International Journal of Applied Research and Sustainable Sciences (IJARSS)
Vol. 3 No. 11, 2025: 885-894

Implementation of Internet of Things (IoT) and Renewable Energy Technologies in an Automated Monitoring System for Tilapia Fish Aquaculture to Achieve Food and Energy Independence

Abdullah[1*], Arridina Susan Silitonga[2], Abdi Hanra Sebayang[3], Moh. Zainul Haq[4], Cholish[5], Nor Aizam bt Muhamed Yusof[6], Naufal Ihsan[7], Akbar Fiki[8], Ajai Dhanratz[9]

[1-5, 7-9]Politeknik Negeri Medan
[6]Politeknik Tuanku Sultanah Bahiyah
Corresponding Author: Abdullah abdullah@polmed.ac.id

A R T I C L E I N F O

Keywords: Tilapia Aquaculture, Automation, Monitoring, Internet of Things, Renewable Energy

Received : 09 September
Revised : 09 October
Accepted: 10 November

A B S T R A C T

Tilapia aquaculture faces challenges related to energy efficiency, water quality stability, and operational management, which is still largely performed manually and therefore lacks sustainability. This study aims to develop an automated and Internet of Things (IoT)-based monitoring system for tilapia aquaculture by integrating IoT technologies with renewable energy. The system is designed with a filtration mechanism to maintain optimal water quality and is equipped with pH, TDS, and temperature sensors, as well as a solar panel power-monitoring module integrated with IoT for real-time supervision and control. The system's energy is supplied by a four-sided reflective solar panel configuration optimized to enhance light absorption efficiency. Experimental results show that the system is capable of maintaining water pH within the range of 6.5–7.2, TDS between 280 and 320 ppm, and temperature between 27 and 30°C. The solar panel provides stable power to support all automation components. The integration of automation, IoT, and solar energy has been proven to improve operational efficiency and maintain environmental quality in the aquaculture system.

DOI: https://doi.org/10.59890/ijarss.v3i11.140
E – ISSN : 3026-0205
https://jpnmultitechpublisher.my.id/index.php/ijarss/index

INTRODUCTION

Tilapia aquaculture is one of the key sectors supporting national food security and self-sufficiency in Indonesia. However, conventional aquaculture practices still encounter several fundamental challenges, including suboptimal water quality management, high electrical energy consumption, reliance on manual supervision, and inefficiencies in resource management. These conditions often lead to reduced productivity, increased operational costs, and diminished environmental carrying capacity. Such challenges indicate the need for an innovative approach that is smarter, more efficient, and sustainable to improve the quality and long-term viability of tilapia aquaculture (Sofiah et al., 2023).

The implementation of automation and monitoring systems based on advanced technologies represents a strategic step toward addressing these issues. Automated monitoring systems enable real-time control of water circulation, feeding, and water quality monitoring, thereby reducing manual intervention and minimizing the potential for human error (Wijaya, Syauqy, & Primananda, 2024). In tilapia aquaculture, parameters such as pH, temperature, and TDS play a crucial role in maintaining fish health, while monitoring solar panel power consumption allows for the optimization of energy use in a sustainable manner. The integration of these technologies promotes rapid responses to changes in water conditions and enhances operational efficiency (Manurun, Abdullah, Haris, & Sitorus, 2023).

As the demand for energy-efficient aquaculture systems increases, the utilization of renewable energy technologies—particularly solar panels—has become an important solution to support energy independence. The use of solar panels not only reduces electricity costs but also ensures that the system can operate autonomously, even in areas far from the electrical grid. The combination of renewable energy technologies and the Internet of Things (IoT) connects sensors and actuators within a unified interface, providing real-time information and enabling remote control through an application (Hidayatullah, Darmawan, & Maulidyawati, 2025).

In this study, a programmable automation system was developed to monitor water quality parameters such as pH, TDS, and temperature, as well as to periodically monitor solar panel power output. Sensors connected to the controller transmit data to the IoT interface, allowing water conditions to be viewed in real-time and enabling remote adjustments, including automatic water refilling when the volume decreases and scheduled feeding. The entire system is powered by reflective solar panels capable of optimizing energy absorption even with variations in the sun's angle of incidence, making the system energy-efficient, adaptive, and highly suitable for small-scale independent aquaculture operations. Thus, the implementation of IoT and renewable energy technologies in this automated monitoring system can support food and energy self-sufficiency while contributing significantly to the sustainability of Indonesia's aquaculture sector.

LITERATURE REVIEW

Tilapia is one of the main freshwater aquaculture commodities in Indonesia. This species exhibits high environmental adaptability, rapid growth, good feed efficiency, and stable market demand throughout the year. In intensive aquaculture systems, production success is strongly influenced by the stability of water quality parameters, including temperature, pH, TDS, and organic matter content. A decline in water quality caused by feed residues, fish metabolites, or environmental pollution can inhibit growth and increase stress levels and fish mortality (Pribadi et al., 2024). Therefore, accurate and continuous water-quality monitoring systems are essential for maintaining productivity. The use of technologies such as automatic sensors and IoT-based monitoring systems has been proven to keep water parameters stable, thus supporting the sustainability of tilapia aquaculture, especially in intensive and high-density stocking systems (Pradani, Fitriani, & Herasmara, 2022) (Kurniawan & Gani, 2023).

A. Internet of Things (IoT) in Monitoring and Control Systems

The Internet of Things (IoT) is a technology that enables physical devices to connect through the internet to transmit data, receive commands, and perform automated control. Within tilapia aquaculture, IoT plays a crucial role in enhancing efficiency, improving monitoring accuracy, and reducing dependence on manual supervision. An IoT system integrates sensors that measure water quality parameters such as pH, temperature, TDS, and water level. In addition, IoT is used to monitor the power consumption of solar panels as the energy source for the system. (Mahendra, Abas, Syahrial, & Pranata, 2025). Sensor data are transmitted to a server or cloud platform and displayed in real time through web- or mobile-based applications, allowing farmers to monitor culture conditions anytime and anywhere. IoT also supports the automation of actuators such as water pumps, water-inlet valves, aerators, and automatic feeders based on predefined schedules or rules. This creates a smart aquaculture ecosystem capable of responding more quickly to environmental changes, reducing the risk of human error, and improving the stability of the cultivation environment (Harahap, 2023).

B. Renewable Energy Technology in Aquaculture Systems

Renewable energy technologies, particularly solar panels, offer a strategic solution to support energy self-sufficiency in aquaculture systems. Solar panels operate by converting sunlight into electrical energy through photovoltaic (PV) cells. In the context of automated monitoring systems, solar panels supply power to sensors, microcontrollers, pumps, aerators, and IoT devices (Rudiyanto, Rachmanita, & Budiprasojo, 2023).

The advantages of using solar panels in aquaculture include: Reducing dependence on grid electricity, especially in remote areas, lowering operational costs, as solar energy requires no subscription fees, supporting sustainable aquaculture aligned with environmentally friendly principles and enhancing system reliability, as energy supply can be maintained independently without the risk of power outages. The integration of reflective solar panels or sun-tracking systems can further improve energy absorption efficiency, even when light intensity varies .

C. Integration of IoT and Renewable Energy

The integration of IoT technology with solar-energy systems creates aquaculture operations that are not only intelligent but also energy-independent. The water-quality monitoring system can operate continuously using power supplied by solar panels. Additionally, data on solar panel power consumption and capacity can be monitored in real time, helping farmers ensure the continuity of the energy supply. The concept of food independence can be achieved through more efficient, stable, and sustainable tilapia production. Meanwhile, energy independence is realized through the utilization of solar energy as the primary resource. The integration of these technologies supports the goals of modern aquaculture development, which aims to be climate-adaptive, energy-efficient, and capable of improving the livelihoods of aquaculture communities.

METHODOLOGY

In general, the method used in this study consists of hardware design and software development for the implementation of the Internet of Things (IoT) and renewable energy technologies in an automated monitoring system for tilapia aquaculture to achieve food and energy independence. The research integrates tilapia cultivation with automation technology, water-quality monitoring, and the efficient utilization of renewable energy. The system is equipped with IoT-based automation to monitor and control water parameters in real time, including pH, TDS, temperature, and solar panel output power. The sensors transmit data to a microcontroller, which is then displayed through an IoT application. The entire system is powered by solar panels to ensure efficient light absorption and reliable energy supply.

A. Research Design

The research design to be carried out can be seen in the Overall System Design Diagram below:

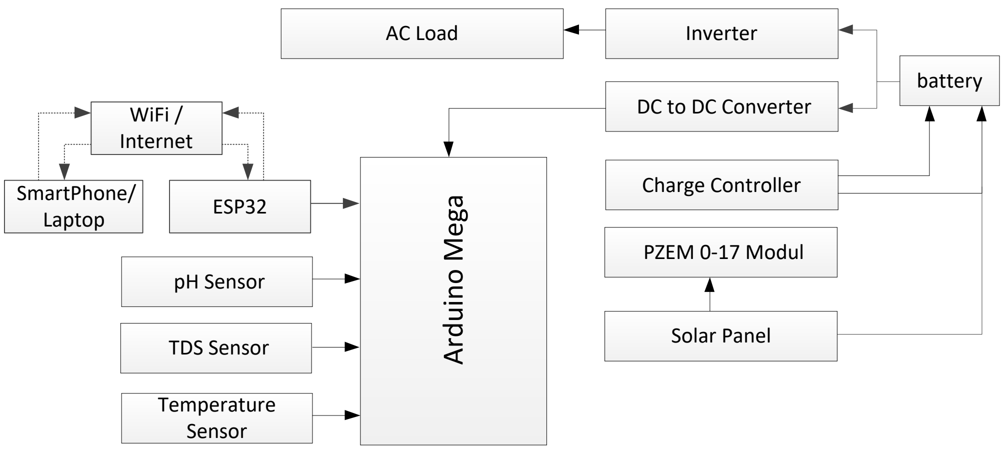

Figure1 . Overall System Design Diagram

Based on the system design diagram above, the system is intended for the implementation of the Internet of Things (IoT) and renewable energy technologies in an automated monitoring system for tilapia aquaculture to achieve food and energy independence. Pond water is circulated through a filtration system, and the pH, TDS, and temperature sensors send data to the Arduino for analysis, which is then displayed via a smartphone- or laptop-based application through an ESP32 connection. This application enables remote monitoring and control. The system's energy is supplied by a solar panel equipped with four reflective mirrors to increase light absorption efficiency. The energy is stored in a battery through a charge controller, then distributed via a converter and inverter to power AC loads. Power consumption is monitored using the PZEM-017 module. The entire system is designed to be efficient, energy-independent, and supportive of sustainable food production.

The software development process was carried out using the Arduino IDE to program both the Arduino Mega and ESP32. Through the Arduino IDE, configurations were implemented for sensor data acquisition, processing of pH, TDS, and temperature values, as well as data transmission using a stable communication protocol between the Arduino and ESP32. In addition, the software includes automation logic such as pump control, critical condition notifications, and remote operation through the application. Data integration into the Blynk IoT platform allows all information to be displayed in real time on a digital dashboard, including water-quality trend graphs, battery status, solar-panel power output, and control buttons for operating equipment such as pumps and the water-filling system. The Blynk application enables users to monitor cultivation conditions at any time and from any location via the internet.

The final stage of the methodology involves comprehensive system testing to ensure sensor accuracy, IoT communication stability, and the reliability of the solar-energy supply. The pH, TDS, and temperature sensors are tested and calibrated using laboratory-grade standards, while the energy system is evaluated under varying weather conditions to assess the solar panel's ability to maintain power supply. IoT testing is conducted by observing connection stability, data-update speed on the Blynk application, and actuator responsiveness to remote commands. Overall, this research methodology is designed to produce an automated monitoring system that is efficient, adaptive, energy-independent, and capable of supporting sustainable food production through modern and integrated tilapia aquaculture.

RESEARCH RESULT

The results and discussion of the research titled Implementation of the Internet of Things (IoT) and Renewable Energy Technologies in an Automated Monitoring System for Tilapia Aquaculture to Achieve Food and Energy Independence consist of three categories of testing: Water-Quality Sensor Testing, Solar Panel Performance Testing, and IoT-Integrated Tilapia Aquaculture Monitoring Testing.

A. Water-Quality Sensor Testing

The water-quality sensor testing presents the measurement results of key water parameters, including pH, TDS (Total Dissolved Solids), and temperature. The data were obtained from sensors integrated into the Internet of Things (IoT) monitoring system. These parameters are essential for maintaining optimal water conditions for tilapia growth, as any fluctuation in water quality can directly affect fish health and growth rate. The measurement results are shown in Table 1 as follows:

Table 1. Water-Quality Sensor Data

Time	pH	TDS (ppm)	Temparature (°C)
06:00	7.81	491	27.68
07:00	7.41	376	27.22
08:00	6.80	399	28.61
09:00	7.36	500	28.02
10:00	7.49	429	26.06
11:00	7.61	308	28.14
12:00	7.80	496	27.46
13:00	7.88	465	27.50
14:00	7.50	498	27.44
15:00	7.24	482	26.97
16:00	7.16	500	30.00
17:00	7.67	483	26.79

Based on the testing results shown in Table 1, the measurements indicate that the pH values ranged from 6.8 to 7.88, reflecting neutral conditions suitable for tilapia. The TDS values ranged from 376 to 500 ppm, indicating relatively clear water with dissolved solid levels that remain within the safe threshold. The water temperature remained stable between 27°C and 30°C, which is the optimal range for tilapia metabolism. These results demonstrate that the monitored water-quality parameters remained within the ideal limits for tilapia aquaculture. The integration of sensors with the IoT system proved effective in detecting and adjusting to environmental changes in real time.

B. Solar Panel Testing for Tilapia Aquaculture Operation

This test was conducted to evaluate the performance of the solar panel system used to support the operational needs of tilapia aquaculture. The test results are presented in Table 2 below.

Table 2. Solar Panel Testing Results

Time	Solar Panel			Weather Status
	Voltage (V)	Current (A)	Power (W)	
08:00	18,13	0,25	4,61	Cloudy
09:00	18,59	0,28	5,28	Sunny
10:00	18,66	0,29	5,49	Sunny
11:00	19,38	0,44	8,61	Sunny
12:00	19,84	0,70	13,97	Sunny
13:00	20,10	0,87	17,57	Sunny
14:00	18,67	0,79	14,83	Sunny
15:00	18,47	0,67	12,45	Cloudy
16:00	18,42	0,44	8,18	Cloudy
17.00	18,30	0,33	6,12	Cloudy

Based on the tests conducted, it can be observed that the solar panel operated effectively in supplying power to the entire system for monitoring tilapia aquaculture operations.

C. IoT-Integrated Tilapia Aquaculture Monitoring Test

The testing of the Implementation of the Internet of Things (IoT) and Renewable Energy Technologies in an Automated Monitoring System for Tilapia Aquaculture to Achieve Food and Energy Independence is an evaluation process designed to assess the system that integrates IoT technology for real-time monitoring and management of tilapia aquaculture. In this system, relevant data are transmitted through the IoT network for analysis. This test aims to ensure that the tilapia aquaculture monitoring system operates properly and reliably. The IoT-integrated monitoring results can be seen in Figure 2 as follows.

Figure 2. Monitoring Results of Tilapia Aquaculture

Based on the tests performed, all data from the Implementation of the Internet of Things (IoT) and Renewable Energy Technologies in an Automated Monitoring System for Tilapia Aquaculture to Achieve Food and Energy Independence can be effectively monitored and controlled within a single Blynk application integrated with the IoT system.

DISCUSSION

The research results indicate that the integration of an IoT-based automation system and renewable energy in tilapia aquaculture provides a significant improvement in operational efficiency and water quality stability. Real-time sensor data allows the system to respond quickly to environmental changes, ensuring that pond conditions remain optimal without requiring intensive manual intervention. The performance of the reflective solar panel also demonstrates its ability to supply consistent energy, supporting the sustainability of the closed-loop recirculation system. These findings confirm that the application of smart technologies and clean energy can strengthen the concept of smart aquaculture that is more efficient, independent, and adaptive to environmental variability.

CONCLUSIONS AND RECOMMENDATIONS

The conclusion of this research is that the implementation of the Internet of Things (IoT) and renewable energy technologies in an automated monitoring system for tilapia aquaculture successfully supports the achievement of food and energy independence. The test results show that the pH, TDS, temperature sensors, as well as solar panel power monitoring, are able to provide accurate real-time information. In addition, the use of solar panels has proven effective in supplying an independent energy source for the system, with stable voltage (V), current (I), and power (P) parameters under various weather conditions. Overall, the integration between IoT technology and renewable energy produces a closed-loop recirculation system that is energy-efficient, environmentally friendly, and supports improved productivity and sustainability in tilapia aquaculture.

ADVANCED RESEARCH

This study represents advanced research aimed at developing a smart automation-based tilapia aquaculture system through the integration of IoT and renewable energy to enhance efficiency, water quality stability, and energy independence. By monitoring pH, TDS, temperature, ammonia, and water level parameters in real time, the system can execute precise automatic responses to changes in pond environmental conditions. Additionally, the optimized use of solar panels strengthens sustainability by providing a stable, independent energy supply under various weather conditions. This advanced research offers an innovative approach to realizing energy-efficient, adaptive smart aquaculture that supports the sustainable improvement of tilapia production.

ACKNOWLEDGMENT

The author would like to thank the Medan State Polytechnic for the funding provided through Contract: B/386/PL5/PT.01.05/2025 which comes from DIPA POLMED funds for 2025.

REFERENCES

Harahap, H. A. (2023). Rancang Bangun Sistem Kontrol Kolam Ikan Nila Berbasis Out Seal PlC. *Jurnal Universal Technic, 2*(1), 1-10.

Hidayatullah, M., Darmawan, I., & Maulidyawati, D. (2025). RANCANG BANGUN ALAT PEMBERIAN PAKAN IKAN OTOMATIS BERBASIS INTERNET of THINGS (IoT) MENGGUNAKAN PANEL SURYA. *Journal Altron; Journal of Electronics, Science & Energy systems, 4*(1), 8-16.

Kurniawan, A., & Gani, A. (2023). Penerapan Model Pengembangan Usaha Budidaya Ikan Nila (Oreochromis niloticus) Pada Masyarakat Distrik Sekanto. *Dinamisia: Jurnal Pengabdian Kepada Masyarakat, 7*(3), 872-877.

Mahendra, B. I., Abas, M. I., Syahrial, S., & Pranata, W. E. (2025). Rancang bangun pengaturan pakan ikan nila berbasis internet of things. *Jurnal Ilmu Komputer (JUIK), 5*(1), 20-35.

Manurun, A. A., Abdullah, A., Haris, M., & Sitorus, N. (2023). Peningkatan Kualitas Pembudidayaan Ikan Nila dengan Sistem Automatisasi Berbasis Internet Of Things. *RELE (Rekayasa Elektrikal dan Energi): Jurnal Teknik Elektro, 5*(2), 117-123.

Pradani, E. R. K., Fitriani, I. M., & Herasmara, R. (2022). Perancangan sistem pemantauan kondisi air pada kolam ikan nila berbasis Internet of Thing. *Metrotech (Journal of Mechanical and Electrical Technology), 1*(3), 111-116.

Pribadi, W., Rezika, W. Y., Ciptaningrum, A., Asngali, B., Saskya, L. F., Yudhiatama, G. D., . . . Pangestu, D. S. (2024). PELATIHAN OPERASIONAL SMART AUTOMATION FISHERY UNTUK BUDIDAYA IKAN AIR TAWAR DENGAN TENAGA SURYA. *Adimas: Jurnal Pengabdian Kepada Masyarakat, 8*(1), 11-26.

Rudiyanto, B., Rachmanita, R. E., & Budiprasojo, A. (2023). *Dasar-Dasar Pemasangan Panel Surya*: unisma press.

Sofiah, L., Jumadi, J., Agustini, A., Putra, I. M., Masriyadi, M., Kardi, K., . . . Yusuf, F. A. (2023). Pemberdayaan kelompok pemuda dalam budidaya ikan nila. *Batara Wisnu: Indonesian Journal of Community Services, 3*(2), 320-326.

Wijaya, J., Syauqy, D., & Primananda, R. (2024). Sistem Monitoring Dan Rekomendasi Kualitas Air Budidaya Bibit Ikan Nila Menggunakan Parameter Kekeruhan, Suhu, Dan PH Dengan Algoritma Random Forest. *Jurnal Pengembangan Teknologi Informasi dan Ilmu Komputer, 8*(3).