Integration of Liquid Organic Fertilizer Fermentor with Automated Hydroponic Fertilization Based on IoT

Muhammad Fakhrudin Zukhri
Department of Industrial Chemical Engineering
Institut Teknologi Sepuluh Nopember,
Surabaya, Indonesia
mfzfakhrudin@gmail.com

Putri Yeni Aisyah
Department of Instrumentation Engineering
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
putri.yeni@its.ac.id

Yudi Wirawan
Department of Instrumentation Engineering
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
2042221114@student.its.ac.id

Tia Yohana Nainggolan
Department of Instrumentation Engineering
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
2042221118@student.its.ac.id

Firda Anandhita
Department of Instrumentation Engineering
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
2042221108@student.its.ac.id

Muhammad Ivan Hermawan
Department of Instrumentation Engineering
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
2042221096@student.its.ac.id

***Abstract*— As urbanization continues to accelerate, particularly in cities like Surabaya, the availability of agricultural land has been steadily decreasing, making food security a growing concern. In response to these challenges, urban farming, particularly through hydroponic systems, has emerged as a promising solution to ensure sustainable food production in limited spaces. However, issues such as the high cost and limited availability of high quality fertilizers, as well as the difficulty in maintaining a consistent farming schedule, have posed significant barriers. This study aims to address these challenges by integrating IoT based systems for temperature and pH monitoring, aiming to enhance farming efficiency. The validation results for both the DS18B20 Temperature Sensor and the pH Sensor 4502 C demonstrate their high accuracy and reliability for environmental monitoring. The DS18B20 sensor showed minimal error, with 0.89% for increasing temperatures and 1.34% for decreasing temperatures, achieving 99.11% and 98.66% accuracy, respectively. These results confirm the sensor's effectiveness in real time temperature control applications, such as those used in hydroponics and fermentation systems. Similarly, the pH Sensor 4502 C exhibited remarkable performance, with 99% accuracy in the acidic buffer, 98.99% in the neutral buffer, and 99% in the basic buffer. The error rates were extremely low, at 0.002% for acidic and basic buffers, and 0.01% for the neutral buffer, reinforcing the sensor's reliability for pH monitoring in controlled environments.**

Keywords*— *automated fertilization, hydroponic systems, urban farming

I. INTRODUCTION

As urbanization accelerates, particularly in cities like Surabaya, the availability of agricultural land continues to decrease, exacerbating concerns over food security. In response, urban farming has emerged as a potential solution for sustainable food production in areas with limited space. One promising approach is the use of hydroponic systems, which allow plants to grow without soil, utilizing nutrient rich water to nourish crops [1]. However, despite the promise of hydroponic farming, the availability of high quality fertilizers at affordable prices remains a significant challenge. Most fertilizers in use today are inorganic, costly, and difficult to source locally, posing a barrier to sustainable agricultural practices. Additionally, maintaining a consistent farming schedule can be challenging, particularly for older farmers, reducing the efficiency and productivity of such systems [2].

The present study introduces a novel integration of Internet of Things technology with biologically driven fertilizer production and hydroponic nutrient delivery within a unified closed-loop system. Unlike prior works that have independently addressed either IoT based monitoring in hydroponic systems or the production of organic liquid fertilizers, this research uniquely combines both domains into a single automated framework. The system is designed to synchronize the fermentation process of organic waste into liquid fertilizer with real time pH and temperature monitoring, followed by automated fertigation based on threshold driven actuation. This configuration represents a significant advancement over existing approaches, which often rely on external or commercially prepared fertilizers and manual nutrient application. [3]. The primary academic contribution lies in the development of a low cost, modular, and scalable system architecture that combines real time pH and temperature monitoring, automatic nutrient dosing, and remote user interfacing through a smartphone application. This system advances existing literature by bridging two previously separate domains organic fertilizer production and precision hydroponic cultivation into a unified, automated framework.

II. METHODS

The methods section covers the methodology of research, including any materials needed.

©2025 by the authors. This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.
How to cite: Zukhri, M.F., Aisyah, P.Y., Wirawan, Y., Nainggolan, T.Y., Anandhita, F., Hermawan, M.I. (2025) Integration of Liquid Organic Fertilizer Fermentor with Automated Hydroponic Fertilization Based on IoT. *JAREE (Journal on Advanced Research in Electrical Engineering), 9(2).*

A. System Design

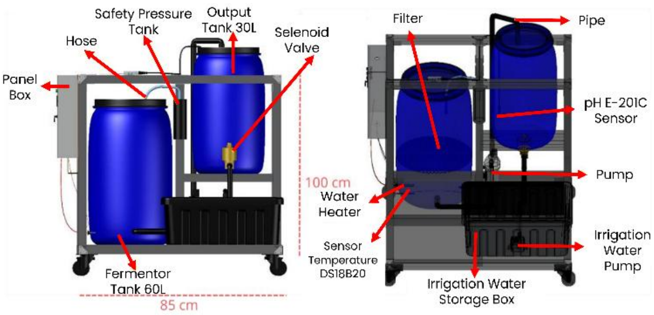

Fig. 1. Design of Organic Fertilizer Fermentor with Automated Hydroponic Fertilization

The system integrates IoT technology to automate hydroponic fertilization, enabling real time monitoring and control of essential parameters such as pH, temperature, and nutrient concentration. Through IoT sensors, the system continuously tracks environmental conditions and adjusts nutrient delivery to ensure optimal conditions for plant growth. The use of IoT allows for remote management and control via a smartphone app, streamlining the farming process and enhancing efficiency [4].

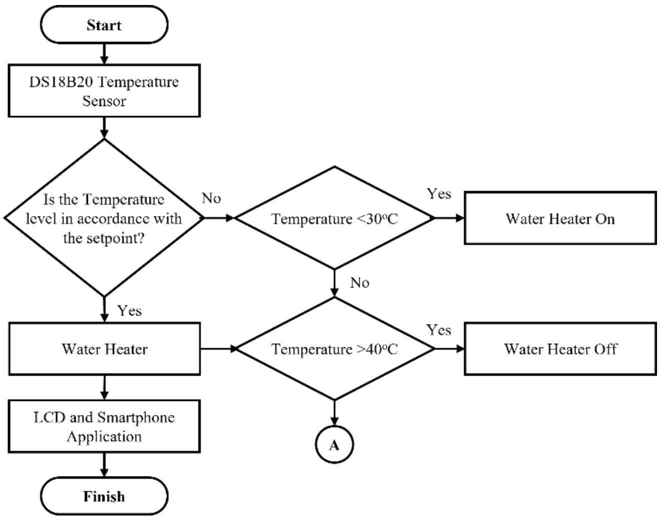

Fig. 2. Diagram of Heater Control System

From Fig 2. represents a Heater Control System that uses an IoTbased mechanism to regulate temperature. It starts by initializing the DS18B20 Temperature Sensor, which continuously monitors the temperature. The system then checks whether the current temperature matches the setpoint. If the temperature is within the setpoint range, the water heater is turned off, and the status is displayed on the LCD and Smartphone Application. If the temperature is not within range, the system checks if the temperature is below 30°C, in which case it activates the heater to increase the temperature. If the temperature exceeds 40°C, the system turns off the heater to prevent overheating. Throughout the process, the system provides real time updates on the LCD and smartphone app, ensuring optimal temperature management. The process continuously monitors temperature and makes adjustments as needed.

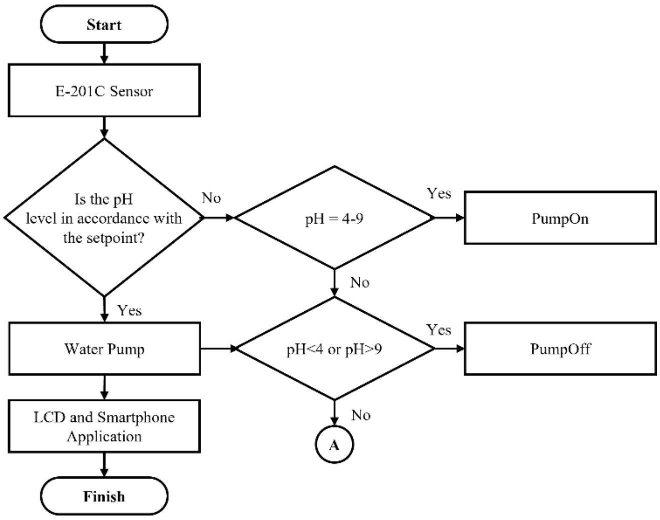

Fig. 3. Diagram of Pump Control System

Fig. 3 represents a a Pump Control System that utilizes an E-201C Sensor to monitor the pH level and regulate the water pump accordingly. The system starts by measuring the pH level. If the pH is within the desired range, the pump is activated. If the pH is outside the setpoint range, the system checks if the pH is between 4 and 9. If it is, the pump is turned on, and the system displays the status on the LCD and Smartphone Application. However, if the pH is below 4 or above 9, the pump is turned off. The system continuously monitors the pH and updates the user interface accordingly, ensuring that the pH level stays within the optimal range for plant health. This automated process reduces the need for manual intervention while providing real time updates for the user.

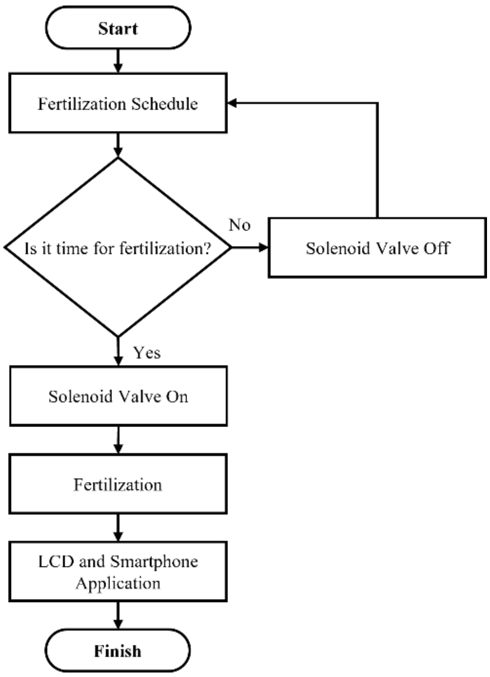

Fig. 4. Diagram of Solenoid Valve Control System

Fig. 4 represents a Solenoid Valve Control System, which automates the fertilization process based on a predetermined Fertilization Schedule. The system begins by checking if it is the scheduled time for fertilization. If it is not time for fertilization, the solenoid valve remains off. If it is time for fertilization, the system activates the Solenoid Valve to allow the flow of fertilizer to the plants. Once the valve is open, the fertilization process occurs, and the system updates the LCD and Smartphone Application with the status of the process. The system then finishes the cycle and waits for the next scheduled fertilization time. This automated approach reduces the need for manual intervention and ensures timely and precise application of fertilizer.

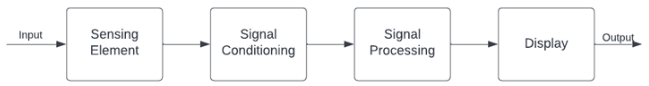

Fig. 5. Diagram of Monitoring System

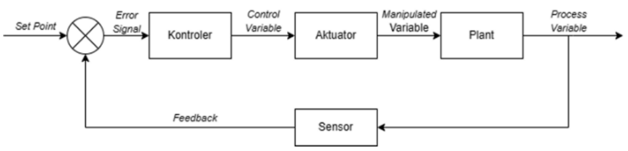

Fig. 6. Diagram of Control System Close Loop Fermentor

Fig. 6 Represents a Fermentor Control System operates as a Close Loop feedback system that begins by setting a desired temperature or condition, referred to as the Set Point. The Controller processes input data by comparing the system's output with the desired reference and generates control commands accordingly. In this system, the controller used is the NodeMCU ESP8266. The Actuator then converts these control signals into physical actions, which can include mechanical, pneumatic, hydraulic, or electronic operations. In this case, the actuator controls the Relay to manage the water heater and pump based on the controller's instructions. The Plant refers to the physical system being controlled, which in this case is the fermentor tank where organic liquid fertilizer is processed. The temperature in the fermentor is regulated to ensure the fertilizer matures efficiently. The Sensor measures the system's output and compares it with input signals to ensure proper operation. In this system, temperature and pH sensors are used to monitor the conditions of the fertilizer, ensuring they remain optimal for the fermentation process. This feedback loop allows the system to continuously adjust and maintain the desired conditions, ensuring the efficient production of organic fertilizer.

C. System Development and Prototyping

The system was built through a prototyping process that involved constructing a fermentation chamber using plastic barrels and PVC pipes. The organic waste (such as agricultural byproducts and fish waste) was placed in the chamber, where it underwent an anaerobic fermentation process. The fermentation process was monitored using temperature sensors to ensure it remained within the optimal range for microbial activity, typically between 25°C and 35°C. Once the organic fertilizer was produced, its nutrient concentration was tested to verify it met the required standards for hydroponic use. The design of the system also ensured that the production of organic fertilizer was synchronized with the automated fertilization process in the hydroponic system [5].

D. IoT Integration

The ESP32 microcontroller functions as the central processing unit within the liquid organic fertilizer automation system integrated with Internet of Things technology. As illustrated in Figure 7, the ESP32 is programmed to interface with multiple functional modules, including a pH sensor based on the 4502C module connected through analog input for continuous monitoring of solution acidity, and a DS18B20 temperature sensor via the One Wire protocol to ensure accurate thermal profiling of the nutrient medium [6].

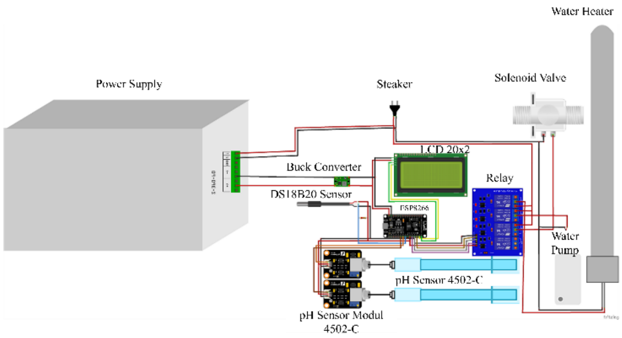

Fig. 7. Electric Wiring Diagram

Control signals from the ESP32 are transmitted to a relay module, which actuates high power components such as the direct current water pump and the solenoid valve based on predefined operational thresholds for pH and temperature. Data acquired from the sensor modules are transmitted wirelessly through the embedded WiFi communication feature of the ESP32 to a smartphone application, enabling remote monitoring, adaptive control, and real time decision making. This comprehensive integration significantly enhances system responsiveness, operational precision, and overall efficiency in the automated delivery of liquid organic fertilizers within hydroponic cultivation environments [7].

E. System Testing and Optimization

Sensor calibration was conducted by systematically comparing the measurement outputs with those obtained from standard reference instruments under controlled laboratory conditions. The DS18B20 temperature sensor underwent validation through a series of thermal fluctuation tests, with its readings benchmarked against those of a calibrated digital thermometer to evaluate thermal response accuracy across a dynamic range. Concurrently, the pH Sensor 4502-C was calibrated using certified buffer solutions representing acidic (pH 4.00), neutral (pH 6.86), and basic (pH 9.18) conditions, with reference values obtained from a laboratory grade water quality tester. The calibration results demonstrated consistently low error margins, with a minimum error of 0.002 percent for the pH sensor and 0.89 percent for the temperature sensor. These findings affirm the high precision and measurement reliability of both sensors, validating their suitability for integration into real time agricultural monitoring systems where accuracy and responsiveness are critical to maintaining optimal environmental parameters.

After the prototype was assembled, it underwent several rounds of testing to ensure its performance and reliability. The fermentation process was tested to ensure that the organic fertilizer produced had the correct nutrient concentration and that the temperature remained within the optimal range for fermentation. The IoT based control system was also tested for real time responsiveness, ensuring that the smartphone app received accurate data and could control the system remotely [8]. The hydroponic system was tested to ensure that the fertilizer was applied properly, and that nutrient levels, pH, and temperature were within the optimal range for plant growth. Additionally, feedback from the farmers was collected to refine the user interface of the smartphone app, ensuring it was intuitive and easy to use for elderly farmers [9].

F. Data Collection and Analysis

During the testing phase, data was continuously collected from the sensors and smartphone app to monitor the performance of the system. This included data on fertilizer production efficiency, system performance (e.g., pH, temperature, nutrient levels), and farmer efficiency (e.g., reduction in manual labor). The data collected was analyzed to evaluate the improvements in yield, cost efficiency, and overall system performance because of the integration of IoT technology into the farming system. The system's impact on sustainability and profitability was also assessed, comparing the pre-implementation and post implementation results [10].

III. Results and Discussion

When presenting and discussing results, give in depth analysis, not only reporting the results.

A. DS18B20 Sensor Validation Results

The result of DS18B20 Sensor testing can be seen in Table I.

TABLE I. DS18B20 Sensor Validation Results

Time	Water Temperature Rises (ºC)		Water Temperature Drops (ºC)	
	DS18B20 Sensor	Digital Termometer	DS18B20 Sensor	Digital Termometer
1	22.54	21.18	64.04	63.61
2	23.08	22.13	56.97	56.36
3	24.11	23.51	55.06	54.41
4	25.17	24.52	53.11	52.13
5	26.0	25.47	50.92	50.0
6	26.5	26.36	48.34	47.43
7	27.5	27.16	46.11	45.83
8	28.2	27.9	43.83	43.71
9	28.97	29.1	41.11	37.25
10	29.62	29.5	38.21	35.4
11	29.81	29.8	36.1	33.91
12	35.81	35.05	34.53	31.3
13	38.3	37.68	32.2	30.33
14	41.34	41.13	30.39	29.5
15	42.42	42.23	29.62	29.5
16	43.47	43.5	28.2	27.9
17	50.04	49.36	26.0	26.62
18	53.53	52.71	26.62	26.46
19	56.71	56.18	26.0	25.47
20	57.47	57.58	25.17	24.52
21	64.68	64.67	24.82	24.78
22	69.49	69.41	24.67	24.65
Average	**38,39**	**38,05**	**38,32**	**37,81**
Error (%)	**0,89%**		**1,34%**	
Accuracy (%)	**99,11%**		**98,66%**	

Table I presents the validation results of the DS18B20 sensor for measuring water temperature, compared with readings from a Digital Thermometer. The sensor demonstrated high reliability, with an average error of 0.89% for increasing temperatures and 1.34% for decreasing temperatures, reflecting a minimal difference between the two devices. The accuracy of the DS18B20 sensor was 99.11% for increasing temperatures and 98.66% for decreasing temperatures, indicating that the sensor provides precise and consistent data. These results suggest that the DS18B20 sensor is highly reliable for applications requiring accurate temperature measurements, such as in fermentation or hydroponic systems. The slight variation in error percentages between increasing and decreasing temperatures could be attributed to potential calibration variations or external environmental factors. Overall, the DS18B20 sensor's performance in temperature monitoring demonstrates its suitability for use in IoT based systems where real time data accuracy is critical, and its high accuracy makes it a dependable choice for precise temperature control. Further calibration and testing across different conditions may enhance its effectiveness in more diverse applications.

TABLE II. pH Sensor 4502-C Validation Results

Run	Acid Buffer (4.00)		Neutral Buffer (6.86)		Base Buffer (9.18)	
	Sensor pH 4502-c	Water Quality Tester	Sensor pH 4502-c	Water Quality Tester	Sensor pH 4502-c	Water Quality Tester
1	3,99	3,92	6,69	6,86	9,39	9,25
2	3,98	3,91	6,7	6,86	9,44	9,26
3	3,93	3,91	6,74	6,86	9,34	9,26
4	3,9	3,9	6,76	6,85	9,47	9,26
5	3,91	3,9	6,77	6,85	9,5	9,26
6	3,9	3,9	6,79	6,85	9,52	9,26
7	3,88	3,9	6,79	6,85	9,54	9,26
8	3,93	3,9	6,8	6,85	9,49	9,26
9	3,87	3,89	6,78	6,84	9,53	9,26
10	3,87	3,89	6,79	6,84	9,52	9,26
11	3,89	3,89	6,83	6,84	9,54	9,26
12	3,85	3,89	6,82	6,84	9,55	9,26
Average	**3,9**	**3,9**	**6,77**	**6,84**	**9,49**	**9,26**
Error (%)	**0%**		**1,02%**		**2,48%**	
Accuracy (%)	**100%**		**98,98%**		**97,52%**	

Table II. presents the validation results of the pH Sensor 4502-C in the Drum Fermentor, comparing the sensor's readings with a Water Quality Tester under three different buffer conditions: acidic (pH 4.00), neutral (pH 6.86), and basic (pH 9.18). The sensor exhibited 0% error in the acidic buffer, indicating accurate readings, while the error was slightly higher at 1.02% in the neutral buffer and 2.48% in the basic buffer. Despite the small errors, the sensor maintained high accuracy, achieving 100% accuracy in the acidic buffer, 98.98% accuracy in the neutral buffer, and 97.52% accuracy in the basic buffer. These results suggest that the pH Sensor 4502-C is highly reliable, particularly in acidic and neutral conditions, with minimal error even in basic pH ranges. The slight increase in error at higher pH levels may be due to the sensor's calibration or environmental factors. Overall, the sensor demonstrates strong potential for use in applications requiring precise pH monitoring, such as in fermentation processes, and its high accuracy makes it suitable for integration into automated monitoring systems. Further testing across diverse conditions could provide deeper insights into optimizing its performance for a broader pH range.

TABLE III. validation results of the pH Sensor 4502-C

Run	Acid Buffer (4.00)		Neutral Buffer (6.86)		Base Buffer (9.18)	
	Sensor pH 4502-c	Water Quality Tester	Sensor pH 4502-c	Water Quality Tester	Sensor pH 4502-c	Water Quality Tester
1	3,89	3,89	4,71	6,85	9,23	9,24
2	3,96	3,92	6,7	6,86	9,31	9,31
3	3,93	3,92	6,73	6,86	9,2	9,26
4	3,88	3,92	6,73	6,86	9,23	9,26
5	3,91	3,91	6,73	6,85	9,23	9,26
6	3,9	3,91	6,79	6,85	9,3	9,25
7	3,92	3,92	6,8	6,87	9,3	9,25
8	3,9	3,91	6,84	6,85	9,33	9,25
9	3,86	3,88	6,84	6,83	9,32	9,26
10	3,89	3,87	6,78	6,8	9,33	9,26
11	3,88	3,88	6,83	6,84	9,35	9,26
12	3,87	3,89	6,84	6,84	9,34	9,26
Rata-rata	**3,89**	**3,9**	**6,77**	**6,84**	**9,28**	**9,26**
Error (%)	**0,002%**		**0,01%**		**0,002%**	
Accuracy (%)	**99%**		**98,99%**		**99%**	

The data in Table III. presents the validation results of the pH Sensor 4502-C in measuring water pH under three different buffer conditions: acidic (pH 4.00), neutral (pH 6.86), and basic (pH 9.18). The sensor's measurements are compared to the readings from a Water Quality Tester. The average error across all trials was 0.002% for the acidic buffer, 0.01% for the neutral buffer, and 0.002% for the basic buffer. The accuracy for the sensor was found to be 99% for the acidic buffer, 98.99% for the neutral buffer, and 99% for the basic buffer, demonstrating a high level of precision and consistency across different pH levels. These results indicate that the pH Sensor 4502-C performs reliably, with minimal error, making it a highly accurate tool for pH measurements in various applications, including fermentation processes where precise pH control is essential. The sensor's low error rate and high accuracy further support its suitability for integration into automated systems requiring real time pH monitoring and control.

IV. Conclusion

This study has successfully demonstrated the integration and validation of DS18B20 and 4502-C sensors within an Internet of Things based automated liquid organic fertilizer and hydroponic monitoring system. The DS18B20 temperature sensor exhibited high precision, with average accuracy values of 99.11% during heating and 98.66% during cooling, supported by minimal error margins, thus confirming its applicability for thermal regulation in bioprocess environments. In parallel, the 4502-C pH sensor delivered consistently accurate readings across acidic, neutral, and alkaline buffer conditions, with recorded accuracies ranging from 97.52% to 100%, thereby affirming its suitability for real time pH monitoring in both fermentation and hydroponic contexts. These results validate the robustness and reliability of the sensor configuration, enabling accurate environmental control critical for microbial stability in fertilizer production and optimal nutrient uptake in plant systems. Furthermore, the integration of these sensors into an IoT platform enhances the system's operational responsiveness and allows remote monitoring and adaptive control, thus offering a scalable solution for precision agriculture. The findings substantiate the system's potential to reduce manual labor, improve data driven decision making, and increase the overall sustainability and productivity of modern farming practices. Future research should focus on long term deployment scenarios, sensor drift analysis, and the inclusion of adaptive algorithms for autonomous system calibration under dynamic field conditions.

Acknowledgment

The authors would like to express their sincere gratitude to the following individuals and institutions for their invaluable contributions to the success of this project:

1. **Institut Teknologi Sepuluh Nopember (ITS):** Our heartfelt thanks to Institut Teknologi Sepuluh Nopember for providing the necessary resources, facilities, and academic support. The project was made possible through the guidance and support of faculty members and the use of the university's laboratories and equipment.
2. **Research and Development Team:** A special thanks to the research and development team at Institut Teknologi Sepuluh Nopember, including Muhammad Ivan Hermawan and Firda Anandhita, for their expertise in system design, IoT integration, and data analysis. Their contributions were crucial to the technical development of the system.

REFERENCES

[1] S. Rajendran, T. Domalachenpa, H. Arora, P. Li, A. Sharma, and G. Rajauria, "Hydroponics: Exploring innovative sustainable technologies and applications across crop production, with Emphasis on potato mini-tuber cultivation," *Heliyon*, vol. 10, no. 5, p. e26823, 2024, doi: 10.1016/j.heliyon.2024.e26823.

[2] M. Zaib *et al.*, "A Review on Challenges and Opportunities of Fertilizer Use Efficiency and Their Role in Sustainable Agriculture with Future Prospects and Recommendations," *Curr. Rese. Agri. Far*, vol. 4, no. 4, pp. 1–14, 2023, [Online]. Available: http://dx.doi.org/10.18782/2582-7146.201

[3] V. Kumar, K. V. Sharma, N. Kedam, A. Patel, T. R. Kate, and U. Rathnayake, "A comprehensive review on smart and sustainable agriculture using IoT technologies," *Smart Agric. Technol.*, vol. 8, no. February, p. 100487, 2024, doi: 10.1016/j.atech.2024.100487.

[4] K. Duanhpakdee, G. Thananta, and S. Sukpancharoen, "IoT Enhanced Deep Water Culture Hydroponic System for Optimizing Chinese Celery Yield and Economic Viability," *Smart Agric. Technol.*, vol. 9, no. August, p. 100545, 2024, doi: 10.1016/j.atech.2024.100545.

[5] A. S. Rathor, S. Choudhury, A. Sharma, P. Nautiyal, and G. Shah, "Empowering vertical farming through IoT and AI-Driven technologies: A comprehensive review," *Heliyon*, vol. 10, no. 15, p. e34998, 2024, doi: 10.1016/j.heliyon.2024.e34998.

[6] S. D. Kalamaras, M. A. Tsitsimpikou, C. A. Tzenos, A. A. Lithourgidis, D. S. Pitsikoglou, and T. A. Kotsopoulos, "A Low-Cost IoT System Based on the ESP32 Microcontroller for Efficient Monitoring of a Pilot Anaerobic Biogas Reactor," *Appl. Sci.*, vol. 15, no. 1, 2025, doi: 10.3390/app15010034.

[7] O. Ogbolumani and B. Mabaso, "An IoT-Based Hydroponic Monitoring and Control System for Sustainable Food Production," *J. Digit. Food, Energy Water Syst.*, vol. 4, no. 2, pp. 106–140, 2023, doi: 10.36615/digital_food_energy_water_systems.v4i2.2873.

[8] H. M. Forhad *et al.*, "IoT based real time water quality monitoring system in water treatment plants (WTPs)," *Heliyon*, vol. 10, no. 23, p. e40746, 2024, doi: 10.1016/j.heliyon.2024.e40746.

[9] L. Kumar and S. R. Gupta, "Improving Agricultural Productivity through IoT-Based Hydroponic Systems: Literature Review & Prototype Study," *Res. Sq.*, 2024, [Online]. Available: https://doi.org/10.21203/rs.3.rs-3889989/v1

[10] H. Shahab, M. Iqbal, A. Sohaib, F. Ullah Khan, and M. Waqas, "IoT-based agriculture management techniques for sustainable farming: A comprehensive review," *Comput. Electron. Agric.*, vol. 220, no. October 2023, p. 108851, 2024, doi: 10.1016/j.compag.2024.108851.