

Automatic Sterilized Drinking Water System for Chickens Using Fuzzy Logic

Rona Aulia Wangsa Sea
Department of Electrical Engineering
UIN Sunan Gunung Djati Bandung
Bandung, Indonesia
rona.aulia2000@gmail.com

Saepul Uyun
Department of Electrical Engineering
UIN Sunan Gunung Djati Bandung
Bandung, Indonesia
saepuluyun@uinsgd.ac.id

Eki Ahmad Zaki Hamidi
Department of Electrical Engineering
UIN Sunan Gunung Djati Bandung
Bandung, Indonesia
ekiahmadzaki@uinsgd.ac.id

Teddy Yusuf
Department of Electrical Engineering
UIN Sunan Gunung Djati Bandung
Bandung, Indonesia
teddy.yusuf@uinsgd.ac.id

Farah Ruqayah
Department of Social & Political
Science
UIN Sunan Gunung Djati Bandung
Bandung, Indonesia
cibiru46@gmail.com

Rina Mardiaty
Department of Electrical Engineering
UIN Sunan Gunung Djati Bandung
Bandung, Indonesia
r_mardiaty@uinsgd.ac.id

Abstract— Automatic sterilized drinking water system is designed to provide adequate supply of sterilized drinking water for chickens. The water is sterilized using a UV lamp to ensure the water is not contaminated with Salmonella bacteria which is then distributed to chickens automatically with fuzzy method. UV lamp irradiation was carried out for 18.627 minutes with a lamp intensity of 0.0136 mW/cm² to obtain the highest dose of Salmonella bacteria needed for 15.2 mWsec/cm². The use of ultrasonic sensor HC-SR04 for reading the water level in tank and both water tube and then the readings are processed by the system to determine the work output. Fuzzy system is done by providing input water level on UV tank of 6 cm, Tube A of 5 cm, and Tube B of 4 cm, which then produces defuzzification results for output Valve Inlet of 4.40, Valve A of 5.60, and Valve B of 5.60. At several times of defuzzification, these values are then collected to be used as the ON/OFF determining value of the output with the ON determinant value is Z* lower than 4.5 and OFF is Z* greater than 6.5. System accuracy testing is also carried out by collecting the total error percentage from fuzzy testing, rule testing, and UV duration testing, then deviated by 100% in order to obtain a system accuracy of 94.944%.

Keywords—Automatic water system, Sterilized drinking water, UV lamp, Salmonella, ultrasonic, fuzzy.

I. INTRODUCTION

Chicken and its processed products have a lot of nutritional ingredients in addition to affordable price, which makes many people consume it. However, based on a report by the European Food Safety Authority and the European Center for Disease Prevention and Control, that during the period of 2004 – 2015, the highest Salmonella infections came from chickens. Salmonella can infect animals and can be transmitted to humans [1].

Salmonella can be transmitted from various media, one of which is contaminated drinking water. So it is necessary to carry out the process of sterilization of drinking water. The method used for sterilization process needs to be considered, in which the use of chemical substances (old way) such as chlorine and phosphorus should be avoided. Therefore, the use of ultraviolet light (UV) is here to answer these needs. The use of UV light has proven to be effective in killing bacteria without direct contact with chemicals. UV light can damage bacterial DNA so that bacteria could not reproduce and die [2].

The process of sterilizing drinking water is not necessarily done manually because it will be inconvenient and increase the workload of the farmers. So we need a system that runs automatically. Sterilized water is given to the chickens automatically so the sterility of water is maintained while reducing the workload of farmers. Provision of drinking water for chickens is carried out regularly to ensure adequate supply of drinking water for chickens [3].

In making the system, a method is needed, both the sterilization process (UV irradiation) and the process of providing drinking water. Abijheet Ashok Paidalwar and Isha P Kheidar have conducted research on water sterilization process (disinfection) [4], which discussed the best types of UV waves and the doses needed to provide effective UV irradiation. Then, in the process of providing water, a method of water level controlling is needed. Research on water level control has been carried out by Fadhillah Azmi, Insidini Fawwaz, Muhathir, and N.P. Dharshinni, where it is stated that fuzzy logic can be used to control water levels [5]. This fuzzy logic is used to determine how the system works. The use of fuzzy logic is the right choice because it has been proven to work properly on the system as in several studies [6] [7] that have been carried out. Especially using of fuzzy logic on controlling plant of the system [8] [9], fuzzy is a good method for it.

II. DETERMINATION OF THE UV IRRADIATION TIME FOR WATER STERILIZATION PROCESS

UV irradiation is used in process of sterilizing drinking water. In order for UV irradiation to be carried out effectively, it is necessary to pay attention to parameters such as the required UV wave type, UV dose, the intensity of UV lamp, and the duration of irradiation [4]. The best type of UV wave for sterilization process is UV type C (UV-C), this is because UV-C has the smallest wavelength among other types as A and B. UV-C has a wavelength range of 100 – 280 nm which is bacteria does not yet have resistance to UV-C [10]. By following the equation [4]:

$$D = I \cdot t \quad (1)$$

with

D : UV dose (mWsec/cm²),

I : Intensity (mW/cm^2),
 t : Exposure time (sec).

TABLE I. UV DOSE FOR SALMONELLA

No.	Bacteria	Dose ($mWsec/cm^2$)
1	Salmonella Enteritidis	7.6
2	Salmonella Paratyphi	6.1
3	Salmonella Thyposa	4.1
4	Salmonella Thypimurium	15.2

Based on TABLE I, a dose of $15.2 mWsec/cm^2$ (Salmonella thypimurium) is used to collect all the required UV doses for Salmonella. With the UV lamp used with an intensity of $0.0136 mW/cm^2$, so that the UV irradiation time can be determined to be

$$t = \frac{D}{I}, \quad t = \frac{15.2 mWsec/cm^2}{0.0136 mW/cm^2} \quad (2)$$

$$t = 1117.65 \text{ seconds} \approx 18,627 \text{ minutes}$$

So it has been known that the UV irradiation time is 18.627 minutes with the assumption that this is the minimum irradiation time.

III. MODELING SYSTEM

A. Flowchart System

The system built has a working method based on the flow chart in Fig 1.

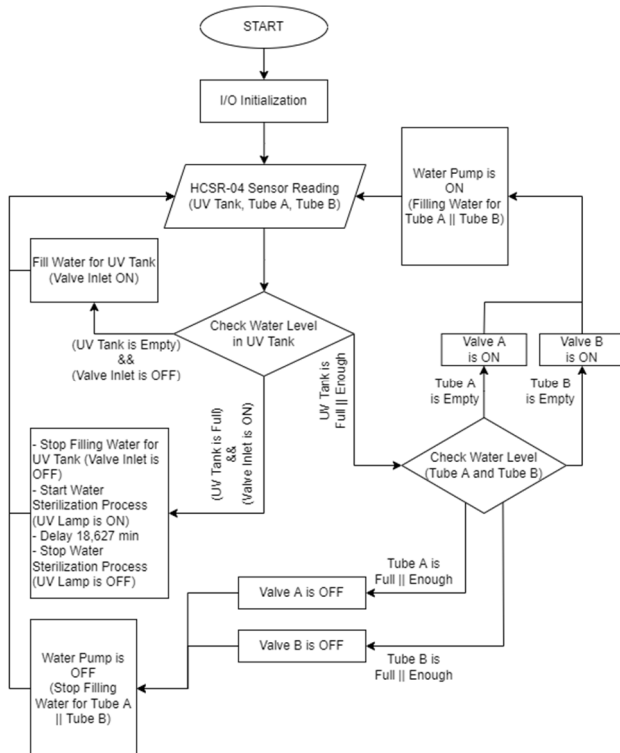


Fig. 1. Flowchart of automatic sterilized drinking water system.

B. Block Diagram System

Automatic sterilized drinking water system works based on fuzzy logic control which consists of 3 stages, namely: input, process, and output.

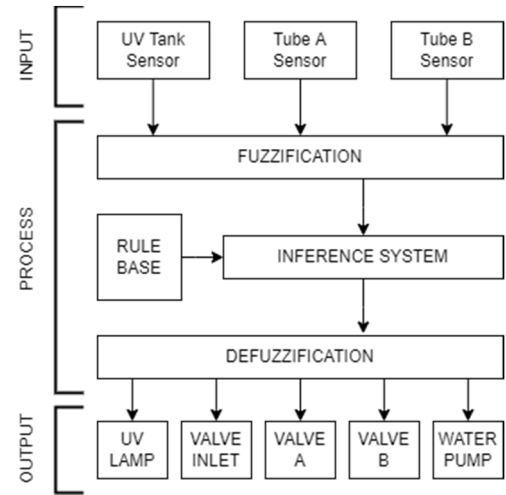


Fig. 2. Block diagram of automatic sterilized water system for chicken.

In general, all these parts shown in Fig. 2 are related to each other, so that an automatic sterilized water system can be created.

1. At the input stage, there are three HC-SR04 sensors (ultrasonic sensors). The sensors are used to measure the distance of water surface and the reading results are converted into water level.
2. In the processing section, it has an important role in the system being made, where the sensor readings (water level) which are input are processed by the Arduino MEGA 2560 microcontroller using the fuzzy logic method. The input (crisp) is fuzzified by the the system, which is then processed until the result of the defuzzification is obtained.
3. Output section is the result of data processing (defuzzification) by the Arduino Mega 2560 microcontroller in the form of defuzzification value. This value is used to determine the output works. The outputs include Valve Inlet, UV Lamp, Water Pump, Valve A, and Valve B.

C. Hardware Design

Wiring is required in hardware design. Wiring for the system created can be seen in Fig. 3.

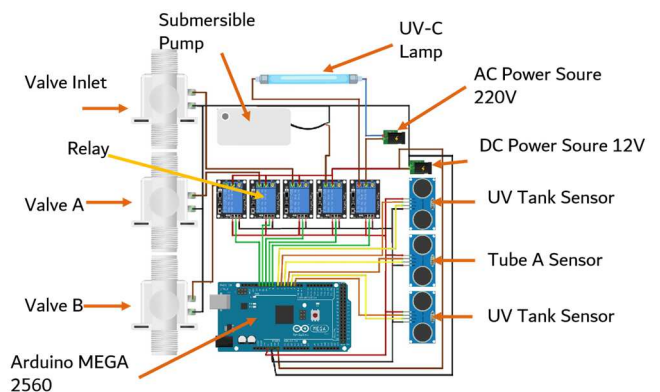


Fig. 3. Schematic system.

Then, at wiring system, certain components are needed. The components used in the system can be seen in TABLE II.

TABLE II. COMPONENTS

NO.	Component	Lots
1	Arduino MEGA 2560	1
2	HC-SR04 Ultrasonic Sensor	3
3	Solenoid Water Valve	3
4	UV-C Lamp	1
5	Submersible Water Pump	1
6	Relay	5
7	Container Box (UV Tank)	1
8	Water Tube	2
9	Chicken Watering Cup	4
10	Cable & Water Hose	Based on needs
11	Power Supply	1

D. Modeling Fuzzy

The fuzzy method used in the system is fuzzy Mamdani (min-max method) [5]. Fuzzy logic is not applied to every single one outputs owing to the fact that there currently are outputs that object over there work simultaneously in addition to sequentially.

E. Membership Function

In the system built, the input variables consist of the water level of UV Tank, Tube A, and, Tube B. Owing to the fact that there currently are many input variables, a linguistic term currently exists needed. Linguistic term for input variables can be seen in TABLE III and TABLE IV.

TABLE II. LINGUISTIC TERM OF UV TANK SENSOR

Water Level (cm)	Linguistic Term
[0 0 4 10]	Empty (E1)
[4 10 10 16]	Adequate (A1)
[10 16 20 20]	Full (F1)

TABLE IV. LINGUISTIC TERM OF TUBE A AND B SENSOR

Water Level (cm)	Linguistic Term	
	Tube A Sensor	Tube B Sensor
[0 0 3 7.5]	Empty (E2)	Empty (E3)
[3 7.5 7.5 12]	Adequate (A2)	Adequate (A3)
[7.5 12 15 15]	Full (F2)	Full (F3)

In addition, there are also output variables and linguistic term is needed. In the system built, fuzzy logic is only applied to the following outputs: Valve Inlet, Valve A, and Valve B. The work of the water pump depends on the conditions of Valve A and B. The water pump starts when one or both Valves A and B are on. Then, the work of the UV lamp is also not applied from fuzzy logic. It will turn on after the water filling process in the UV is completed. Linguistic term for output variables can be seen in TABLE V.

TABLE III. LINGUISTIC TERM OF VALVE INLET, VALVE A, AND VALVE B

Determinant Value	Linguistic Term		
	Valve inlet	Valve A	Valve B
[0 0 2 8]	ON (ON1)	ON (ON2)	ON (ON2)
[2 8 10 10]	OFF (OFF1)	OFF (OFF2)	OFF (OFF2)

For membership function that have been created, graph plotting is required for each membership function, both input and output variables. The type of membership function graph used is a combination of trapezoid and triangle. Membership function for input variables can be seen in Fig. 4, Fig. 5, and TABLE VI. Meanwhile, membership function for output variables can be seen in Fig. 6 and TABLE VII.

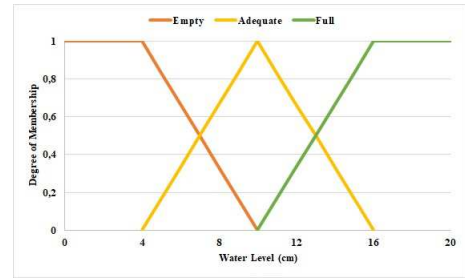


Fig. 4. Membership function of UV tank water level.

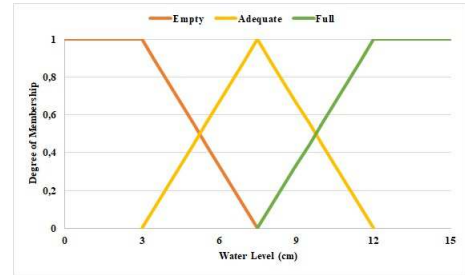


Fig. 5. Membership function of tube A and tube B water level.

TABLE VI. EQUATION TERM OF INPUT MEMBERSHIP FUNCTION

μ of UV Tank Water Level	$\mu_{E1} = \begin{cases} 0; x \geq 10 \\ \frac{10-x}{6}; 4 \leq x \leq 10 \\ 1; x \leq 4 \end{cases}$
	$\mu_{A1} = \begin{cases} 0; x \geq 16 \text{ or } x \leq 4 \\ \frac{x-4}{6}; 4 \leq x \leq 10 \\ 1; x \leq 4 \\ \frac{16-x}{6}; 10 \leq x \leq 16 \end{cases}$
	$\mu_{F1} = \begin{cases} 0; x \leq 10 \\ \frac{x-10}{6}; 10 \leq x \leq 16 \\ 1; x \geq 16 \end{cases}$
μ of Tube A and Tube B Water Level	$\mu_{E2} = \mu_{E3} = \begin{cases} 0; x \geq 7.5 \\ \frac{7.5-x}{5}; 3 \leq x \leq 7.5 \\ 1; x \leq 4 \end{cases}$
	$\mu_{A2} = \mu_{A3} = \begin{cases} 0; x \geq 12 \text{ or } x \leq 3 \\ \frac{x-3}{4.5}; 3 \leq x \leq 7.5 \\ 1; x \leq 7.5 \\ \frac{12-x}{4.5}; 7.5 \leq x \leq 12 \end{cases}$
	$\mu_{F2} = \mu_{F3} = \begin{cases} 0; x \leq 7.5 \\ \frac{x-7.5}{4.5}; 7.5 \leq x \leq 12 \\ 1; x \geq 12 \end{cases}$

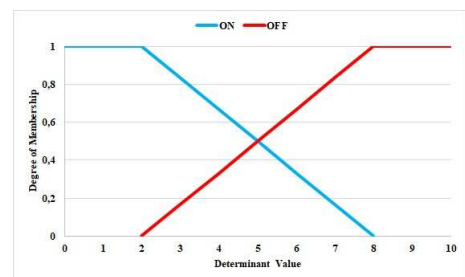


Fig. 6. Membership function of valve Inlet, valve A, and valve B.

TABLE VI. EQUATION TERM OF OUTPUT MEMBERSHIP FUNCTION

μ of Valve Inlet, Valve A, and Valve B
$\mu_{ON1} = \mu_{ON2} = \mu_{ON3} = \begin{cases} 0; & x \geq 8 \\ \frac{8-x}{6}; & 2 \leq x \leq 8 \\ 1; & x \leq 2 \end{cases}$
$\mu_{OFF1} = \mu_{OFF2} = \mu_{OFF3} = \begin{cases} 0; & x \leq 12 \\ \frac{x-2}{6}; & 2 \leq x \leq 8 \\ 1; & x \geq 8 \end{cases}$

In fuzzy logic, it is necessary to make fuzzy rules, so that the system is made as desired. Fuzzy rules in this system can be seen in TABLE VIII.

TABLE VII. FUZZY RULES

Rules	Input			Output		
	UV Tank	Tube A	Tube B	Valve Inlet	Valve A	Valve B
1	Full	Full	Full	OFF	OFF	OFF
2	Full	Full	Adequate	OFF	OFF	OFF
3	Full	Full	Empty	OFF	OFF	ON
4	Full	Adequate	Full	OFF	OFF	OFF
5	Full	Adequate	Adequate	OFF	OFF	OFF
6	Full	Adequate	Empty	OFF	OFF	ON
7	Full	Empty	Full	OFF	ON	OFF
8	Full	Empty	Adequate	OFF	ON	OFF
9	Full	Empty	Empty	OFF	ON	ON
10	Adequate	Full	Full	OFF	OFF	OFF
11	Adequate	Full	Adequate	OFF	OFF	OFF
12	Adequate	Full	Empty	OFF	OFF	ON
13	Adequate	Adequate	Full	OFF	OFF	OFF
14	Adequate	Adequate	Adequate	OFF	OFF	OFF
15	Adequate	Adequate	Empty	OFF	OFF	ON
16	Adequate	Empty	Full	OFF	ON	OFF
17	Adequate	Empty	Adequate	OFF	ON	OFF
18	Adequate	Empty	Empty	OFF	ON	ON
19	Empty	Full	Full	ON	OFF	OFF
20	Empty	Full	Adequate	ON	OFF	OFF
21	Empty	Full	Empty	ON	OFF	OFF
22	Empty	Adequate	Full	ON	OFF	OFF
23	Empty	Adequate	Adequate	ON	OFF	OFF
24	Empty	Adequate	Empty	ON	OFF	OFF
25	Empty	Empty	Full	ON	OFF	OFF
26	Empty	Empty	Adequate	ON	OFF	OFF
27	Empty	Empty	Empty	ON	OFF	OFF

IV. SYSTEM TESTING

Fuzzy logic is tested by simulation, microcontroller, and manual calculations. The test is carried out by giving inputs of:

- UV Tank Water Level = 6 cm.
- Tube A Water Level = 5 cm.
- Tube B Water Level = 4 cm.

A. Manual Calculation

Step 1. Fuzzification

All input values (crisp) are fuzzified to get the membership degree based on TABLE III and IV.

UV Tank Water Level

$$\mu_{E1}[6] = \frac{10-x}{6} = \frac{10-6}{6} = 0.67$$

$$\mu_{A1}[6] = \frac{x-4}{6} = \frac{6-4}{6} = 0.33$$

$$\mu_{F1}[6] = 0$$

Tube A Water Level

$$\mu_{E2}[5] = \frac{7.5-x}{4.5} = \frac{7.5-5}{4.5} = 0.56$$

$$\mu_{A2}[5] = \frac{x-3}{4.5} = \frac{5-3}{4.5} = 0.44$$

$$\mu_{F2}[5] = 0$$

Tube B Water Level

$$\mu_{E3}[4] = \frac{7.5-x}{4.5} = \frac{7.5-4}{4.5} = 0.78$$

$$\mu_{A3}[4] = \frac{x-3}{4.5} = \frac{4-3}{4.5} = 0.22$$

$$\mu_{F3}[4] = 0$$

Step 2. The Implication Function

In Fuzzy Mamdani, the min method is applied to implication function. The min result values are the value used for the next step. Based on the results of the fuzzification that has been carried out from the rules in TABLE VIII, there are 8 only rules that fulfill the implication function, including: [R14], [R15], [R17], [R18], [R23], [R24], [R26], [R27].

[R14] : **IF** UV Tank is Full **AND** Tube A is Adequate **AND** Tube B is Adequate, **THEN** Valve Inlet is OFF **AND** Valve A is OFF **AND** Valve B is OFF

$$\begin{aligned} \alpha_{R14} &= \mu_{F1} \cap \mu_{A2} \cap \mu_{A3} \\ \alpha_{R14} &= \min(\mu_{F1}, \mu_{A2}, \mu_{A3}) \\ \alpha_{R14} &= \min(0.33, 0.44, 0.22) = 0.22 \end{aligned}$$

[R15] : **IF** UV Tank is Adequate **AND** Tube A is Adequate **AND** Tube B is Empty, **THEN** Valve Inlet is OFF **AND** Valve A is OFF **AND** Valve B is ON

$$\begin{aligned} \alpha_{R15} &= \mu_{A1} \cap \mu_{A2} \cap \mu_{E3} \\ \alpha_{R15} &= \min(\mu_{A1}, \mu_{A2}, \mu_{E3}) \\ \alpha_{R15} &= \min(0.33, 0.44, 0.78) = 0.33 \end{aligned}$$

[R17] : **IF** UV Tank is Adequate **AND** Tube A is Empty **AND** Tube B is Adequate, **THEN** Valve Inlet is OFF **AND** Valve A is ON **AND** Valve B is OFF

$$\begin{aligned} \alpha_{R17} &= \mu_{A1} \cap \mu_{E2} \cap \mu_{A3} \\ \alpha_{R17} &= \min(\mu_{A1}, \mu_{E2}, \mu_{A3}) \\ \alpha_{R17} &= \min(0.33, 0.56, 0.22) = 0.22 \end{aligned}$$

[R18] : **IF** UV Tank is Adequate **AND** Tube A is Empty **AND** Tube B is Empty, **THEN** Valve Inlet is OFF **AND** Valve A is ON **AND** Valve B is ON

$$\begin{aligned} \alpha_{R18} &= \mu_{A1} \cap \mu_{E2} \cap \mu_{E3} \\ \alpha_{R18} &= \min(\mu_{A1}, \mu_{E2}, E) \\ \alpha_{R18} &= \min(0.33, 0.56, 0.78) = 0.33 \end{aligned}$$

[R23] : **IF** UV Tank is Empty **AND** Tube A is Adequate **AND** Tube B is Adequate, **THEN** Valve Inlet is ON **AND** Valve A is OFF **AND** Valve B is OFF

$$\begin{aligned}\alpha_{R23} &= \mu_{E1} \cap \mu_{A2} \cap \mu_{A3} \\ \alpha_{R23} &= \min(\mu_{E1}, \mu_{A2}, \mu_{A3}) \\ \alpha_{R23} &= \min(0.67, 0.44, 0.22) = 0.22\end{aligned}$$

[R24] : **IF** UV Tank is Empty **AND** Tube A is Adequate **AND** Tube B is Empty, **THEN** Valve Inlet is ON **AND** Valve A is OFF **AND** Valve B is OFF

$$\begin{aligned}\alpha_{R23} &= \mu_{E1} \cap \mu_{A2} \cap \mu_{E3} \\ \alpha_{R23} &= \min(\mu_{E1}, \mu_{A2}, \mu_{E3}) \\ \alpha_{R23} &= \min(0.67, 0.44, 0.78) = 0.44\end{aligned}$$

[R26] : **IF** UV Tank is Empty **AND** Tube A is Empty **AND** Tube B is Adequate, **THEN** Valve Inlet is ON **AND** Valve A is OFF **AND** Valve B is OFF

$$\begin{aligned}\alpha_{R23} &= \mu_{E1} \cap \mu_{E2} \cap \mu_{A3} \\ \alpha_{R23} &= \min(\mu_{E1}, \mu_{E2}, \mu_{A3}) \\ \alpha_{R23} &= \min(0.67, 0.56, 0.22) = 0.22\end{aligned}$$

[R27] : **IF** UV Tank is Empty **AND** Tube A is Empty **AND** Tube B is Empty, **THEN** Valve Inlet is ON **AND** Valve A is OFF **AND** Valve B is OFF

$$\begin{aligned}\alpha_{R23} &= \mu_{E1} \cap \mu_{E2} \cap \mu_{E3} \\ \alpha_{R23} &= \min(\mu_{E1}, \mu_{E2}, \mu_{E3}) \\ \alpha_{R23} &= \min(0.67, 0.56, 0.78) = 0.56\end{aligned}$$

Step 3. Rule Composition

The result of rule composition could be seen in TABLE IX.

TABLE IX. RULE COMPOSITION

Rules	Output	X Value
[R14]	Valve Inlet (OFF)	3.32
	Valve A (OFF)	3.32
	Valve B (OFF)	3.32
[R15]	Valve Inlet (OFF)	3.98
	Valve A (OFF)	3.98
	Valve B (ON)	6.02
[R17]	Valve Inlet (OFF)	3.32
	Valve A (ON)	6.68
	Valve B (OFF)	3.32
[R18]	Valve Inlet (OFF)	3.98
	Valve A (ON)	6.02
	Valve B (ON)	6.02
[R23]	Valve Inlet (ON)	6.68
	Valve A (OFF)	3.32
	Valve B (OFF)	3.32
[R24]	Valve Inlet (ON)	5.36
	Valve A (OFF)	4.64
	Valve B (OFF)	4.64
[R26]	Valve Inlet (ON)	6.68
	Valve A (OFF)	3.32
	Valve B (OFF)	3.32
[R27]	Valve Inlet (ON)	4.64
	Valve A (OFF)	5.36
	Valve B (OFF)	5.36

After that, the point of intersection of t1 and t2 is determined in each Valve Inlet, Valve A, and Valve B which can be seen in TABLE X.

TABLE X. INTERSECTION VALUE OF OUTPUT

Output	t ₁	t ₂
Valve Inlet	3.98	5.36
Valve A	3.98	5.36
Valve B	3.98	5.36

Step 4. Defuzzification

The defuzzification produces a crisp value which is then used to determine the work of output.

$$Z^* = \frac{\int \mu(z)z dz \rightarrow M_{Total}}{\int \mu(z)dz \rightarrow A_{Total}} \quad (3)$$

Valve Inlet

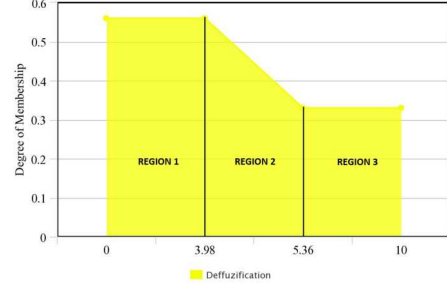


Fig. 7. Valve Inlet defuzzification.

In Fig. 7, the region after Valve Inlet defuzzification process are shown.

$$\mu(z) = \begin{cases} 0.56 ; Z \geq 3.98 \\ \frac{Z-2}{6} ; 3.98 \leq Z \leq 5.36 \\ 0.33 ; Z \geq 5.36 \end{cases}$$

- $M_1 = \int_0^{3.98} 0.56 z dz = 4.44$
- $M_2 = \int_{3.98}^{5.36} \left(\frac{z-2}{6}\right) z dz = 2.9$
- $M_3 = \int_{5.36}^{10} 0.33 z dz = 11.76$
- $A_1 = \int_0^{3.98} 0.56 dz = 2.23$
- $A_2 = \int_{3.98}^{5.36} \frac{z-2}{6} dz = 0.61$
- $A_3 = \int_{5.36}^{10} 0.33 z dz = 1.53$

$$Z^* = \frac{M_1 + M_2 + M_3}{A_1 + A_2 + A_3} = \frac{4.44 + 2.9 + 11.76}{2.23 + 0.61 + 1.53} = \frac{19.1}{4.37} = 4.37$$

Valve A

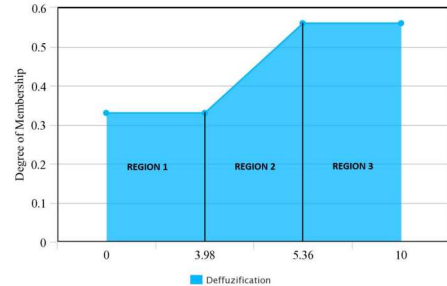


Fig. 8. Valve A defuzzification.

In Fig. 8, the region after Valve A defuzzification process are shown.

$$\mu(z) = \begin{cases} 0.33 ; Z \geq 3.98 \\ \frac{Z-2}{6} ; 3.98 \leq Z \leq 5.36 \\ 0.56 ; Z \geq 5.36 \end{cases}$$

- $M_1 = \int_0^{3,98} 0.33 z dz = 2.61$
- $M_2 = \int_{3,98}^{5,36} \left(\frac{z-2}{6}\right) z dz = 2.9$
- $M_3 = \int_{5,36}^{10} 0.56 z dz = 19.96$
- $A_1 = \int_0^{3,98} 0.33 dz = 1.32$
- $A_2 = \int_{3,98}^{5,36} \frac{z-2}{6} dz = 0.61$
- $A_3 = \int_{5,36}^{10} 0.56 z dz = 2.6$

$$Z^* = \frac{M_1+M_2+M_3}{A_1+A_2+A_3} = \frac{2.61+2.9+19.96}{1.32+0.61+2.6} = \frac{25.47}{4.53} = 5.62$$

Valve B

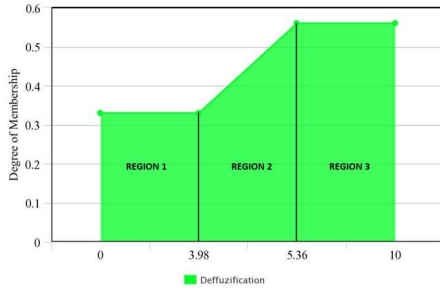


Fig. 9. Valve B defuzzification.

In Fig. 9, the region after Valve B defuzzification process are shown.

$$\mu_{(Z)} = \begin{cases} 0.33 ; Z \geq 3.98 \\ \frac{Z-2}{6} ; 3,98 \leq Z \leq 5.36 \\ 0.56 ; Z \geq 5.36 \end{cases}$$

- $M_1 = \int_0^{3,98} 0.33 z dz = 2.61$
- $M_2 = \int_{3,98}^{5,36} \left(\frac{z-2}{6}\right) z dz = 2.9$
- $M_3 = \int_{5,36}^{10} 0.56 z dz = 19.96$
- $A_1 = \int_0^{3,98} 0.33 dz = 1.32$
- $A_2 = \int_{3,98}^{5,36} \frac{z-2}{6} dz = 0.61$
- $A_3 = \int_{5,36}^{10} 0.56 z dz = 2.6$

$$Z^* = \frac{M_1+M_2+M_3}{A_1+A_2+A_3} = \frac{2.61+2.9+19.96}{1.32+0.61+2.6} = \frac{25.47}{4.53} = 5.62$$

B. Simulation Testing

Fuzzy testing is done by using simulation software. Simulation testing is considered ideal and is used as the main reference for the accuracy of the results. Simulation of fuzzy test input can be seen in Fig. 10.

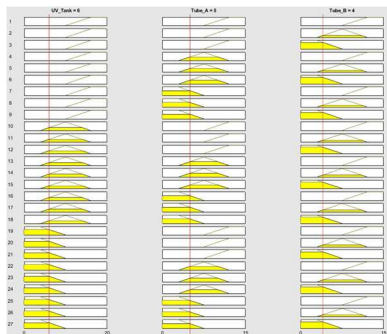


Fig. 10. Simulation of fuzzy test input.

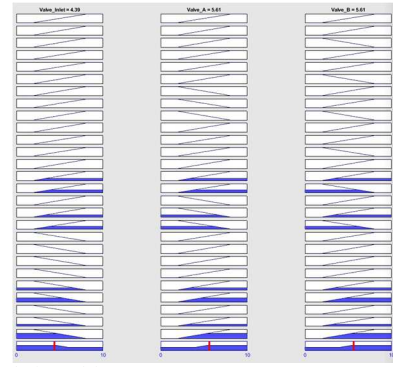


Fig. 11. Simulation of fuzzy test output.

The results of the defuzzification carried out in the simulation test are shown in Fig. 11 with the results of the defuzzification Valve Inlet is 4.39, Valve A is 5.61, and Valve B is 5.61.

C. Microcontroller Testing

Fuzzy testing on the microcontroller is done by Arduino Mega 2560 with the help of a certain library and displaying value of the defuzzification results on the Serial Monitor as shown in Fig. 12.

```

*****
Input :
Tank UV : 6.00
Wadah A : 5.00
Wadah B : 4.00

Defuzzification Result:
Valve Inlet: 4.40
Valve A: 5.60
Valve B: 5.60

```

Fig. 12. Microcontroller fuzzy test output.

The results of the defuzzification carried out in the microcontroller test are shown in Fig. 12 with the results of the defuzzification Valve Inlet is 4.39, Valve A is 5.61, and Valve B is 5.61.

D. Comparison of Fuzzy Testing Results

From the three fuzzy tests carried out, the comparison can be seen. All three have values that tend to be same as written errors in TABLE XI.

TABLE XI. FUZZY TESTING RESULT COMPARISON

Simulation			Microcontroller			Manual Calculation		
Valve Inlet	Valve A	Valve B	Valve Inlet	Valve A	Valve B	Valve Inlet	Valve A	Valve B
4.39	5.61	5.61	4.40	5.60	5.60	4.37	5.62	5.62

$$\%error_{Fuzzy} = \left| \frac{microcontroller - simulation}{simulation} \right| \times 100\%$$

$$\%error_{valve\ Inlet} = \left| \frac{4.40 - 4.39}{4.39} \right| \times 100\% = 0.228\%$$

$$\%error_{valve\ A} = \left| \frac{5.60 - 5.61}{5.61} \right| \times 100\% = 0.178\%$$

$$\%error_{valve\ B} = \left| \frac{5.60 - 5.61}{5.61} \right| \times 100\% = 0.178\%$$

E. Determining Output Work by Defuzzification Result

Determination of the output work based on defuzzification results is obtained after the defuzzification process is done for multiple times with various inputs. Then the appropriate defuzzification value is obtained and used

as a determining value for output work. Value of determinant can be seen in TABLE XII.

TABLE VIII. OUTPUT WORK DETERMINER VALUE

Work	Valve Inlet	Valve A	Valve B
ON	$Z^* < 4.5$	$Z^* < 4.5$	$Z^* < 4.5$
OFF	$Z^* > 6.5$	$Z^* > 6.5$	$Z^* > 6.5$

F. Sensor Testing

Sensor testing is carried out for each sensor embedded in the UV Tank, Tube A, and Tube B by measuring the difference between the sensor readings and the measuring tool. Data from the sensor reading can be seen in TABLE XIII, TABLE XIV, and TABLE XV.

TABLE VIII. UV TANK SENSOR TEST

NO.	Ruler (cm)	Sensor (cm)	% Error
1	2	1.88	6.00
2	4	3.88	3.00
3	6	5.99	0.17
4	8	8.12	1.50
5	10	10.01	0.10
6	12	12.07	0.58
7	14	14.13	0.93
8	16	16.16	1.00
9	18	17.97	0.17
10	20	20.11	0.55
Average			1.40

TABLE IX. TUBE A SENSOR TESTING

NO.	Ruler (cm)	Sensor (cm)	% Error
1	1	0.99	1.00
2	2	1.93	3.50
3	3	3.03	1.00
4	4	4.21	5.25
5	5	5.02	0.40
6	6	5.97	0.50
7	7	7.08	1.14
8	8	8.11	1.38
9	9	8.87	1.44
10	10	10.01	0.10
11	11	10.93	0.64
12	12	11.88	1.00
13	13	13.01	0.08
14	14	13.99	0.07
15	15	14.94	0.40
Average			1.19

TABLE XV. TUBE B SENSOR TESTING

NO.	Ruler (cm)	Sensor (cm)	% Error
1	1	0.96	4.00
2	2	1.94	3.00
3	3	3.22	7.33
4	4	3.94	1.50
5	5	5.04	0.80
6	6	5.96	0.68
7	7	7.09	1.29
8	8	8.12	1.50
9	9	8.99	0.11
10	10	10.14	1.40
11	11	10.93	0.64
12	12	11.93	0.58
13	13	13.3	2.31
14	14	13.95	0.36
15	15	14.91	0.6
Average			1.74

G. Rule Testing

Testing on fuzzy rules is done by providing conditions in accordance with the 27 rules that have been made. Test

results obtained where as many as 27 rules run well with 0% error.

H. UV Lamp Duration Test

The system is set to turn on the UV lamp automatically whenever the UV tank filling has just stopped. The UV lamp is set to keep on for 18.627 minutes. The test is carried out by comparing the duration of the reference with a stopwatch. Data from UV lamp duration testing can be seen in TABLE XVI.

TABLE XVI. UV LAMP DURATION TEST

Attempt	Reference (minute)	Stopwatch (minute)	Error (minute)	% Error
1	18.627	18.600	0.027	0.145
2	18.627	18.660	0.330	0.177
3	18.627	18.660	0.330	0.177
4	18.627	18.660	0.330	0.177
5	18.627	18.630	0.003	0.016
6	18.627	18.660	0.330	0.177
7	18.627	18.660	0.330	0.177
8	18.627	18.630	0.003	0.016
9	18.627	18.660	0.330	0.177
10	18.627	18.660	0.33	0.177
Average			0.026	0.142

I. System Accuracy

The accuracy of the system is obtained by getting the percentage of total error which is then offset by 100%. The error value obtained during system testing can be seen in TABLE XVII.

TABLE XVII. TOTAL SYSTEM ERROR

% error	Value (%)
% error Valve Inlet	0.228
% error Valve A	0.178
% error Valve B	0.178
% error UV Tank Sensor	1.400
% error Tube A Sensor	1.190
% error Tube B Sensor	1.740
% error UV Duration	0.142
% error Rule Test	0
TOTAL	5.056

$$\text{System Accuracy} = 100\% - \% \text{Total error}$$

$$\text{System Accuracy} = 100\% - 5.056\% = 94.944\%$$

V. CONCLUSION

The automatic sterilized drinking water system that has been built is designed to sterilize drinking water (using of UV) and provide the sterilized water to chickens automatically using fuzzy logic. Fuzzy testing was carried out by providing water level input to the UV Tank of 6 cm, Tube A of 5 cm, and Tube B of 4 cm which resulted in a defuzzification value (microcontroller results) at Valve Inlet of 4.40, Valve A of 5.60, and Valve B of 5.60. In the system, the output works according to the determinant value of the defuzzification result with the ON determinant $Z^* < 4.5$ and the OFF determinant $Z^* > 6.5$.

The system takes 18.627 minutes to sterilize water from Salmonella bacteria. The time of 18.627 minutes is assumed to be the minimum duration for UV irradiation of chicken drinking water.

After testing, the error calculated for each of the fuzzy testing, rule testing, and UV lamp duration testing, which then produces the total error of 5.056%, with the result that

the system has an accuracy of 94.944% and fuzzy logic is proven to be successful to be applied to this system.

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