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Design of Internet of Thing (IoT)-based Control and Monitoring System of Eco-Aquaculture

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***Abstract*— Aquaculture plays a vital role in global food supply, contributing nearly 43% of the food consumed by humans. The rapid growth in aquaculture production demands a significant amount of electricity, which accounts for approximately 40% of the total energy costs. The primary energy sources in aquaculture used fossil fuels, it can be reduced by utilizing alternative energy sources. This research aims to develop a prototype of a floating net cage using an Internet of Things (IoT)-based water quality monitoring system powered by solar energy. The water quality parameters monitored in this study include temperature, pH, salinity, and dissolved oxygen levels. The sensors used for monitoring these parameters have undergone testing. The results indicate that the sensors can perform accurate measurements with over 90% accuracy. The solar panels installed in the system are capable of generating sufficient power to meet the operational demands, allowing the system to operate for approximately two days without sunlight. By maintaining well-controlled aquatic environmental conditions through IoT-based monitoring and control systems supported by renewable photovoltaic solar energy, environmentally friendly aquaculture operations can be conducted efficiently and productively. Ultimately, this leads to the production of high-quality aquaculture products, cost-effective operations, and the utilisation of eco-friendly energy sources.**

Keywords— Control System, Eco-aquaculture, Environmental quality, Monitoring System, Renewable Energy

I. INTRODUCTION

Aquaculture is the practice of cultivating fish and other marine organisms in a controlled environment, ensuring both their growth and sustainability [1]. This industry holds significant development potential in Indonesia, given that a large portion of the country is comprised of marine areas. Indonesia spans approximately 7.9 million square kilometres, consisting of 1.8 million km² of land and 3.2 million km² of territorial waters. With an extensive coastline of around 105,000 km across its many islands, there is considerable opportunity to expand marine aquaculture. This activity is commonly carried out using floating net cages (FNCs) in coastal waters and around small islands, with key commodities including shrimp, grouper, and various other species, as illustrated in Figure 1.

Aquaculture is a vital component of the global food supply, contributing approximately 43% of the total food consumed by humans [1]. Aquaculture involves the cultivation of various aquatic species such as fish, crustaceans, and molluscs for commercial purposes. According to the Food and Agriculture Organization, global aquaculture production reached a record high of 114.5 million tonnes in live weight in 2018, with a market value of USD 263.6 billion [2]. The rapid growth of aquaculture requires a substantial amount of electricity to operate ponds and floating net cages, accounting for approximately 40% of the total energy costs. The primary energy sources for these operations include petrol, diesel, and other fossil fuels. However, the associated energy expenses and carbon emissions have become major concerns.

In marine aquaculture, electricity plays a vital role in operating various environmental monitoring devices, such as sensors for temperature, salinity, pH levels, and dissolved oxygen, as well as other equipment essential for effective aquaculture management. Solar energy, recognised as one of the cleanest and most promising renewable energy sources globally, offers numerous advantages. It reduces CO_2 emissions, combats global warming through environmentally friendly energy production, and provides an innovative and cost-effective solution for sustainable aquaculture. As a renewable energy source, solar power is eco-friendly and does not contribute to global warming. It is harnessed as electromagnetic radiation from the sun and converted into thermal or electrical energy through mechanical systems [3], [4].

The aquaculture process today has undergone significant advancements across various parts of the world, particularly through the adoption of more sophisticated technologies. These innovations contribute to the production of higher-quality yields and enable more efficient operational processes. The use of the Internet of Things (IoT) in aquaculture has become increasingly widespread as a means of monitoring water quality. This is achieved by utilising various water quality parameters, including temperature, pH level, dissolved oxygen, salinity, ammonia concentration, and water level [5], [6], [7], [8]. In its implementation, various challenges arise, one of which is the electricity

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demand required as the main power source for the existing IoT installations. Consequently, several studies have proposed the use of renewable energy sources, particularly through the application of solar panels, as a sustainable solution [9], [10]. This study aims to develop a prototype of a floating net cage by integrating Internet of Things (IoT) technology for water quality monitoring and utilizing solar panels as the main energy source. This prototype represents a further advancement of previous research [11], and it is expected that, in the future, the outcomes of this developed prototype will contribute to enhancing both the quality of aquaculture processes and products in general, particularly in the context of Indonesia.

Figure. 1. Marine Aquaculture and Measurement of Water Quality

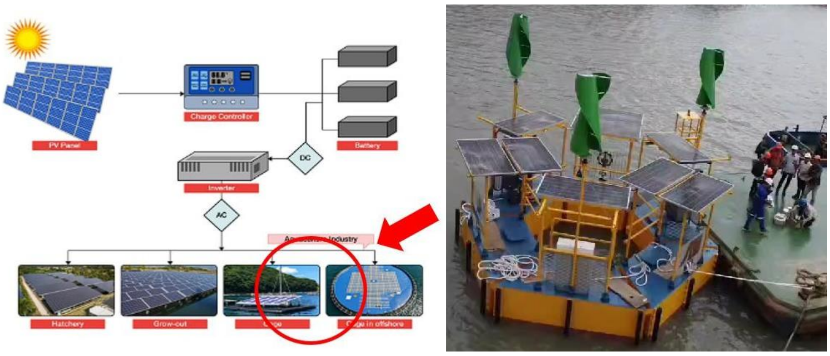


Figure. 2. Develoment of Renewable Energy in Aquaculture (a) Photovoltaic for Aquaculture (b) Multi Purpose Floating Platform

II. Method

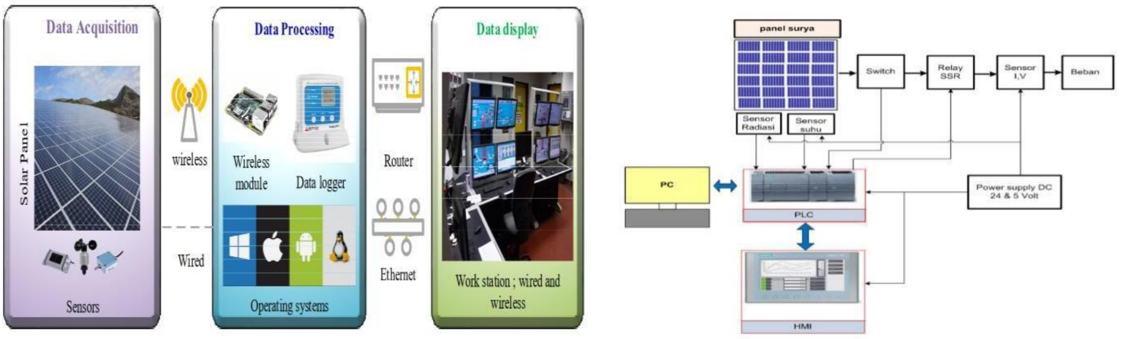
A. Literature Review

Based on the results of the literature review, there are various research themes related to the design and use of IoT for monitoring water quality in the field of aquaculture. The application of IoT in aquaculture has been carried out through the design of prototypes for water quality monitoring, including in the cultivation of guppy fish [8], tiger shrimp [7], tilapia fish [5], dan barramundi fish [6]. In each prototype developed, there are differences in the selection of water quality parameters being monitored, which are tailored to the needs based on the type of aquatic organisms being cultivated. In guppy fish farming, the water quality parameters used include water temperature, water level, oxygen content, and pH level [8]. In giant tiger shrimp farming, the selected water quality parameter is water temperature, with the aim of comparing two different types of sensors. The use of appropriate sensors is essential in shrimp farming, as an increase in temperature can lead to various serious issues such as stunted growth, reduced productivity, and an increase in mortality rates among the cultured organisms [7].

In tilapia farming, the water quality parameters monitored include pH, water temperature, and water turbidity. The research findings indicate that the IoT prototype designed for monitoring water quality achieved an accuracy rate of over 90% [5]. In barramundi farming, the water quality parameters used include water temperature, pH, oxygen levels, ammonia gas concentration, and salinity. The prototype was designed using low-cost sensors. The study demonstrated that the accuracy of the low-cost sensors could be significantly improved through calibration based on linear regression. The results showed that the accuracy of the calibrated low-cost sensors ranged from 76% to 97% [6].

In designing and utilizing IoT systems in aquaculture, there are various challenges faced by practitioners in the field. These challenges are categorized into three groups based on their scope. The first challenge relates to infrastructure, particularly concerning the power requirements for the IoT system and internet connectivity. The second challenge involves the transmission and storage of data obtained from the IoT system. The third challenge pertains to differences in perceptions, which lead to varying levels of understanding regarding the utilization of IoT systems in aquaculture [12].

In addressing challenges related to infrastructure, several studies have developed prototypes that utilize renewable energy technology, one of which is used to supply power to aerators through solar energy. Aerators are essential equipment in aquaculture practices to maintain oxygen levels in the water. The aerators are designed to harness solar power through solar panels as the primary energy source. The use of solar panels as the power source for aerators can reduce electricity costs, particularly in remote areas, when compared to using fossil fuel-powered generators as the energy source [13]. The use of solar energy as the primary electricity source for IoT systems has been developed in research studies [9], [10]. The use of solar energy has also become a focus in the development of the designed IoT prototype, as the combination of batteries and solar power can meet the daily electricity needs of the prototype [14].



(a) (b)

Figure. 3. Monitoring and Control System (a) System Architecture (b) Block Diagram of Monitoring System

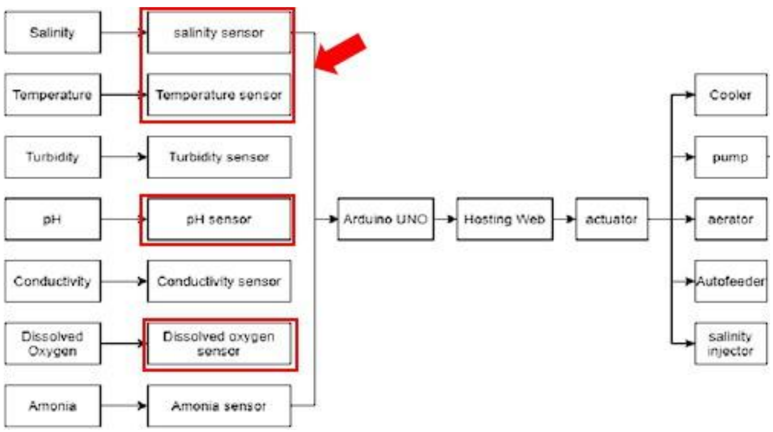


Figure. 4. Block Diagram for Monitoring of Environmental Parameter

Regarding data transmission issues, a data transmission architecture has been developed, which is an enhancement of the generally used IoT architecture. Typically, data transmission in existing IoT prototypes consists of a 3-layer architecture: IoT-edge-cloud. However, this study proposes a 4-layer data transmission architecture. The concept offered involves the integration of sensor technology, storage, data analysis, and communication. Unlike the 3-layer architecture where data is directly stored in the cloud, the proposed difference is the addition of data analysis through the use of machine learning methods [15].

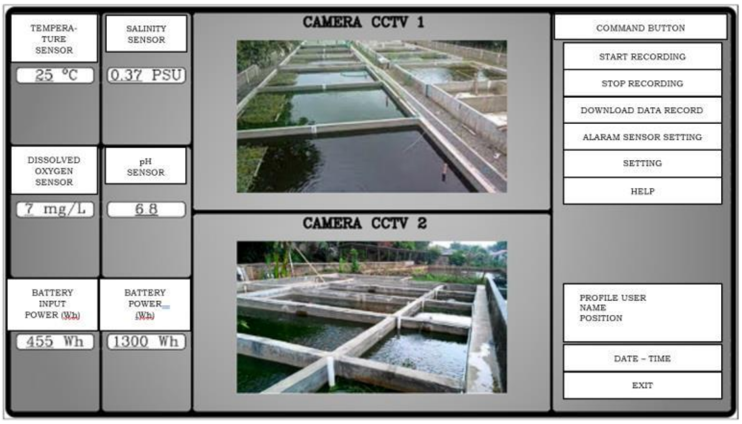


Figure. 5. Design of User Interface.

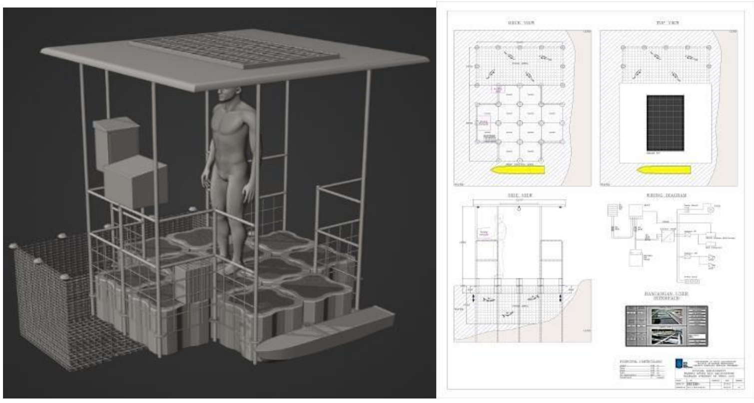


Figure. 6. General Arrangement of Prototype (a) Isometric View (b) General Arrangement

Perception issues are also an important factor to consider when implementing IoT in the aquaculture sector. The majority of stakeholders in the aquaculture industry operate on a small to medium scale. In Indonesia, particularly, small-scale fish farmers represent the most vulnerable community [16]. This is because small to medium-scale fish farmers generally have low levels of education, which affects their ability to maintain sustainable harvests. On the other hand, these farmers typically rely on traditional manual methods to monitor water quality in aquaculture ponds through labor, which incurs additional costs and is prone to errors [17]. Monitoring water quality is an essential step in maintaining the sustainability of fisheries. Therefore, it is recommended that the government also provide facilities aimed at improving the capacity of human resources, particularly fish farmers, in monitoring sustainable aquaculture, as well as other supporting facilities [16].

B. Utilization of Solar PV

A Photovoltaic (PV) system consists of several PV devices, often referred to as PV cells, which use semiconductor materials to convert solar energy into electricity. These interconnected cells form what is known as a PV module. Common PV systems include components such as inverters, batteries, electrical cables, and mounting systems. PV systems can be interconnected to increase their electrical capacity, ranging from a few watts to 100 kW [18]. In recent developments, various types of PV modules have been created based on the semiconductor materials used in the cells [19]. Several PV system configurations are now widely applied, including rooftop systems, canal-top systems, offshore systems, and floating PV systems [20], [21] as shown in Figure 2a.

In previous research conducted under the Kedaireka Program in 2023, as shown in Figure 2b, the Solar Power System (PLTS) was used as the energy source for the Multipurpose Floating Platform [11]. This platform serves as a buoy for the lighthouse at Karang Jamuang, located at the northern boundary of the Madura Strait.

C. Taxonomy of Solar PV Monitoring Systems

The architecture of the solar PV monitoring system consists of three main levels: data acquisition, data processing, and data display and storage. In the data acquisition phase, sensors measure parameters such as voltage, current, temperature, humidity, and radiation, and then transmit the collected information to the next level through wired or wireless communication systems [22]. In the data processing stage, the data is temporarily stored in a data logger, processed, and then sent to the final stage. At the data display and storage level, the processed data is sent to a workstation, allowing the system to perform the necessary configurations. This data can also be accessed remotely via the internet, providing real-time monitoring capabilities from any location.

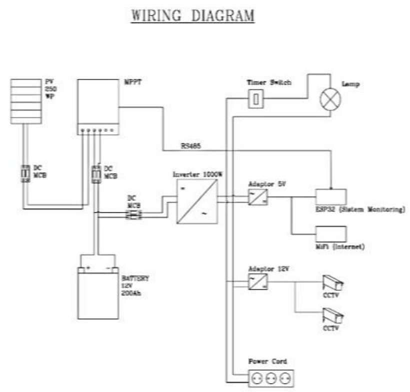


Figure. 7. Electrical Installation Circuit

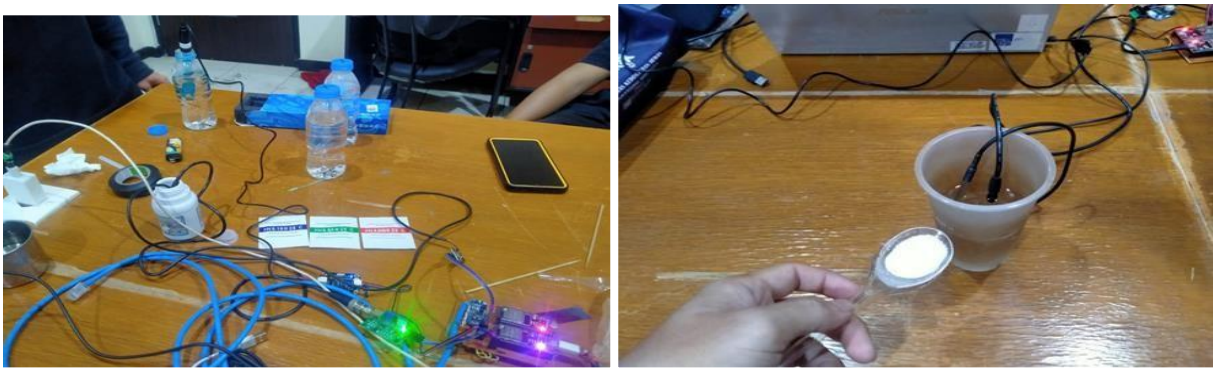


Figure. 8. Sensor Testing Process

Studies have extensively analyzed the data processing modules and transmission protocols used in solar PV monitoring systems. These modules facilitate real-time data acquisition, device control, and network management by acting as intermediaries that integrate various devices using cloud computing technology [23]. Typically, solar-powered monitoring systems operate on a four-layer framework. The sensor layer collects electrical and environmental data, including panel voltage, current, temperature, and humidity [24]. The network layer monitors data transmission through protocols such as ZigBee, Wi-Fi, Bluetooth, or LoRa. The data processing layer utilizes hardware such as Raspberry Pi or Arduino to handle the acquired data. Finally, the application layer provides an interface that connects end devices to the network, as illustrated in Figure 3a.

D. Monitoring and Control System Development

The design method for this equipment consists of several stages, starting with hardware design to determine the components required to create a device or system aimed at solving specific problems. As shown in Figure 3b, the block diagram of the solar panel monitoring system includes the Human Machine Interface (HMI) and Programmable Logic Controller (PLC), both of which require a 24-volt DC input. The parameters to be monitored include voltage, current, power, solar radiation on the panel surface, and panel temperature [25]. Data for these parameters are collected through sensors, processed by the PLC, and then displayed on the HMI screen. Monitoring these parameters provides valuable insights for designing an effective control and monitoring system.

E. Design of Sensor System

The quality of the marine environment is a crucial factor in determining the success of marine aquaculture. Water quality can be assessed through its physical and chemical characteristics. Physical parameters include solids, turbidity, color, odor, taste, and temperature—factors that are important for understanding the habitat conditions for aquatic plants and animals. Chemical parameters include measurements such as pH, salinity, and the concentration of various chemical compounds [26].

An innovative automated system has been designed to assist fish farmers in addressing water quality challenges by providing real-time environmental condition monitoring and initiating automatic corrective actions when parameters deviate from optimal levels. This system integrates various sensors to measure key factors such as pH, salinity, temperature, dissolved oxygen, conductivity, ammonia, and turbidity. By utilizing Internet of Things (IoT) technology, the system enables users to manage and optimize electronic and electrical equipment remotely through internet connectivity. This capability allows for a quick response to emerging issues, significantly reducing the likelihood of crop failure due to poor water quality.

The water quality control sensor system, as shown in Figure 4, is designed by installing seven sensors, with the consideration that the more parameters used, the more accurate the analysis and decision-making will be [27]. In this study, four water quality sensors, one battery monitoring system, and one CCTV camera will be installed, all of which will be controlled and presented through a user interface tailored to the needs of the users, as shown in Figure 5, as follows:

1) Water temperature plays a crucial role in regulating the biological processes of aquatic organisms, affecting their metabolism rate, reproduction, and life cycle. Temperature changes—whether increasing, decreasing, or fluctuating—can speed up, slow down, or even stop these metabolic processes.
2) pH levels are a key chemical factor that affects aquatic life. Excessive acidity or alkalinity in water can alter the activity of H+ or OH- ions, disrupting biochemical reactions in aquatic organisms and potentially causing harm or death. Typically, natural waters have a pH range of 6 to 9, influenced by dissolved substances from bedrock, soil, or other materials in the watershed area.
3) The salinity sensor works using two electrodes that pass an electric current through the water. As the current flows, saline water acts as a strong electrolyte, effectively conducting electricity.
4) The dissolved oxygen (DO) sensor operates as an electrochemical device, where the interaction between oxygen gas and the electrolyte solution generates an electrical signal. This signal corresponds to the concentration of oxygen present in the water.

III. RESULTS AND DISCUSSION

A. General Arrangement of Aquaculture Pontoon

Consist of two major parts of the results and the discussions without having to firmly separate between the parts. The general plan for the fish cage outlines the main components needed to build a stable fish cage in water areas, as shown in Figure 6a. The pontoon is used as the primary buoyancy component, ensuring that the cage remains stable and floats on the water's surface. Bolts and locking pins serve to secure the connections between the pontoons, ensuring the cage structure remains sturdy even when exposed to water currents and wind. Poles and fences provide protection for fish cage operators, preventing them from falling. The roof design offers protection from the sun and rain for both the

TABLE 1.
LIST OF COMPONENTS

No.	Items and Specification	Number	Unit
1	Pontoon (50x50x40 cm)	14	pcs
2	Pontoon locking bolt	8	pcs
3	Pontoon locking pin	21	pcs
4	Railing Pillars	13	pcs
6	Roof (2120 x 2120 cm)	1	set
7	Nets 2 x 1 x 1 m	4	m
8	Buoy	9	pcs

TABLE 2.
LIST OF ELECTRICAL COMPONENTS

No.	Item and Specification	Number	Unit	No.	Item and Specification	Number	Unit
1	Solar Panel 250 Wp	1	unit	10	Sensor of Dissolved Oxygen	1	unit
2	Lifepo4 battery 12V 200 Ah	1	unit	11	Sensor of Salinity	1	unit
3	MPPT Epever Tracer 20A	1	unit	12	Box Panel Outdoor	1	unit
4	Inverter 1000W	1	unit	13	10 W Lamp and Fitting	1	unit
5	Kabel Konektor PV - MPPT - Inverter	1	unit	14	Lighting Timer	1	unit
6	ESP32S	2	unit	15	MCB DC 63 A and 10 A	1	set
7	RS485 to TTL	1	unit	16	Electric Stop Contact	1	unit
8	Sensor of pH	1	unit	17	CCTV EZVIZ Outdoor	2	unit
9	Sensor of Temperature	1	unit	18	Mifi Orbit N1	1	unit

TABLE 3.
RESULT TEST OF PH SENSOR

No.	Sample Condition	Reference pH	Actual pH	Error	% Error	% Accuracy
1	Initial Calibration	11.00	10.5	0.50	4.50	95.50
2		7.00	6.6	0.40	5.70	94.30
3		4.00	3.8	0.20	5.00	95.00
4	Coffee (250 ml)	-	5.1	-	-	-
5	Tap Water (600 ml)	-	6.7	-	-	-
6	Drinking Water (600 ml)	-	7.1	-	-	-
7	Drinking Water (600 ml) + 1 pinch of salt	-	6.6	-	-	-
8	pH Buffer Powder Tester	6.86	6.6	0.26	3.79	96.21
9		9.18	11.3	2.12	23.09	76.91
10		4.00	4.2	0.20	5.00	95.00

operators and electrical components, while the fishnet ensures that the fish stay within the farming area without the risk of escaping. The pontoons also provide a protected working area for placing electrical outlets and laptops. With proper planning, the fish cage design shown in Figure 6b is expected to operate optimally in supporting aquaculture activities.

The designed floating net cage prototype is a simplified version of the research previously developed [11]. The previous research developed a multipurpose floating platform made of steel, with solar panels and wind turbines as the primary power sources. In this study, a simpler pontoon prototype version was assembled using commercially available HDPE pontoons. Both the steel and HDPE cages that have been developed offer advantages in terms of flexibility, as their sizes can be adjusted according to the needs. They are also equipped with renewable energy technology, thus reducing the cost burden for electricity needs.

The development of this simpler prototype is based on the need for aquaculture in inland water areas with high potential, whereas the previously developed steel pontoon prototype is more suitable for aquaculture in open waters. This prototype is appropriate for installation in inland water areas such as rivers, lakes, or fishponds, making it suitable for small-scale fish farmers. On the other hand, the designed prototype has lower installation costs and is easier to assemble compared to the previously developed steel prototype, making it ideal for small-scale fish farmers. The components used for the

TABLE 4.
SCENARIO RESULT TEST OF PH SENSOR

pH Value Sensor Testing Result								
No.	Scenario 1 pH 6.86		Scenario 2 pH 6.86		Scenario 3 pH 4.08		Scenario 4 pH 4.08	
	Actual Value	Error Value	Actual Value	Error Value	Actual Value	Error Value	Actual Value	Error Value
1	6.51	0.35	6.47	0.39	4.17	0.09	4.19	0.11
2	6.52	0.34	6.50	0.36	4.22	0.14	4.19	0.11
3	6.51	0.35	6.53	0.33	4.27	0.19	4.13	0.05
4	6.51	0.35	6.51	0.35	4.10	0.02	4.17	0.09
5	6.54	0.32	6.49	0.37	4.30	0.22	4.21	0.13
6	6.52	0.34	6.50	0.36	4.24	0.16	4.17	0.09
7	6.50	0.36	6.49	0.37	4.26	0.18	4.18	0.10
8	6.47	0.39	6.50	0.36	4.22	0.14	4.20	0.12
9	6.51	0.35	6.50	0.36	4.31	0.23	4.10	0.02
10	6.50	0.36	6.51	0.35	4.28	0.2	4.11	0.03
11	6.49	0.37	6.51	0.35	4.26	0.18	4.22	0.14
12	6.51	0.35	6.53	0.33	4.25	0.17	4.15	0.07
13	6.48	0.38	6.48	0.38	4.28	0.2	4.28	0.20
14	6.52	0.34	6.54	0.32	4.25	0.17	4.16	0.08
15	6.47	0.39	6.54	0.32	4.16	0.08	4.14	0.06
Average	6.50	0.36	6.51	0.35	4.24	0.158	4.17	0.09
% Error	5.19		5.15		3.87		2.29	
%Accuracy	94.81		94.85		96.13		97.71	

TABLE 5.
RESULT TEST OF SALINITY AND TEMPERATURE SENSOR

No.	Sample Condition	Salinity (ppm)	Temperature (°C)
1	Drinking Water (600 ml)	160	36
2	Drinking Water (600 ml) + 1 pinch of salt	310	36
3	Drinking Water (600 ml) + 2 pinch of salt	550	36
4	Tap Water (600 ml)	249	30
5	Tap Water (600 ml) + 1 pinch of salt	421	30
6	Tap Water (600 ml) + 2 pinch of salt	697	30
7	Coffee (250 ml)	510	29
8	TDS Calibration Solution 500 PPM	450	25

installation of the net cage are shown in Table 1.

B. Electrical Installation Circuit

The electrical installation system designed for the fish cage, as shown in Figure 7, aims to meet the energy needs of various electronic devices and sensors used in the IoT-based monitoring system. This system uses solar panels as the primary energy source, supported by components such as Lifepo4 batteries, MPPT Epever Tracer, and inverters that function to store and distribute energy. The installed solar panels collect energy from sunlight, which is then stored in batteries for use at night or during cloudy weather. The inverter plays a crucial role in converting the DC energy from the solar panels and batteries into AC energy, which can be used by the electronic devices in the fish cage. Additionally, the system is equipped with various sensors to monitor the water environmental quality, such as pH, temperature, dissolved oxygen (DO), and salinity sensors.

The data obtained from these sensors is transmitted in real-time through the IoT network, enabling remote monitoring and control of the fish cage conditions. The integration of CCTV and lights into the system also serves to enhance the security and operation of the cage, particularly during nighttime. By utilizing renewable energy from solar panels, this electrical installation system is designed to operate autonomously, environmentally friendly, and efficiently, supporting the sustainability of aquaculture operations in marine environments. A list of the electrical installation components used in this research prototype is summarized in Table 2.

The testing of the sensors used to monitor water quality, as shown in Figure 8, was conducted using four different scenarios. Scenario 1 involved testing the

TABLE 6.
RESULT TEST OF SALINITY SENSOR

Salinity Value Sensor Testing Result								
No.	Scenario 1 Calibration Solution TDS 500 ppm		Scenario 2 Hot Water		Scenario 3 Calibration Solution TDS 500 ppm		Scenario 4 Hot Water	
	Actual Value	Error Value	Actual Value	Error Value	Actual Value	Error Value	Actual Value	Error Value
1	570.83	70.83	115.13	-	478.98	21.02	203.48	-
2	546.78	46.78	159.79	-	545.79	45.79	226.73	-
3	467.77	32.23	163.70	-	516.27	16.27	154.41	-
4	467.8	32.2	205.79	-	502.61	2.61	220.46	-
5	468.16	31.84	124.37	-	531.87	31.87	182.12	-
6	547.66	47.66	148.10	-	510.10	10.1	119.51	-
7	549.39	49.39	215.75	-	492.27	7.73	203.95	-
8	549.82	49.82	177.60	-	469.97	30.03	173.18	-
9	549.05	49.05	159.60	-	495.15	4.85	169.38	-
10	548.09	48.09	192.25	-	475.54	24.46	145.96	-
11	549.82	49.82	184.87	-	520.87	20.87	216.59	-
12	549.13	49.13	138.08	-	475.12	24.88	183.60	-
13	548.43	48.43	226.66	-	467.97	32.03	116.41	-
14	476.00	24	120.67	-	557.88	57.88	205.71	-
15	542.91	42.91	148.73	-	511.22	11.22	160.97	-
Average	528.78	28.776	165.41	-	503.44	22.77	178.83	-
% Error	5.76		-		4.55		-	
%Accuracy	94.24		-		95.45		-	

sensor with a 500 ppm TDS calibration solution with a pH of 6.86. Scenario 2 tested the sensor with a hot water solution at a pH of 6.86. Scenario 3 involved testing the sensor with a 500 ppm TDS calibration solution at a pH of 4.08. Scenario 4 tested the sensor with a hot water solution at a pH of 4.08. Each of the solutions described in the scenarios was used to test the four sensors employed to monitor water conditions. The results of these tests were then validated using data from prior research. The testing outcomes and the discussion of the reliability of each sensor are outlined as follows:

1) The pH sensor testing was conducted based on the scenarios described in the previous section. Before applying the pH sensor tests using the designed scenarios, the pH sensor was used to test several different solutions as shown in Table 3. The results indicated that the average accuracy percentage of the pH sensor when tested with different solutions was 92.15%, demonstrating that the pH sensor performs well across different types of solutions. The pH sensor, which had been tested on various types of solutions, was then tested under several scenarios outlined previously. The results of the pH sensor testing based on the existing scenarios showed satisfactory outcomes with low error values, as presented in Table 4. In scenario 1 and scenario 2, where the pH was 6.86 for both solutions, the sensor measurements were 6.50 and 6.51, resulting in accuracy percentages of 94.81% and 94.85%, respectively. In scenario 3 and scenario 4, where the pH was 4.08 for both solutions, the accuracy of the sensor measurements was 96.13% and 97.71%. The average accuracy percentage of the pH sensor was 95.875%.
2) The procedure for testing the salinity sensor follows the same steps as those used in the pH sensor testing. The salinity sensor was first tested on various types of solutions, and the measurements obtained are shown in Table 5. The sensor measurement results indicate that the addition of salt to the solution led to an increase in salinity, as reflected by the ppm values. This suggests that, in general, the sensor operates effectively across different types of solutions. The sensor used has a maximum salinity measurement limit of 1600 ppm. The sensor was then tested on solutions that were conditioned according to the scenarios outlined earlier. The salinity sensor measurement validation was carried out using a 500 ppm TDS calibration solution, as used in scenario 1 and scenario 3. The measurement results in Table 6 show that the salinity sensor demonstrates good accuracy and is capable of providing consistent measurements. In scenario 1, the sensor's accuracy percentage is

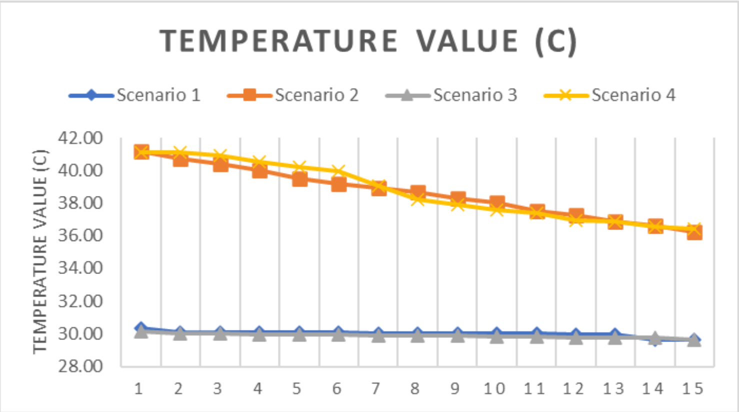


Figure. 9. Result Test of Temperature Sensor

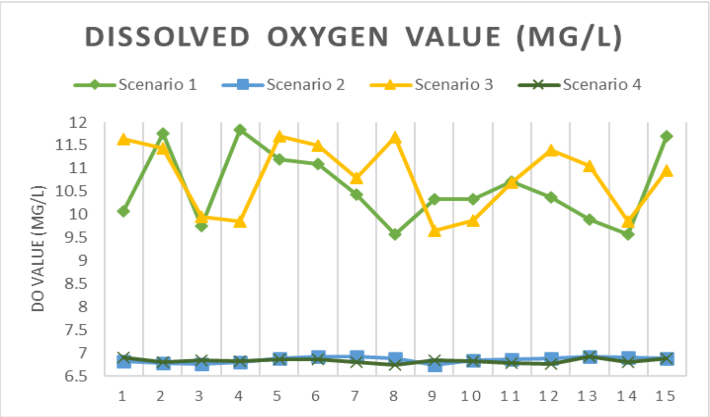


Figure. 10. Result Test of Dissolved Oxygen Sensor

94.24%, and in scenario 3, the sensor's accuracy percentage reaches 95.45%. The average accuracy percentage of the salinity sensor after testing with the 500 ppm calibration solution is 94.845%.

3) In this study, the temperature sensor used was the DS18B20. This type of sensor was also used in previous research [6]. The accuracy testing procedure for the temperature sensor is the same as the procedure used for the salinity sensor. Before the temperature sensor was tested using the pre-designed scenarios, it was first tested on different solutions. The results of the temperature sensor tests on various solutions can be seen in Table 5. The results show that the temperature sensor works well when tested on different types of solutions and produces the same values for the same type of solution. The next step involved testing the temperature sensor by applying each of the pre-designed scenarios. Scenario 2 and Scenario 4 used solutions with warm temperatures, while Scenario 1 and Scenario 3 used solutions with normal temperatures. The results of the temperature sensor tests in each scenario showed that the sensor worked well and provided results consistent with the solutions being tested, as shown in Figure 9. The figure illustrates that in Scenario 2 and Scenario 4, where warm temperature solutions were used, there was a decrease in each sample taken. This was because the initially warm solution gradually returned to normal temperature over time due to the influence of ambient temperature. In Scenario 1 and Scenario 3, consistent values were observed because the solutions used had normal temperatures.

4) The DO sensor test was conducted by measuring the dissolved oxygen levels in the solution according to the predetermined scenarios. In this study, the DO sensor used has the same specifications as the one used in previous research [8], with a measurement range of 0-20 mg/L. The results of the DO sensor test are shown in Figure 10. Scenario 1 and Scenario 3 represent solutions with normal temperatures, while Scenario 2 and Scenario 4 represent solutions with warm temperatures. The figure shows that solutions with normal temperatures have higher dissolved oxygen levels compared to warm-temperature solutions. This demonstrates that water temperature can affect the dissolved oxygen levels in water. Higher water temperatures can reduce the dissolved oxygen levels in water [28].

C. Electrical Power Calculations

The calculation of electrical power for this floating net cage aims to estimate the total daily power requirements of all the devices used, so that the necessary power supply can be determined. The devices installed on this prototype include CCTV, lights, mifi, and an IoT-based monitoring system that operates continuously. Based on the estimated power consumption shown in Table 7, the total daily power consumption for all devices reaches 1056 Wh. The CCTV and monitoring system are the devices with the highest power demand because they operate 24 hours a day, while the lights are used for 12 hours at night for illumination. This calculation is crucial to ensure that the electrical system of the floating net cage can provide sufficient power for its operation.

The next step is to calculate the input power from the solar panels. The purpose of this calculation is to determine the number of solar panels that need to be provided in order to generate enough energy to meet the daily power requirements of the floating net cage. In this study, one solar panel with a capacity of 250 Wp is used. The average sunlight exposure time is 8 hours per day with an efficiency of 80%, resulting in a total power output of 1600 Wh per day, as shown in Table 8.

Based on the calculation of electricity power requirements and the estimated power output, the electrical system in the prototype can generate more power than needed for daily operations. This surplus power can be stored in the battery for use when there is no sunlight, such as during the night or on cloudy days. The battery capacity used in the prototype is 2400 Wh. The calculation shows that the battery can store enough energy to operate the system for approximately 2.2 days without sunlight as estimated in Table 9.

TABLE 7.
ESTIMATION OF OUTPUT POWER

No	Devices	Unit [1]	Power (W) [2]	Operation Time / Day Hour [3]	Total (Wh) [1]x[2]x[3]
1	CCTV	2	10	24	480
2	Lighting Lamp	2	10	12	240
3	Mifi	1	4	24	96
4	Monitoring System	1	10	24	240
Total Daily Power Consumption (Wh) [4]					1056

TABLE 8.
ESTIMATION OF INPUT POWER

No	Devices	Unit [5]	Capacity (Wp) [6]	Charging Time (Hour) [7]	Total (Wh) [8]=[5]x[6]x[7]
1	Solar Panel	1	250	8	1600

TABLE 9.
ESTIMATION OF DURATION AND ELECTRICAL POWER STORAGE

No	Device	Unit [9]	Voltage (V) [10]	Capacity (Ah) [11]	Total (Wh) [12]=[8]x[9]x[10]
1	Battery	1	12	200	2400
Duration of Battery Charging (day) [12]/ [8]					1.5
Duration of Operation without sun-lighting (day) [12]/ [4]					2.2

IV. Conclusion

Aquaculture is a process of fish farming and growth that requires very high water quality, making the monitoring and control of water quality essential and must be conducted continuously. A system for monitoring and controlling water quality, such as temperature, pH, salinity, and dissolved oxygen levels, can be implemented with the aid of sensors that are automatically controlled and monitored in real time. This study successfully developed a prototype of a water quality monitoring system for aquaculture using IoT technology, powered by renewable energy sources in the form of solar panels. The results of the sensor tests used to monitor water quality showed good accuracy, with sensor data collection accuracy reaching up to 90%. The power requirements for the operation of the sensors and electrical devices in the prototype have the advantage of enabling automatic and real-time monitoring of water quality 24/7 without human intervention. This advantage makes the developed prototype capable of operating autonomously and only requiring remote monitoring. This prototype is suitable for use in remote areas, especially for small to medium-scale fish farmers, due to its relatively low construction cost and its potential to improve efficiency and the quality of harvests. The prototype has been shown to perform well through the use of sensors with good accuracy. Moving forward, calibration mechanisms to maintain and enhance sensor accuracy need to be developed.

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