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Design and Implementation of Fuzzy Logic Control System for Water Quality Control

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Abstract— **Water quality in aquaculture is influenced by several parameters, both physical and chemical, and parameters that have a great effect on water quality for aquaculture is the dissolved oxygen (DO) level. In this paper, a fuzzy logic-based model is presented for maintaining DO at a desired value. Because DO level is strongly influenced by temperature, in this control system, water temperature is included as one of the control input parameters. The running time of the system will be regulated so that the system can avoid overheating. The fuzzy logic controller (FLC) system applied to the microbubble aeration has been successfully maintaining the water quality parameters and did not cause overheating due to continuously running of the microbubble aeration.**

Keywords— Water quality; Dissolved Oxygen; Microbubble Aeration; Fuzzy Logic

I. Introduction

Water as a living media for aquatic organisms, has certain requirements for the organism to live and grow normally [1]. Water quality conditioning is an effort to create water quality and water fertility parameters to suit the requirements for live and growth of fish, so that pond environment is able to provide optimum living and optimal fish growth conditions to gain high productivity of fisheries [2].

The water quality indicators in aquaculture can be seen from several indicators, including temperature, degree of acidity (pH), salinity, and oxygen dissolved in water [3]. However, one of the important issues that aquaculture farmers are facing is how to efficiently monitored and manipulate water into desired water quality.

Water quality monitoring can be used to protect source waters by identifying pollutant levels. Water quality can be monitored by measuring physical, chemical, or biological characteristics of the water [4]. Without gathering information on the physical and chemical parameters of water quality along with the associated ecological factors, it is almost impossible to perform the appropriate water quality control [3]. Parameters that greatly affect water quality for fisheries are the DO level [5].

Dissolved oxygen determines the growth of the fish [6]. The low DO level in the pond can cause the fish will be easily infected by bacteria. The ideal DO level for aquaculture is higher than 5 ppm [7]. However, DO level in water is strongly influenced by temperature. The higher the water temperature, it will reduce the ability of water in absorbing oxygen, thus DO level in water reduced [8].

A lot of research has been published about methods to control the DO level in order to improve the process. Water quality monitoring system using microbubble aeration has been presented [9]. Parameters commonly used to monitor water quality are DO, pH, and Temperature. Based on previous monitoring system, the change of indicator caused by microbubble aeration is on DO and Temperature indicator, while pH water tends to be stable that is in neutral condition [10]. However, in such monitoring systems, microbubble aeration is continuously turned on. This method is less effective because the continuously running of microbubble aeration could increases the water temperature generated by the aeration, so the desired DO level is difficult to achieve. The classical methods of control (PID) are not suitable for use. In process control, FLCs can be applied in time-varying, ill-defined and non-linear systems [11]. One of these systems is aeration in biological water treatment process.

In this paper, a fuzzy logic-based model is presented for maintaining DO level at desired value. The inputs of FLC are the outputs of the DO and temperature sensors. A set of linguistic fuzzy rules are developed by monitoring data on microbubble aeration which show the performance character of microbubble aeration which influences DO level. The output signal from the FLC will determine whether the microbubble aeration is ON or OFF mode and how long the microbubble aeration is ON/OFF, so microbubble aeration does not work continuously.

II. System Design

A. Design of Fuzzy Logic Control

In order to maintain the DO level at a desired value, FLC architecture is employed. Fuzzy Logic was first introduced by Prof. Lotfi Zadeh in 1965 [12]. Currently Fuzzy Logic is widely used in many fields, one of which is in the field of control (control process). In general, FLC consists of several components, namely Fuzzifier, Fuzzy Rule Base, Fuzzy Inference Engine and Defuzzifier [13], as shown in Fig. 1.

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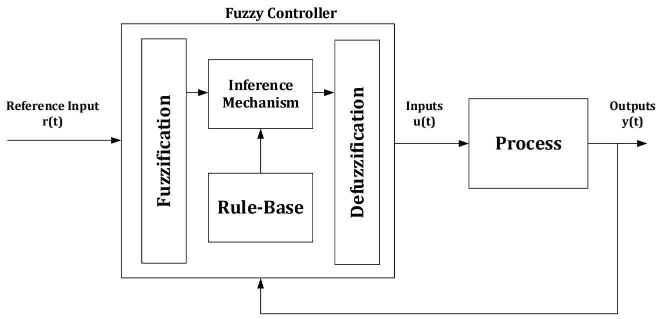


Fig. 1. Schematic diagram of FLC [14].

TABLE I. THE RANGES OF INPUT VARIABLE e AND De MEMBERSHIP FUNCTION

	Negative	Zero	Positive
e (°C)	-4 – 0	-0.5 – 0.5	0 – 4
de (°C)	-4 – 0	-0.5 – 0.5	0 – 4

Design of FLC is processed in MATLAB. Designing of FLC software begins by forming membership function from input and output crisp. The input of this control system comes from DO and temperature sensor readings.

The DO sensor used has a range of values from 0.01 to 35.99 ppm with an accuracy of ± 0.2 ppm [15]. While the temperature sensor has a range of -55 - 125 ° C with the accuracy of ± 0.5 ° C for the range of measurement -10 - 80 ºC. The output in this control process will be carried out by microbubble aeration. Microbubble aeration used is a model 20QY CNP – 1 that *self-suction* pump gas-liquid mixing pump type. These pumps have a discharge of $1m^3$/H and have a gas-liquid ratio of 1: 9.

Based on the measurement data of DO and temperature parameter, microbubble aeration can increase DO level by 1.9 ppm in 10 minutes of running time. However, the remaining DO level is only 4.2% after microbubble aeration is turned off. Meanwhile, when the microbubble aeration is turned on for 30 minutes, DO level will 1.86 ppm increased with the remaining DO by 13.4%. In the last experiment, microbubble aeration was turned on for 3 hours, the increase of DO did not occurred. This is caused by water saturation exceeds 100%, when the water temperature is more than 29.19 ° C [16]. The greater the value of water saturation, the smaller the absorption of oxygen in water.

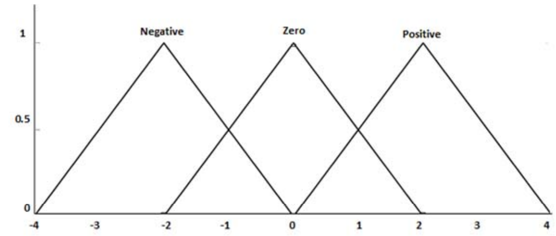
In this control system, the desired DO level to be achieved is 6 ppm (set point). Where the FLC input will calculate the error (e) value and the error change (de) of the desired DO level against the readable DO level, while also consider the reading of the temperature sensor.

The value of e and de is determined by (1) and (2).

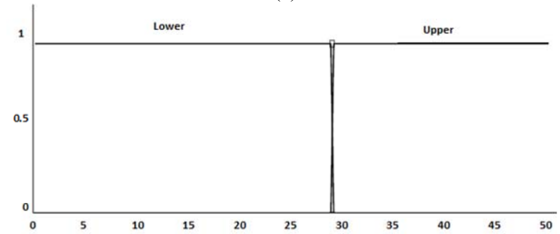
$$e = \mathrm{SP} - \mathrm{PV} \quad (1)$$

$$\mathrm{d}e = e(n) - e(n-1) \quad (2)$$

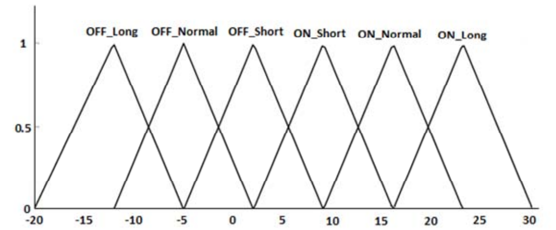
Where SP the value of set point, PV is the output value at t, $e(n)$ is error at t, and $e(n-1)$ is error at t-1.



(a)



(b)



(c)

Fig. 2. Membership function of (a) input: e and de, (b) input: temperature, (c) output : microbubble aeration time delay.

TABLE II. RULE BASE FOR CONTROL DESIGN WHEN (A) TEMPERATURE IS HIGH, AND (B) LOW

Temp	e / de	N	Z	P
Lower	**N**	OFL	OFS	ONN
	Z	OFN	OFN	ONL
	P	ONS	ONS	ONL
Upper	**N**	OFL	OFS	ONS
	Z	OFN	OFS	ONS
	P	OFN	OFS	ONN

As shown in Table I, the number of label membership functions used for e and de are 3 labels, i.e. Negative (N), Zero (Z), and Positive (P), with a limit of -4 - 4 ppm. The membership function of triangular type is used in e and de. While the membership function for temperature input is using trapezium with lower (L) and upper (U) labels, where the lower label is when the temperature below 29°C and upper label when the temperature is more than 29 °C (Fig. 2).

The output of FLC will determine the microbubble aeration in ON or OFF mode and determine the duration of aeration in the ON/OFF mode. Number of label membership function used for Output is 6, i.e. OFF_Long (OFL), OFF_Normal (OFN), OFF_Short (OFS), ON_Short (ONS), ON_Normal (ONN), and ON_Long (ONL), where membership function of triangular type is used. Negative value on crisp output will be interpreted as the duration delay time of the microbubble aeration OFF mode, while the positive value is the duration of the aeration in ON mode.

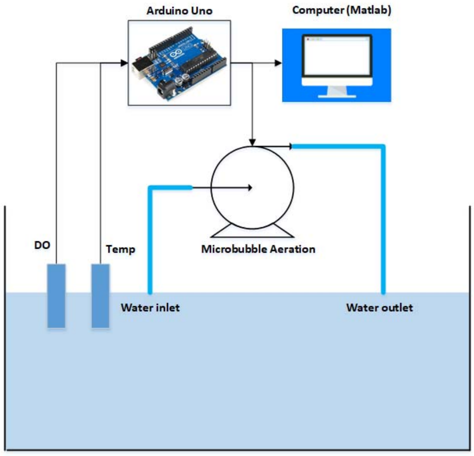


Fig. 3. System design for water quality control.

In order to define fuzzy set logical operators, first consider crisp set operators, which are union, intersection, and complement, which correspond to OR, AND, and NOT operators, respectively [17]. IF-Then rules are needed to determine the relationship between input and output of fuzzy sets. In this control system, the logical operator used is AND, and the rules used are 18 as shown in Table II.

Outputs for all rules are then aggregated. To obtain a crisp decision, fuzzified the fuzzy set or the set of singletons. Therefore, we have to choose one representative value as the final output [18].

FLC that has been designed in MATLAB, then converted to Arduino Uno which used as a processor in this process control.

B. Design of Process Control

As shown in Fig. 3, process control is carried out on ponds with water of 0.216 m3 with a pH of water 7. The water quality parameters are measured by the DO and the temperature sensor and acquired by Arduino Uno. The readings of both sensors are inputs for a processor to process data with FLC algorithms that have been designed before.

Sensor readings of DO will be used to calculate the value of e and de to the DO desired set point value of 6 ppm. While the temperature sensor will be used as a disturbance that will turn off the aeration even if DO level has not been reached. By these values, a FLC process will determine the output value, whereas if the output value of the FLC process in the form of positive values will turn on the microbubble aeration while the negative output value will turn off the microbubble aeration. Arduino Uno will send a signal to turn on or off the relays that connected to the microbubble aeration and provide a delay as much as the output value from FLC. After the output process is implemented, it will be re-read both sensors. The process will happen continuously. Monitoring readings from both sensors and the effect of microbubble aeration outputs will be shown in MATLAB GUI (Graphical User Interface) by serial communication from Arduino Uno to facilitate in evaluating the results of previously designed process controls.

III. RESULT AND DISCUSSION

The test of the control design were performed on the pool for 76 minutes. The monitoring results of the sensor readings and the responses from the sensor readings are plotted on the graph to evaluate how much the control design affected to the desired water quality parameters.

At the start of the test as shown in Fig. 6, DO level is 2.42 ppm and can be increased by 1.2 ppm after the microbubble aeration is turned on for 23 minutes. From the monitoring results as shown in Fig. 5 part output response, it can be seen that the desired value of DO has been reached at minute 55, but at minute 62 the reading of DO sensor decrease. This is because the control system turns off the microbubble aeration for 5 minutes (The minus sign of output response graph in Fig. 5 shows that microbubble aeration is turn off). After the decrease of DO level caused by the death of the microbubble aeration, DO level can no longer reach the set point, with an average reading value of only 5.78 ppm as shown in Fig. 6. In Fig. 7, the largest difference of e and de to the desired DO level is at 55 minutes of initial test. After e and de values close to 0, the given output to the microbubble aeration is only to turn on the microbubble aeration in a short time. The inability of the control system to achieve the desired set point value, caused by the control system design processed by FLC, where the system identifies that the read of DO is close to the set point value.

Fig. 4. Experimental setup of water quality control.

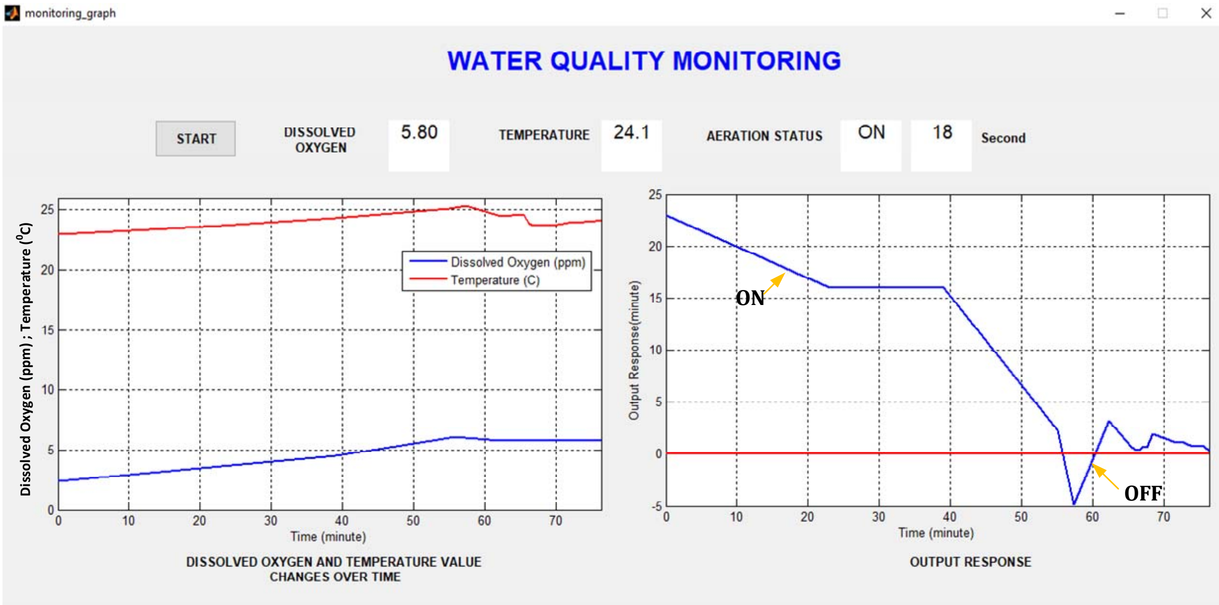


Fig. 5. Display of MATLAB GUI during the test.

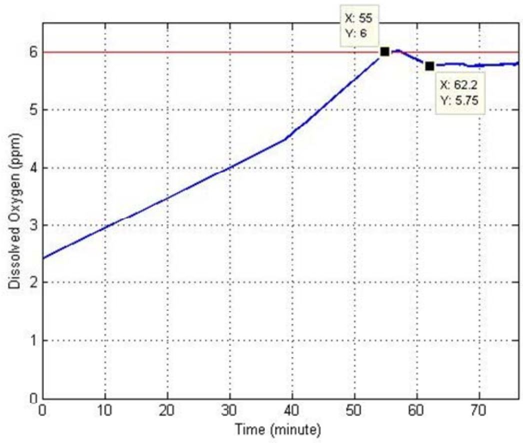


Fig. 6. The reading of DO sensor.

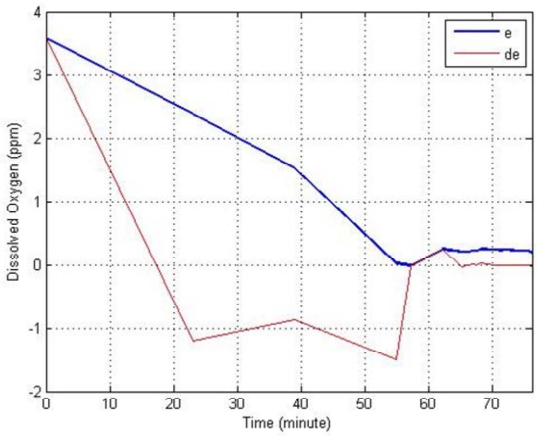


Fig. 7. Error (e) and error change (de) of DO to desired value.

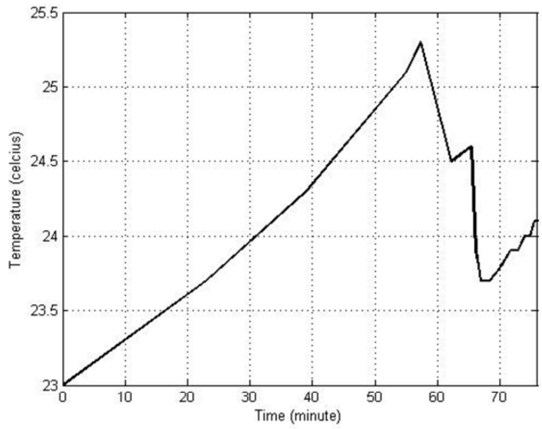


Fig. 8. The reading of temperature sensor.

Based on the results of the tests that have been done as shown in Fig. 8, the change of water temperature caused by aeration is not too significant. The average of water temperature reading during the test process is 24.1 ^{0}C with an initial temperature of 23 ^{0}C. This is because the aeration does not work continuously during the test. In addition, the implementation of control systems using FLC can save the energy. However, because at the time of the test, the DO and temperature sensor readings are not monitored continuously, thus the calculation of how much energy savings by this control compared with the conventional control process that continuously turns on the microbubble aeration cannot be shown.

IV. CONCLUSION AND FUTURE WORK

The proposed FLC system is successfully implemented to the microbubble aeration to control water quality by using Arduino Uno. The control system can increase DO significantly at desired value, however there is an error in the steady state. But overheating caused by a continuously running of the microbubble aeration is not found during the test.

In future, an evaluation of FLC is necessary so that DO level can be achieved without steady state errors, and the analysis of power efficiency compared to conventional control systems is required to see the performance of control system implementation.

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