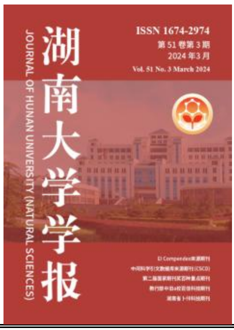

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# Optimization of Energy Utilization in Aquaculture Ponds by Automation and IoT Monitoring


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**Abstract:** Maintaining water quality in aquaculture, such as temperature and pH, is crucial because the life of organisms is dependent on the quality of the water. The water temperature can indicate the condition of the dissolved oxygen (DO) concentration. Aerators play an important role in the aeration system of aquatic ponds. However, it requires quite large operational costs, especially due to the large energy consumption by the aerator system. The research reported here provides a method to optimize the energy management in aquaculture aeration systems using automation and monitoring systems based on the Internet of Things (IoT). The research developed a system that can guarantee the optimum DO concentration and pH with efficient energy consumption. The rotation speed of the aerator motor is set proportional to the water temperature, which relates to the DO concentration. The higher the concentration, the higher the rotation speed of the aerator because it indicates a lower DO concentration. This results in the concentration of DO being optimized with optimum energy consumption. The pH of water is set to neutral by regulating the salt sprinkler. If the pH is low, the salt sprinkler will pour the salt until the pH is neutral. The controlled parameters are also remotely monitored via IoT and displayed on an LCD and smartphone. The research results show that the system can optimize the energy used by the aerator system to guarantee the optimum condition of aquatic water because the aerator and pH controller function proportionally to the real need. The results can help aquatic farmers to optimize the energy use by the aerator system without sacrificing the water quality by using an automated IoT real-time monitoring system. The monitoring system can record data that can be used by farmers to further improve yield and reduce cost.



**Keywords:** aerator, aquaculture, energy, Internet of Things, automation.


# 通过自动化和物联网监控优化水产养殖池塘的能源利用


**摘要**：维持水产养殖中的水质（例如温度和酸碱度值）至关重要，因为生物体的生命取决于水质。水温可以指示溶解氧（做）浓度的状况。增氧机在水产池塘增氧系统中发挥着重要作用。然而，它需要相当大的运营成本，特别是由于曝气系统的能耗很大。本文报告的研究提供了一种使用基于物联网(物联网)的自动化和监控系统来优化水产养殖曝气系统能源管理的方法。该研究开发了一种系统，可以保证最佳的做浓度和酸碱度值，并有效消耗能源。曝气机电机的转速与水温成正比，水温与溶解氧浓度有关。浓度越高，曝气机的转速越高，因为这表明溶解氧浓度较低。这使得做浓度得到优化，能耗达到最佳。通过调节盐喷头将水的酸碱度值设置为中性。如果酸碱度值较低，撒盐器将倒入盐直至酸碱度值呈中性。受控参

数还可以通过物联网进行远程监控，并显示在液晶显示屏和智能手机上。研究结果表明，该系统可以优化曝气系统使用的能量，以保证水体处于最佳状态，因为曝气器和酸碱度控制器的功能与实际需要成比例。结果可以帮助水产养殖户通过使用自动化物联网实时监控系统来优化增氧机系统的能源使用，而不牺牲水质。监测系统可以记录数据，农民可以利用这些数据进一步提高产量、降低成本。

**关键词**：增氧机、水产养殖、能源、物联网、自动化。

# 1. Introduction

The production of the aquaculture sector has increased significantly in the last few years. Wild aquatic animals in the oceans, lakes, rivers, etc. have been main sources of protein [1, 2]. However, due to the increasing population, the production of wild aquatic animals is not sufficient anymore. Since then, aquaculture has become an industry. It has a large impact on job creation and business opportunities, which enhances community income at the village, regional, and national levels [3]. Based on data from the Food and Agriculture Organization (FAO) of the United Nations, in 2020, countries on the Asian continent became the main producers of fish by supplying 70% of world fisheries production, followed by the Americas, Europe, and Africa [4]. There are many types of fisheries that can be cultivated in aquaculture or ponds, such as shrimp, tilapia, gourami, snakehead, and catfish.

Water quality in aquaculture is very crucial because the life of aquatic animals depends on the water quality. Many physical, chemical, and biological parameters can influence water quality, including dissolved oxygen (DO), temperature, salinity, turbidity, pH, nitrogen, ammonia, nitrite, nitrate, phosphate, silica, chlorophyll, fecal coliform, vibrio, and bacteria [5]. One parameter may affect other parameters, e.g., water temperature can influence chemical and biological parameters. The magnitude of the influence of water temperature on aquatic animals is determined by the tolerance and rate of change of the water temperature [6]. In general, aquatic animals can live comfortably at water temperatures between 28°C and 30°C [7]. Another important parameter in aquaculture is the acidity level of the water, which is expressed as the pH (power of hydrogen) of the water. The optimum water pH for aquatic animals is in the range of 7.5–8.5 (neutral) [7] because this range shows an optimal balance between oxygen and carbon dioxide and various harmful microorganisms to develop. Water quality parameters need to be controlled and checked periodically. Sudden changes in water quality can endanger aquatic animals if they are not overcome quickly, which can result in the mass death of aquatic animals and failure in aquaculture harvesting.

Oxygen is freely available in the atmosphere. However, it requires aerator equipment to optimize oxygen absorption into water. An aerator enhances the aeration process in an aquatic pond to transfer oxygen from the atmosphere into the water [8]. Various types of mechanical aerators are commonly used in aquaculture, such as paddle wheel aerators, vertical turbines, diffusers, impellers, propellers, and venturi [9, 10]. In addition to an aerator's oxygen absorption from air into water, it requires large operating costs due to large energy consumption. The energy required to operate the aerator is high because the aerator is usually operated 24 h/day to support good productivity in aquaculture [11].

In many cases, large energy consumption for aeration is unnecessary. This happens because the aerator system operates without energy management. Hence, it is compulsory to operate an aerator system equipped with an energy management system. The energy management system reported in this paper is an automation system to control the rotation speed of aerator paddles and the automation system to control salt sprinklers. The rotation speed of the aerator was proportional to the DO concentration indicated by the water temperature. High temperature indicating a low DO concentration increases the rotation speed of the aerator motor. In contrast, the lower the pH, the more salt sprinkling is required to bring the pH back to neutral. The criteria for selecting the right aerator system are being able to maintain water quality in aquaculture and being economical [12]. There are several ways and opportunities to overcome wasteful energy consumption in aeration systems, such as choosing the right aerator and rotation speed and implementing automatic systems and artificial intelligence [13-15].

It has been reported by [15-17] that variations in the number of blades and holes in the paddle wheel type aerators affect the energy efficiency in the aeration process. In addition to selecting the correct number of holes and blades, energy efficiency in aeration processes can also be achieved using automated real-time monitoring systems [18]. The research reported here developed an automation system to control temperature and pH in an aquatic pond. However, temperature is related to DO concentration. Hence, it ultimately controls the DO concentration in an aquatic pond [19, 20]. The temperature, which is proportional to the DO concentration, determines the rotation speed of the motor, which turns the aerator blades. The higher the temperature, the lower the DO concentration, the higher the rotation speed of blades, and the higher the energy consumption. In Indonesia, controlling the pH in aquaculture is needed during the rainy season. After rain, the pH of aquaculture ponds in Indonesia usually becomes increasingly acidic. Acidic pH values can interfere with the growth of aquatic animals. Farmers usually spread salt to the pond after rain to stabilize the pH of the water pond back to neutral. In the system developed in the research reported here, acidic pH is neutralized by automatically sprinkling salt on the water.

Rosaline and Sathyalakshimi [19] investigated an IoT-based aquaculture monitoring and control system. They used five main sensors to measure important parameters such as temperature, water level, salinity, DO, and ammonia. It used a microcontroller NodeMCU ESP12E. The results were transferred via Ubidots, which is an IoT platform that can be sent via email or text message regarding the results of each parameter. Another research was conducted by [20] on the design of a water quality monitoring system for aquaculture ponds based on the Narrow Band Internet of Things (NB-IoT) technology. The system used an STM32L151C8 microcontroller with sensors of temperature, pH, and DO concentration, which can control the activation and deactivation of the aerator. Generally, previous research mainly focused on the applications of a parameter monitoring system and control of the activation and deactivation of the aerator.

The research reported here is devoted to optimizing energy management by controlling the rotation speed of the aerator motor and sprinkling salt on aquaculture to guarantee the optimum DO concentration and pH with efficient energy consumption. The criteria for the system developed in this research are being inexpensive, insignificant energy consumption, very low operational cost, user friendliness, compactness, and robustness. The main objective of the research reported here was to provide a system that can optimize the energy use by an aerator system without sacrificing the water quality of an aquatic pond by using an automated IoT-based real-time monitoring system. The monitoring system can record the data as well, so the data can be used by farmers to further study their aquaculture to optimize yield and reduce cost. The parameters controlled, monitored, and recorded here are temperature, which indicates the DO concentration, pH of the pond, and electrical consumption.

## 2. Materials and Methods

The research started by designing the system, then prototyped, and experimented to test the performance of the prototype. The design of the aeration system was carried out to obtain an optimal model for the effective and efficient use of energy, particularly in terms of electrical power consumption. This research is a follow-up to [15-17], which resulted in 3D printing paddle wheel aerators with a size of 1:4 of the original size with variations in the number of blades (4, 6, and 8) and variations in the number of holes (12, 16, and 20). The aerators were tested at rotational speeds of 80, 100, 120, and 140 rpm. It was found that an aerator with eight blades and 16 holes with a rotation speed of 120 rpm was optimal. Due to this result, a paddle wheel aerator with eight blades and 16 holes per blade was used in this research.

### 2.1. Materials and Tools

Fig. 1 shows the equipment used in the research. The materials and tools used in this study were as follows:

1. Paddle wheel aerator with eight blades and 16 holes per blade;
2. Pool with dimensions 60 cm x 29 cm x 45 cm;
3. Water 27840 $cm^3$ (27.84 liters);
4. AC motor;
5. Salt tube;
6. Controller system;
7. AC dimmer;
8. Servo motor;
9. Digital watt meter.

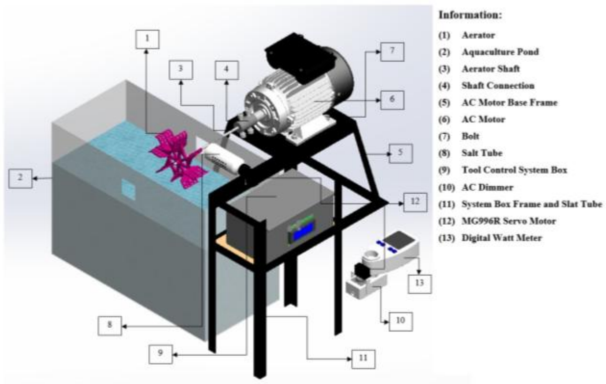


Fig. 1 Experimental setup (Developed by the authors)

Fig. 2 is the block diagram of the developed tool, which provides an overview of the tools designed, including the input, process, and output. The tool (Fig. 1) uses a 220 Vac and 5 Vdc. AC dimmers (Fig. 1 (10)) and AC motors (Fig. 1 (6)) were connected directly to the grid 220 Vac voltage source, while other electronic devices were connected directly to a 5 Vdc voltage source via a DC regulator power supply to convert AC to DC voltage.

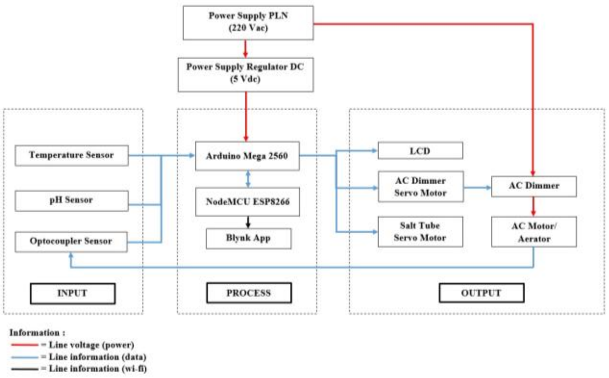


Fig. 2 Block diagram of the equipment (Developed by the authors)

• *Inputs*

There were three sensors in the input: temperature, pH, and rotational speed (optocoupler). The temperature and pH sensors were installed in the aquaculture pond, while the rotational speed sensor (optocoupler) was installed at the AC motor shaft.

• *Process*

The process stage used the Arduino Mega 2560 microcontroller as the control center and the NodeMCU ESP8266 as the link to the Blynk application. System programing was made using Arduino IDE software.

• *Outputs*

There were several output components: an AC dimmer, an AC motor, an AC dimmer servo motor, a salt tube servo motor, and an LCD screen. The monitoring sensor input data were displayed on the LCD screen and the Blynk app on the smartphone.

Fig. 3 is a schematic of the electronic circuit of the developed system, including the input, processor, and output. The inputs were a DS18B20 temperature sensor, E-201-C pH sensor, and rotational speed sensor (optocoupler). The processor consists of an Arduino Mega 2560 microcontroller and an ESP8266 NodeMCU. Meanwhile, the outputs were an AC dimmer MG996R servo motor, a salt tube MG996R servo motor, and a 20x4 LCD.

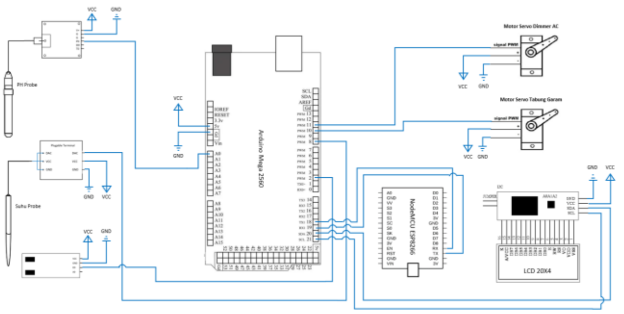

Fig. 3 Electronic circuit of the system (Developed by the authors)

## 2.2. Experiments

There were three sensors: a temperature sensor, a pH sensor, and a rotational speed sensor (optocoupler). In the sensor reading stage, each sensor displayed the results on the LCD screen and the Blynk application. Each sensor had several conditions that had been programed to determine its output. In the temperature sensor, there were nine conditions that determined the output of the AC dimmer servo motor, which led to the regulation of the rotational speed of the AC/aerator motor. In the pH sensor, there was one condition that determined the output of the salt tube servo motor, which led to the regulation of salt sprinkling. Meanwhile, the rotational speed sensor (optocoupler) had no conditions, so it immediately displayed the sensor reading results. This process is summarized in Fig. 4.

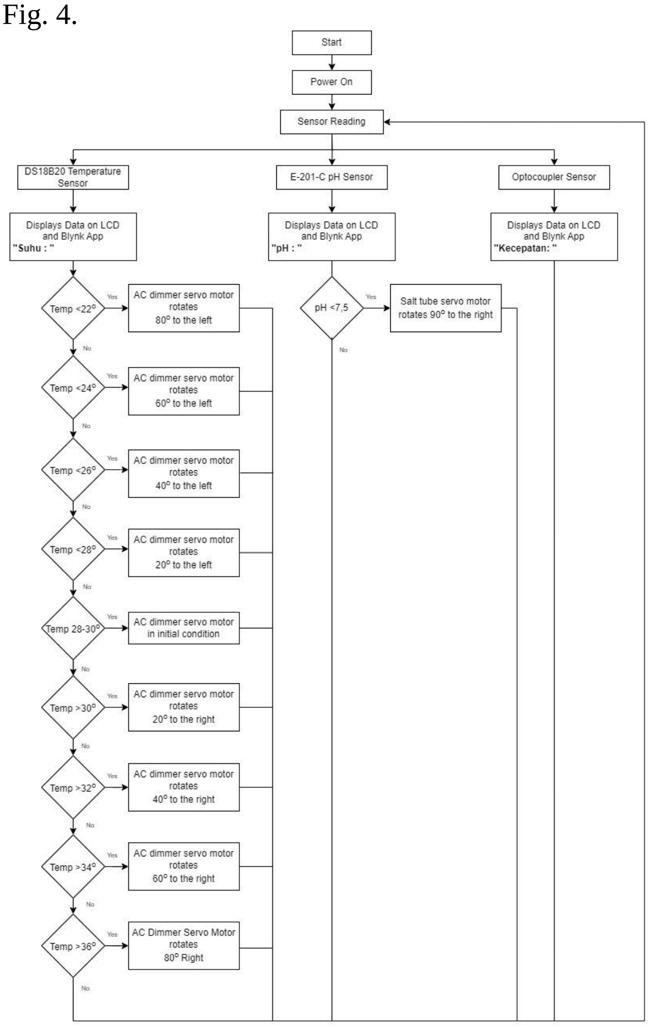


Fig. 4 Flowchart of the tool operation (Developed by the authors)

Regulating the decrease or increase in the rotation speed of the AC/aerator motor was intended to regulate the DO levels in water [16]. The temperature is inversely proportional to the DO concentration. The higher the temperature, the smaller the DO concentration, and vice versa. The AC dimmer servo motor was connected directly to the AC dimmer rotation, which regulated the rotation speed of the AC motor. Hence, the rotation speed of the AC motor can be controlled with the AC dimmer servo motor.

Salt sprinkling is intended to stabilize the pH value to normal conditions when the pH of the water becomes acidic during rainfall [4], [5]. The salt tube servo motor was connected directly to the salt spray bottle.

Testing of the monitoring system developed in this research was carried out by observing parameters in real time on the LCD screen and the Blynk application.

Testing of the aerator monitoring and control system based on temperature data was carried out to determine the effect of temperature on electrical power (watts) consumption and aerator rotation speed (rpm). The results were used to determine and analyze energy management optimization, so that energy usage (electrical power) could be saved according to the needs and no energy waste.

## 3. Results and Discussion

### 3.1. Experiment on an Aerator Monitoring and Control System Based on DO Concentration

Table 1 shows that the data collection was carried out under three main conditions: when the optimal temperature was 28°C–30°C [7], when the temperature was above 30°C, and when the temperature was below 28°C. The data collection was performed for 30 s to observe the shape of the graph that would be obtained when conditioning was performed, as shown in Fig. 5. It was observed that the delay was insignificant, around a second, which was the delay created in the program. This means that the system has almost no delay.

Table 1 Data from testing the aerator (Developed by the authors)

| **Temp. (°C)** | **Power (Watt)** | **Rot. Speed (rpm)** | **Dimmer motor AC** | **Notes** |
|---|---|---|---|---|
| 29.50 | 131.8 | 112 | Still | Normal speed |
| 29.25 | 131.5 | 118 | Still | Normal speed |
| 37.75 | 158.2 | 146 | Turning to the right 80° | Acceleration |
| 33.75 | 139.3 | 125 | Aurning to the right 40° | Acceleration |
| 30.50 | 135.6 | 122 | Turning to the right 20° | Acceleration |
| 29.75 | 131.8 | 115 | Still | Normal speed |
| 29.25 | 131.5 | 118 | Still | Normal speed |
| 22.50 | 109.6 | 82 | Turning to the left 80° | Deceleration |
| 22.75 | 110.2 | 81 | Turning to the left 80° | Deceleration |
| 26.75 | 116.7 | 97 | Turning to the left 20° | Deceleration |
| 27.75 | 124.3 | 104 | Turning to the left 20° | Deceleration |
| 28.50 | 131.5 | 115 | Still | Normal speed |

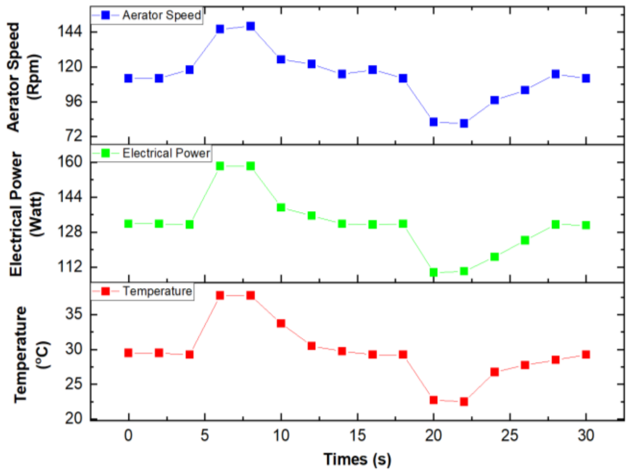


Fig. 5 Curves of the aerator monitoring and control test results based on temperature (Developed by the authors)

Based on Table 1, the initial data obtained were a temperature of 29.50°C (normal temperature) with an electrical power of 131.8 watts, an aerator rotation speed of 112 rpm, which was normal, and the AC dimmer servo motor was still. When the temperature was increased, the AC dimmer servo motor rotated to the right, the aerator speed was accelerated, and the electrical power consumption increased. When the temperature decreased below normal, the AC dimmer servo motor turned to the left, the aerator rotation speed decelerated, and the electrical power decreased. The results in Table 1 are plotted as graphs in Fig. 5.

Fig. 5 shows that the electrical power consumption and aerator rotation speed (rpm) are directly proportional to the temperature of the water. These results agree with the working principle of the developed system, where when the temperature of water is above 30°C, which means a lack of DO concentration in water [7], the AC dimmer servo motor will rotate to the right to increase the aerator rotation speed from normal, which results in increasing electrical power consumption. Vice versa, if the temperature is below 28°C indicating slightly high DO concentration [7], the AC dimmer servo motor will rotate a few degrees to the left to reduce the aerator rotation speed from normal, which results in decreasing electrical power consumption.

Fig. 5 shows that the developed equipment can operate optimally in energy management. Energy usage, especially electrical power consumption, can be optimized effectively according to the need. This operational need is also adapted to the function of the aerator as a mechanical tool to supply DO to the water in an aquatic pond [21] to support productivity in aquaculture [8]. The water temperature and DO concentration have a mutually influencing relationship with each other [7], [16], where the temperature of an aquatic pond water is inversely proportional to DO concentration in a water pond. The higher the temperature of the aquatic pond water, the smaller the DO concentration, and vice versa [7], [13]. Hence, the working principle of the developed equipment is that when the temperature is above 30°C, the aerator rotation speed increases to increase the DO concentration, and when the temperature is below 28°C, the aerator rotation speed decreases. Therefore, with this developed system, the electrical power consumption is proportional to the temperature of the aquatic pond water, which is inversely proportional to the DO concentration. It helps the energy management of aquaculture to optimize the energy consumed by the aeration system.

### 3.2. Experiment on a Salt Sprinkler Monitoring and Control System Based on pH

Testing of the salt sprinkler monitoring and control system based on pH was carried out to evaluate the response of the salt sprinkler to the pH value of the water pond to restabilize water pH in an aquatic pond. The salt tube and sprinkler, as shown in Fig. 1, were placed directly behind the mechanical aerator so that the salt could be evenly spread in the pond. Table 2 shows that when the pH of water decreased below 7.5 or became acidic, the salt was sprinkled on the water pond. The delay in the tool system was approximately 1 s. This agrees with the program created, namely a delay of around 1 s. Hence, the tool system could operate effectively.

Table 2 Data from testing the salt sprinkler (Developed by the authors)

| pH | Servo Motor of the Salt Sprinkler | Notes |
|---|---|---|
| 7.58 | Still | Normal |
| 7.47 | Turn to the right 90°, sprinkling salt | Sprinkling salt |
| 7.82 | Still | Normal |

Table 2 shows that when the pH of the water pond was 7.58 (normal), the salt tube and sprinkler servo motor were stationary, so that no salt sprinkling occurred. Next, conditioning was carried out by lowering the pH, which resulted in the salt tube and sprinkler servo motor rotating to the right to sprinkle salt over the pond to raise the pH. If the pH increased again back to normal, the salt tube and sprinkler servo motor returned to silence, resulting in no salt sprinkling. The pH of water influences the rotation of the salt tube servo motor to sprinkle salt or not. Sprinkling salt on an aquatic pond can bring the acid water back to neutral pH. It can be concluded that the developed equipment operates optimally to control the salt sprinkler, so that the pH of the water pond can be maintained at a normal and stable pH. Normal pH conditions are related to the life of organisms in aquaculture. Under normal pH conditions, the life of organisms in aquaculture is optimal and rapid growth [22].

The system developed in [19, 20] had functions to control DO concentration in water by activating and deactivating the aerators automatically (on-off control system) and monitor the measured water parameters. Meanwhile, the system developed in this research has functions to control DO concentration in water by automatically adjusting the rotation speed of the aerator blades, control the pH of water, and monitor and record water parameters. By adjusting the rotation speed of aerator blades based on the requirement of DO concentration automatically (proportional control system), instead of activating and deactivating the aerator, the system developed in this research results in better energy management and water quality. Because pH is an important parameter of water, controlling the pH of water in the system developed in this research ensures better water quality. In addition, the system developed in this research not only monitors water parameters but also continuously records them. The recorded data of water parameters can be used to further study the characteristics of the aquatic farm to improve the yield and quality of aquatic animal products.

## 4. Conclusions

The performance of the developed system to control and monitor DO concentrations in and pH of aquatic pond water achieves optimal energy management. Hence, energy use, especially electrical power, can be optimized according to operational needs and recorded. Electric power consumption and the aerator rotation speed are directly proportional to the water temperature, which is inversely proportional to the DO concentration.

The salt sprinkler monitoring and control system works by referring to the pH of the aquatic pond water. It also operates optimally to control the pH of water all the time, so that the pH conditions in an aquatic pond remain normal and stable with optimum energy use. The pH of water affects the rotation of the salt tube servo motor whether to sprinkle salt or not. Sprinkling salt on aquaculture can adjust its pH conditions.

The results of this research can be used to develop an independent and energy-efficient aquatic farm that has optimum water quality for aquatic animals to grow and breed. Hence, it can reduce the operational cost of aquatic farms significantly and improve the yield of aquaculture. Using IoT technology, the aquatic farm can be monitored remotely, and the measured water parameters can be recorded accordingly. The recorded data can be used in further study by both farmers and researchers.

The system should be further studied for other functions, such as the facility for the operator to remotely intercept the system in case of necessity and change the set point of controlled parameters. Since the developed system results in energy-efficient aquatic farms, the implementation of independent power producers using renewable energy should be developed and studied.

## Acknowledgment

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