is open source, in this project HA has been customized for greenhouse management. Another of the main features offered by HA is that it allows the integration of a large number of smart devices from different manufacturers. Although In this project HA manages the physical variables of humidity, luminosity and temperature of the greenhouse, it also allows to scale the greenhouse management in case of increasing and/or changing the control of the physical variables for the management of other types of seeds. The following figure shows the main control panel of the Home Assistant along with the management of the physical variables of the greenhouse.

It is worth mentioning that the ultraviolet light comes into action automatically when there is low natural light. Figure 11 shows the greenhouse under the above situation.

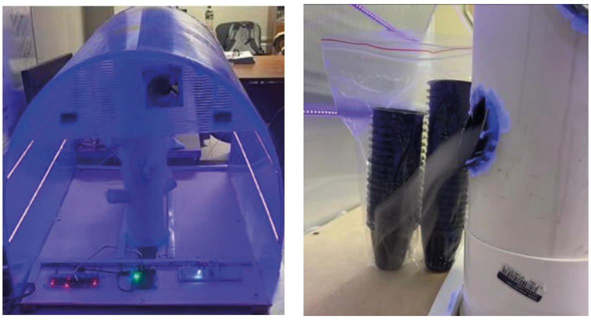


Figure 5. Automatic operation of UV light and humidification.

The user has the possibility to constantly monitor the presence of any event inside the greenhouse either locally or remotely via Telegram notifications. The following figure shows some events such as the status of temperature, humidity, time and quality of exposure.

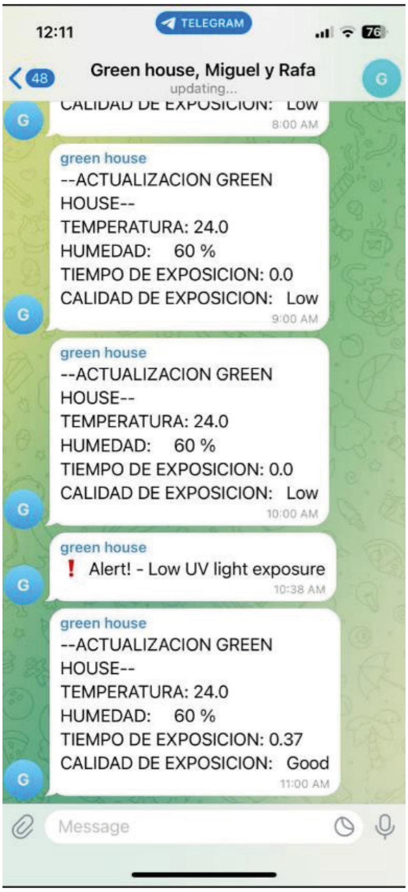
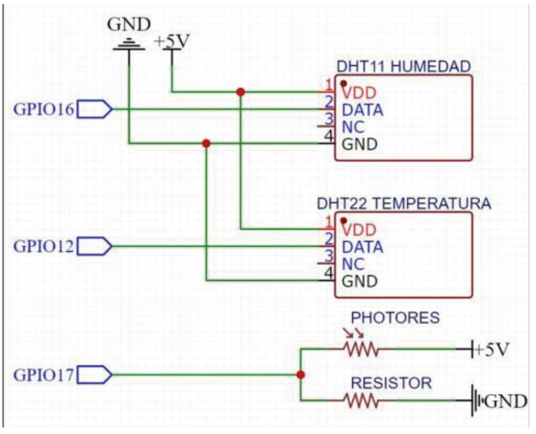
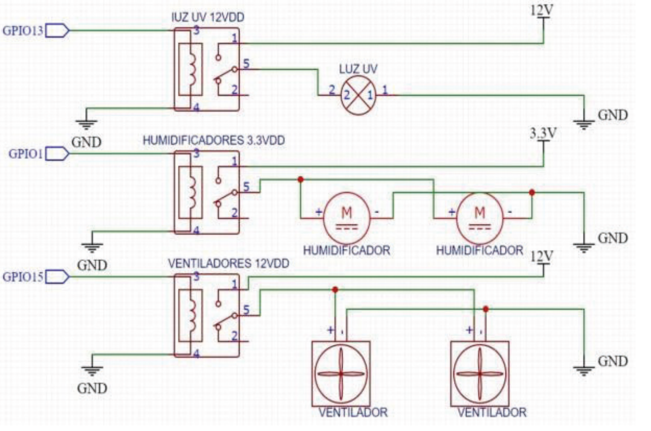


Figure 6. Interaction with the Greenhouse bot in Telegram for monitoring the main physical variables.

Journal of Engineering Research ISSN 2764-1317 DOI https://doi.org/10.22533/at.ed.3174272407113

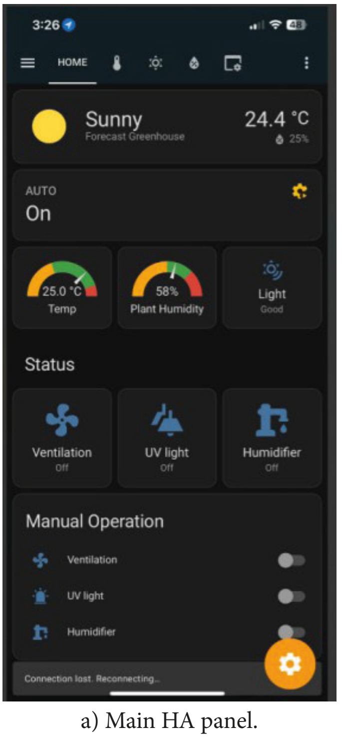




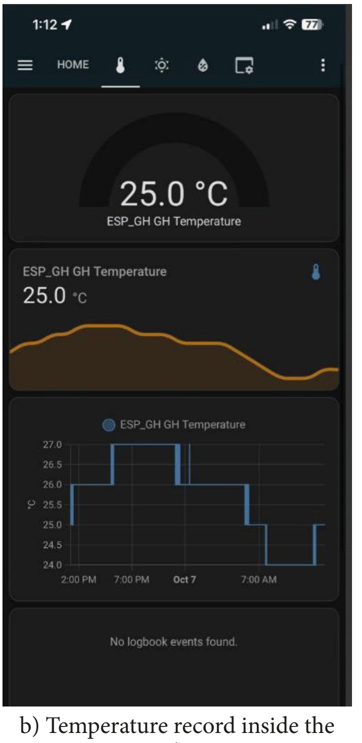
a) Electrical connection of the sensors.

b) Electrical connection of the actuators.

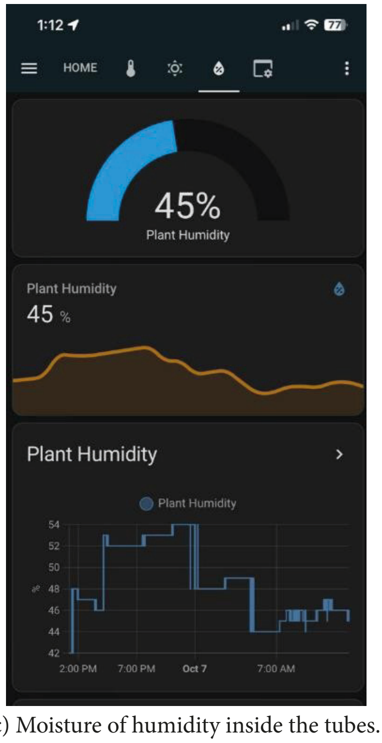
Figure 9. General electrical diagram of the Greenhouse.



a) Main HA panel.



b) Temperature record inside the greenhouse.



c) Moisture of humidity inside the tubes.

Figure 10. Home Assistan main panel for greenhouse management.

As the next phase of this project, fuzzy logic will be used to control all the control processes generated inside the greenhouse. For example, the interior temperature control process, the tuning of the ultraviolet light depending on the type of seed germination, the humidity of the towers, among other physical variables.

CONCLUSIONS

The use of the Internet of Things in agriculture has revolutionized the way we manage and optimize farming operations. IoT sensors allow real-time monitoring of various critical parameters, such as soil moisture, temperature, ambient humidity. This accurate and continuous data collection capability facilitates informed decision making, promoting more efficient and sustainable agricultural practices.

Implementing IoT sensors in agriculture offers multiple benefits. Farmers can adjust irrigation and temperature precisely, reducing water and nutrient wastage and improving crop yields. The next phase of Greenhouse implementation will be the adoption of fuzzy logic which, together with IoT, will enable a major step towards precision agriculture; providing advanced tools that help meet the challenges of modern agricultural production and ensuring more responsible and efficient resource management.

REFERENCES

Atzori, L., Iera, A., & Morabito, G. (2020). The Internet of Things: A survey. *Computer Networks*, 54(15), 2787-2805.

Bailey-Serres, J., Parker, J. E., Ainsworth, E. A., Oldroyd, G. E. D., & Schroeder, J. I. (2019). Genetic strategies for improving crop yields. *Nature*, 575(7781), 109- 118.

Bello-Orgaz, G., Jung, J. J., & Camacho, D. (2021). Social big data: Recent achievements and new challenges. *Information Fusion*, 28, 45-49.

Brady, N. C., & Weil, R. R. (2019). *The Nature and Properties of Soils*. Pearson. FAO (2021). The future of food and agriculture: Trends and challenges. Rome. *Food and Agriculture Organization of the United Nations*

Gaur, A., Scotney, B., Parr, G., & McClean, S. (2021). Smart home technologies: Overview, analysis, and challenges. *IEEE Access*, 7, 90945-90972.

Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2021). Internet of Things (IoT): A vision, architectural elements, and future directions. *Future Generation Computer Systems*, 29(7), 1645-1660.

Guo, X., Xu, L., & Li, S. (2021). Integration of IoT with Home Assistant for smart home automation. *Journal of Systems Architecture*, 104, 101713.

Kozai, T., Fujiwara, K., & Runkle, E. S. (2020). Plant Factory: An indoor vertical farming system for efficient quality food production. *Academic Press*.

Lakhiar, I. A., Gao, J., Syed, T. N., Chandio, F. A., & Buttar, N. A. (2018). Modern plant cultivation technologies in agriculture under controlled environment: A review on aeroponics. *Journal of Plant Interactions*, 13(1), 338-352.

Martínez, L., & Pérez, G. (2021). Sistemas hidropónicos y aeropónicos en México: Innovación y sostenibilidad en la producción agrícola. *Ciencia y Tecnología Agropecuaria*, 22(2), 45-58.

Medina, G., & Gutiérrez, F. (2022). Innovación en sistemas de cultivo aeropónico para mejorar la producción agrícola. *Ciencia y Tecnología Agropecuaria*, 12(3), 91-104.

Sánchez-Lizarraga, A. L., & Carrillo-López, A. (2020). Agricultura de precisión y su impacto en la producción agrícola en México. *Revista Mexicana de Agronegocios*, 24(3), 123-133.

Schneider, D. (2020). Home Assistant for smart home control: An open-source approach. *IEEE Consumer Electronics Magazine*, 9(5), 45-48.

Sharma, N., Acharya, S., Kumar, K., Singh, N., & Chaurasia, O. P. (2019). Hydroponics as an advanced technique for vegetable production: An overview. *Journal of Soil and Water Conservation*, 18(4), 364-371.

SIAP. (2023). RÁBANO. Consultado Junio 24, 2024, de https://www.gob.mx/cms/uploads/attachment/file/726314/Rabano.pdf

Tailscale Inc. (2024). Secure, remote access to. https://tailscale.com/

Xu, L. D., He, W., & Li, S. (2019). Internet of Things in industries: A survey. *IEEE Transactions on Industrial Informatics*, 10(4), 2233-2243.

Zhang, Y., & Ling, Q. (2021). Aeroponics: A tool for accelerated crop improvement. *Horticultural Science*, 26(2), 65-73.