Fuzzy Logic Controlled Paddle Wheel Aerator

Ertie C. Abana, Ariel M. Lorenzo, Krizel Angelie Argal, Ian Kim Bacud, Jeric Barcena, Mervin Gabriel Anthony Berbano, Khristian Russell Littaua, Shawn Wayne Tiangco

Abstract*: Aeration, as an essential process in the aquaculture industry, has incorporated mechanical aerators especially paddle wheel which is dubbed as the most efficient type. However, an operation of such a device depends on traditional on/off mechanisms based on human intuitions when the need for aeration is necessary. In this paper, Mamdani Fuzzy Logic was integrated into automating the paddlewheel aerator to control and to ensure the correct level of dissolved oxygen in ponds. A microcontroller based on the received output from the dissolved oxygen sensor is capable of automatically controlling the impellers appropriate to the current environment condition. Series of testing was conducted to look at the accuracy of the sensing mechanism and a mean relative error of 1.32% was detected. The researchers compared theoretical and actual supply voltage for all possible dissolved oxygen readings and interpreted a 0.73% mean relative error. With the incorporation of Fuzzy Logic Controller, the system was able to maintain 6 parts per million in the test environment. The system can also reduce power consumption to 65.13% compared to traditional switching. The aerator developed in this study can be used in maintaining the dissolved oxygen in aquaculture farms without human intervention.

***Keywords*: Aquaculture, Dissolved Oxygen Sensor, Fuzzy Logic, Paddlewheel Aerator**

I. INTRODUCTION

Aquaculture in the Asia-Pacific region has undergone a long journey and involves numerous species and farming practices in diverse ecosystems. Most of the production comes from the farming of seaweed, milkfish, tilapia, shrimp, carp, oyster and mussel. According to the Food and Agriculture Organization (FAO), aquaculture provides opportunities to the country's food security, employment, and revenue generation in the Asia-Pacific region. However, with the advent of climate change, global warming threatens aquaculture because of its direct negative impact [1] which includes an increase of temperature. An increase in air temperature could be reflected in temperature increases in aquaculture ponds [2], meaning, any rise of temperature in the surrounding will have an effect on the temperature of the water in ponds. Since dissolved oxygen content of the water is greatly affected by temperature, a significant increase in temperature corresponds to a greater depletion of oxygen. This circumstance is very crucial in aqua farming because low dissolved oxygen concentration is recognized as a major cause of stress, poor appetite, slow growth, disease susceptibility and mortality in aquaculture animals [3]. Hence, the minimum daily dissolved oxygen concentration in pond culture systems is of greatest concern.

Unfortunately, full demand of oxygen supply cannot be met through natural aeration process only particularly with the presence of the aforementioned natural phenomenon which adds up to the other existing parameters that contribute to the declining of dissolved oxygen in pond waters. Therefore, artificial aeration through mechanical aerators becomes essential for the semi-intensive and intensive type of aquaculture. Aerator creates a greater amount of contact between the air and water to enhance the transfer of gases [4]. By mechanically altering the water, the air is being introduced allowing the water to increase its concentration of dissolved oxygen. Currently, only few aquaculture farms in the Asia-Pacific region employ mechanical aerators because of some issues such as power consumption and the cost of the aerator itself. Among those farms that use mechanical aerators, the operation is done manually based on the data gathered separately by Dissolved Oxygen Meter or worse, based on intuitions only. Hence, the tendency of not meeting the required level of dissolved oxygen to be maintained may occur or else, the scenario of oversaturation happens putting the investment for the device in vain.

In relation to this, the researchers take into consideration the means of adopting Fuzzy Logic Controller for the automation of paddlewheel aerator for ponds in order to safeguard the growth and survival of cultured species for maximum production. Fuzzy Logic Controller has been identified to be a good replacement of conventional control technique, considering its ability to adjust from the unpredictable variation and uncertainties of the factors being observed [5].

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With the multi-valued feature of fuzzy logic which is comparable to human thinking and interpretation [6], the project aims to elevate the aerator's automation by filling up the gap between the off and on function with a corresponding output (speed of the aerator) that matches to any set of input data (reading of the dissolved oxygen sensor) allowing the aerator to react immediately, even in just a small deviation of dissolved oxygen below the desired level.

II. MATERIALS AND METHODS

Automating the aeration system with the aid of Mamdani Fuzzy Logic makes use of both mechanical and electronic components including an embedded algorithm. Fig. 1 presents the system comprising of the dissolved oxygen sensor, signal converter board, microcontroller, LCD, servo motor, voltage regulator, relay, motors, and impellers. In a real-time manner, the sensor gathers data with regard to the DO content of the water in the form of an analog signal and will be converted into its digital equivalent using the signal converter board. The microcontroller will then interpret the database from the decision of the fuzzy rules. The reading from the DO sensor will determine the necessary rotational speed of the impeller based on its level. Thus, commanding the servo motor to position the potentiometer of the voltage regulator to produce the output which conforms to its level.

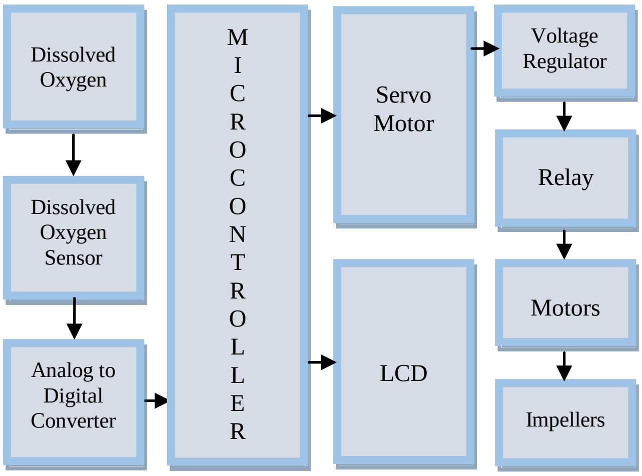

Fig. 1. Block diagram of the system.

Fig. 2 presents the schematic diagram of the device. Arduino Uno R2 microcontroller, as the prime mover and where all the data meet, executes the program resulted from the implementation of the Fuzzy Rules. Arduino Uno was used because it is a well known and established general-purpose microcontroller used in electronic projects [7-9]. The four motors arranged in a row, with PWM Motor Drivers attached in each, perform the command elicited in the form of the rotational speed of the impeller. With relevant connections of wires that bind the different components to form a single device, the system was configured to act in accordance with its function defined by the researchers.

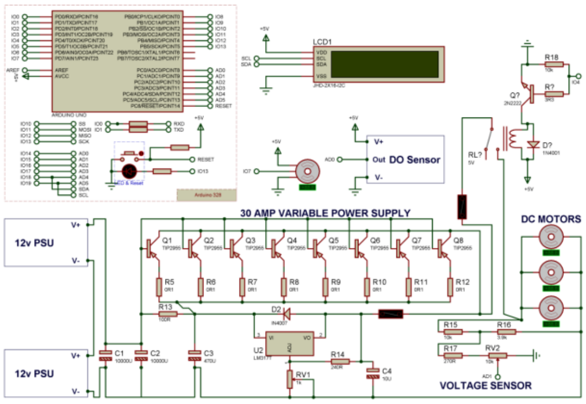

Fig. 2.Connection of the different materials in the system.

A. Fuzzy Logic Control

Table-1 illustrates the different levels of the dissolved oxygen concentration based on the DO Standards adopted by the researchers. These standards were utilized as the lone crisp input to create the Membership Function (MF) being distributed in five levels and implemented to construct the fuzzy rule which is the 'if-then' statement with a condition and conclusion to control the output variable.

Table- I: Dissolved Oxygen Standards for Aquatic Life in Freshwater

Aquatic Life Use Level	Dissolved Oxygen (ppm)
Critical	0-3
Limited	3.1-4.0
Intermediate	4.1-5.0
High	5.1-5.9
Exceptional	6-above

Fig.3 shows the different levels of dissolved oxygen concentration that were then taken as the input parameter to create the input membership function during the fuzzification. Combination of trapezoidal and triangular membership functions was utilized to easily achieve the desired output which is presented in the succeeding figures.

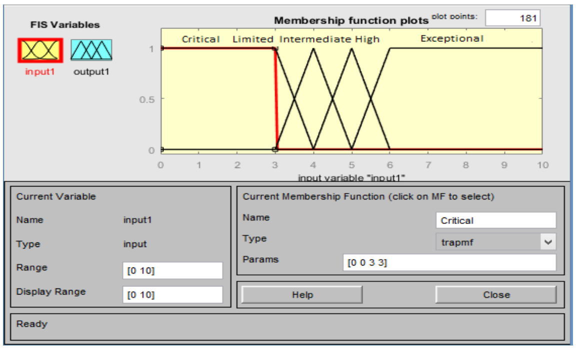

Fig. 3. Input membership function.

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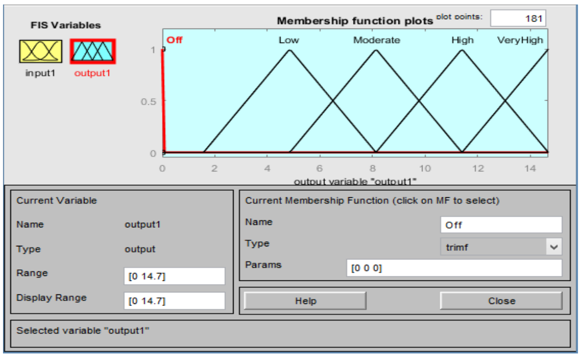

Fig. 4. Output membership function.

On the other hand, the voltage to be supplied in the motor was selected as the output parameter. A 12-volt dc supply must be controlled to vary the speed of the motor; hence, distributed into five levels. However, it was identified that the voltage supply needed for the motor's minimum rotational speed is 4 Volts, and in order to achieve a maximum of 12 Volts in the defuzzification, the upper limit of the range was adjusted to 14.7v as shown in Fig. 4.

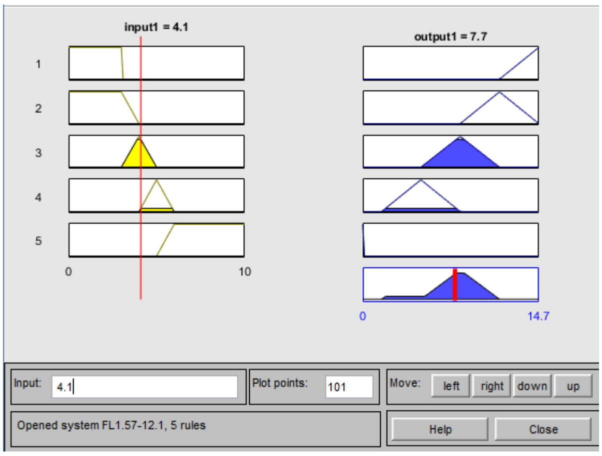

Fig. 5. Rule viewer.

Fig. 5 shows diagnostic rules on inference sentences featuring the if-then rule that was employed to relate the input and output parameters. A total of five fuzzy logic rules was developed to manipulate the motor. A certain input value coming from the DO sensor will correspond to a specific voltage for the motor. Thus, the variation of the rotational speed of the paddlewheel aerator was observed based on the fuzzy rules.

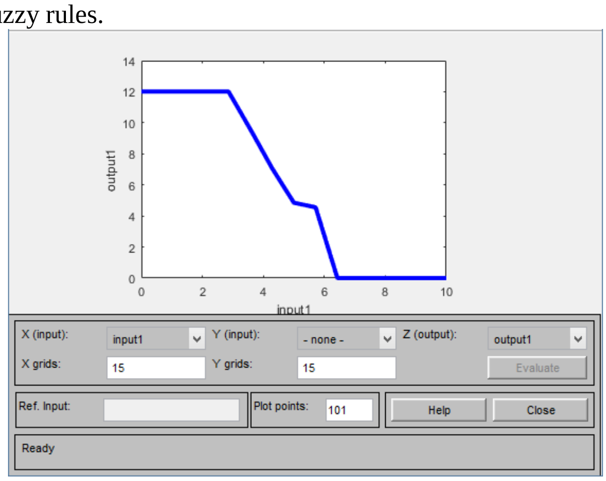

Fig. 6. Surface plot.

Fig. 6 shows that the ultimate goal for the proposed operation of the aerator was obtained from the fuzzy logic implementation. The maximum voltage must be sustained as the Dissolved Oxygen concentration falls within the critical level which ranges from 0-3 ppm to achieve the maximum rotational speed of the aerator, considering that it is in this scenario that the water needs aeration the most.

As the Dissolved Oxygen increases, the voltage decreases. Once the DO concentration reaches 6 ppm and beyond which were designated as Exceptional level, the aerator will be automatically turned off. Whenever the sensor's reading falls below 6 ppm, the motor will again start with the equivalent voltage that is only necessary to stabilize the Dissolved Oxygen concentration.

Table- II: Fuzzy Values

DO *(ppm)*	Voltage
≤3	12.00
3.1	11.0
3.2	10.6
3.3	10.3
3.4	10.0
3.5	9.8
3.6	9.5
3.7	9.2
3.8	8.9
3.9	8.6
4.0	8.1
4.1	7.7
4.2	7.3
4.3	7.0
4.4	6.8
4.5	6.5
4.6	6.2
4.7	6.0
4.8	5.6
4.9	5.3
5.0	4.9
5.1	4.8
5.2	4.8
5.3	4.8
5.4	4.8
5.5	4.7
5.6	4.7
5.7	4.6
5.8	4.4
5.9	4.0
≥6	0

Table II summarizes the results obtained from the defuzzification of the if-then rules. Such voltage values filled the gap between the traditional on and off state of the aerator that only uses 12V and 0V. These crisp outputs became the basis for the aerator's setup.

B. Relative Error Formula

Relative Error formula (1) is a useful tool for determining accuracy when calculating the results that are aiming for known values. It is the difference between the Measured Value (MV) and the Theoretical Value (TV) when compared to the theoretical value.

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It can be expressed in percent error which is the relative error expressed in terms of per 100. MVs are obtained from a series of testing while TVs are the result of a system implementation wherein for this study is the fuzzy logic implementation.

$$\% \, Error = \left| \frac{TV - MV}{TV} \right| x100\% \qquad (1)$$

III. RESULTS AND DISCUSSION

A. Fuzzy Logic Controlled Paddle Wheel Aerator

The paddlewheel aerator shown in Fig. 7 was customized in a manner that conserves space without sacrificing its functional feature. The motors and controller are placed in the center of the metal frame and are housed by a waterproof casing to prevent the motors and controller from stray water splashes. The Dissolved Oxygen Sensor Probe is carefully placed underneath the protective casing, through a water proofed tube, in order for it to be submerged in water. An LCD is placed in front of the housing and will display the current Dissolved Oxygen Sensor Output.

The paddles are long enough to be in contact with the water's surface when the aerator is floating, and are placed on both sides of the motor. The aerator is then kept afloat by a pair of air-filled floaters made from rubber tire interiors.

Fig. 7. The fuzzy logic controlled paddle wheel aerator.

B. Testing of the System

The system was brought in the Bureau of Fisheries and Aquatic Resources Regional Office 2 (BFAR-RO2) laboratory located at Tuguegarao City, Philippines to test its accuracy in measuring dissolved oxygen. Three groups of standard aqueous solutions set by the technician using a commercial dissolved oxygen meter in the laboratory as the reference were measured in three trials: 7.23 ppm, 8.21 ppm, and 3.92 ppm. Compared with the reference samples, the experimental data in Table III shows that the mean relative error is computed using (1) is 1.32%. Hence, it conforms to the accuracy requirement of dissolved oxygen sensing which is below ± 2% relative error [10].

Table- III: Accuracy Test in Measuring Dissolved Oxygen by the System

Reference Samples (ppm)	Measurement Trials (ppm)			Average (ppm)	Relative Error
	1	*2*	*3*		
7.23	7.5	7.47	7.48	7.48	3.46%
8.21	8.17	8.2	8.31	8.23	0.24%
3.92	3.85	4	3.94	3.93	0.26%

Actual voltages resulted from manipulation of the controller were also taken into account. The researchers manually set all possible dissolved oxygen (DO) reading in the system and recorded its voltage output which is measured using a digital voltmeter. Table IV enumerates the results of various measurements made for the different voltage levels. The recorded measurements imply that voltage to be supplied to the motors has a mean relative error of 0.73%. The capability of the developed system to follow the expected voltage based on the voltage output generated in the defuzzification indicates that fuzzy logic is applicable in controlling the rotation speed of the paddle wheel of an aerator. This fuzzy logic control has not been implemented yet on existing aerators [4, 11, 12].

Table-IV: Theoretical vs. Measured Voltages

DO (ppm)	Theoretical Voltage	Measured Voltage			Average	% Error
		Trial 1	*Trial 2*	*Trial 3*		
≤3.0	12	11.9	12	11.8	11.90	0.83
3.1	11	11	11.1	11.4	11.17	1.52
3.2	10.6	10.5	10.5	10.6	10.53	0.63
3.3	10.3	10.3	10.3	10.3	10.30	0.00
3.4	10	10	9.9	9.9	9.93	0.67
3.5	9.8	9.7	9.8	9.7	9.73	0.68
3.6	9.5	9.4	9.5	9.3	9.40	1.05
3.7	9.2	9.3	9.2	9	9.17	0.36
3.8	8.9	8.9	8.9	9	8.93	0.37
3.9	8.6	8.6	8.5	8.3	8.47	1.55
4	8.1	8	8.2	8.3	8.17	0.82
4.1	7.7	7.6	7.6	7.8	7.67	0.43
4.2	7.3	7.3	7.2	7.3	7.27	0.46
4.3	7	7	7	7	7.00	0.00
4.4	6.8	6.8	6.8	6.9	6.83	0.49
4.5	6.5	6.5	6.5	6.5	6.50	0.00
4.6	6.2	6.2	6.2	6.3	6.23	0.54
4.7	6	6	6.1	6	6.03	0.56
4.8	5.6	5.6	5.7	5.8	5.70	1.79
4.9	5.3	5.3	5.3	5.1	5.23	1.26
5	4.9	4.9	5	5.1	5.00	2.04
5.1	4.8	4.8	4.9	4.8	4.83	0.69
5.2	4.8	5	4.8	4.8	4.87	1.39
5.3	4.8	4.8	4.8	4.8	4.80	0.00
5.4	4.8	4.8	4.8	4.7	4.77	0.69
5.5	4.7	4.7	4.8	4.7	4.73	0.71
5.6	4.7	4.7	4.8	4.7	4.73	0.71
5.7	4.6	4.6	4.6	4.7	4.63	0.72
5.8	4.4	4.5	4.4	4.4	4.43	0.76
5.9	4	4.2	4	4.1	4.03	0.83
≥6.0	0	0	0	0	0.00	0.00

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The ability of the system to maintain the dissolved oxygen was also tested. The test was conducted at BFAR-RO2 and begun at 12:00 pm to 6:00 am, which is critical time due to the absence of sunlight for photosynthesis of aquatic plants. The system took readings for every 10 minutes allowing the aerator to make respective response to maintain the dissolved oxygen level into 6 ppm.

Fig. 8 shows the increasing level of dissolved oxygen upon starting the system until it reaches the desired level. Whenever the level goes beyond it, the system responds in such a way that the backlog is being filled. Moreover, the system was able to prevent the decrease of dissolved oxygen into its critical level. The application of just the right amount of power to the paddle wheel will allow the system to prolong its lifespan since it will only be used extensively when needed. The application of fuzzy logic to the system not only enables the system to be automated but also to be intelligent as it only provided the right power to the paddle wheels.

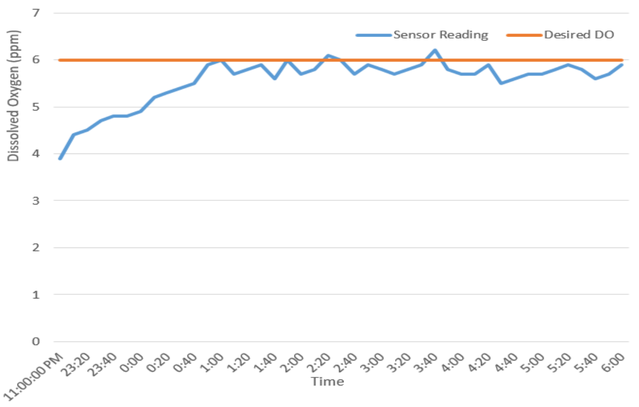

Fig. 8. The dissolved oxygen graph.

The tradition switching and fuzzy logic control of the paddlewheel aerator was tested for 7 hours each. Power was then measured and presented in Table V. The motors, using the Fuzzy Logic Controller consume 65.13 % less compared to the set up driven by a traditional on-off control. This result addresses the recommendation of previous work of El-Nemr and El-Nemr [13] to carry out a study on power consumption with the presence of a control system.

Table- V: Power Consumption

Setup	Power Consumption (KWh)
Traditional Switching	0.499 KWh
Fuzzy Logic Control	0.174 KWh

IV. CONCLUSION

This study developed a Fuzzy Logic Controlled Paddle Wheel Aerator that can be a better choice than using the manually operated on-off traditional aerators based on the testing presented. The system was able to detect the actual dissolved oxygen and provide the correct paddle wheel rotation speed to keep a good environment for the fishes. Aside from keeping the dissolved oxygen level of the test environment to an optimum level, incorporating the fuzzy logic to the aerator saved more power compared to traditional aerator. The researchers recommend applying the fuzzy logic method used in the study for other types of surface aerator systems like low speed surface aerator, fountains, and floating surface aerators.

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