

Bloomigo: A Wireless IoT-Based Hydroponics Control System for Efficient and Sustainable Farming

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Abstract— This study presents the development and evaluation of *Bloomigo*, a wireless Internet of Things (IoT)-based automation system designed to optimize environmental conditions in hydroponic greenhouses. The project addresses key challenges in traditional hydroponic farming, including labor-intensive monitoring, inconsistent climate control, and inefficient resource use. *Bloomigo* integrates temperature and humidity sensors with actuators for fans, lights, misting, and irrigation, all controlled via an Android mobile application. The system features three control modes—*Manual*, *Automation*, and *Machine Learning*—to provide flexibility and precision in managing growing environments. Field deployment across three greenhouse locations in Cebu, Philippines, demonstrated high sensor accuracy (MAE < 0.254 °C for temperature and < 0.698% for humidity), rapid actuator response times (average delay of 1.83 seconds), and strong user satisfaction (UI usability mean score of 4.39/5). Post-implementation results show significant reductions in manual tasks, enhanced operational efficiency, and improved environmental stability. This research highlights *Bloomigo*'s potential to make hydroponic farming more accessible, efficient, and sustainable, particularly for small- to medium-scale urban agriculture initiatives.

Keywords— Bloomigo, Hydroponic Farming, IoT Automation, Environmental Monitoring, Smart Agriculture

I. INTRODUCTION

Hydroponic farming presents a sustainable solution to food security challenges, especially in urban areas with limited arable land. As population growth and urbanization strain traditional agriculture, hydroponics enables soil-free cultivation in controlled environments. However, maintaining optimal temperature, humidity, and lighting remains challenging due to manual monitoring, often leading to inconsistent crop yields.

While IoT-based automation improves precision, many hydroponic systems remain costly and inflexible, limiting accessibility for small-scale growers. Advanced sensors and wireless controls enable real-time adjustments, but high costs and proprietary designs restrict widespread adoption. A more affordable and scalable solution is needed to make smart hydroponics viable for broader use.

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Bloomigo addresses these gaps with an IoT-based system featuring three operation modes: *Automation*, *Manual*, and *Machine Learning*. Its real-time monitoring and AI-driven adjustments maintain ideal growing conditions while conserving energy. With remote control via a mobile app and an integrated AI assistant, *Bloomigo* offers an accessible, efficient solution for urban and small-scale hydroponic farming.

II. METHODOLOGY

This experimental study evaluated the effectiveness of this study tested *Bloomigo*, an IoT-based hydroponics system using an ESP32 microcontroller and SHT30 sensor to monitor and adjust temperature and humidity via fans, misting, and grow lights. Data was sent to Firebase and accessed via a Flutter app.

Conducted in three Philippine greenhouses with hydroponics experts, the study compared environmental data before and after implementation, assessed sensor accuracy, response times, and user feedback. Participants consented, and data was anonymized.

A. Architecture Diagram

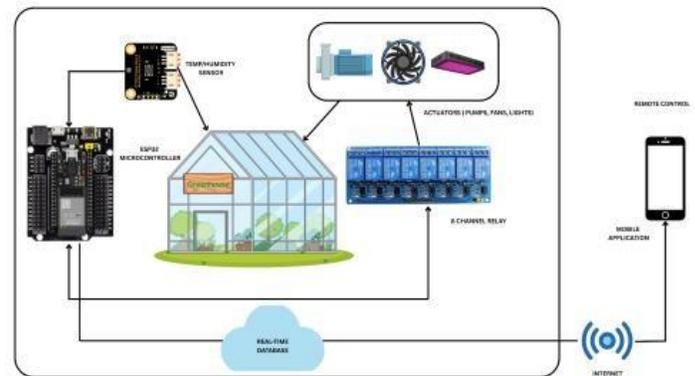


Fig. 1. Architecture Diagram of the System.

The system architecture features an ESP32 microcontroller connected to a temperature and humidity sensor and an 8-channel relay module, which controls actuators like pumps, fans, and lights. Sensor data is sent to a real-time cloud database for monitoring and control via a mobile app, enabling automated and remote greenhouse management.

B. Block Diagram

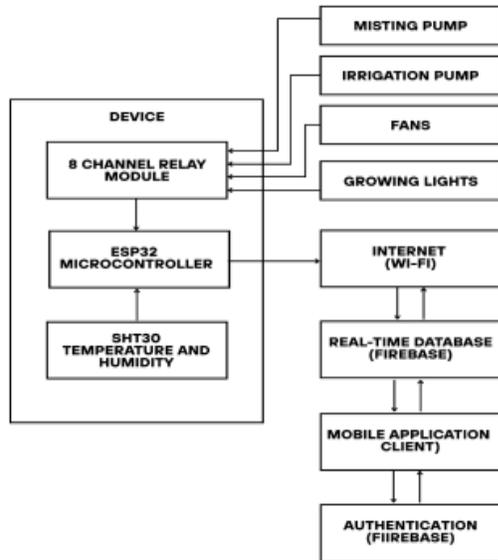


Fig. 2. Block Diagram of the System

The block diagram shows a wireless IoT-based hydroponics system using an ESP32 microcontroller connected to an SHT30 temperature and humidity sensor and an 8-channel relay module. The relays control devices like a misting pump, irrigation pump, fans, and growing lights. The ESP32 connects to the internet via Wi-Fi and communicates with Firebase, which handles real-time data storage and user authentication.

A mobile app allows users to monitor conditions and control the system remotely. This setup enables real-time, remote management of the hydroponic environment.

C. Flow Chart

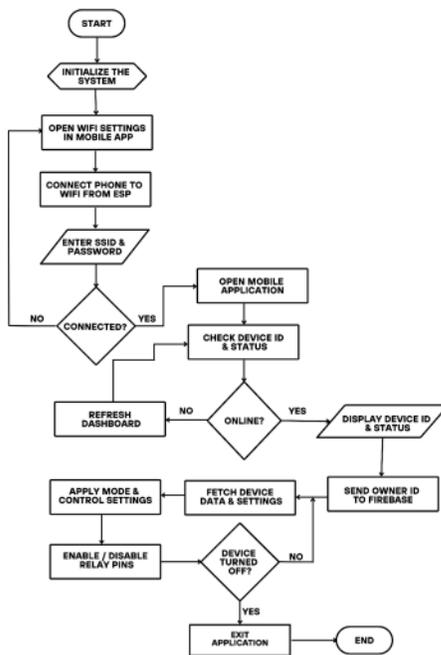


Fig. 3. Flow Chart of the Device

The ESP32 initializes hardware and creates a temporary Wi-Fi network. The user connects via a mobile app, inputs local Wi-Fi credentials, and retries if connection fails. Upon success, the app verifies the device ID, links it to Firebase, and retrieves settings and sensor data. If the device is off, the process stops. Otherwise, it activates relays for irrigation, misting, and lighting based on control settings, enabling real-time monitoring and automated greenhouse control.

D. Design of Experiments

1. Sensor Accuracy Test

Verifies the reliability and precision of the SHT30 sensor's temperature and humidity readings by comparing them against reference-grade instrumentation. The data collected were analyzed using the following formula:

$$MAE = \frac{1}{n} \sum_{i=1}^n |SHT_{30} - Reference_i| \tag{1}$$

2. Actuators Response Time Test

This test measures how quickly Bloomigo's actuators (fans, misting systems, and lights) respond to environmental changes, ensuring fast response and energy efficiency. The delay is calculated as the difference between the time the sensor threshold is breached and the time the actuator is triggered.

$$Actuator\ Delay = t_{Actuator\ ON} - t_{Sensor\ Breach} \tag{2}$$

3. Mobile Application Testing

Involves participants using the app to monitor temperature and humidity in real time, followed by a 5-point Likert scale survey to assess usability, data accuracy, and satisfaction. Weighted means are calculated from the survey data.

$$\bar{x} = \frac{\sum W_i X_i}{W_i} \tag{3}$$

III. RESULTS AND DISCUSSION

TABLE I. SENSOR TEMPERATURE DATA

LOCATION	TIMESTAMP	ACTUAL TEMPERATURE	TEMPERATURE OBTAINED BY THE DEVICE	ABSOLUTE ERROR
	11:09:09 AM	30.8 °C	31.01 °C	0.21 °C
	11:10:01 AM	30.2 °C	30.62 °C	0.42 °C
	11:12:19 AM	27.5 °C	27.85 °C	0.35 °C
	11:16:12 AM	26.3 °C	26.69 °C	0.39 °C
	11:17:51 AM	26.7 °C	26.63 °C	0.07 °C
	11:18:51 AM	27.1 °C	26.85 °C	0.25 °C
	11:19:54 AM	26 °C	26.3 °C	0.3 °C
	11:20:46 AM	28.6 °C	28.46 °C	0.14 °C
	11:21:51 AM	29.4 °C	29.18 °C	0.22 °C
	11:22:54 AM	30.1 °C	30.29 °C	0.19 °C
Summation of Absolute Error				2.54 °C
Mean Absolute Error				0.254 °C
	9:32:07 AM	31.2 °C	31.4 °C	0.2 °C
	9:33:45 AM	32 °C	31.84 °C	0.16 °C
	9:35:12 AM	31.7 °C	31.57 °C	0.13 °C
	9:36:58 AM	32.3 °C	32.06 °C	0.24 °C

	9:38:03 AM	31.4 °C	31.57 °C	0.17 °C
	9:39:41 AM	30.5 °C	30.68 °C	0.18 °C
	9:41:29 AM	30 °C	30.18 °C	0.18 °C
	9:43:16 AM	30.9 °C	30.68 °C	0.22 °C
	9:45:02 AM	30.6 °C	30.46 °C	0.14 °C
	9:46:55 AM	31.4 °C	31.18 °C	.22 °C
Summation of Absolute Error				1.84°C.
Mean Absolute Error				0.184°C
	01:24:37 PM	33.6 °C	33.45 °C	.15 °C
	01:25:12 PM	32.3 °C	32.56 °C	.26 °C
	01:26:49 PM	33.1 °C	32.84 °C	.26 °C
	01:27:05 PM	33.4 °C	33.17 °C	.23 °C
	01:28:58 PM	33.8 °C	33.62 °C	0.18 °C
	01:29:21 PM	33 °C	32.9 °C	0.1 °C
	01:30:44 PM	31.5 °C	31.79 °C	0.29 °C
	01:31:33 PM	32.1 °C	32.29 °C	0.19 °C
	01:32:15 PM	32.6 °C	32.4 °C	0.2 °C
	01:33:51 PM	32.8 °C	32.62 °C	0.18 °C
Summation of Absolute Error				2.04 °C
Mean Absolute Error				0.204°C
Overall Mean Absolute Error				0.214°C

If you are using *Word*, use either the Microsoft Equation Editor or the *MathType* add-on (<http://www.mathtype.com>) for equations in your paper (Insert | Object | Create New | Microsoft Equation *or* MathType Equation). “Float over text” should *not* be selected.

Table I presents the temperature data collected from three greenhouse locations—Don Bosco Boys Home (Liloan), Sto. Niño (Danao City), and Cambanay (Danao City)—demonstrate the accuracy of the SHT30 Gravity Analog Sensor in recording real-time environmental temperatures. The Mean Absolute Error (MAE) for each site was 0.254 °C, 0.184 °C, and 0.204 °C respectively, with an overall MAE of 0.214 °C.

Based on standard accuracy ranges, an MAE between 0.21 °C and 0.50 °C indicates low error, confirming that the sensor provides reliable performance suitable for real-time applications. The low deviation from actual values across all three locations validates the sensor’s stability and accuracy under varying conditions. Overall, the SHT30 sensor proves to be a dependable and efficient tool for automated environmental monitoring systems.

TABLE II. SENSOR HUMIDITY DATA

LOCATION	TIMESTAMP	ACTUAL TEMPERATURE	TEMPERATURE OBTAINED BY THE DEVICE	ABSOLUTE ERROR
	11:09:09 AM	33%	32.86%	0.14%
	11:10:01 AM	35%	34.3%	0.7%
	11:12:19 AM	41%	40.59%	0.41%
	11:16:12 AM	44%	43.44%	0.56%
	11:17:51 AM	42%	43.2%	1.2%
	11:18:51 AM	44%	43.31%	0.69%
	11:19:54 AM	42%	43.1%	1.1%
	11:20:46 AM	39%	40.85%	1.85%
	11:21:51 AM	37%	36.82%	0.18%
	11:22:54 AM	36%	35.85%	0.15%
Summation of Absolute Error				6.98%
Mean Absolute Error				0.698%
	9:32:07 AM	35%	34.038%	0.962%
	9:33:45 AM	33%	32.76%	0.24%
	9:35:12 AM	34%	33.43%	0.57%
	9:36:58 AM	31%	32.29%	1.29%
	9:38:03 AM	30%	31.31%	1.31%
	9:39:41 AM	35%	34.81%	0.19%
	9:41:29 AM	34%	33.7%	0.3%
	9:43:16 AM	35%	34.41%	0.59%
	9:45:02 AM	36%	35.11%	0.89%
	9:46:55 AM	33%	32.66%	0.34%
Summation of Absolute Error				6.81%
Mean Absolute Error				0.681%
	01:24:37 PM	31%	32.09%	1.09%
	01:25:12 PM	30%	31.01%	1.01%
	01:26:49 PM	36%	35.75%	0.25%
	01:27:05 PM	31%	30.95%	0.05%

	01:28:58 PM	29%	28.53%	0.47%
	01:29:21 PM	33%	32.86%	0.14%
	01:30:44 PM	31%	30.91%	0.09%
	01:31:33 PM	33%	32.09%	0.91%
	01:32:15 PM	31%	30.41%	0.59%
	01:33:51 PM	30%	29.64%	0.36%
Summation of Absolute Error				5.0%
Mean Absolute Error				0.500%
Overall Mean Absolute Error				0.626%

Table II presents the humidity data collected from three greenhouse locations—Don Bosco Boys Home (Liloan), Sto. Niño (Danao City), and Cambanay (Danao City)—demonstrating the SHT30 Gravity Analog Sensor’s high accuracy in measuring humidity levels. The Mean Absolute Error (MAE) for each site was 0.698%, 0.681%, and 0.500%, respectively, with an overall MAE of 0.626%.

According to standard interpretation, an MAE below 1% indicates excellent sensor precision and minimal deviation from actual values. These low error values confirm the sensor’s reliability and consistency across varying environmental conditions, validating its effectiveness for real-time humidity monitoring and automation.

TABLE III. ACTUATOR RESPONSE TIME

Location	Test	Actuator	tSensor Breach	tActuator ON	Delay (s)
Don Bosco Boys Home, Liloan, Cebu (Greenhouse)	1	Fan	12:13:05	12:13:07	1.7
		Misting Pump	12:14:12	12:14:13	1.3
		Irrigation Pump	12:15:23	12:15:25	1.8
		Lights	12:16:35	12:16:36	1.2
	2	Fan	12:34:40	12:34:42	1.9
		Misting Pump	12:35:47	12:35:49	1.5
		Irrigation Pump	12:37:00	12:37:01	1.3
		Lights	12:38:10	12:38:11	1.2
Sto. Niño, Sabang, Danao City, Cebu (Greenhouse)	3	Fan	10:05:00	10:05:02	2.4
		Misting Pump	10:06:07	10:06:09	2.1
		Irrigation Pump	10:07:20	10:07:22	2.5
		Lights	10:08:31	12:25:56	1.8
	4	Fan	10:16:00	10:16:02	2.4
		Misting Pump	10:17:30	10:17:31	1.1
		Irrigation Pump	10:17:30	10:18:44	1.9
		Lights	10:20:23	10:22:01	2.0
Cambanay, Danao City, Cebu (Greenhouse)	5	Fan	01:41:39	02:41:41	2.1
		Misting Pump	02:42:38	02:42:40	1.9
		Irrigation Pump	02:43:50	02:43:52	2.2
		Lights	02:45:01	02:45:02	1.3
	6	Fan	02:52:43	02:52:45	2.2
		Misting Pump	02:54:03	02:54:05	1.7
		Irrigation Pump	02:55:18	02:55:20	2.5
		Lights	02:56:28	02:56:30	1.9
Mean	Fan = 2.12s		Irrigation Pump = 2.03s		
	Misting Pump = 1.60s		Lights = 1.57s		
	General Weight Average			1.57s	

Table III summarizes the response times of four greenhouse actuators: Fan (2.12s), Misting Pump (1.60s), Irrigation Pump (2.03s), and Lights (1.57s). The overall average response time across all devices is 1.83 seconds. The data indicates

consistently fast actuator responses, with the Fan and Irrigation Pump showing slightly higher activation delays compared to the Misting Pump and Lights.

Nevertheless, all devices operate well within a 3-second range, reflecting an efficient and responsive control system that meets the real-time demands of automated hydroponic operations.

TABLE IV. USER INTERFACE AND USABILITY

Statement	Weight (Total number of responses)					Weighted Mean
	5	4	3	2	1	
The Bloomigo app is easy to use and navigate.	18	8	4	0	0	4.47
I can easily click buttons and recognize the icons in the app.	16	10	4	0	0	4.40
The instructions for setting up a new device are easy to follow.	15	10	5	0	0	4.33
The app shows clear and easy-to-understand information.	17	9	4	0	0	4.43
The design of the app is simple, and I can easily find what I need.	14	12	4	0	0	4.33
I can easily switch between different sections of the app without getting confused.	13	11	6	0	0	4.23
The app responds quickly to user actions.	19	8	3	0	0	4.53
Text and visuals are comfortable to read.	18	10	2	0	0	4.53
I feel confident using the app without needing much help or guidance.	17	11	2	0	0	4.50
General Weighted Mean						4.39

Table IV presents the *Bloomigo* app receives high marks for user-friendliness with a general weighted mean of 4.39. Users find it easy to navigate, with clear instructions for setup and simple design.

The app is responsive, and the text and visuals are easy to read. While users can switch between sections smoothly, there's a small opportunity to improve navigation flow, as it received the lowest score. Overall, the app is intuitive, and users feel confident using it without much guidance.

TABLE V. FUNCTIONALITY AND CONTROL

Statement	Weight (Total number of responses)					Weighted Mean
	5	4	3	2	1	
The temperature and humidity readings in the dashboard are accurate.	17	10	3	0	0	4.47
The device's online or offline status is shown correctly in the app.	18	9	3	0	0	4.50
It is easy for me to switch the control modes.	15	11	4	0	0	4.37
The manual controls respond quickly when I trigger the	16	10	3	1	0	4.40

loggles.						
I can turn on or off the actuators (like fans, lights, or pumps) anytime I want.	17	10	2	1	0	4.43
The automation mode reacts quickly when the system needs to adjust something.	16	11	3	0	0	4.43
The machine learning mode automatically controls my hydroponics without needing manual input.	14	12	3	1	0	4.30
I can control my hydroponics anywhere as long as I am connected to Internet.	18	9	2	1	0	4.47
I can easily customize rules in the automation mode.	15	9	4	2	0	4.17
The app is responsive and smooth when I interact with it.	19	8	2	1	0	4.47
General Weighted Mean						4.38

Table V shows that users are highly satisfied with the *Bloomigo* app's performance. The app excels in areas like accurate temperature and humidity readings, correct device status display, and quick manual control responses. Users appreciate the flexibility of controlling actuators at any time and the responsiveness of the automation mode.

While the machine learning mode received positive feedback, it was slightly less favored compared to other features. The ability to control the system remotely is highly valued, but there is room for improvement in customizing automation rules. The app is praised for its smooth user experience, making it an effective tool for hydroponic management.

TABLE VI. TRADITIONAL MANUAL TASKS VS AFTER USING BLOOMIGO

Traditional Hydroponics Farming						
Statement	5	4	3	2	1	Weighted Mean
Traditional hydroponic systems involve travel time-consuming tasks, as I have to visit the system frequently to manage various processes.	15	10	5	0	0	4.33
Misting and irrigation require manual operation, which can take up valuable time and effort.	20	7	3	0	0	4.57
I have to manually refill water, which can be tedious and time-consuming.	18	8	4	0	0	4.47
Checking and adjusting temperature and humidity levels is done manually, requiring constant attention.	22	5	3	0	0	4.63
Turning the lights on and off is done manually, adding to the overall time spent managing the system.	17	9	4	0	0	4.43
General Weighted Mean						4.49
After using Bloomigo						
With Bloomigo, travel time is reduced since I can control and monitor everything remotely, without needing to physically visit the system.	23	5	2	0	0	4.7
The misting and irrigation is	25	4	1	0	0	4.8

automated, so I no longer need to handle them manually.						
Water refilling is also automated, reducing the need for constant manual checks and interventions.	24	5	1	0	0	4.77
Temperature and humidity are automatically monitored and adjusted by the system, saving me from having to do manual checks.	26	3	1	0	0	4.83
The lights are controlled by Bloomigo, so I no longer have to manually turn them on and off.	27	2	1	0	0	4.87
Overall, Bloomigo significantly reduces the time and effort required to manage the hydroponic system.	28	2	0	0	0	4.93
General Weighted Mean						4.82

Table VI shows the results that traditional hydroponic farming is perceived as time-consuming and labor-intensive, with a general weighted mean of 4.49. In contrast, *Bloomigo* received a higher mean of 4.82, indicating that users find it significantly more efficient and less demanding.

The automation features of *Bloomigo*, including remote control and monitoring, effectively reduce manual tasks, making hydroponic management more convenient and time-saving.

IV. CONCLUSION

The system demonstrated excellent sensor accuracy, with low Mean Absolute Errors (MAE) for temperature and humidity, confirming its reliability in real-time applications. The actuators also performed well, with an average response time of 1.83 seconds, ensuring timely adjustments to maintain optimal conditions for plant growth.

User feedback further supported the effectiveness of *Bloomigo*, with an overall general weighted mean of 4.82, compared to 4.49 for traditional hydroponic systems. This highlights a significant reduction in time and labor required to manage the hydroponic system. The *Bloomigo* mobile app, with its user-friendly interface and real-time data visualization, was praised for its convenience and ease of use.

The system's automation capabilities not only improved operational efficiency but also increased user confidence in managing their hydroponic setups. These results position *Bloomigo* as a meaningful advancement in smart farming technologies, offering the potential for scalability across various hydroponic methods and climatic conditions. Looking ahead, further integration of predictive 72 analytics could enhance its performance, making *Bloomigo* a pivotal tool in the future of sustainable and efficient hydroponic farming.

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REFERENCES

- [1] Agnal, A. S., Sanaadhani, V. P., & Reshma, L. (2024). Automated IoT Indoor Hydroponic Farm. 1–6. <https://doi.org/10.1109/ICPECTS62210.2024.10780276>
- [2] Akter, T., Mahmud, T., Chakma, R., Datta, N., Hossain, M. S., & Andersson, K. (2024). Smart Monitoring and Control of Hydroponic Systems Using IoT Solutions. 761 <https://doi.org/10.1109/ICICI62254.2024.00128>
- [3] AlShrouf, A. (2017). Hydroponics, Aeroponic and Aquaponic as Compared with Conventional Farming. *American Scientific Research Journal for Engineering, Technology, and Sciences*, 27(1), 247–255.
- [4] Arabzadeh, V., Kotilainen, T., Herranen, P., Miettinen, P., Rautkari, L., & Kumm, M. (2023). Improving Wind Power Integration in Vertical Farming with Modifying the Power Demand. <https://doi.org/10.2139/ssrn.4512904>
- [5] Athirah, N., Hatipi, M., Sarmin, S. S., Nor, M., Dohad, M. R., Farah, N., Kamaruzaman, E. N., Naim, N. F., & Idris, A. (2024). IoT-Based Smart Vertical Hydroponic System for Chili Plant. *Journal of Advanced Research in Applied Sciences and Engineering Technology*.
- [6] Aurasopon, A., Thongleam, T., & Kuankid, S. (2024). Integration of IoT Technology in Hydroponic Systems for Enhanced Efficiency and Productivity in Small Scale Farming. *Acta Technologica Agriculturae*, 27(4), 203–211. <https://doi.org/10.2478/ata-2024-0027>
- [7] Avhad, A. (2024). IOT based Smart Plant Monitoring System and Control System. *Indian Scientific Journal Of Research In Engineering And Management*.
- [8] Banda, N. (2023). Mobile Application Development for Optimizing Management Information Systems. *Journal Informatic, Education and Management*.
- [9] Benke, K., & Tomkins, B. (2017). Future food-production systems: vertical farming and controlled-environment agriculture. *Sustainability: Science, Practice and Policy*, 13(1), 13–26. <https://doi.org/10.1080/15487733.2017.1394054>
- [10] Bhojar, C. N. (2023). Smart Agriculture System Using IoT Based. *International Journal For Science Technology And Engineering*, 11(4), 2434–2437. <https://doi.org/10.22214/ijraset.2023.50651>
- [11] Bianyosa, W., Wibiya, A., & Nasuha, A. (2024). Monitoring Smart Applications for Monitoring and Controlling of IoT-Based Strawberry Hydroponic Plants.
- [12] Buratto, W. G., Muniz, R., Nied, A., Barros, C. F. de O., Cardoso, R., & González, G. V. (2024). A Review of Automation and Sensors: Parameters Control of Thermal Treatments for Electricity Generation. <https://doi.org/10.20944/preprints202401.1060.v1>
- [13] Chauhan, K., & Thakor, M. A. (2023). Ui/ux-centric design of in-the-field agricultural data acquisition system. *International Journal of Engineering Applied Science and Technology*. <https://doi.org/10.33564/IJEAST.2023.v08i06.010>
- [14] Cota-Luna, X. Y., Casas-Gómez, V. M., Hidalgo-Baeza, M. del C., & Martínez-Román, A. (2024). Automatic irrigation of hydroponic lettuce cultivation with IoT. *Revista de Tecnologías En Procesos Industriales*. <https://doi.org/10.35429/JTIP.2024.8.18.1.9>

- [15] de Sousa, R., Bragança, L., da Silva, M. V., & Oliveira, R. S. (2024). Challenges and solutions for sustainable food systems: The potential of home hydroponics. *Sustainability*, 16(2), 817. <https://doi.org/10.3390/su16020817>
- [16] Dharani, N., Krishnan, K., & Mohan, K. V. (2021). Wireless Sensor Network for Industrial Monitoring and Controlling. *International Conference Intelligent Computing and Control Systems*, 254–257. <https://doi.org/10.1109/ICICCS51141.2021.9432238>
- [17] Dubey, V., Kumari, P., Patel, K., Singh, S., & Shrivastava, S. (2024). Amalgamation of Optimization Algorithms With IoT Applications. *Practice, Progress, and Proficiency in Sustainability*, 176–204. <https://doi.org/10.4018/979-8-3693-7322-4.ch009>
- [18] Ekanayake, J., & Luckshitha, S. (2020). E-AGRO: Intelligent Chat-Bot. *IoT and Artificial Intelligence to Enhance Farming Industry*. 12(01), 15–21. <https://doi.org/10.7160/aol.2020.120102>
- [19] Elijah, O., Rahman, T. A., Orikumhi, I., Leow, C. Y., & Hindia, M. N. (2018). An overview of Internet of Things (IoT) and data analytics in agriculture: Benefits and challenges. *IEEE Internet of Things Journal*, 5(5), 3758-3773. <https://doi.org/10.1109/JIOT.2018.2844296>
- [20] Foyosal, F. M., Mondal, S., Riyad, T., Sikder, S. S., Hasan, J., M, A., Mishu, S. S., & Rahman, M. S. (2025). Scalable IoT-based Smart Plant Monitoring and Control System for Sustainable Agriculture. *Journal of Engineering Research and Reports*, 27(1), 16–32. <https://doi.org/10.9734/jerr/2025/v27i11365>
- [21] Găgeanu, I., Tăbărașu, A.-M., Persu, C., Gheorghe, G., Nițu, M., Cujbescu, D., IONESCU, A., & ANGHELACHE, D. (2024). Hydroponic vertical systems: enhancing climate resilience, water efficiency, and urban agriculture. *INMATEH Agricultural Engineering*, 94–109. <https://doi.org/10.35633/inmateh-73-08>
- [22] Gonzalez-Usach, R., Yacchirema-Vargas, D. C., Julián-Seguí, M., & Palau Salvador, C. (2019). Interoperability in IoT (pp. 149–173). *IGI Global*.
- [23] Hassija, V., Chamola, V., Saxena, V., Jain, D., Goyal, P., & Sikdar, B. (2019). A survey on IoT security: Application areas, security threats, and solution architectures. *IEEE Access*, 7, 82721-82743. <https://doi.org/10.1109/ACCESS.2019.2924045>
- [24] Herman, N. S. (2019). Intelligent Monitoring and Controlling System for Hydroponics Precision Agriculture. *International Conference on Information and Communication Technology*, 1–6. <https://doi.org/10.1109/ICoICT.2019.8835377>
- [25] Kamilaris, A., Gao, F., Prenafeta-Boldú, F. X., & Ali, M. I. (2016). Agri-IoT: A semantic framework for Internet of Things-enabled smart farming applications. *2016 IEEE World Forum on Internet of Things (WF-IoT)*, 1-6. <https://doi.org/10.1109/WF-IoT.2016.7845467>
- [26] Kota, H. R. (2024). IOT-Powered Automatic Irrigation System and Soil Monitoring. *International Journal For Science Technology And Engineering*, 12(11), 671–676. <https://doi.org/10.22214/ijraset.2024.65103>
- [27] Kulkarni, P. V., Gohokar, V., & Kulkarni, K. (2024). Smart Hydroponic Systems: Optimizing Nutrient Levels with IoT Connectivity. *Journal of Electrical Systems*. <https://doi.org/10.52783/jes.1472>
- [28] Leong, W. Y., Leong, Y. Z., & Leong, W. S. (2024). Enhancing Poultry Farm Operations with IoT and Smart Manufacturing Systems. 1–5. <https://doi.org/10.1109/ICTKE62841.2024.10787167>
- [29] Li, W., Matsuhisa, N., Liu, Z., Wang, M., Luo, Y., Cai, P., Chen, G., Zhang, F., Li, C., Liu, Z., Lv, Z., Zhang, W., & Chen, X. (2021). An on-demand plant-based actuator created using conformable electrodes. 4(2), 134–142. <https://doi.org/10.1038/s41928-020-00530-4>