BASIL AS A MICROGREEN: CULTIVATION AND MONITORING USING AN AUTOMATED IOT-DRIVEN FOGPONICS SYSTEM

Undergraduate Capstone Project
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In Partial Fulfillment
of the Requirements for the degree of
Bachelor of Science in Computer Engineering

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BIOGRAPHICAL DATA

Gerimae V. Buen was born in Bancal Center, Carmona, Cavite on the third day of October in 2003. A 21-year-old that currently lives at Core House, Bancal, Carmona, Cavite. She is the youngest daughter of Mrs. Jenny V. Buen, a factory worker and Mr. Melchor B. Buen, a general maintenance. Her older sister's name is Mel Jane V. Buen, 24 years old, an Information Technology graduate from Cavite State University–Carmona Campus, the same place where she is currently studying. While her older brother, John Melbert V. Buen, 23 years old, is studying at the Cavite State University–Main Campus Indang, pursuing and graduating with a Bachelor of Science in Applied Mathematics.

She completed her secondary education at Bulihan Integrated National High School in Bulihan, Silang, Cavite, from junior high education to senior high, graduating in 2022. She was a consistent honor student from junior high obtaining "*with honors*" and receiving two special awards, the *"Gawad Lingkod Kabutihang Asal"* and *"Gawad Lingkod Kababayan"*. She pursued her senior high education at the same institution obtaining and graduating with a high honor in grade 12 in Science, Technology, Engineering, and Mathematics (STEM).

She then enrolled and started attending Cavite State University (CvSU)–Carmona Campus to pursue the Bachelor of Science in Computer Engineering program in her tertiary education. In her first and second year in college, she received an academic excellence award and was consistently considered a dean's list for two consecutive years. Additionally, she also received educational assistance every semester provided by Mayor Dahlia Loyola and Mayor Roy Loyola's scholarship program, known as the *Bawat Tahanan may Scholar (BTS)* program from the year 2022 until now.

Kenji H. Cadano was born in Antipolo City. A 20-year-old who currently resides in Hacienda La Joya, Imus City, Cavite. He is the youngest son of Mr. Uri C. Cadano and Mrs. Salvacion H. Cadano, both working as security officers. His older sister, Pherngy H. Cadano, 22 years old, graduated with a bachelor's degree in Tourism and Business Management from the Polytechnic University of the Philippines last 2023 is currently employed as a Virtual Assistant in a private company.

He completed his secondary education at Bacoor National High School – Molino Main Campus from grade 7 to grade 9. He then transferred to Emilio Aguinaldo National High School for grade 10, where he was a consistent honor student and graduated with honors. For his senior high school education, he studied at Senior High School in Bacoor Elementary School as a Science, Technology, Engineering, Mathematics (STEM) student, where he consistently earned academic honors from grade 11 to grade 12.

Then enrolled at Cavite State University to pursue a Bachelor of Science in Computer Engineering, driven by his passion for technology, problem-solving, and innovation. Fascinated by the interaction between hardware and software, he aims to contribute to advancements in automation and computing. He is striving to develop innovative solutions for various industries while continuously enhancing his skills in the field.

Jhon Christopher E. Santos was born on October 20, 2003, in Saudi Arabia. A 21-year-old who currently resides in Sto. Tomas, Biñan, Laguna. He is the youngest son of Mrs. Katherine E. Santos and Mr. Tamerlane B. Santos.

He completed his secondary education at La Consolacion College Biñan, where he studied from grade 7 to grade 12. In senior high school, he pursued the Science, Technology, Engineering, and Mathematics (STEM) strand, consistently earning academic honors in grades 11 and 12. He is also a recipient of the *Iskolar ng Laguna* program, a scholarship he has held since 2022.

Driven by his passion for technology and innovation, he then enrolled at Cavite State University to pursue a Bachelor of Science in Computer Engineering. With a keen interest in problem-solving and computing, he aspires to develop innovative solutions that bridge the gap between hardware and software, contributing to advancements in automation and various industries.

Mark Luis E. Virata was born in Cavite City Hospital, Cavite, on the twenty-fifth day of November in 2003. A 21-year-old who currently resides at 549 4th Street, Salinas 1, Bacoor, Cavite. He is the only child of Mrs. Marites E. Virata, a teacher, and Mr. Leandro D. Virata, a driver.

He completed his junior high school education at Bacoor Unida Evangelical School, where he consistently performed well academically, obtaining "with honors" and receiving special recognition, the "Loyalty Award." For his senior high school education, he attended Theresian School of Cavite, further developing his academic and technical skills.

Currently, he is pursuing a Bachelor of Science in Computer Engineering at Cavite State University–Carmona Campus, where he has been studying since 2022. His education is supported by the *Tulong Dunong Program* (TDP), which has provided him with financial assistance throughout his academic journey.

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THE RESEARCHERS

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AUTOMATED IOT-DRIVEN FOGPONICS SYSTEM FOR OPTIMIZED PLANT CULTIVATION

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An undergraduate capstone project titled automated Iot-driven fogponics system for optimized plant cultivation submitted to the faculty of the department of Industrial and Information Technology, Cavite State University - Carmona Campus, Carmona, Cavite in partial fulfillment of the requirements for the degree of Bachelor of Science in Computer Engineering under the supervision of Mr. Nomar C. Bersamin.

INTRODUCTION

With the rising demand for sustainable food production, traditional soil-based farming faces limitations in resource efficiency and scalability. This has led to the adoption of soilless techniques like fogponics, which delivers nutrients through a fine mist, significantly reducing water usage while enhancing nutrient absorption—making it a highly efficient and eco-friendly approach (Jones & Smith, 2020).

According to Brown and Green (2021), integrating IoT technology maximizes fogponics' potential by using sensors to monitor and adjust temperature, humidity, and nutrient delivery in real-time. Automation minimizes manual intervention, improves efficiency, and ensures optimal plant health (Davis & Taylor, 2022). This study focuses on developing an Automated IoT-Driven Fogponics System to optimize plant cultivation. By automating nutrient delivery and environmental adjustments, the system enhances resource efficiency and maximizes crop yield (Wilson, 2021).

Overall, this research demonstrates how IoT-driven fogponics supports sustainable agriculture, offering a scalable solution for both urban and large-scale farming (Patel & Kumar, 2022).

Background of the Study

Agriculture plays a crucial role in food security, yet traditional farming faces challenges such as water scarcity, inefficient nutrient delivery, and climate instability. In response, fogponics, an advanced form of aeroponics that uses nutrient-rich fog to nourish plant roots, has gained attention for its efficiency in water and nutrient usage. A fogponic system provides multiple advantages, such as improved nutrient absorption, as the enriched fog penetrates root tissues, keeping them moist and well-nourished. Moreover, it minimizes water and nutrient consumption by up to 50% (Uddin & Sulaiman, 2021). However, existing fogponic systems often lack real-time monitoring and automation, leading to inefficiencies in maintaining optimal growth conditions.

With the rise of Internet of Things (IoT) technology, integrating sensors and automation into fogponic systems presents a promising solution. IoT has transformed the agricultural sector by enabling smart object connectivity, remote data acquisition, and automation. Through cloud-based analysis and decision-making, IoT optimizes resources, mitigates climate effects, and enhances crop yields (Lee, Kim, & Park, 2022).

This study aims to enhance fogponics with IoT by developing a smart system that optimizes environmental conditions, reduces resource waste, and increases productivity. By addressing the limitations of traditional fogponic systems, this research seeks to contribute to the advancement of smart agriculture, particularly in urban and resource-limited environments.

Statement of the Problem

This study seeks to address the limitations of traditional fogponic systems, particularly their lack of real-time monitoring, automation, and data-driven optimization, which often lead to inefficient resource utilization, hindered crop growth, and difficulties in maintaining ideal environmental conditions. While IoT technology has been widely applied in various agricultural practices, its integration with fogponics remains underexplored, creating a gap in research and implementation. By developing a scalable and intelligent IoT-based fogponic system, this study aims to enhance automation, resource efficiency, and environmental adaptability, particularly in urban and resource-constrained environments where sustainable agricultural solutions are crucial.

Specifically, this sought to answer the following questions:

1. How does the integration of IoT Technology impact the efficiency and productivity of fogponic systems?
2. What specific limitations of traditional fogponics systems can be addressed through IoT-enabled solutions?
3. How does an IoT-integrated fogponic system optimize resource utilization and improve climate adaptability in modern plant cultivation?
4. What potential challenges arise in the implementation of IoT-based fogponic systems, and strategies can be employed to overcome them?

Overview of the Current State of Technology

Soilless farming has become a key innovation in modern agriculture, offering solutions for growing plants in controlled environments without traditional soil. Technologies such as hydroponics, aeroponics, and fogponics have gained popularity due to their efficiency in water and nutrient use.

1. Hydroponics

Hydroponic systems grow plants in a nutrient-rich water solution, eliminating the need for soil.

1.1. Deep Water Culture (DWC): Plant roots are suspended in an oxygenated nutrient solution, promoting rapid growth but requiring constant aeration.

1.2. Nutrient Film Technique (NFT): A thin film of nutrient solution flows over the roots, ensuring a steady supply but making plants vulnerable to pump failures.

1.3. Ebb and Flow (Flood and Drain) System: Roots are periodically flooded with nutrients and then drained, allowing oxygen absorption while requiring precise timing.

1.4. Drip Irrigation System: Nutrients are delivered directly to roots via drip emitters, making it efficient for large-scale farming but prone to clogging.

1.5. Wick System: Nutrients are passively drawn to roots using capillary action, making it a low-cost, electricity-free option but less effective for large plants.

1.6. Aerated Hydroponics (Bubbleponics): A variation of DWC where nutrients are actively sprayed onto roots, enhancing oxygen uptake and accelerating plant growth.

2. Aeroponics

Aeroponics improves upon hydroponics by suspending plant roots in the air and delivering nutrients through mist. It eliminates the need for a growing medium, reducing resource use and root rot risk. However, it relies on precise misting, stable power, and regular maintenance. Despite these challenges, aeroponics is ideal for vertical farming and controlled environment agriculture due to its space and water efficiency.

3. Fogponics

Fogponics, an advanced form of aeroponics, uses ultra-fine mist to deliver nutrients more efficiently.

3.1. Low-Pressure Fogponics (LPF) utilizes low-cost ultrasonic foggers to generate mist, making it ideal for small-scale or experimental setups due to its affordability. However, it requires careful monitoring to ensure proper fog particle size and nutrient distribution.

3.2. High-Pressure Fogponics (HPF) uses specialized high-pressure nozzles to produce an ultra-fine mist, making it more efficient for large-scale commercial applications. This method provides better control over nutrient concentration and fog saturation, ensuring optimal plant growth.

Despite the advancements in soilless farming, the lack of IoT-driven monitoring and automation remains a challenge. Many systems still rely on manual checks, making them inefficient and prone to human error. Integrating IoT sensors, real-time data analysis, and automated control systems can greatly improve the efficiency and reliability of soilless farming technologies.

Objectives of the Study

The general objective of this study is to produce, develop and provide an alternative way of planting by using modern technologies, innovating the process of producing crops and plants, and maximizing the resource efficiency while enhancing the plant and crop growth.

Specifically, it aimed to provide the followings:

1. Design and Implement an IoT-based fogponics system
    a. Automated nutrient fogging system
    b. Real-time environmental monitoring sensors
        b.1. temperature
        b.2. Humidity
    c. Smart humidity and temperature regulation
    d. Mobile and web-based control interface

2. Develop the system using the following technologies:

a. ESP 32 as the main IoT platform for data acquisition and control.

b. Cloud computing for real-time data processing and storage.

c. Mobile and web-based application for remote system monitoring.

d. Automated control algorithms for optimized fogponics operation.

e. wireless communication protocols

e.1. MQTT or HTTP

e.2. Wi-Fi / Mobile Data

e.3. Bluetooth

Significance of the Study

The study aimed to improve the process of fogponics using modern technologies in the agricultural field providing sustainable, cost-effective, and intelligent solutions by integrating automated IoT-driven fogponics. One of the major advantages of fogponics is its ability to maintain consistent moisture levels in plant roots while keeping up with the modernization of technologies as this was an IoT-driven fogponics. In traditional soil-based farming, the soil dries out quickly, especially during the summer season. The process of fogponics reduces water and nutrient waste while maintaining crop production. These developed IoT-driven fogponics devices increase output and maximize crop production while requiring less maintenance allowing low water consumption. This method ensures effective use, especially in small areas, as it is not impacted by soil which requires less fertilizer for producing crops. (Uddin & Suliaman, 2021).

Farmers. The automated IoT-driven fogponics provides cost-effective and real-time monitoring which helps the farmers in planting and harvesting easily. By using modern technologies, this will improve the process of planting which will produce more crops and help crops to grow healthy and nutritious as this will lessen the use of artificial fertilizers and reduce the consumption of water.

AgriTech Enthusiasts. The study of fogponics using IoT allows professionals and people interested in crops and agriculture to specialize in innovation and agricultural technology to maintain production of crops more efficiently.

Agribusiness Entrepreneurs. The automation of IoT-driven fogponics offers a cost-effective, sustainable farming method, and high-yield that maximizes output while minimizing resource consumption like water, fertilizer, and soil which is important to the agribusiness companies. This is an innovative investment opportunity in contemporary agriculture as its potential for automation, scalability, and in urban farming applications.

Agricultural Scientist. The study of IoT-driven fogponics provides agricultural scientists with innovative solutions to enhance crop production efficiency. By utilizing real time data and automation,scientists can develop new strategies to improve plant growth, optimize resource utilization, and contribute to sustainable agricultural practices. This research serves as a foundation for future advancements in precision farming and smart agriculture.

Future Researchers. This study will serve as a foundational reference for future researchers exploring IoT-integrated fogponic systems. It provides insights into automated nutrient delivery, real-time monitoring, and resource-efficient cultivation. Through this research, future studies can further refine fogponic technology, enhance agricultural automation, and can contribute to the advancement of sustainable farming practices.

Time and Place of the study

The study was conducted at Adelina 3, Sto. Tomas, Binan, Laguna from March 2025 to June 2025. The location was chosen for its accessibility to all group members, availability of necessary resources, and enough space to set up and monitor the fogponics system properly.

Scope and Limitations of the Study

This study focuses on developing an Automated IoT-Driven Fogponics System that enhances plant growth by integrating fogponics with Internet of Things (IoT) technology. The system will automate nutrient delivery and regulate key environmental factors such as temperature, humidity, and fog distribution to ensure optimal plant conditions. To keep the project cost-effective and accessible, we will use commercially available components and an ESP 32 microcontroller for system automation and real-time monitoring. By reducing water and nutrient waste while increasing crop yield, this research aims to provide a sustainable and scalable solution for both urban and large-scale farming.

While the system offers many advantages, there are some limitations. First, it depends on a stable network connection and power supply, which could affect performance in areas with limited connectivity. Second, this study will focus only on microgreens such as oregano and parsley which are suitable for fogponics, meaning the system's effectiveness for other plant varieties will not be explored. Third, while the system improves environmental control, it does not directly address external factors such as pests or extreme weather conditions. Finally, although the use of market-available components and ESP32 helps reduce costs, the initial setup may still be a challenge for small-scale farmers.

Despite these limitations, this study lays a strong foundation for future advancements in smart agriculture. With further improvements, this system can be more efficient, affordable, adaptable to different farming needs.

Definition of Terms

1. **Internet of things (IoT) -** A network of interconnected devices that communicate and exchange data over the internet, allowing real-time monitoring and automation in various applications, including smart agriculture and fogponics.

2. **Fogponics -** An advanced form of aeroponics that delivers nutrient-rich water in the form of fine mist to plant roots, improving nutrient absorption and reducing water consumption.
3. **Aeroponics -** A soilless cultivation method where plant roots are suspended in the air and misted with a nutrient-rich solution, promoting faster growth and better oxygen absorption compared to traditional hydroponics.
4. **Hydroponics -** A method of growing plants without soil by using a water-based nutrient solution, providing essential minerals directly to the roots for optimal growth.
5. **Sensors -** Electronic devices used to monitor environmental factors such as temperature, humidity, pH levels, and nutrient concentration in an automated fogponics system to ensure optimal plant conditions.
6. **Microcontroller -** A small computer integrated into the IoT-driven fogponics system to process sensor data and automate nutrient delivery, fog cycle and environmental adjustments.
7. **Nutrient Solution -** A carefully formulated liquid containing essential minerals and nutrients required for plant growth in a fogponics system, ensuring optimal development without soil.
8. **Environmental monitoring -** The process of continuously tracking climate factors such as temperature, humidity, and air quality to optimize growing conditions in the fogponic system.
9. **Smart Agriculture -** The application of modern technology, including IoT, automation, and real-time data analytics, to improve farming efficiency, sustainability, and crop production.
10. **Fog** – A collection of tiny water droplets suspended in the air, used in fogponics to deliver nutrients directly to plant roots in an ultra-fine mist, enhancing nutrient absorption and minimizing water usage
11. **Real-Time Monitoring** - The process of continuously tracking and displaying live data from sensors, allowing immediate observation and response to environmental changes.

12. **Microgreens -** Edible plants ideal for fogponics due to their fast growth, minimal space needs, and high nutrient content, making them suitable for efficient indoor farming systems.

Conceptual Framework

This study explores IoT integration in fogponics, a soilless farming method, to improve efficiency, scalability, and sustainability. By enabling real-time data collection, automated nutrient delivery, and precise environmental control, IoT-driven fogponics systems minimize resource waste, reduce manual labor, and ensure optimal plant growth conditions.

The focus of this study was taken by the following framework dividing into three parts of process: the input, process and output.

Input: This includes the major materials, resources, and independent variables in conducting the device that is needed for the fogponics process.

Process: In the process, it includes the making process, experimentation, assembly, analyzation, and observation of the fogponics with the IoT.

Output: The study should demonstrate the efficiency of fogponics as an alternative planting method, the efficacy of the fogponics process in the agricultural sector, and the ability to monitor the planting process in real time using an automated fogponics system powered by the Internet of Things (IoT).

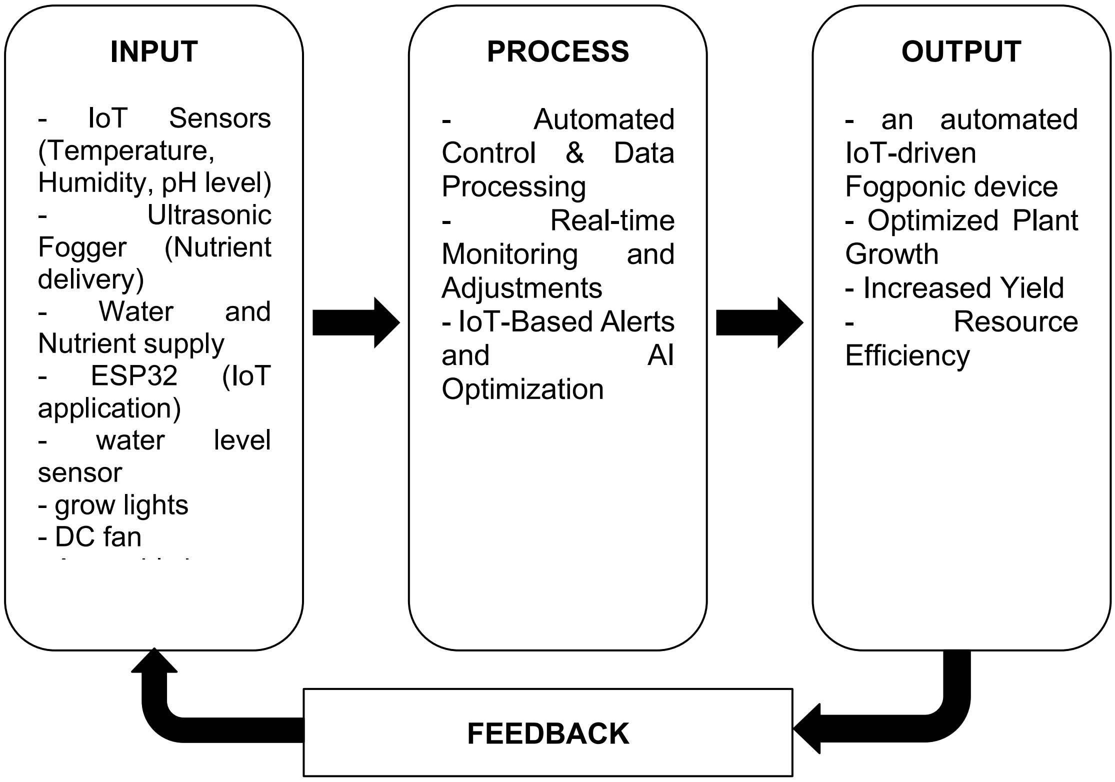

Figure 1. Conceptual Framework model

REVIEW OF RELATED LITERATURE

Local Literature

IoT in Philippine Agriculture

Garde, P. (2022) stated that precision agriculture, enabled by the Internet of Things, allows better use of natural resources by gathering real-time data on crop production, climate, weather, and air quality to help agriculture workers and farmers make better decisions about planting, fertilizing, and harvesting crops. Farmers will use this technology to successfully produce better yields and, as a result, earn higher revenues.

According to "How is IoT Transforming Agriculture in the Philippines" (2025), as IoT technology continues to evolve, its potential to transform Philippine agriculture grows even more promising. By harnessing data-driven insights, farmers can make more precise decisions, reduce costs, and improve sustainability. The integration of IoT in agriculture is not just about increasing efficiency; it's about ensuring food security, improving livelihoods, and adapting to the ever-changing climate. With the right infrastructure and support, the widespread adoption of IoT in Philippine agriculture could lead to a more resilient and prosperous farming industry. Embracing this digital revolution is key to securing a sustainable future for farmers and the nation as a whole.

Recent local initiatives support this claim. A study by Reyes et al. (2023) from the Technological Institute of the Philippines deployed an IoT-based soil monitoring system that collects data on soil moisture, temperature, and pH levels. The system improved the irrigation scheduling and fertilization practices in small-scale vegetable farms in Bulacan, resulting in a 20% increase in crop productivity and a 15% reduction in water usage.

The Department of Science and Technology (DOST) launched the Smart Agriculture program, which provides kits and training to farmers in Nueva Ecija. According to DOST (2023), the program led to a measurable improvement in harvest timing and resource management. Farmers involved in the program reported better crop health and increased income after applying sensor-driven recommendations.

Sustainable Agriculture

According to Central Philippine University (2023), hydroponic farming is revolutionizing food production by promoting sustainability, reducing dependency on arable land, conserving water, and optimizing nutrient absorption. This method has proven to be highly effective in urban farming environments where land is limited. Sustainable agriculture plays a vital role in addressing both food security and environmental challenges in the Philippines. It involves farming practices that ensure long-term food production while minimizing environmental harm. Hydroponics, an alternative to traditional soil-based farming, has gained attention due to its resource-efficient nature.

In addition, the integration of Internet of Things (IoT) technology has significantly improved sustainable agricultural practices. A study by Delos Reyes and Martinez (2023) developed an automated nutrient delivery system for soilless farming using IoT technology. The system used real-time sensors to monitor pH levels, electrical conductivity, and nutrient concentrations, ensuring optimal plant growth. Their findings showed that IoT-driven nutrient management systems significantly enhanced resource efficiency by reducing water and fertilizer consumption, while also improving crop yields. This research underscores the potential of IoT in optimizing agricultural sustainability and scalability in the Philippines.

Moreover, vertical farming, combined with IoT automation, has emerged as another promising solution for sustainable agriculture. Villanueva and Reyes (2024) conducted a study on vertical farming systems in urban areas. Their research demonstrated that combining vertical farming with IoT-based monitoring could reduce water usage and improve crop yields in urban spaces. This approach aligns with the Philippines' need to address food security challenges in a growing urban population, where agricultural land is increasingly scarce.

Microgreens in Fogponic

Research by Cadelina et al. (2023) demonstrated the potential of incorporating microgreens—particularly indigenous varieties—into the Filipino diet, citing their ease of cultivation, rich nutritional content, and adaptability to soilless environments. Microgreens, known for their rapid growth and dense nutritional value, are increasingly recognized in the Philippines as a viable solution to food security and urban agricultural challenges. These young seedlings of vegetables and herbs can be harvested within 7 to 21 days, making them ideal for short-cycle farming.

The integration of microgreens into controlled-environment agriculture, especially through fogponic systems, has seen notable advancement. According to Vertical Farm Daily (2023), microgreens are gaining traction in urban agriculture settings across Metro Manila and nearby provinces due to their low space requirements and minimal resource consumption. These characteristics make them well-suited for vertical and indoor farming setups, where space and water conservation are critical.

Sarangani et al. (2024) introduced an automated fogponics system specifically designed for cultivating microgreens. This system employed IoT sensors and machine learning algorithms to maintain ideal humidity (90%–96%) and temperature (27°C–30°C), leading to improved growth rates and reduced spoilage. Their study confirmed that such technological integration enhances plant health while conserving water and nutrients compared to hydroponics or soil-based systems.

According to Ramos and Del Mundo (2024) from the University of the Philippines Los Baños explored the market potential of microgreens grown via fogponics in Laguna-based urban farms. Their research showed increasing demand for microgreens among health-conscious consumers and restaurants, with fogponic systems proving economically viable for small-scale producers due to their low operational costs and quick crop turnover.

Soilless Farming

According to (Garuda, 2023). Soilless farming methods such as hydroponics and fogponics are gaining momentum in the Philippines due to their sustainability, resource efficiency, and adaptability to limited-space environments. These innovative systems are increasingly being explored as viable alternatives to traditional agriculture, especially in urban and peri-urban settings. The efficiency of soilless farming methods, such as hydroponics and fogponics, has been extensively studied in the Philippines. A cost-benefit analysis conducted in Tagaytay City confirming their economic and environmental viability. The study highlighted hydroponics as a strategic method to mitigate soil degradation, reduce water use, and adapt to the challenges posed by climate change. This method has shown promise particularly for urban dwellers with limited access to arable land.

Alcantara et al. (2021) developed an automated fogponics system for cultivating Volvariella volvacea (Paddy Straw Mushroom), which was evaluated by 60 respondents, including experts and probable users. The study concluded that fogponics effectively facilitated mushroom cultivation using a humidifier, with dried banana leaves serving as a viable alternative to soil. The system enabled indoor cultivation by providing necessary heat, improving both the quality and quantity of mushrooms compared to traditional methods. However, ultrasonic pest repellents were ineffective against springtails, though pest infestation was prevented due to UV light sterilization and the enclosed tent structure. For future improvements, the researchers recommended using stainless steel to prevent rusting and incorporating a moisture sensor to enhance environmental monitoring.

Aquino and Reyes (2024) from the Polytechnic University of the Philippines implemented a community-level hydroponics project in Quezon City using recycled materials and solar-powered nutrient pumps. Their findings showed that lettuce and spinach grown in these systems matured faster and used 60% less water than soil-based cultivation. The initiative also provided an accessible income source for low-income households, promoting food security at the barangay level.

The Department of Agriculture (2024) introduced fogponic pilot programs in Davao City, aimed at improving the production of leafy greens in enclosed spaces. Results showed a 30% increase in yield consistency, especially during unpredictable weather conditions, reinforcing the reliability of fogponics for climate-resilient agriculture.

Foreign Literature

Internet of Things (IoT)

The Internet of Things (IoT) has revolutionized modern agriculture by enabling real-time monitoring, automation, and data-driven decision-making. Through the use of interconnected smart sensors, farmers can track environmental parameters such as soil moisture, temperature, pH, and humidity, significantly improving crop productivity and resource efficiency (Vidya et al., 2023). These advancements have laid the foundation for precision farming, where interventions are tailored based on specific field conditions, resulting in optimal crop performance.

Globally, IoT integration has been crucial in advancing smart agriculture. For instance, Chen and Wang (2021) reported that IoT-enabled systems in China facilitated automated irrigation and nutrient delivery in greenhouse settings, leading to a 25% reduction in water usage and a 15% increase in yield. Similarly, in India, Kumar and Patel (2021) highlighted how IoT-based pest detection systems using image recognition and environmental sensors helped reduce crop loss while minimizing pesticide usage.

Rahman et al. (2020) emphasized that high initial costs, lack of technical expertise, and data privacy concerns hinder IoT adoption, especially among smallholder farmers. Addressing these barriers through affordable technology, training programs, and secure data platforms is critical for global scalability.

Additionally, researchers in the Netherlands developed an AI-integrated IoT platform that combines climate control and hydroponic systems for vertical farming, showing increased lettuce production under monitored conditions (de Vries et al., 2022). These technologies illustrate the global potential of IoT in supporting sustainable agriculture, especially in urban and controlled environments such as fogponics systems.

Fogponics

Fogponics, an advanced subset of aeroponics, delivers nutrient-rich mist directly to the plant roots, ensuring maximum nutrient absorption and promoting accelerated plant growth. This technique has gained international recognition for its efficiency in water usage and space-saving capabilities, particularly in urban and vertical farming applications. According to Smith et al. (2019), fogponic systems outperform traditional hydroponics by significantly reducing water consumption while enhancing root oxygenation and nutrient uptake, leading to improved plant development.

The role of automation in fogponics has also proven critical. Zhao and Li (2022) demonstrated that automating nutrient delivery and humidity control in a fogponic setup resulted in a 20% increase in crop yield and reduced labor dependency in controlled-environment agriculture. Real-time data collection and actuator responses allowed for more stable growing conditions, which are essential for consistent crop production.

Furthermore, Garcia et al. (2020) explored the integration of Internet of Things (IoT) technologies in fogponic systems. By utilizing microcontrollers and environmental sensors, the researchers achieved real-time monitoring and autonomous environmental adjustments, increasing nutrient delivery precision and minimizing system inefficiencies. This approach enhanced overall crop uniformity and sustainability in enclosed farming environments.

Recent studies also emphasize fogponics' compatibility with smart vertical farming. A European study by Müller and Krüger (2023) found that fogponic systems implemented in a smart greenhouse setup enabled year-round leafy vegetable production with 30% less energy compared to conventional hydroponics, making it suitable for densely populated urban regions seeking sustainable food production methods.

Microcontrollers

Microcontrollers have become essential tools in advancing precision agriculture by enabling smart automation and real-time monitoring. According to Ahmed and Kumar (2023), microcontrollers like the ESP32 and Arduino have transformed traditional farming into data-driven systems, facilitating efficient irrigation, crop monitoring, and environmental control through sensor-based automation. These technologies are particularly beneficial in reducing human labor, conserving resources, and increasing crop productivity in diverse agricultural settings.

The ESP32 microcontroller, in particular, is favored for its dual-core processor, low power consumption, and integrated Wi-Fi and Bluetooth, making it ideal for wireless agricultural applications. Gupta et al. (2021) demonstrated its use in monitoring soil moisture, temperature, and humidity in greenhouse settings, achieving precise environmental regulation and improving overall plant health. This technology has allowed farmers to make informed decisions using real-time sensor feedback, thereby increasing efficiency while reducing resource waste.

Furthermore, Garcia et al. (2020) developed an ESP32-based smart irrigation system that activated water pumps automatically based on soil conditions. Their findings indicated a 30–40% reduction in water consumption compared to manual irrigation. Similarly, Lee and Kim (2022) integrated ESP32 with cloud-based platforms, enabling farmers to remotely monitor crops through mobile apps. This integration also facilitated data logging and analytics, which supported predictive farming and timely interventions.

Microcontroller systems, such as those utilizing the ESP32, have proven essential in optimizing key agricultural operations through automation and environmental monitoring. In a study by Alotaibi and El-Sayed (2023), the ESP32 microcontroller was successfully used to regulate irrigation based on real-time data from soil moisture and temperature sensors. The system significantly improved water use efficiency by ensuring that irrigation occurred only when necessary. This demonstrates the effectiveness of microcontrollers in supporting precision farming and resource conservation, especially in regions facing water scarcity and unpredictable weather patterns.

Efficient Nutrients Delivery

Fogponics, a highly advanced form of aeroponics, utilizes ultrafine nutrient-rich mist to deliver essential minerals and water directly to plant roots, improving nutrient uptake and overall plant growth. Compared to hydroponics and soil-based farming, fogponics allows more precise absorption and uses significantly less water. According to Miller and Thompson (2021), this technique improves water efficiency by up to 70%, offering a more sustainable option for controlled-environment agriculture.

In addition to water savings, fogponics promotes superior oxygenation of the root zone, which is critical for plant respiration and nutrient assimilation. Lee et al. (2020) highlighted that the mist environment in fogponic systems enhances oxygen availability around plant roots, reducing the occurrence of root-borne diseases such as rot and fungal infections often found in hydroponic setups.

The delivery of nutrients in fine mist particles also ensures a more uniform distribution of essential micronutrients across the entire root surface. Rodriguez and Kim (2019) demonstrated that ultrasonic foggers used in fogponic systems provide a consistent supply of nutrients, leading to improved root development and better overall plant health when compared to liquid nutrient delivery systems.

Moreover, fogponics has shown considerable promise in increasing crop yields and efficiency in space-constrained environments. A comparative study by Andersson and Weber (2022) found that leafy vegetables grown in fogponic systems under controlled conditions had a 25% increase in biomass production compared to those in traditional nutrient film technique (NFT) systems, reinforcing its viability for vertical farming and indoor agriculture.

Sharma et al. (2021) noted that nutrient mist particles created through ultrasonic atomization allow for higher nutrient uptake efficiency and reduced waste. This precision makes fogponics an ideal choice for sustainable urban farming systems and supports more rapid crop turnover, especially in densely populated regions with limited arable land.

Synthesis

In the Philippines, IoT is becoming a vital tool in precision agriculture, enabling farmers to monitor real-time data on crop conditions and resource use. According to Garde (2022) and the *2025 Telecom Review*, this data-driven approach boosts productivity, income, and sustainability by optimizing water, fertilizer, and energy use.

These insights support the goals of the ESP32-powered fogponics system in this study, designed as an affordable, automated solution for small to medium-scale farms.

Soilless farming methods like hydroponics and fogponics are increasingly promoted as sustainable alternatives to traditional soil-based agriculture. Central Philippine University (2023) and Delos Reyes & Martinez (2023) note that these systems efficiently recycle water and nutrients, making them ideal for urban environments. The use of IoT-based nutrient delivery ensures optimal pH and nutrient levels essential to the automated fogging and monitoring design of this study.

Fogponics is also gaining traction for microgreen cultivation due to its efficient use of space and resources. Cadelina et al. (2023) and *Vertical Farm Daily* (2023) highlight the rapid growth and nutritional benefits of microgreens, while Sarangani et al. (2024) demonstrated that IoT integration allows precise temperature and humidity control. These align with the current project's goal of maintaining stable growing conditions through intelligent feedback loops.

Internationally, IoT has revolutionized agriculture through automation of irrigation, climate control, and nutrient delivery. Vidya et al. (2023), Chen & Wang (2021), and Gupta et al. (2021) highlight the effectiveness of microcontrollers like ESP32 in enabling real-time environmental monitoring. Lee & Kim (2022) further support its use with cloud integration for data analysis. Fogponics enhances nutrient uptake by misting plant roots and reduces water use by up to 70% (Miller & Thompson, 2021). Smith et al. (2019), Rodriguez & Kim (2019), and Zhao & Li (2022) confirm fogponics improves root oxygenation and accelerates plant growth.

Overall, local and foreign literature confirm that combining IoT and fogponics enhances efficiency, sustainability, and scalability in agriculture. This project contributes to the ongoing shift toward smart, resilient urban farming in the Philippines.

METHODOLOGY

Materials

Materials needed for the prototype. The project of implementing an *“automated IoT-driven Fogponics system for optimized plant cultivation”* incorporates several planting materials used for fogponics and electronic materials to ensure its functionality and efficiency.

Material 1. ESP32 microcontroller known as the system's central control unit, which reads sensor data, makes actions, and turns on parts like the fan, grow lights, and fogger. Additionally, it makes IoT connectivity possible for remote control and monitoring.

Material 2. ESP32 cover used as the protective case that holds ESP32 microcontroller preventing it from dusts, moistures, and accidental contact, ensuring safety and durability.

Material 3. Ultrasonic Humidifier Fogger with Module. This component generates nutrient-rich fog by vibrating water at ultrasonic frequencies. The fog is then delivered to the plant roots, promoting efficient nutrient absorption in a soilless environment.

Material 4. Humidity and Temperature Sensor (DHT22) keeps an eye on the system's internal surroundings. The information gathered facilitates the maintenance of ideal growing conditions for plant health and, if required, initiates system modifications.

Material 5. pH Level Sensor ensures that the nutrient solution remains within the optimal range for plant absorption by measuring its acidity or alkalinity.

Material 6. Water Level Sensor keeps the fogger from running out of nutritional solution by measuring the amount in the reservoir and enabling automatic refills when necessary.

Material 7. Relay Module functions as a switch to enable automation of various system processes by controlling high-power components (such as grow lights, fans, and foggers) in response to commands from the microcontroller (ESP32).

Material 8. Grow Lights give plants artificial lighting that mimics sunshine so they can photosynthesize efficiently even in indoor or low-light conditions.

Material 9. Small DC Fan enhances the system's air circulation, which inhibits the growth of mold and guarantees that the temperature and humidity are distributed evenly.

Material 10. Assembly box acts as part of the system's base enclosure or holds and arranges structural elements while construction is underway.

Material 11. Electronic box ensures safety and ease of maintenance by encasing and shielding electronic parts like the wires, sensors, relay module, and ESP32.

Material 12. Net pots are little planters with mesh edges that let roots spread out into the mist. These guarantee enough nutrient exposure and support seedlings.

Material 13. Seed Foam used to secure seeds inside the net pots. During germination, it offers early support and holds onto moisture.

Material 14. PVC Pipe forms the system's primary framework for the electrical wires, supporting and using it as a cover to prevent tangled and electrical accidents.

Material 15. PVC Elbow connects PVC pipes at 90-degree angles; it is utilized in locations where piping or the construction has to change direction.

Material 16. PVC Tee is a T-shaped connector, used in covering wires circulating the model system, permits branching in PVC piping.

Material 17. Sintra Board is a sturdy, lightweight plastic board that serves as the system's base panel,roof and grow light holder.

Material 18. Nutrient Solution Water is the primary source of water-soluble vital nutrients. The fogger atomizes this solution and delivers it to the roots of the plants.

Material 19. Liquid Electrical Waterproofing Insulation is to stop short circuits brought on by moisture in the fogponics environment, a protective coating is placed to exposed electronic contacts.

Material 20. Stranded Wires used to connect grow lights, sensors, actuators, the relay module, and the ESP32 electrically. Adaptable and appropriate for low-voltage uses.

Material 21. Transparent Screws used to assemble transparent or ornamental components in a neat and unobtrusive manner, offering strength and visual appeal.

Material 22. White Nylon Screw Spacer reduces heat transmission and avoids short circuits by providing insulation and space between electronic boards and mounting surfaces.

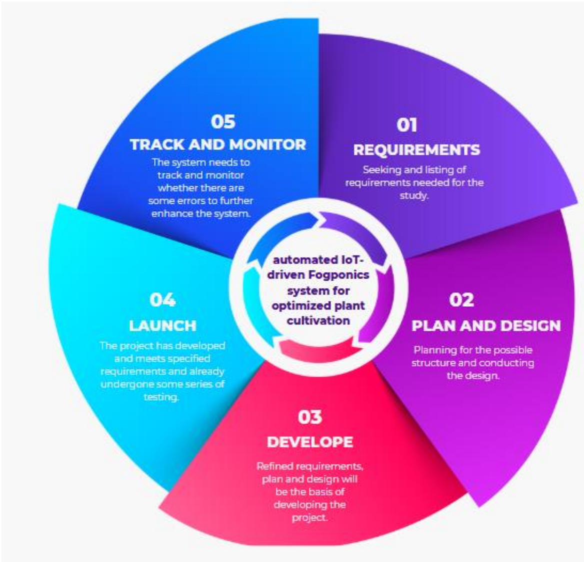

Figure 2. Agile-based development cycle for an automated IoT-driven fogponics system

This study will be using the Agile Methodology as the Research Methodology. This method is more flexible than traditional methods because changes can be easily made even after a project starts. As shown in figure, the agile method has 5 phases: the Requirements, Plan and Design, Develop, Release and lastly, The track & Monitor. Each phase has its own contribution for the development of the system.

Material costs. All of the components needed for the automated IoT-driven fogponics system intended for optimal plant cultivation are outlined, along with their specific pricing and amounts. This thorough analysis offers a clear picture of all the items needed to construct the prototype, including sensors, structural components, electronic components, and other auxiliary materials. The thorough costing guarantees budgetary transparency and aids in determining the viability and affordability of a successful system implementation (Table 1).

Table 1. Component cost breakdown for the automated IoT-based fogponics system

ITEM	UNIT	QTY	UNIT PRICE (Php)	TOTAL (Php)
ESP32 Microcontroller	pc	1	231.00	231.00
ESP32 Cover	pc	1	149.00	149.00
Ultrasonic Humidifier Fogger with module	pc	2	82.00	164.00
Temperature and Humidity Sensor (DHT22)	pc	1	166.00	166.00
pH level Sensor	pc	1	520.00	520.00
Water level Sensor	pc	1	40.00	40.00
Relay Module	pc	1	99.00	99.00
Grow Lights	m	3	37.60	113.00
Small DC Fan	pc	1	100.00	100.00
Assembly container	box	1	148.00	148.00
Electronic container	box	1	164.00	164.00
Net Pots	pc	30	2.75	82.50
Seed Foam	pc	30	2.75	82.50
PVC Pipe (1in)	m	3	120.00	120.00
PVC Elbow (32mm)	pc	8	7.00	56.00
PVC Tee (32mm)	pc	4	12.00	48.00
Sintra Board (3mm)	A3	5	225.00	225.00
Nutrient solution water (500ml bottle)	ml	2	100.00	200.00
Liquid electrical waterproofing insulation (125ml)	ml	1	85.00	85.00
2mm Stranded wires	m	2	25.00	50.00
Transparent screws	pc	50	57.00	57.00

Table 1. Continued

ITEM	UNIT	QTY	UNIT PRICE (Php)	TOTAL (Php)
White nylon screw spacer	pc	30	52.00	52.00
TOTAL				**2,952.00**

The table above presents the list of materials required for constructing the prototype of the automated IoT-driven fogponics system. Each item is specified along with its quantity, items, unit price, and total cost, providing a transparent overview of the resources needed. All components, including sensors, microcontrollers, tubing, containers, and other hardware, are accounted for in the breakdown. Based on the listed prices, the total estimated cost for building the complete prototype amounts to ₱2,839.00. This amount covers all necessary expenses, ensuring that the system can be developed efficiently within a reasonable budget.

Functional block diagram. The functional block diagram of the IoT-driven fogponics system shows how the ESP32 microcontroller automates plant growth using sensor data. It receives input from a DHT sensor (temperature/humidity), a pH sensor, and a float-based water level sensor. The ESP32 uses a relay module to control the ultrasonic fogger, fan, and grow lights. Sensor readings and system status are sent to the html viewer. *Blynk app via Wi-Fi* (subject for testing), enabling remote monitoring and control through a smartphone. This setup maintains an ideal environment for plant growth with minimal manual intervention.

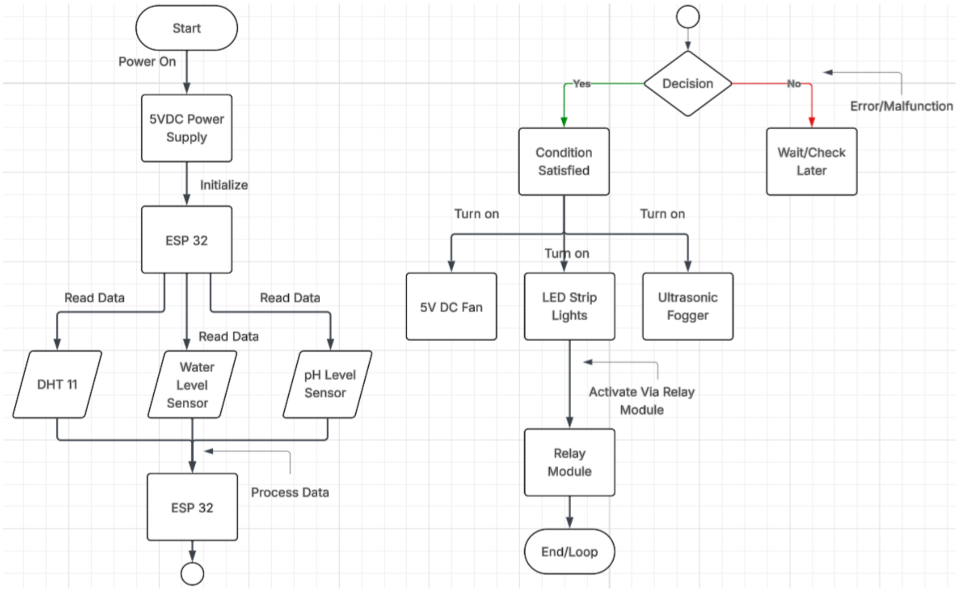

Figure 3. Workflow diagram of the IoT-based fogponics automation process

An IoT-based fogponics automation system's workflow diagram, shown in Figure 3, describes the step-by-step procedure for keeping an eye on and preserving ideal conditions for soilless plant cultivation. This diagram illustrates how different sensors and parts are integrated and controlled by an ESP32 microcontroller to automate crucial tasks like environmental lighting, nutrient delivery through fog, and humidity control. It creates a closed-loop system for real-time agricultural management by graphically illustrating the connection between sensor inputs, data processing, condition assessment, and output device activation.

When the 5V DC power supply is turned on, the ESP32 microcontroller connected to the pH level sensor, a water level sensor, and a DHT22 for temperature and humidity are initialized. The ESP32 processes environmental data that is gathered by these sensors. The system assesses whether the conditions are appropriate for plant growth based on predetermined parameters. Through a relay module, the ESP32 activates the 5V DC fan, LED strip lights, and ultrasonic fogger if the requirements are satisfied. The system goes into a wait/check state to prevent incorrect operation if conditions are not met. This automated process guarantees accuracy, minimizes manual labor, and promotes effective and sustainable plant growth in a regulated fogponic setting.

General process block. The general process block diagram illustrates the logical operation of the smart fogponic system, outlining the flow of data from environmental sensors to the ESP32 microcontroller, which processes the inputs and controls the activation of actuators. The system continuously monitors temperature, humidity, water level, and pH, and responds based on predefined thresholds to maintain optimal growing conditions. This representation highlights the sequential interactions between sensing, decision-making, and actuation that enable automated environmental regulation and efficient nutrient delivery within a controlled fogponic environment.

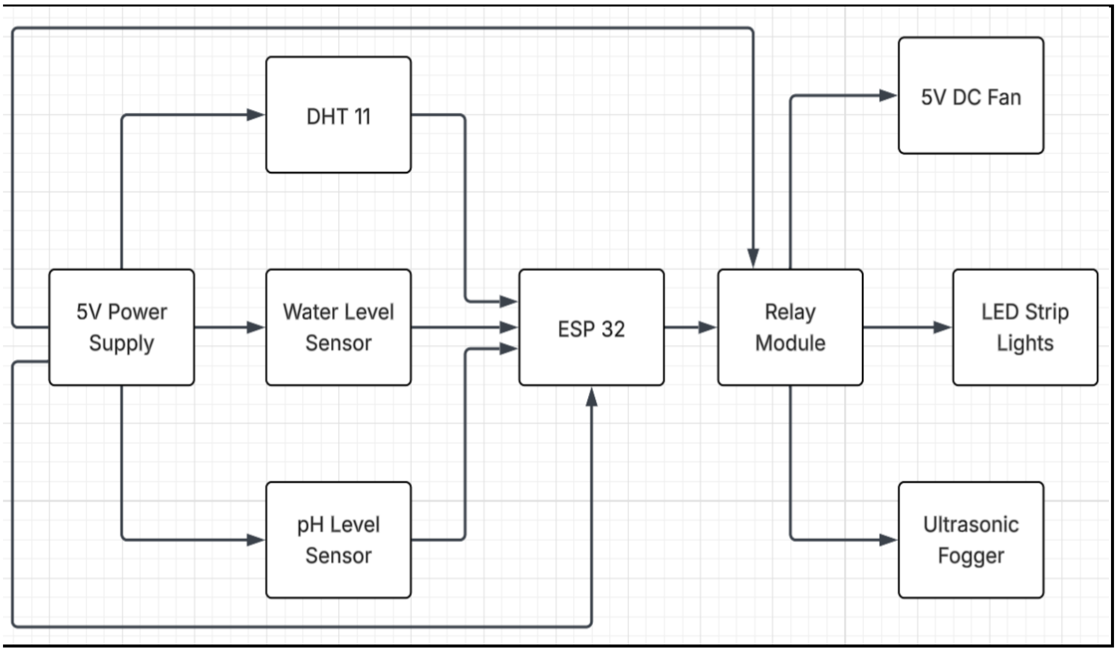

Figure 4. Block diagram of the automated IoT-driven fogponics system architecture.

The IoT-based fogponics system's general process block diagram, which shows the main parts and how they work together to automate plant cultivation, is shown in Figure 4. In contrast to the workflow diagram, which highlights decision-making and operational flow, this block diagram focuses on the system's functional architecture. It provides a concise but thorough overview of the interactions between the system's input devices (sensors), central controller (ESP32), and output actuators (fan, lights, and fogger), highlighting data flow and control mechanisms.

The ESP32 microcontroller and the sensors such as DHT22 for temperature and humidity, water level sensor, and pH level sensor are powered by a 5V power source at the start of the system. These sensors gather environmental data in real time and send it to the ESP32, which interprets the information and decides on the best course of action. The relay module, which serves as a switch to regulate the activation of output devices, including the ultrasonic fogger for delivering nutrient mist, the LED strip lights for illumination, and the 5V DC fan for airflow, is communicating with the ESP32. In a regulated soilless fogponic environment, this setup guarantees that the system reacts to environmental changes precisely and effectively, preserving ideal growing conditions for plants.

Schematic diagram. The diagram (Figure 5) shows the schematic diagram of the fogponics system prototype for the study. It includes the connections and electrical flow that will be used in the system's process.

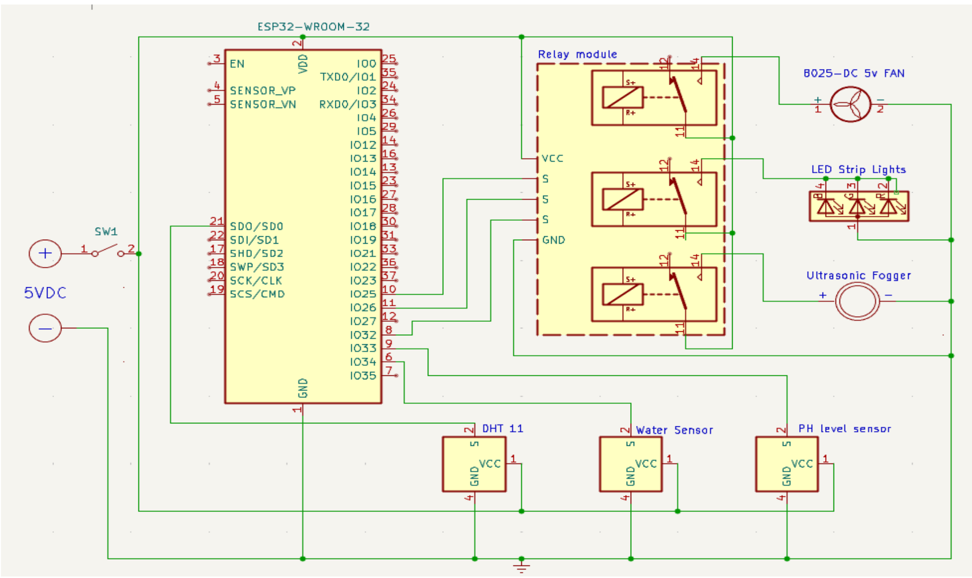

Figure 5. Circuit diagram of the automated IoT-driven fogponics system

The automated IoT-driven fogponics system's circuit diagram shows the electrical connections and interactions between its main parts. It consists of a microcontroller (ESP32), sensors (temperature and humidity (DHT22), and water level), power supply units, relay modules, and actuators (DC fan and Ultrasonic foggers). The flow of data from sensors to the microcontroller, which processes the data and transmits signals to turn on or off particular devices, is clearly depicted in the diagram. IoT modules are combined to allow for remote control and monitoring using a mobile application or cloud platform. This schematic acts as a guide for putting the electrical parts together and making sure the system is operating correctly.

3D model of the prototype. In order to understand and visualize the physical implementation, design, and functionality of the system, a 3D model of the automated IoT-driven fogponics prototype was developed. This model visually represents different views and angles of the prototype, with accurate figures, sizes, quantities, and dimensions digitally reflecting the actual design.

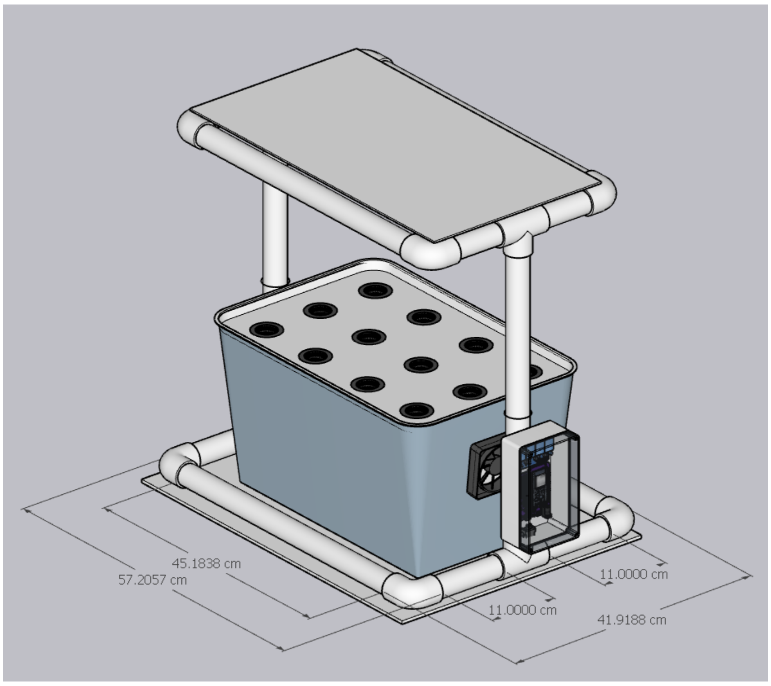

Figure 6. Isometric view 3D model of the fogponics system

The figure above shows the isometric view of the 3D model of the automated IoT-driven fogponics system. This model functions as a digital depiction of the tangible prototype, faithfully capturing the configuration, size, and positioning of different parts. It offers a thorough representation of the system's architecture, making it easier to see how each component fits into the larger scheme. Before the prototype is ever fabricated, the 3D model helps assess its functioning and viability by displaying various viewpoints and spatial arrangements.

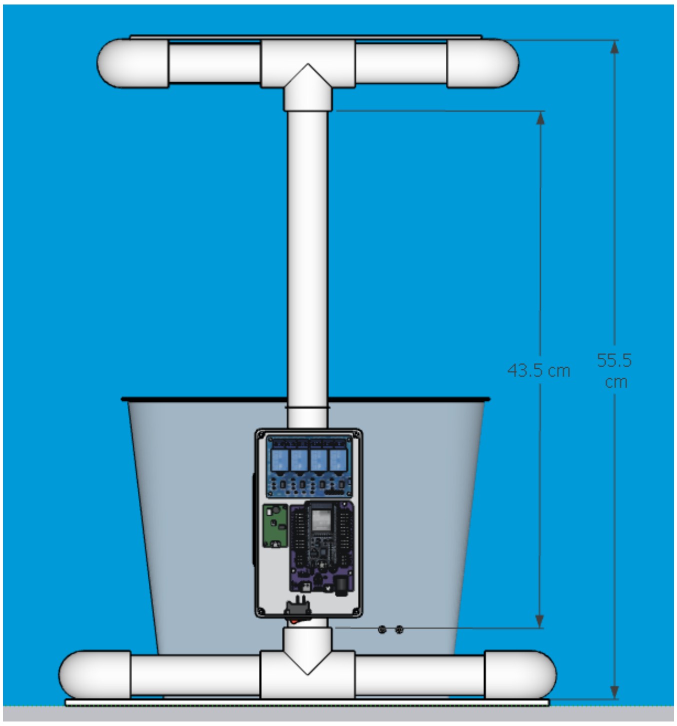

Figure 7. Side view 3D model of the fogponics system

The model graphically depicts the side view of the automated IoT-driven fogponics system's 3D prototype. This view emphasizes how important parts, including the electrical box, assembly box where the plants and system take place, DC Fan behind the electronic box, and supporting frame, are positioned and aligned in space. The model makes it easier to see how each component is connected and incorporated into the system by offering a thorough side perspective. By guaranteeing precise measurements and appropriate spacing prior to actual construction, this depiction is essential for evaluating the design's viability.

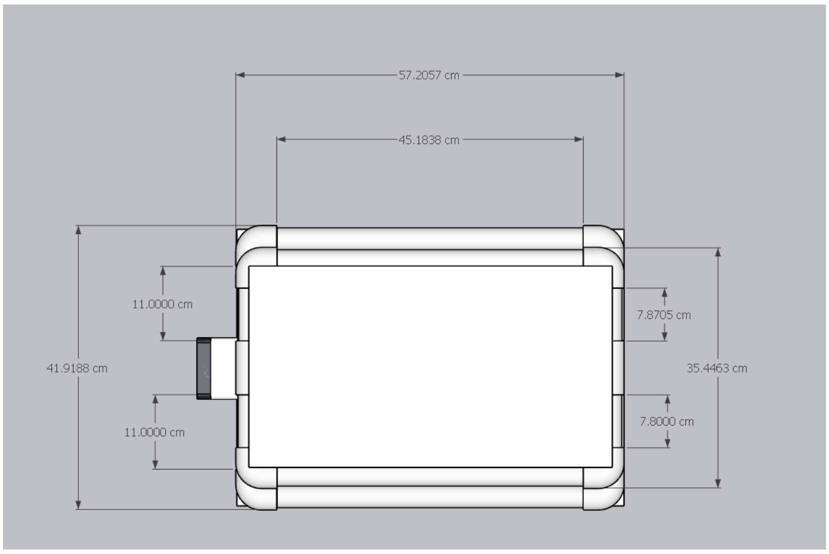

Figure 8. Top view 3D model of the fogponics system

The top view of the 3D model of the automated IoT-driven fogponics system is displayed in Figure 8, giving a clear picture of the upper design and spatial arrangement of its parts. This picture shows the PVCs where the wires will be placed in order to have organized and proper positions of the electrical wirings, preventing defects on wires and tangled wires, and also the structural board supports for the upper side where the grow lights are attached, located within the system.

Parts of the prototype (in 3D). This section discusses the main components of the automated IoT-based fogponic system prototype. The system monitors and regulates critical environmental elements to support optimal plant growth, fusing smart technology with conventional farming practices. By using embedded electronics and automation, it ensures reliable environmental control, suitable humidity, and an efficient supply of nutrients. The integration of sensors, control modules, and structural elements allows the system to function with minimal human help. This portion provides an overview of the essential elements that enable the prototype to do these objectives in a fogponics setup.

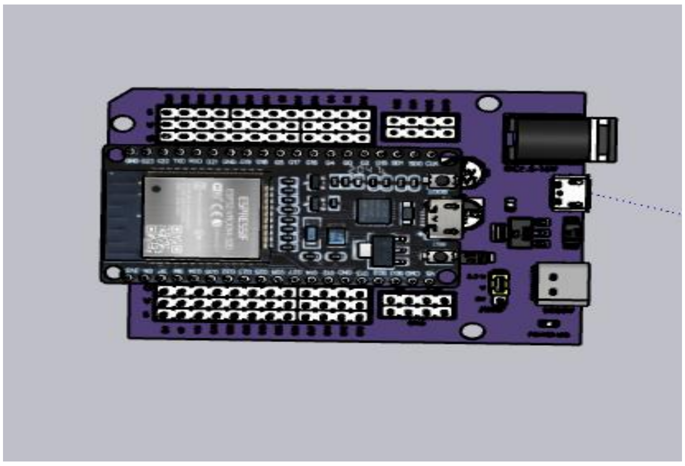

Figure 9. ESP32 Microcontroller

The ESP32 microcontroller serves a key function in the fogponic system as it is the main controller that automates and regulates the other components in the process. It is the one responsible for gathering data and real-time monitoring from the range of sensors (DHT22, pH level, water). The ESP32 uses sensor data to drive actuators such as the grow lights, DC fan, and ultrasonic fogger through a relay module, maintaining the optimal conditions for plant growth. Additionally, users can examine system statistics or make changes using a connected device thanks to the ESP32's built-in Bluetooth and Wi-Fi capabilities, which enable remote monitoring and control. Enhancing the fogponic system's scalability, durability, and efficiency makes it more intelligent and flexible enough to grow in a variety of settings.

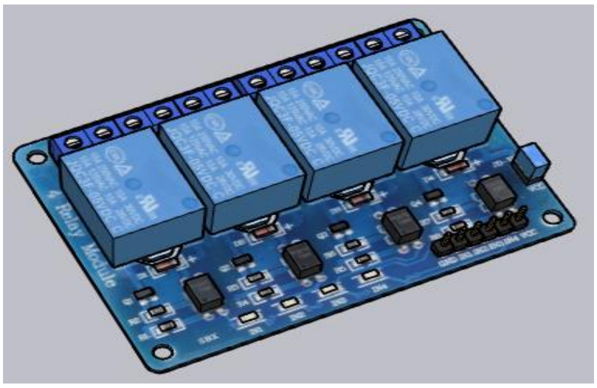

Figure 10. 5V 4-Channel relay module

The fogponic system's 4-channel relay module is in charge of managing the activity of several actuators. It serves as a switch that enables the ESP32 microprocessor to activate or deactivate gadgets like the lighting system, DC fan, and ultrasonic fogger in response to sensor data and preprogrammed conditions. Multiple devices can be precisely and independently controlled by assigning a specific component to each relay channel. By serving as a bridge between the ESP32's low-power logic and the actuators' greater power needs, this module enables safe and effective switching. The relay module is essential to ensuring ideal conditions for plant growth in the fogponic environment because it automates the timing and operation of each actuator.

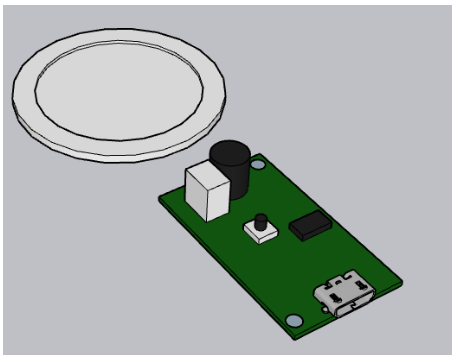

Figure 11. Ultrasonic humidifier fogger

The ultrasonic humidifier fogger is in charge of turning nutrient-rich water into a fine mist that is subsequently sent straight to the roots of the plants. Without being submerged, this mist enables the roots to effectively absorb water and vital nutrients, fostering quicker and more robust growth. By keeping the root zone continuously covered in water, the fogger ensures that the plants receive adequate hydration and food and permits better oxygen availability than traditional hydroponic approaches. This function is crucial in fogponic systems because it has a direct impact on how well and efficiently plants grow.

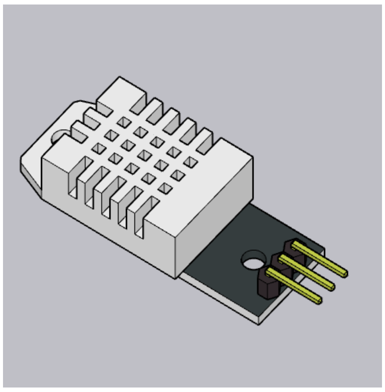

Figure 12. Temperature and humidity sensor (DHT22)

The fogponic system's DHT22 sensor, a small but crucial component shown in Figure 12. Its responsibility is to monitor the setup's temperature and humidity, essentially determining the area's relative warmth and humidity levels. This data aids the system in determining the best course of action to maintain the plants' health. The fan, for instance, activates to remove excess moisture if it becomes too humid. To warm things up if it becomes too cold, the grow light turns on. The DHT22 sensor allows the system to optimize the growing environment for the plants by making adjustments automatically.

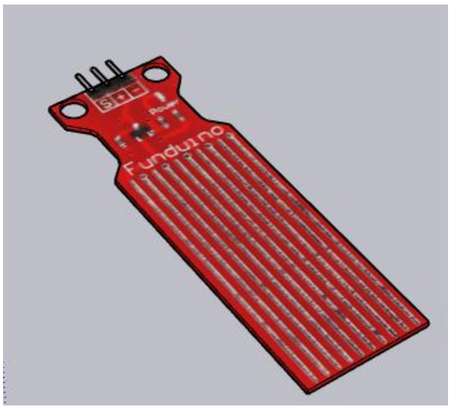

Figure 13. Capacitive water level sensor

A significant component of the fogponic system, the capacitive water level sensor keeps track of the reservoir's nutrient-rich water level. This sensor, in contrast to conventional float sensors, detects the presence or absence of liquid without coming into physical contact with it by using variations in capacitance. It keeps checking to see if there is enough water available to create the fog that plants require to flourish. The system can notify the user by sending a signal when the water level falls too low, or if it is integrated, it can even start an automatic refill procedure. This helps to create a steady and wholesome atmosphere for the plants by guaranteeing that the fogger always has enough water to operate as intended.

Software walkthrough. This software walkthrough describes the implementation of a custom HTML-based web interface for monitoring and controlling the automated IoT-driven fogponics system using the HTTP protocol. The system hosts a local web server on the ESP32 microcontroller, enabling real-time access to essential sensor data such as temperature, humidity, pH level, and fogging activity through any browser-enabled device. Using HTML and HTTP GET/POST methods, the interface allows users to view system status and send control commands remotely. While the interface is fully custom-built, the layout and functional flow were conceptually guided by existing IoT platforms like Blynk, which served as a visual and structural reference. This lightweight, cost-efficient approach ensures reliable operation, offline accessibility, and user-friendly interaction, making it a practical and scalable solution for managing fogponics environment parameters effectively.

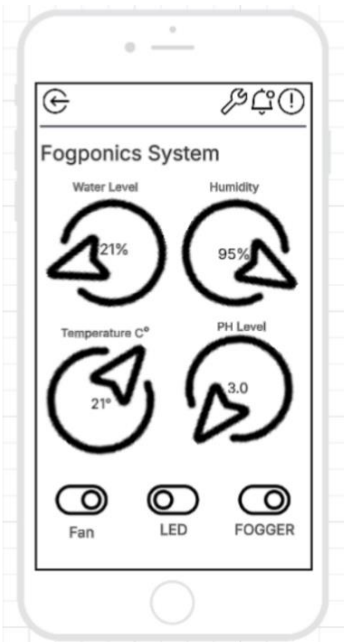

Figure 14. Main control panel interface for smartphones

Figure 14 is designed to remotely monitor and control the fogponics system in real-time, displaying key environmental parameters such as water level, humidity, temperature, and pH level. The water level indicator ensures that the nutrient solution remains within the optimal range for consistent fog generation. Humidity monitoring helps maintain adequate air moisture, essential for root health and efficient nutrient uptake. Temperature readings support regulation of the growing environment, preventing stress on the plants. The pH level gauge ensures that the nutrient solution remains balanced for optimal absorption. Additionally, toggle controls for the LED, fan, and fogger allow manual or automated operation of lighting, air circulation, and nutrient mist delivery, enhancing precision and automation in maintaining ideal growing conditions.

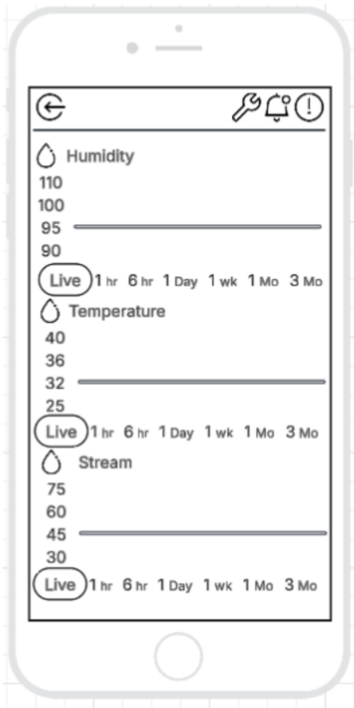

Figure 15. Real-time graphical monitoring interface for smartphones

Figure 15 presents real-time monitoring of key environmental variables within the fogponics system. The humidity graph tracks atmospheric moisture levels to ensure they remain within the optimal range for effective root absorption and plant health. The temperature graph records thermal fluctuations, which are essential for maintaining stable and controlled growing conditions. Additionally, the data stream graph visualizes real-time sensor data transmission, confirming continuous communication between the hardware and the monitoring platform. These dynamic visual tools enable quick identification of trends, detection of anomalies, and timely system adjustments, thereby improving overall responsiveness and reliability of the fogponics environment.

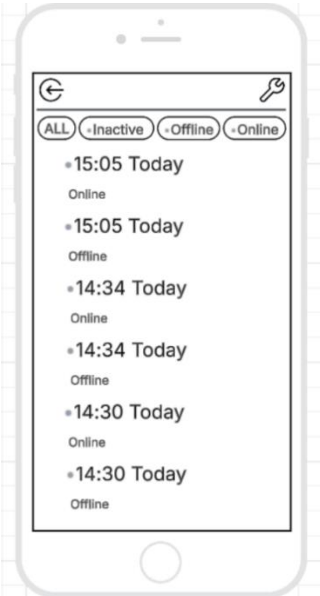

Figure 16. Notification and event’s interface for smartphones

Figure 16 is a mobile interface that presents a compact and responsive dashboard specifically designed for smartphones and other handheld devices. It allows users to view time-stamped system status updates and apply filters such as Inactive, Offline, or Online to easily monitor device activity. The layout is optimized for smaller screens, prioritizing readability and fast navigation to ensure efficient remote monitoring. This design enables users to stay informed and responsive to system changes while on the go.

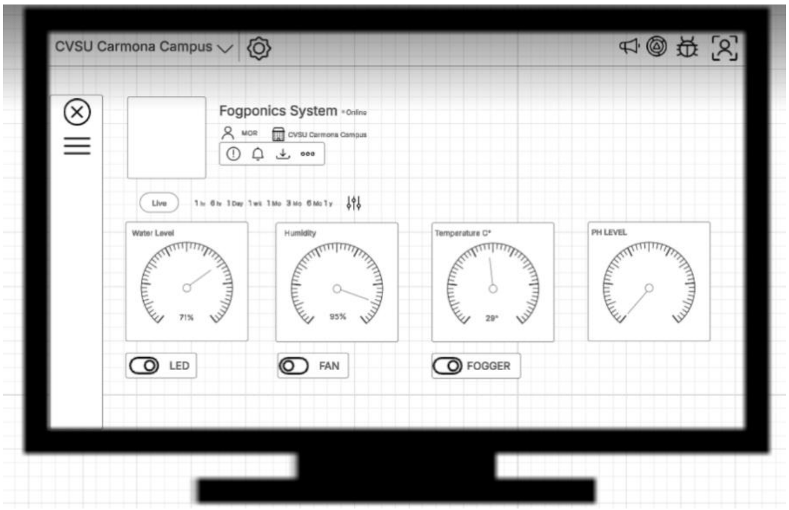

Figure 17. Main control panel interface for computers

Figure 17 Is a desktop control panel interface that displays real-time environmental data from the fogponics system using intuitive circular meter gauges. Key readings include water level, humidity, temperature in Celsius, and pH level, enabling users to monitor critical growing conditions at a glance. Below the gauges, toggle switches allow manual control of essential system components such as the LED for plant lighting, the fan for air circulation, and the fogger for nutrient mist delivery. This layout provides an integrated platform for both monitoring and managing the system, ensuring precise environmental regulation and effective operation.

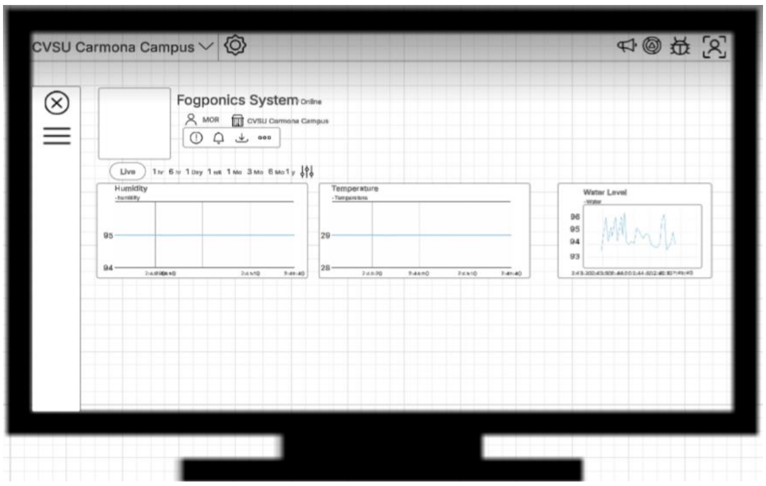

Figure 18. Real-time graphical monitoring interface for computers

Figure 18 is the section of the desktop interface that focuses on the graphical representation of environmental data through line graphs that display trends in humidity, temperature, and water level over time. These visualizations allow users to monitor how conditions within the fogponics system fluctuate throughout the day or over extended periods. By analyzing these trends, users can detect anomalies, evaluate system performance, and make informed adjustments to optimize growing conditions based on historical data patterns.

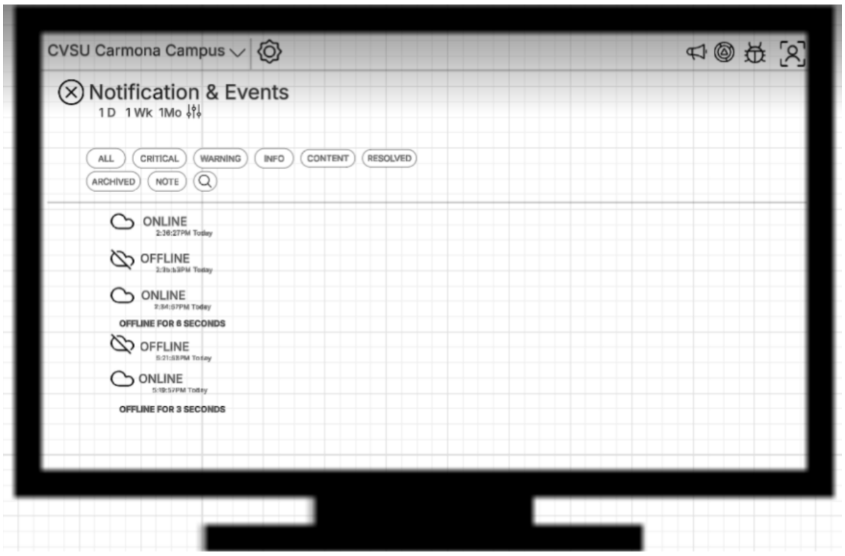

Figure 19. Notification and event’s interface for computers

Figure 19 provides a detailed event log with precise timestamps, indicating when system components go "Online" or "Offline." Users can filter notifications by time ranges such as 1 day, 1 week, or 1 month or by type, including Critical, Warning, and Informational alerts. This functionality enables efficient monitoring, diagnostics, and quick identification of system status changes. It supports timely decision-making and enhances the overall reliability and responsiveness of the fogponics system.

Methods

Experimental design. This experiment will use a repeated measures design to compare the growth of microgreens under IoT-based and non-IoT fogponics conditions using the same system. By applying both treatments to the same experimental units, this design helps control for variability between samples and allows for a more accurate assessment of the effect of IoT automation on plant growth.

Uncontrollable factors. Despite the automation, some factors remain outside the system's control, including natural variations in seed quality, slight ambient temperature changes in the grow area, and potential power fluctuations.

Controllable factors. These are the variables that our IoT-based fogponics system can precisely regulate, such as fogging frequency, lighting duration, water level, temperature, humidity, pH, and precise airflow

Response or Output. The primary response variables in this experiment are the growth and health indicators of the microgreens, specifically their height and fresh weight. These outputs provide quantifiable measures of how effectively the fogponics system supports plant development under IoT-based automation versus manual control. Additional observations such as leaf color and overall plant health may also be noted to assess plant quality.

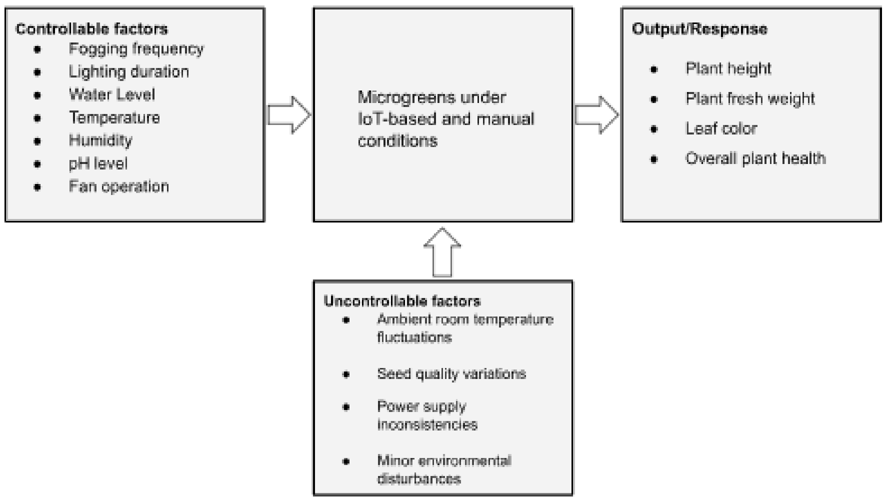

Figure 20. Overview of the fogponics setup highlighting controllable and uncontrollable factors influencing microgreens growth.

Experimental treatment. The experiment is designed to evaluate the effectiveness of an IoT-driven fogponics system by comparing it to a traditional, manually controlled fogponics setup. The same group of microgreens will undergo both treatments under controlled environmental conditions. The first phase serves as the baseline using conventional operation methods, while the second phase introduces the automated control system utilizing the ESP32 microcontroller and integrated sensors. These repeated measures approach ensures that plant samples experience both conditions, thereby reducing biological variability and increasing the accuracy of the comparison. Each treatment is implemented for a specific time period, with a one-week gap to evaluate immediate impacts of automation after its deployment.

T_0 (Traditional Fogponics): Microgreens are cultivated using the standard fogponics system with all controls—fogger, lighting, and pH management—operated manually without any automation or IoT monitoring features.

T_1 (IoT Integrated Fogponics): The same system is operated under the implemented IoT automation setup, where the ESP32 controls fogging intervals, lighting duration, humidity regulation, and pH balancing based on real-time sensor inputs.

Experimental layout. This experiment uses a single fogponics system to evaluate two treatments under identical environmental conditions. The setup remains consistent throughout, using the same grow chamber, lighting, nutrient solution, and planting schedule to eliminate variability. In the first trial, the system operates with IoT-based automation, where an ESP32 microcontroller manages fogging, lighting, pH regulation, and environmental monitoring through real-time sensor feedback. After completing this phase, the system is reset and used again for the second trial under traditional manual operation, where all controls are managed without automation. Both treatments are conducted sequentially at the same time of day and for the same duration, using identical seed quantities and grow media. This layout ensures that the only variable is the method of control, allowing for an accurate and direct comparison of plant development and system performance.

Data to be gathered. Data collection in this study follows the principles of ISO/IEC 25010, which defines product quality characteristics, and ISO 56002:2019, which supports the evaluation of innovation outcomes. Quantitative data will include plant height, leaf count, and fresh biomass to assess growth performance, while environmental metrics such as temperature, humidity, pH level, and water level will be recorded using calibrated sensors integrated into the IoT system. In accordance with ISO/IEC 25010, key quality attributes such as system reliability (e.g., uptime of automation), functional suitability (e.g., sensor accuracy), performance efficiency (e.g., timely fogging and lighting response), and usability (e.g., interface responsiveness) will be monitored through system logs and user observations. To align with ISO 56002, innovation-related data such as the system's ability to optimize resource use, improve plant health, and enhance operational consistency will also be assessed to evaluate the effectiveness and scalability of the IoT-driven fogponics solution as an innovative agricultural method.

Data Category	Specific Data	Measurement Method	Related ISO/IEC 25010 Quality Attribute	Related ISO 56002 Innovation Area
Plant Height	Total height of plants (cm)	Manual measurement using a ruler	Accuracy, Functional Suitability	Innovation Value: Growth Improvement
Fresh Weight	Weight of harvested plants (g)	Weighing scale after harvest	Performance Efficiency, Reliability	Innovation Outcome: Biomass yield
Leaf Count	Total number of leaves per plant	Manual counting	Functional Suitability, Usability	Innovation Value: Vegetative performance
Visual Plant Health	Color, structure, signs of chlorosis/wilting	Visual scoring (rating scale or checklist)	Reliability, Functional Suitability	Innovation Indicator: Health and vitality improvement

Table 2. Plant Growth Data and Evaluation

Analysis and statistical treatment of data. The collected data will be analyzed using selected statistical methods appropriate to the scope and structure of the study. Descriptive statistics will be applied to summarize and present data on plant height, fresh weight, and leaf count values across both treatments. Key descriptive metrics will include the mean, standard deviation, and range, providing a clear representation of central tendency and variability in plant growth and environmental conditions.

Formula for Range: range = max – min

$$s = \sqrt{\frac{\sum(x_i - \overline{x})^2}{n-1}}$$

where,

s = sample standard deviation

x_i = elements in sample

$\overline{x}$ = sample mean

n = sample size

$\sum$ = summation of;

To evaluate the significance of differences between the IoT-based and manually operated fogponics treatments, a paired t-test will be used. This statistical test is well-suited for the study's design, which involves comparing two related groups using the same system under different modes. The paired t-test will assess whether the differences in plant growth and health indicators are statistically significant, assuming a normal distribution of differences.

Formula for Paired T-test:

$$t = \frac{\sum d}{\sqrt{\frac{n\,(\sum d^2) - (\sum d)^2}{n-1}}}$$

where,

t = T – test

d = difference per paired value

n = number of samples

$\sum$ = summation of;

For effective data communication, line graphs will be used to illustrate trends in environmental conditions over the course of the trials, while bar charts and boxplots will visually compare growth outcomes between the automated and manual setups. These visualizations will support the quantitative findings and enhance the interpretability of the results. Overall, this statistical approach will enable the researchers to draw evidence-based conclusions regarding the effectiveness and reliability of IoT automation in fogponics systems.

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