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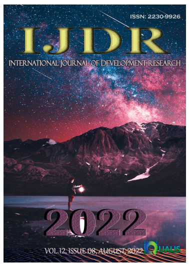

RESEARCHARTICLE OPENACCESS

AUTOMATION OF TAMBAQUI FISH POND AERATION FOR ENERGY EFFICIENCY IN THE BRAZILIAN AMAZON

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ABSTRACT

The increase in the demand for fish highlights the aquaculture potential of the Brazilian Amazon. The high cost of electric energy, lack of technical staff and inexistence of continuous control of water quality parameters are some of the factors that hinder the growth of this activity. We evaluated two opportunities for automation and optimization in commercial tambaqui farms in ponds in Amazonasstate, Brazil. The first is the manual control and recording of physical-chemical properties of the water, and the second is the high consumption of electricity by the aerators. Thus, we developed a continuous monitoring of water quality parameters, through automatic gauging, using a floating platform with onboard sensors, which was called autonomous experimental station (AES), which controls the startup and shutdown of the aerators according to established parameters, providing oxygen necessary for maintaining fish life, eliminating electricity waste and recording the parameters evaluated. As result, after integrating the AES in excavated tanks, it was possible to reduce 26% in electric energy consumption for adult fish and 52% for juvenile fish, besides registering the values of DO, pH, and temperature, generating savings for the producer and contributing to the sustainability of the activity in the Amazon.

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INTRODUCTION

To ensure the life of the species raised in fish farming systems, is necessary to monitor and control the physical-chemical parameters of the water, among them the most important is thewater oxygenation, performed through supplemental aeration (SA) or emergency aeration (AE) (Kubitza 1998). In the SA mode the aerators are turned on daily between 21:00 and 07:00 and there is no need for monitoring during the dawn, in the AE mode the aerators are turned on only when the dissolved oxygen is below ≤ 3.0 mg/l, and DO monitoring is required every two hours during the dawn (Kubitza 1998, Tucker & Hargreaves 2008). Fish farming in ponds, which are reservoirs built on the ground that need a waterproof covering, is the most common system used in the northern region of Brazil. At present the controls are done manually and registered in workbooks or spreadsheets, and the aerators are turned on during the whole night period and on cloudy days to supplement the oxygenation of the water. Dissolved oxygen (DO) concentrations tend to drop during the night and the most critical period is between midnight and 7 am (Boyd & Queiroz 2004, Tidwell 2012). Under normal temperature conditions (20°C to 28°C) the dissolved oxygen consumption of fish is 300 mg O2/kg fish/hour (Boyd & Tucker 1998).

Aerators are employed as a result of extreme rearing conditions, such as high densities of individuals, conditions in which fish consume high levels of DO (Minucci *et al*. 2005, Costa, 2012).Low levels of DO concentration in the excavated ponds for tambaquifishfarms require investments in the purchase of aeration equipment, with the objective of improving the homogenization and supplementation of oxygen in the water column, besides decreasing the stress of the animals and increasing production gains (Minucci *et al*., 2005). Based on these principles, it is understood that SA requires an average 9 hours per day of aerators on to perform oxygen addition to the water column at night and on cloudy days (Boyd *et al*. 2018). Due to the long period of SA, about 90% of the value of electricity consumption of tambaquifishfarms in excavated ponds comes from the use of aerators, reflecting in the operational costs of the enterprise (source the producer where the research was conducted). Another important point is the maintenance of the life guarantee of the cultivated species, and for this the adequate controlof the physicochemical parameters of the water is necessary (Pawar *et al*. 2009, Ruiz-Velazco *et al*. 2010, Torrans *et al*. 2015). The monitoring of physical-chemical water parameters is usually performed manually in Amazonas state, where one person needs to collect and test the samples periodically to decide whether or not to interfere in the management (Izel *et al*. 2013). Because this activity depends directly on human variable, there may be failures inherent to the work routine. The failure to measure the parameters at the appropriate time can cause losses in the weight gain of the fishes and even mass mortality of the fishfarms. The objective of this research is to develop a low-cost experimental platform for water quality control with focus on reducing the consumption of electrical energy used in the aeration of excavated fishponds without affecting the development of the tambaqui and also to assist the fishfarmers in the sampling of water quality parameters.

MATERIALS AND METHODS

The autonomous experimental station (AES) for monitoring water quality was built to assist the rural producer in his work routine. The materials and construction techniques were designed and developed according to the flow demonstrated in the figure below (Figure 01).

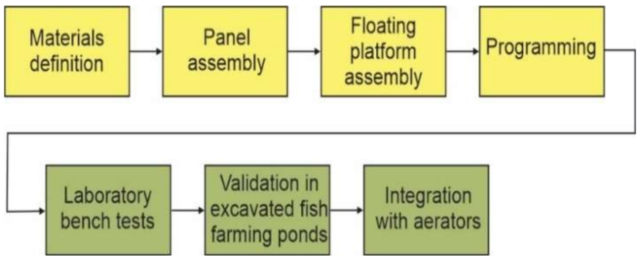

Figure 1. Workflow: assembly, validation and application of the Autonomous Experiment Station (AES)

Material Definition:To define the materials two premises were considered, low cost and free hardware, based on this information we elaborated the project and then the list of materials to be purchased according to table 01. In possession of this, we carried out a market survey to find the necessary materials for the AES construction.

Table 01 - List of electronic materials used in the construction and control of the Autonomous Experimental Station (AES) of fishponds. Number = description corresponding to figure 02

Number	Description of the material	Quantity
1	Control Board	1
2	Expansion board I/O	1
3	Temperature Sensor	1
4	DO sensorDFRobot	1
5	PH sensorDFRobot	1
6	Triggeringrelay 5V	1
7	Solar management board	1
8	Module RTC DFRobot	1
9	Solar painel 9V	4
10	Reader Card SD	1
11	Lithium battery pack 3,7 V 2.500 mAh	8

Assembling the Panel and Floating Platform: The Autonomous Experiment Station (AES) is a compact floating platform constructed of engineering plastic (HDPE and PVC), which has on board three monitoring sensors (temperature DFROBOT KIT0021, pH DFROBOT SEN0161, and dissolved oxygen DFROBOT SEN0237-A), positioned on the underside of the platform in the optimal position to be fully submerged.On top of the platform was installed a control panel (Cemar 913414) containing the following components, a micro controller board with SD card input, ethernet and port expansion (Keyestudio KS0304), as well as the solar energy management system (DFROBOT DFR0535), the three probe signal conversion boards (DFROBOT DFR0605), an RTC clock (DFROBOT DFR0469), the Li-ion 18650 mAh batteries (Energ Power 18650) and the aerator activation relay (DFROBOT DFR0017). On the outside, next to the control panel, four 9.0 volts solar panels (DFROBOT FIT0330) were installed, they are responsible for generating energy to run the control panel and charge the battery for use at night. Alltheelectroniccomponents are fromfree hardware platforms.

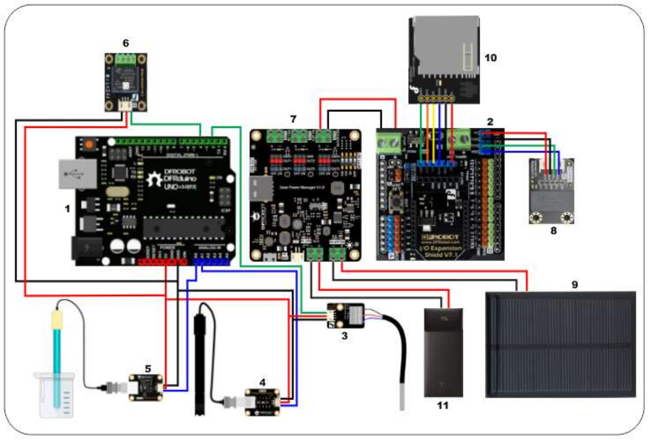

Figure 02. Schematic of the electronic materials used for the automatic control of the Autonomous Experiment Station (AES) of fishponds

Programmation and Logic: The programming of the AES controller is based on the C language. To create this program the Integrated Development Environment Software (IDE) of open platform was used. The logic of the AES operation was established in the following way, the sensors read and transmit the measurements every five minutes to the controller board, where the information is registered on an SD card in txt format. At the same time that these data are stored, they are compared with the pre-set technical parameters registered in the program. According to Izel *et al*. (2013), when the DO is below 3.0 mg/l the feed is suspended. Therefore, when the measured dissolved oxygen (DO) value is below 2.99 mg/l the aerators are turned on, as soon as in a new measurement it is detected that the DO is equal to or greater than 4.0 mg/l, the aerators are turned off.

Validation: For the AES validation, laboratory tests were performed in order to evaluate the electrical connections, programming logic, integration between the parts and the floatability of the platform. Tests and data collection in excavated fishpond of commercial production were also performed to evaluate with quality and accuracy the use of AES in real conditions of use, exposed to the inclemencies of the Amazonian climate, thus ensuring the application and its use by fish farmers.

Integration: Data collection in fishponds was divided in two stages: (1) validation of AES and verification of accuracy of data storage; (2) integration of aerators to AES control. Both stages were carried out in the municipality of Rio Preto da Eva(2° 41' 55" S, 59° 42' 3" W), Amazonas State, Brazil, in commercial fish farms with excavated ponds. The first stage was carried out in August 2021, and the second in June and July 2022. The data were analyzed and graphs plotted with the help of Excel software version 2206.In this research we combine emergency aeration and supplemental aeration, which we call combined aeration (CA), the aerators are rearranged so that one part operates in supplemental mode and the other part is activated automatically upon dissolved oxygen readings.For the data collection two scenarios were defined, the first tank (tank 8) with 7,000 juveniles tambaquis of the species *Colossomamacropomum* (Cuvier 1816), with an average weight of 750 g, and the second, another tank (tank 3) stocked with 9,000 adult tambaquis weighing 3.5 kg on average. The quantity of vertical pump aerators in the tanks was not altered, for the tests with aerator control, two aerators were selected in tank 08 (fish in the juvenile phase) to be used in an emergency way (turning on upon low levels of pre-established DO) and one for supplemental (turned on during the entire period of night aeration). In tank 03 (adult fish) three aerators were selected for emergency operation and six were kept in the supplementary format. In each scenario pH, temperature and dissolved oxygen data were collected.The calculation used to evaluate the energy savings were performed using the data collected during the field research. To estimate the energy savings in monetary values, the following equations were applied.

$$PA = \frac{UP}{N} \quad (1)$$

$$C_{SA} = PA.H_{TSA}.D.V \quad (2)$$

$$C_{CA} = PA.H_{TCA}.D.V \quad (3)$$

Where;

UP = Useful power in KW
PA = Power absorbed in KW
N = Percentage yield
H_{TSA} = Total SA usage time in hours
H_{TCA} Total time of CA use in hours
D = Days in use
C_{SA}= SA cost in Dollars
Cc_{A} = CA cost in Dollars
V = KWh value in dollars

RESULTS

For the development of the AES, laboratory and field tests were performed to evaluate its performance, application, and use. The AES (Figure 03) and all components used in this research had an acquisition cost of U$ 600.00 dollars without taxes in 2021, therefore we can affirm that it is possible to build a low cost platform to monitor and interact with fishponds in the Brazilian Amazon and optimize the use of natural resources, as well as generate savings for the producer. The AES proved to be easy to use, affordable, and of low investment. Its photovoltaic energy system supplied the demand for AES's energy consumption, as well as charging the batteries for energy supply during the night.

Figure 3. Image of the autonomous experimental station (AES) developed and tested in commercial fishponds in the state of Amazonas, Brazil

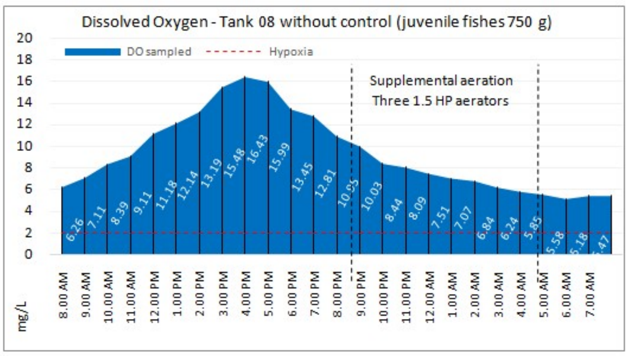

Figure 4. Graph of the average dissolved oxygen (DO) throughout the day showing the entrance and exit of supplemental aeration in tank 08. The dashed line shows the minimum limit of DO that the tambaqui can tolerate

The data collected (pH, DO and temperature) are represented in the following graphs, showing the hourly average of the period studied. In figure 04 it is possible to observe the graph of the average DO data over 24 hours, and the entry and exit points of the SA in the tank of juvenile tambaqui fish weighing approximately 750 g (tank 8).Figure 05 presents the same information as Figure 04, with data obtained in the same tank and under the same conditions, however, the AE input and output control is installed.

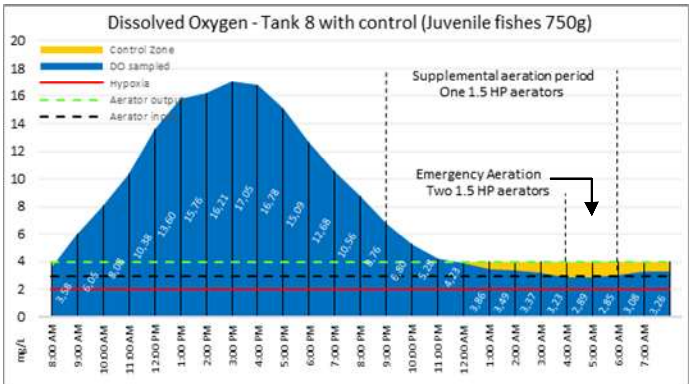

Figure 5. Graph of the average dissolved oxygen (DO) throughout the day showing the input and output of supplemental aeration and emergency aeration in tank 08

With the use of AES for juvenile fish the electric energy savings reached 52% with the use of AC (combined aeration), SA + AE, as shown in figure 06. When we extend this saving to every day of the month and for 12 months, we have a saving of 6,336 Kw, that is, approximately U$ 1,000.00 dollars of annual savings in electric energy in a tank in the previously mentioned conditions, considering the Brazilian electric energy reference values.

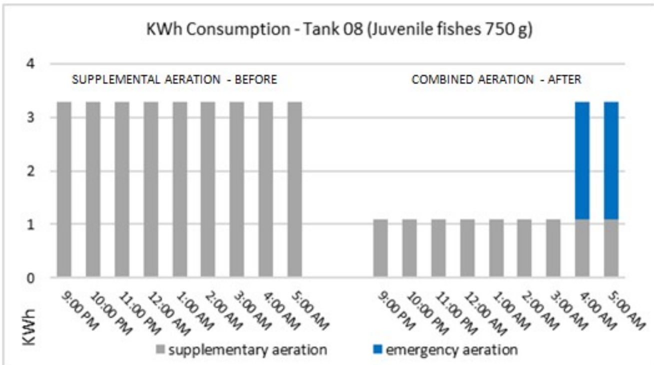

Figure 6. Graph of the average consumption in KWh of the aerators in tank 08 for the two scenarios (without control and with control)

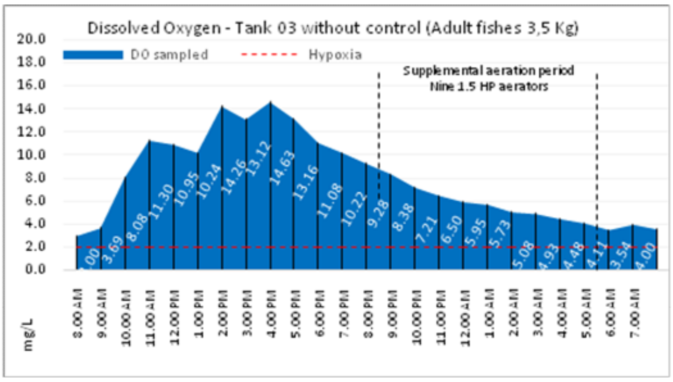

Figure 07. Graph of the average dissolved oxygen throughout the day showing the input and output of supplemental aeration in tank 03

Figure 07 shows the graphical representation of the average DO data over 24 hours, the entry and exit points of the SA in an adult fish tank with an average weight of 3.5 kg (tank 3).Figure 08 presents the same information as Figure 07, with data obtained from the same tank and under the same conditions, however, the AE input and output control is installed.

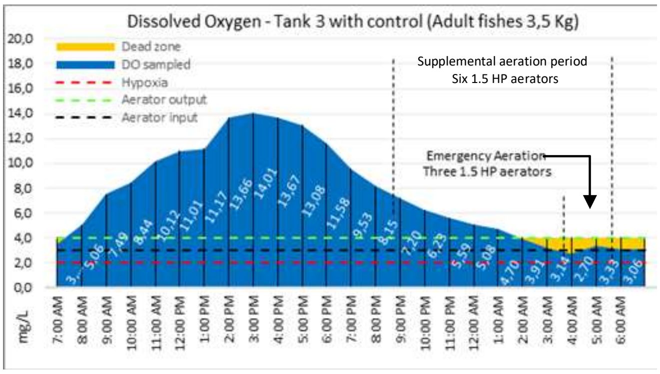

Figure 8. Graph of the average dissolved oxygen throughout the day showing the input and output of supplemental aeration and emergency aeration in tank 03

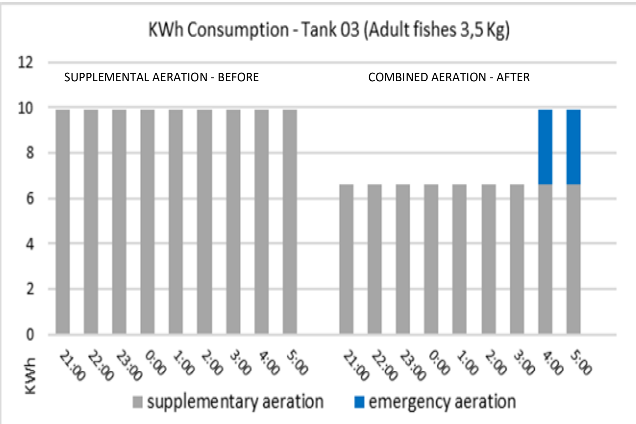

Figure 9. Graph of the average consumption in KWh of the aerators of tank 03 for the two scenarios(without control and with control)

Integrating AES in the adult fish pond we reach a 26% electrical energy saving with the use of AC as shown in figure 09. Extrapolating this saving to every day of the month and for 12 months, we have a saving of 8,316 Kw, i.e., approximately US$ 1,500.00 of annual savings in electric energy in a pond under the conditions cited above.Like the dissolved oxygen data, the temperature (figures 10) and pH data (figures 11) were collected following the same methodology, and in the respective graphs the minimum and maximum limits for each parameter were indicated according to Izel & Melo (2004). The three sensors presented resistance and reliability during the data collection period.

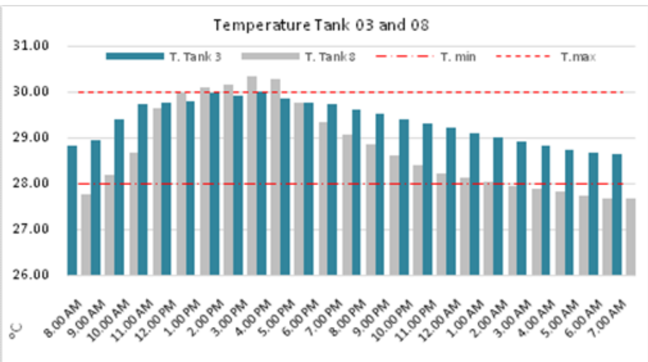

Figure 10. Graph of the average temperature throughout the day in tank 03 and 08

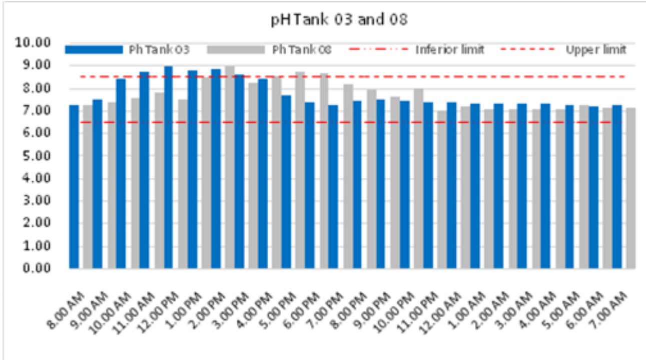

Figure 11. Graph of the average pH over the day in tank 03 and 08

The temperature and pH data showed similar results between the ponds, despite the different fish sizes.During the interaction with the producers, we observed another application of AES regarding the sizing of the amount of aerators in tanks at different phases of fish development, because the data collected by AES helps technicians to define the required amount of aerators with greater accuracy, thus avoiding waste of energy and equipment.

DISCUSSION

Dissolved oxygen is one of the main variables to be controlled in high density fish farming, as the level of dissolved oxygen in the water is often considered the main limiting parameter for production intensification, it is trivial to control with affordable aeration or oxygenation technologies (Hargreaves 2006). Currently, in Amazonas and much of the tropical region, this control is done manually, with daily measurements at dawn and dusk. In intensive fish farming, aeration is used every night and when DO levels are low and also throughout cloudy days, or even continuously (Boyd *et al*. 2018). Because the aerators are started (turned on) manually, energy is wasted by keeping the system on continuously, and beyond what is necessary. Especially since there is no continuous control of the oxygen concentration levels in the water. Artificial aeration is a technology that contributes to the prevention of hypoxia cases in intensive production systems by optimizing oxygen transfer between the atmosphere and water (Boyd 1998). The maintenance of water quality increases productivity, culture survival and better growth rates of fish, which can be achieved by installing aerators and using appropriate strategies (Pawar *et al*. 2009, Ruiz-Velazco *et al*. 2010, Torrans *et al*. 2015). All these benefits are directly related to water quality, which in the case of OD is directly related to electricity consumption due to the use of supplemental aeration, especially during the night period.

There are devices to turn the aerators on and off automatically. Timers can be used to turn aerators on and off at predetermined times. Companies are selling equipment that starts and stops the aerators in response to the DO levels in the water (Boyd 1998). Hoagland (1998) studied energy use in shrimp ponds where aerators were turned on and off by DO sensors, timers and manually over DO concentrations. According to this author, aerators integrated with DO sensors consumed 62% less electricity than those operated by timers and 80% less electricity than manually operated aerators. In the present study, we found energy savings of 52% for juvenile fish and 26% for adult fish, demonstrating the importance of using these systems for the direct benefit of the farmer and indirectly for the consumer and the environment. Boyd (1998) predicted that this practice could be improved and become common in the future, however, this technology did not achieve the use initially predicted, largely due to the high cost of the probes and reliability of the equipment. Based on the results presented in this paper, low-cost automation for the automatic control of aeration through the integration of oxygen sensors, and consequently the reduction of electrical energy consumption for this task may be close to being achieved.According to Tanveer *et al*. (2019), the aeration system should be carefully selected and properly operated, which contributes to the mitigation of environmental risks in intensive fish farming and reduces electricity consumption. Sanchez-Estrada *et al*. (2018), states that one of the aerators with the best performance in terms of DO, are the vertical pump aerators, the same as used in this research.Boyd (1990, 1998) suggested that aeration during the night should be done as needed to ensure stable growth in fish culture. Although aeration is beneficial for water quality and fish growth, excess DO supply through aeration leads to considerable losses of electrical energy, increasing the operational cost, which is reflected in the final value of the product. Therefore, the control of aerator activation and shutdown according to the DO levels in the pond is of fundamental importance for the economic sustainability of intensive pond fish farming. Currently there are studies of a new production model called intelligent production, where fish start to be monitored through biometric identification, although embryonic, Schraml (2021) evaluated this possibility and concluded that it is possible to identify fish individually. Evidencing that there is room for insertion of new technologies in aquaculture.With the frequent increases in energy tariffs, as it occurs nowadays in Brazil, works focused on the reduction of electric energy consumption will be more and more relevant for pisciculture. This work represents an opportunity to optimize the process of raising fish in the Amazon, using automation technology to reduce the consumption of electricity, and assist the producer in monitoring the parameters of water quality. With the advent of Industry 4.0, in the near future we will see tanks integrated with big data and remotely controlled with the help of artificial intelligence.

CONCLUSION

- After verifying the values used to construct the AES, and the results obtained, the possibility of developing a lowcost platform for aerator automation was confirmed.
- As we conclude the studies, it was demonstrated that it is possible to reduce the consumption of electrical energy for the aeration of fishponds by automatically turning the aerators on and off depending on the dissolved oxygen levels present.
- Just as this platform helped us collect data for this research, it can also help other researches on water quality monitoring or even process improvements through the monitoring and storage of DO, water temperature, and pH data in fishponds under different management forms and development stages of the fish.
- AES can also be used to size the amount of aerators in the ponds at different stages of fish development, helping the fish farmer to reduce energy and monetary waste.

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