Fuzzy logic implementation in water quality monitoring and controlling system for fishwater cultivation

Milda Gustiana Husada
Informatics
ITENAS
Bandung - Indonesia
mghusada@itenas.ac.id

Muh. Zulian Nurhidayat
Informatics
ITENAS
Bandung - Indonesia
muhamad.jul97@gmail.com

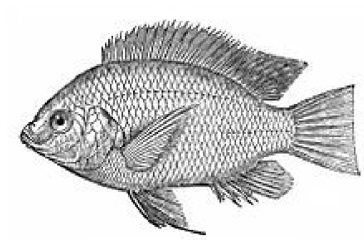
***Abstract*— Freshwater fish cultivation is determined by the water quality of temperature and acidity, which are $26^{o}C$ - $30^{o}C$ and pH of 6 - 8, respectively, based on research by Balai Pengembangan Benih Ikan Air Tawar (BPBIAT)[1], and turbidity level at 128 NTU maximum[3]. In this paper, water quality, in term of temperatue, acidity and turbidity, monitoring and controlling are carried out by applying the Mamdani method of fuzzy logic to a microcontroller-based system as data acquisition which is interconnected with a computer device as a processing device. The reading error rate of the temperature sensor and acidity (pH) sensor are compared with standard measuring instruments are 0.67% and 2.48%, respectively. The results of the turbidity level test ranged from 55, as not turbid, and 300 as turbid.The test was carried out to the hatching of goldfish eggs, which the result showed that the number of hatching was 96%.**

Keywords—Fuzzy logic, Mamdani method, water quality

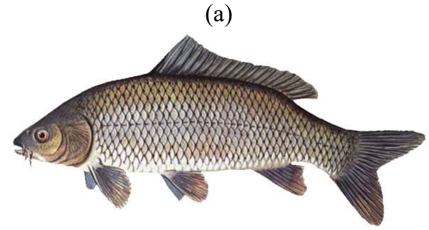
I. INTRODUCTION

To increase community economic growth in terms of income, welfare and open employment opportunities, the fish cultivation in terms of eggs hatchery and grown up, plays an important role. Among fish that are strong in the raising process are tilapia (*oreochromis niloticus*) and goldfish (*cyprinus carpio*) but we have problems in the availability of seeds to increase product, according to Balai Pengembangan Benih Ikan Air Tawar (BPBIAT)*), in Wanayasa, Purwakarta, West Java. BPBIAT reported that it takes four days for hatcheries. The quality of water also determines the process of cultivating freshwater fish, namely temperatures around $26^{o}C$ - $30^{o}C$ and acidity in pH 6 - 8 [1]. In [2] it was stated that the quality of water for tilapia and goldfish hatcheries includes temperature, acidity, nutrient and dissolved oxygen. In addition, the level of water turbidity adversely affects the hatching rate of fish eggs where the maximum value is 128NTU[3]. Freshwater tilapia and goldfish are shown by Fig.1

To succeed the freshwater fish cultivating, the hatchery process may a need to be supported by a monitoring and control system for water quality to comply with known conditions, namely temperature, acidity and turbidity [1,2,3]. In this paper, the design and testing of a control system using an Arduino-based microcontroller which is integrated through the internet media with a desktop-based computer has been carried out as a monitoring part in the form of a web. Supporting devices for obtaining water quality conditions are temperature sensors, acidity sensors and turbidity sensors so that the control system can detect and maintain the temperature area around $26^{o}C$ - $30^{o}C$, the acidity in the pH area 6 - 8, and turbidity at a maximum of 128NTU as mentioned in [1,2,3]. The control applied to this system is fuzzy logic that can represent wider than binary ('true-false' or '1-0') logic. Fuzzy logic covers in between '1-0' condition which can also be translated in linguistic such as 'warm' (between 'hot' and 'cold)'. The fuzzy logic applies the inference technique of Mamdani method since in control system it is commonly used and the most efficient implication[11]. Goldfish eggs are used as the object of the hatchery.



(a)



(b)

Fig. 1. (a) Tilapia and (b) Goldfish

*) Freshwater Fish Seed Development Center

II. Knowledge Background

A. Fuzzy logic Concept and Mamdani Method

In general, the process of applying fuzzy logic consists of three stages. They are a) the fuzzification process, which is the process of decomposing system input and / or output into one or more fuzzy sets, b) the process of decision making that uses knowledge base for controlling the system, and c) the defuzzification process that is the process of obtaining a direct value (crisp) from the fuzzy area. The entire fuzzy-based control process is shown in Fig.2[4].

The following is an explanation of the process of Fig.2[4]. The fuzzy control process stages are a) identifying inputs with respect to names and range of values, b) identifying outputs with respect to names and range of values, c) creating fuzzy degree membership functions of inputs and outputs, d) developing rules (rule base) that will be operated, e) decide the action to be carried out by specifying the strength of each rule, and f) combining the rules and processing the output defuzzification

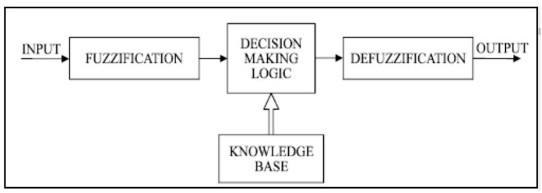


Fig. 2. Fuzzy control process

B. Fuzzification process

The fuzzification process is the first step in the calculation of fuzzy logic which converts the input definite (crisp) values into values in the form of one or more membership of fuzzy sets of the appropriate level. Eq.(1) is to state the fuzzification result.

$$\mu A[x] = \begin{cases} 0 & ; x < a \text{ or } x > d \\ \frac{x-a}{b-a} & ; a \le x \le b \\ 1 & ; b \le x \le c \\ \frac{d-x}{d-c} & ; c \le x \le d \end{cases} \qquad \textbf{(1)}$$

In (1) it is stated that $\mu A[x]$ is the fuzzification function, x is the input value of the variable, a is the minimum limit of the second of fuzzy set, b is the maximum limit of the first of fuzzy set, c is the minimum limit of the third of fuzzy set, and, d is the maximum limit of the second of fuzzy set.

C. Decision making process and knowledge base

The decision making section is responsible for determining how fuzzy logic operates and using a knowledge-base to decide based on the implication function in the form of IF - THEN rules which are generally written

IF <*antecendent*> THEN <*consequent*> (2)

where *antecendent* is a statement contained in the "IF" clause of a conditional proposition, and *consequent* is a statement that contains the meaning of something that has happened.

Following the implication function process is to provide membership value of the data by applying (3).

$$\begin{aligned} \alpha &= \mu_1 \cap \mu_2 \cap \cdots \cap \mu_n \\ &= \min(\mu_1 \cap \mu_2 \cap \cdots \cap \mu_n) \end{aligned} \qquad (3)$$

D. Defuzzification process

Defuzzification is the process of converting fuzzy output based on a certain membership function into a definite (crisp) value. In this defuzification process, the method used is the centroid of area method to obtain the exact value that uses (4)

$$z = \frac{\sum_{j=i}^{n} z_j \mu(z_j)}{\sum_{j=i}^{n} \mu(z_j)} \qquad (4)$$

which z represents defuzzification value.

III. Designing Activities

A. Designed hardware system

There are two subsystems in general, namely the data acquisition subsystem and the control and monitoring display subsystem. The data acquisition subsystem is implemented by an Arduino Uno-based microcontroller system that receives number of inputs from sensors, and gives number of outputs to pumps and electrical heater through relays as shown by Fig.3.

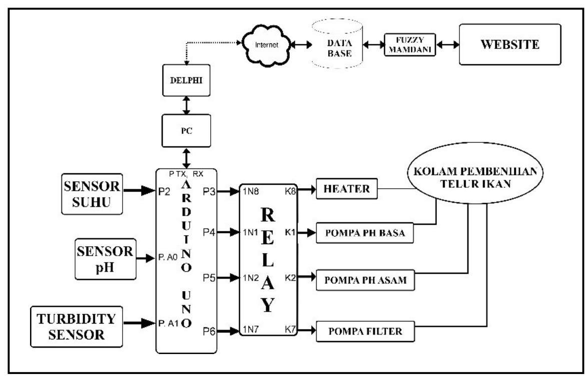


Fig. 3. Designed system

In the data acquisition subsystem, the components used are a) the input device is three sensor units, namely (i) temperature sensor, (ii) acidity sensor and (iii) turbidity sensor; b) the control unit is Arduino Uno which (i) three analog ports are used to read data from each sensor, (ii) a serial port for interconnection with a computer (PC) as a connection to the internet; c)the output device is a relay module that connected to (i) three pump units that one unit is to regulate turbidity, and, two units are to regulate acidity by adding an acid liquid or an alkaline liquid, and (ii) an electric heater to increase the temperature. In this design, there is no device to reduce the water temperature therefore the electric heater will be shut off when the temperature is already in normal condition.

The control and monitoring subsystem uses a computer (PC) that runs the Mamdani method of fuzzy logic control application program that also connects to the internet with the mySQL server as data storage.

B. Fuzzification determination

This part will explain fuzzification determination of temperature, acidity and turbidity in sequence.

a) Temperature fuzzification. Based on information [1], a suitable temperature is 26ºC - 30ºC. The temperature values can be classified into a number of fuzzy data set groups namely cold, normal and hot which are identified respectively by the names of A1, A2 and A3 as shown in Table 1.

TABLE I. FUZZIFICATION OF TEMPERATURE

Set of Temperature	Temperature range	Catagories
A1	$0^{O}C \leq T \leq 28^{O}C$	COLD
A2	$26^{O}C < T \leq 32^{O}C$	NORMAL
A3	$30^{O}C < T \leq 100^{O}C$	HOT

By using (3) we can define set of temperature, A1, A2 and A3, as follows, and. for graphical representation is shown by Fig.4.

$$A1[temp] = \begin{cases} 0 & ; temp < 0 \ or \ temp > 28 \\ \dfrac{28 - temp}{28 - 26} & ; 28 \leq temp \leq 26 \\ 1 & ; 0 \leq temp \leq 26 \end{cases}$$

$$A2[temp] = \begin{cases} 0 & ; temp < 26 \ or \ temp > 32 \\ \dfrac{temp - 26}{28 - 26} & ; 26 \leq x \leq 28 \\ \dfrac{32 - temp}{32 - 30} & ; 30 \leq x \leq 32 \\ 1 & ; 28 \leq x \leq 32 \end{cases}$$

$$A3[temp] = \begin{cases} 0 & ; temp < 30 \ or \ temp > 100 \\ \dfrac{temp - 30}{32 - 30} & ; 30 \leq temp \leq 32 \\ 1 & ; 32 \leq temp \leq 100 \end{cases}$$

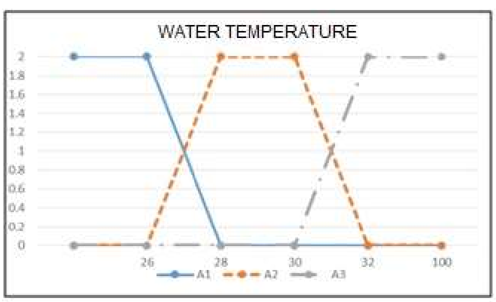


Fig. 4. Temperature fuzzifizcztion graph

b) Acidity fuzzification. In[2] mentioned that a suitable acidity is pH 6 - 8. The acidity values can be classified into a number of fuzzy data set groups namely acid, neutral and alkali which are identified respectively by the names of B1, B2 and B3 as shown in Table II.

TABLE II. FUZZIFICATION OF ACIDITY

Set of acidity	Acidity (pH) range	Catagories
B1	$0 < pH \leq 7$	ACID
B2	$6 < pH \leq 8$	NEUTRAL
B3	$7.5 < pH \leq 14$	ALKALI

By using (3) we can define set of acidity, B1, B2 and B3, as follows, and. for graphical representation is shown by Fig.5.

$$B1[pH] = \begin{cases} 0 & ; pH < 0 \ or \ pH > 7 \\ \dfrac{7 - pH}{7 - 6} & ; 6 \leq temp \leq 7 \\ 1 & ; 0 \leq pH \leq 6 \end{cases}$$

$$B2[pH] = \begin{cases} 0 & ; pH < 6 \ or \ pH > 8 \\ \dfrac{pH - 6}{7 - 6} & ; 6 \leq pH \leq 7 \\ \dfrac{8 - pH}{8 - 7.5} & ; 7.5 \leq pH \leq 8 \\ 1 & ; 7 \leq pH \leq 8 \end{cases}$$

$$B3[pH] = \begin{cases} 0 & ; pH < 8 \ or \ pH \geq 14 \\ \dfrac{pH - 7.5}{8 - 7.5} & ; 7.5 \leq pH \leq 8 \\ 1 & ; 8 \leq pH \leq 14 \end{cases}$$

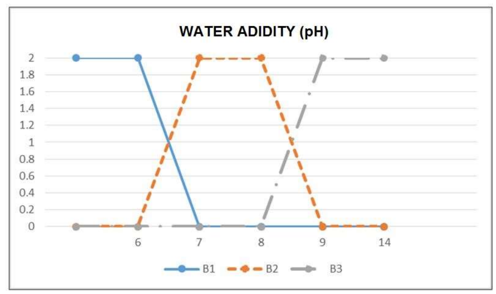


Fig. 5. Acidity fuzzifizcation graph

c) Turbidity fuzzification. In[3] mentioned that a suitable turbidity is a maximum of 128NTU. The turbidity values can be classified into a number of fuzzy data set groups namely acid, neutral and alkali which are identified respectively by the names of C1, C2 and C3 as shown in Table III.

TABLE III. FUZZIFICATION OF TURBIDITY

Set of turbidity	Turbidity range (NTU)	Catagories
C1	$0 \leq NTU \leq 120$	Non turbid
C2	$100 \leq NTU \leq 220$	Turbid
C3	$200 \leq NTU \leq 300$	Very turbid

By using (3) we can define set of turbidity, C1, C2 and C3, as follows, and. for graphical representation is shown by Fig.6.

$$C1[turbid] = \begin{cases} 0 & ; turbid < 0 \ or \ turbid > 28 \\ \dfrac{120 - turbid}{120 - 100} & ; 100 \leq turbid \leq 120 \\ 1 & ; 0 \leq turbid \leq 100 \end{cases}$$

$$C2[turbid] = \begin{cases} 0 & ; turbid < 100 \ or \ turbid > 220 \\ \dfrac{turbid - 100}{120 - 100} & ; 100 \leq turbid \leq 120 \\ \dfrac{220 - turbid}{220 - 200} & ; 200 \leq turbid \leq 220 \\ 1 & ; 120 \leq x \leq 220 \end{cases}$$

$$C3[turbid] = \begin{cases} 0 & ;turbid < 200 \text{ or } turbid > 300 \\ \dfrac{turbid - 200}{220 - 200} & ;200 \le turbid \le 220 \\ 1 & 220 \le turbid \le 300 \end{cases}$$

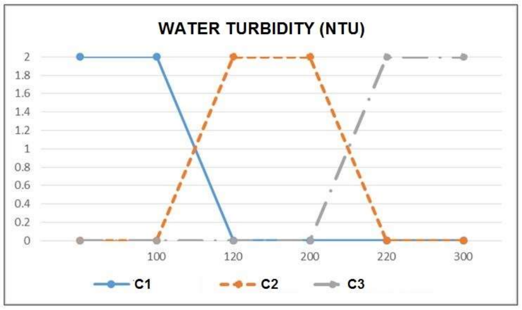


Fig. 6. Turbidity fuzzifizcation graph

There are three conditions each of variable, therefore the number of rules base on combination of each condition. The condition of each variable can activate five output devices i.e acid liquid pump, alkali liquid pump, turbidity pump and electrical heater that is shown by Table IV

TABLE IV. OUTPUT DEVICE ACTIVATION

Output devices	Activating condition (ON)	Not activating condition (OFF)
Electrical heater	COLD	NORMAL OR HOT
Acid liquid pump	ALKALI	ACID OR NEUTRAL
Alkali liquid pump	ACID	ALKALI OR NEUTRAL
Turbidity pump	TURBID OR VERY TURBID	NON TURBID

C. Decisision making process

The inference logic rules are based on condition of sensors' reading for temperature, acidity and turbidity, that activates the output devices as shown in Table IV. Table V summarizes the base for defining all conditions.

TABLE V. AFFECTING CONDITION

	Temperature	Acidity	Turbidity
Condition that activates or not activates output device	COLD	ACID	NON TURBID
	NORMAL	NEUTRAL	TURBID
	HOT	ALKALI	VERY TURBID

According to Table IV and Table V, the implication logics are developed. Herewith, some examples of the logic as shown by Tabel VI..

TABLE VI. RULE EXAMPLES

Rule examples	Logic
I	**IF** *temp* = COLD **AND** pH = NEUTRAL **AND** *turbid* = NON TURBID **THEN** *heater* is activated
II	**IF** *temp* = COLD **AND** pH = NEUTRAL **AND** *turbid* = TURBID **THEN** *heater* and turbid pump are activated
III	**IF** *temp* = COLD **AND** pH = NEUTRAL **AND** *turbid* = NON TURBID **THEN** *heater* is activated

Here an example to show the use implication logic and data membership value. Assume the data of temperature, acidity and turbidity are 27^{o}C, 7 and 117 NTU respectively.

a) Temperature calculation

COLD : $A1(27) = \dfrac{28-27}{28-26} = 0.5$

NORMAL : $A2(27) = \dfrac{27-26}{28-26} = 0.5$

b) Acidity calculation

NEUTRAL : $B2(7) = \dfrac{7-6}{7-6} = 1$

c) Turbidity calculation

NON TURBID: $C1(117) = \dfrac{120-117}{120-100} = 0.15$

TURBID: $C2(117) = \dfrac{117-100}{120-100} = 0.85$

By taking those into account is to define membership value as follows.

$$\alpha_1 = A1_{COLD} \cap B2_{NEUTRAL} \cap C1_{NON\ TURBID} = \min(0.5; 1; 0.15) = 0.15$$

$$\alpha_2 = A1_{COLD} \cap B2_{NEUTRAL} \cap C2_{TURBID} = \min(0.5; 1; 0.85) = 0.5$$

$$\alpha_3 = A2_{NORMAL} \cap B2_{NEUTRAL} \cap C1_{NON\ TURBID} = \min(0.5; 1; 0.85) = 0.5$$

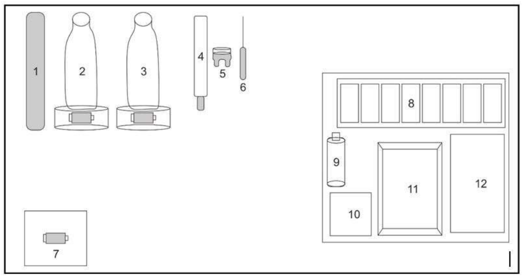
$$\alpha_4 = A2_{NORMAL} \cap B2_{NEUTRAL} \cap C2_{TURBID} = \min(0.5; 1; 0.85) = 0.5$$

IV. IMPLEMENTATION ACTIVITIES

A. Data aqcuisition subsystem

The designed system of data aqcuisition subsystem is implemented which is shown by Fig.7.

Each units of data aqcuisition subsystem are indicated by numbers: (1)electrical heater, (2)acid liquid bottle with pump, (3)alkali liquid bottle with pump, (4)acidity sensor, (5)turbidity sensor, (6)temperature sensor, (7)turbid pump with water filter, (8)relay modul, (9)power supply, (10)acidity sensor, (11)Arduino Uno-based microcontroller, and, (12)breadboard.



(a)

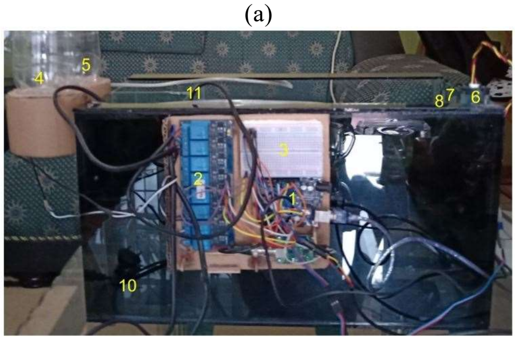


Fig. 7. (a)Unit identity, (b)Real implementation

B. Monitoring User Interface

Monitoring user inferface is implemented in web-based and has four part of areas, i.e. one graph to show all variables in one display, and graphs to show three variables in each display. The pictures of graph are is shown by Fig.8.

Fig. 8. Monitoring display

V. Experimental Testing

A. Sensor error reading testing

Experimantal testing is performed to evaluate sensor reading compare to standard measuring equipment. Until this moment, the sensors which tested are temperature sensor that compared with thermometer, and acidity sensor that compared to pH-meter. Percentage or error reading is calculated by using (5)[3].

$$Error = \frac{|MS - MT|}{MS} \times 100\ \% \qquad (5)$$

which *MS* is the reading of standard measuring equipment, and *MT* is the reading of tested measuring sensor. Testing is conducted 10 times to both sensors, and the error reading results are 0.67% and 2.48% for temperature sensor and acidity sensor respectively.

B. Fuzzy control testing of individual variable and

Each of fuzzy control for temperature, acidity and turbidity are tested in respect of time duration and control process results.

The testing results for temperature fuzzy control are shown by Tabel VII.

TABLE VII. Temperature control process results

No	Before controlling process (^oC)	*Duration of heater activation* (second)	After controlling process (^oC)
1	20	73	26.2
2	20.5	68	26.0
3	21	63	26.5
4	21.5	58	26.2
5	22	53	26.2
6	22.5	48	26.2
7	23	43	26.5
8	23.5	38	26.2
9	24	33	26.1
10	24.5	28	26.5

From the Table VII, it is shown that temperatures are controlled to be appropximately 26 ^oC in average as in the range of normal.

The testing results for turbidity fuzzy control are shown by Tabel VIII.

TABLE VIII. Acidity control process results

No	Before controlling process (pH)	*Duration of alkali liquid activation* (second)	*Duration of acid liquid activation* (second)	After controlling process (pH)
1	5	10	-	6.5
2	5.25	8	-	6.4
3	5.5	5	-	6.25
4	5.75	3	-	6.1
5	9	-	10	7.6
6	8.75	-	8	7.8
7	8.5	-	5	7.9
8	8.25	-	3	8.0

From the Table VIII, it is shown that acidity are controlled to be appropximately in the range of neutral that is pH of 6 – 8.

The testing results for turbidity fuzzy control are shown by Tabel IX.

TABLE IX. TURBIDITY CONTROL PROCESS RESULTS

No	Before controlling process (NTU)	*Duration of pump activation* (second)	After controlling process (NTU)
1	300	60	99.9
2	275	55	99.9
3	250	50	68.9
4	225	45	68.9
5	200	40	35.9
6	175	35	35.9
7	150	30	68.9

C. Testing environment in a miniature plant

The fuzzy logic monitoring and controlling system has been tested in a miniature plant control (small aquarium) that goldfish eggs were put inside as shown by Fig.9. The small aquarium consist of goldfish eggs approximately 50 eggs. The result of controlling process produces 96% eggs hatched (48 of 50 eggs) as in Fig.10.

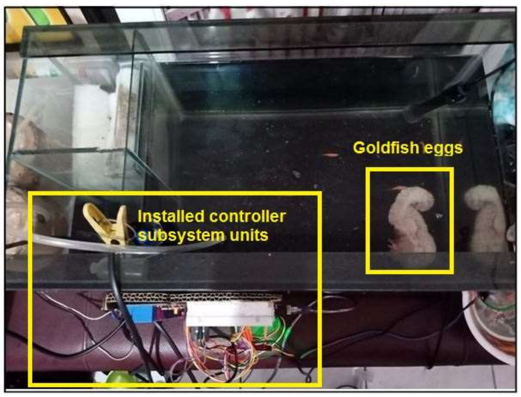


Fig. 9. Installed monitoring and controlling system and goldfish egg

Fig. 10. Hatched goldfish egg

VI. CONCLUSION

In this paper, we explained about Mamdani method fuzzy controller-based in monitoring and controlling system for temperature, acidity, and turbidity condition. The results of temperature sensor and acidity sensor are 0.67% and 2,48% error respectively compare with standard measuring equipment. Duration activation of each output device to control the variables, i.e electrical heater, turbid pump, acid liquid pump and alkali liquid pump, are performed and affect to the water condition that complied with the terms of BPBIAT stated as the temperature range is in 26ºC - 30ºC, the acitidy range is in pH 6 - 8, and the turbidity is below 128NTU.

VII. FUTURE WORK

For future work, we intend to perform the testing in two plants area that both contain approximately the same number of goldfish eggs, which no controller will be installed in one plant and the other will be equipped. One of our concern is to compare the degree of success in egg hatching of both plants.

REFERENCES

[1] Ramadhan, M. S., & Rivai, M. (2018). Sistem Kontrol Tingkat Kekeruhan Pada Aquarium Menggunakan Arduino Uno. JURNAL TEKNIK ITS Vol. 7 , 2337-3520.

[2] Abdullah, M., susanto, E., & Wibawa, I. P. (2016). Rancang Bangun Sistem Pendeteksi Kualitas Air Menggunakan Metode Fuzzy Logic. e-Proceeding of Engineering , 1322.

[3] Cholilullah, M., Syauqy, D., & Tibyani. (2018). Implementasi Metode Fuzzy Pada Kualitas Air Kolam Bibit Lele Berdasarkan Suhu dan Kekeruhan. Jurnal Pengembangan Teknologi Informasi dan Ilmu Komputer , 1813-1822

[4] Azeem, Moh.Fazle, Fuzzy Inference System-Theory and Application, INTECH, 2012

[5] Abrori, M., & Prihamayu, A. H. (2015). Aplikasi Logika Fuzzy Metode Mamdani Dalam Pengambilan Keputusan Penentuan Jumlah Produksi. Kaunia Vol. XI No. 2 , 91 – 99. DAFTAR RUJUKAN

[6] Anwar, H., Hermida, I. D., & Waslaluddin. (2015). Rancang Bangun Sistem Telemetri Wireless Realtime Monitoring Kualitas Air Terintegrasi Dengan Automatic Sampling dan Aplikasi Database Berbasis Mikrokontroler. Fibusi (JoF) Vol. 3 No. 3 , 100.

[7] Astria, F., Subito, M., & Nugraha, D. W. (2014). RANCANG BANGUN ALAT UKUR PH DAN SUHU BERBASIS SHORT MESSAGE SERVICE (SMS) GATEWAY. Jurnal MEKTRIK , 2356-4792.

[8] Bahri, S., & Fikriyah, K. (2018). Prototype Monitoring Penggunaan dan Kualitas Air Berbasis Web Menggunakan Raspberry Pi. Jurnal Elektrum , 1979-5564.

[9] Bhawiyuga, A., & Yahya, W. (2019). SISTEM MONITORING KUALITAS AIR KOLAM BUDIDAYA MENGGUNAKAN JARINGAN SENSOR NIRKABEL BERBASIS PROTOKOL LORA. Jurnal Teknologi Informasi dan Ilmu Komputer (JTIIK) , 99-106.

[10] Desmira, Aribowo, D., & Pratama, R. (2018). PENERAPAN SENSOR pH PADA AREA ELEKTROLIZER DI PT. SULFINDO ADIUSAHA. Jurnal PROSISKO Vol. 5 No. 1 , 2597-9922.

[11] Runtong Zhang, Yannis A. Phillis, Vassilis S. Kouikoglou,, Fuzzy Control of Queuing Systems, Springer, 2005