Water level control based fuzzy logic controller: simulation and experimental works

M Khairudin\textsuperscript{1}, AD Hastutiningsih\textsuperscript{2}, THT Maryadi\textsuperscript{3}, and HS Pramono \textsuperscript{4}

\textsuperscript{1,3,4}Electrical Engineering Education Dept., Universitas Negeri Yogyakarta, Yogyakarta, Indonesia
\textsuperscript{2}Civil Engineering Education Dept., Universitas Negeri Yogyakarta, Yogyakarta, Indonesia

E-mail: moh_khairudin@uny.ac.id

Abstract. This paper presents an automatic control system for Water Level Control (WLC) using Fuzzy Logic Controller (FLC). The use of FLC on the WLC system so that it can work automatically regulates the rotation speed of the motor (water pump). This system uses the input of Light-Dependent Sensor (LDR) as a light detector sensor outside space and ultrasonic detection sensors as the height of the water. As for the output of the motor rotation be as a replacement water pump for filling water in the reservoir of the water automatically. The working principle of this system is in a light sensor to detect outdoor LDR and Ultrasonic Sensor obstructed water level then the sensor will provide the input signal to the microcontroller in the form of Analog data when it is converted into a digital form signal using an Analog to Digital Converter (ADC). The data is processed using the FLC algorithm. The results show that the lighter in the outdoors and higher low water, the water-pumping Motor speed the faster or maximal. As for when the high water is medium and a bright light or daylight then the speed of motor rotation is medium and at the time of the highest water is maximal then the motor will die. Conversely, if the light on the outdoor is darker or at night and water levels are low or medium, the motor rotation speed will be medium too.

1. Introduction

It is highly important for studying a Water Level Control (WLC) especially in the industrial implementation like a boiler and other liquid tanks in nuclear power plants [1]. Nowadays the use of electric energy increases. In 2013, the use of electric energy in Indonesia increased by 7.2% from 2012, i.e. from 84.43 Tera Watt Hour (TWh) to 90.48 Tera Watt Hour (TWh) [2]. This one was caused by the waste of home electricity use. Among the system's power consumption that is often used is the utilization of electric motor as water pumps in the tank. One of the equipment that uses an electric motor is the water pump that is normally controlled by a Water Level Control (WLC) [3]. It is necessary several techniques to achieve a safe and comfortable [4].

During the time, found high water control system using the float as a switch for disconnect and connect the water pumps, e.g. with mercury float switch [5]. Using conventional methods, to detect the level of liquid within a tank, generally using a float switch. Normally, the switch can be operated in an indicator, an alarm and a pump.
However, the WLC system is the uncertainties and nonlinearities that can be categorized as a complex system. Many methods have been used to obtain the WLC system is effective and efficient. In most residential areas are used combined water tank system.

Conventional control methods cannot support to make a convenient and solve the complexity [6]. It is necessary an intelligent control system to solve it. An alternative technique that can be implemented for developing a nonlinear and linear system using intelligent system [7]. Reshmi [1] presented Fuzzy Logic Controller (FLC) and implemented this technique using Matlab and Simulink to assess the WLC behaviour. Similarly, with the work to simulate of FLC for water tank level reached by [8], it was realised by combining between FLC and PID control and using simulation package that is Fuzzy Logic Toolbox and Simulink within MATLAB software.

Several methods can be used in developing an FLC technique, namely Mamdani, Sugeno and Tsukamoto. Dhaanya et al [9] studied Mamdani method to assess the system for various inputs through the Fuzzy Inference System (FIS) Toolbox within Matlab for solving the uncertainties of WLC, the FLC can consider to solve an automation problem of WLC.

However, to make a comparison between a conventional control system and FLC in order to solve uncertainties problems of WLC, [10] explain comparison results between PID and FLC. The comparison conducted with kinds of methods namely integral squared error (ISE), integral absolute error (IAE), integral of time and squared error (ITSE) and integral of time and absolute error (ITAE) and the performance of FLC more enhanced compared to PID performance.

For the experimental works, [11] applied WLC through FLC within the hardware for the switching namely transistor and then the data processor using PIC16 microcontroller and then connected to a PC with serial communication.

This paper presents a system control WLC with FLC using Sugeno method for simulation and experimental works. Only a few studies that presented comparing between simulation and experimental works for WLC based FLC. This paper uses the input data with Light sensor FLC Dependent Resistors (LDR) as the outdoor light detector and ultrasonic sensors to detect high low water in the tank. While the output on a WLC with this FLC is the round motor that will pump water to be appointed into the tank so that it can fully automatically.

The results show that the lighter of the outdoors and the higher low water, the water-pumping motor speed is faster or maximal. While the high water is medium and the bright light or daylight then the motor rotation speed is medium and when the water is maximal then the motor will die. Conversely, if the outdoor light is darker or at night and water levels are low or medium, the motor rotation speed will be medium. The challenge of this paper is presented by comparing between simulation and experimental works for WLC based FLC. The result shows similar results as simulation results using Matlab and Proteus can be obtained by extensive effort in experimental works.

2. Method

The sensors applied in this study were LDR and ultrasonic of SRF04 that were assembled at the outdoor side and the inside of tank respectively. The ultrasonic sensor of SRF04 has four pins namely GND, VCC, ECHO and Trigger. Pins of Echo and Trigger were connected to the microcontroller with of pins of PINA.0 and PINA.1 respectively.

The input of analogue was raised both LDR and ultrasonic were processed through Analogue to Digital Converter (ADC) that within a microcontroller. Programming process in this study was conducted through the CPU of 2.90 GHz, Intel(R) Core™ i7 2.70 GHz, and RAM of 8.00 GB, the software and hardware capacity which were operated respectively. To monitor the system performance was showed using LCD monitor. However, the Microcontroller of Atmega 16 assembled for data processing in this study.
Control and data acquisition were accomplished by employing the microcontroller of Atmega 16 that provided a direct interface between the processor, motor and sensors through ADC for analogue input, analogue dan digital output. LDR and ultrasonic sensors will be driven by two analogue inputs were required in the experimental rig. The motor was used as representative for a Pompa air. The software required editor and compiler of AVR CodeVision, meanwhile it was necessary to edit and to compile. To assess the functionality and reliability of WLC system using LDR and ultrasonic sensors with the algorithm of FLC, it is necessary to confirm between water volume level and natural lighting from the sun.

WLC Automatic Control System is using FLC which consist of input and output. The number of inputs in this system there are 2 connected with 1 fruit sensors ultrasonic sensors and as well as the LDR output using either a round motor. Setting input LDR consists of two membership function (MF) that is day and night. While ultrasonic input consists of three MF i.e. low, medium and high. As for the motor output setting consists of three MF, namely off, medium, fast. So this study, there are 3 fuzzy variables, namely Ultrasound Sensors, LDR and motor as water-pumping.

The LDR variable is divided into 2 sets of fuzzy, namely: night and day. While ultrasonic variable is divided into 3 sets of fuzzy, namely: low, medium and high. Meanwhile, variable motor divided into 3 sets of fuzzy, namely: off, medium and fast.

The universal set is a whole value that is allowed to be operated in a fuzzy variable. As for the fuzzy set domain variable on the LDR is:

- Universal Set for LDR variable : [0 1000]
- Universal Set for ultrasonic variable : [0 80]
- Universal Set for motor variable : [0 255]

The domain of the entire set of fuzzy are values permitted in the Universal Set and can be operated in a fuzzy set. As for the fuzzy set domain variable on the LDR is

- Night = [0:1000:1000]
- Day = [0:0:1000]

While the set domain of fuzzy on ULTRASONIC variable is

- Low = [0:0:40]
- Medium = [0:40:80]
- High = [40:80:80]

Meanwhile, the set domain variable of fuzzy on MOTOR is

- Off = [0]
- Medium = [127.5]
- Maximal = [255]

The function of membership function (MF) is a curve that shows the mapping of input data points to engage in value that an interval between 0 to 1. While the output of automatic control system on the flame of water pump used the motor rotation.

The next step is the determination of the fuzzification on LDR input and ultrasonic. The specified input variables of LDR \( \mu \), namely the value of the analog to digital converter (ADC) for example with a value of 100. As for the determination of fuzzification with the MF Sugeno night model to get the error value \( \mu \) is using the formula:

\[
\mu_{MF\ \text{Night}} = \begin{cases} 
1; & x \leq a \\
(b-x)/(b-a); & a \leq x \leq b \\
0; & x \geq b 
\end{cases}
\]

(1)
Figures 1 and 2 show the membership function of ultrasonic input and motor as output respectively.

![Figure 1. The membership function of ultrasonic input](image1)

![Figure 2. The membership function of output of motor](image2)

With $x$, $b$, $a$ are input variable of LDR sensor, upper and lower bounds respectively. So, if for the night given MF $x=100$, $a=0$ and $b=1000$, it will get $\mu_{\text{night}} = 0.9$

While the fuzzification determination with Sugeno model on the day MF to get the value of the error ($\mu$) is by using the formula:

$$\mu_{\text{MF Day}} = \begin{cases} 
0; & x \leq a \\
(x-a)/(b-a); & a \leq x \leq b \\
1; & x \geq b 
\end{cases}$$

(2)

While $x$, $b$, $a$ are input variable of LDR sensor, upper and lower bounds respectively, the MF day that is given $x=100$, $a=0$ and $b=1000$, will be got $\mu_{\text{day}} = 0.1$.

For the type of the specified input variable ultrasonic input ($x$) is named the echo input and analog value output with a trigger to digital converter (ADC) for example with a value of 50. As for the
determination of fuzzification with the Sugeno model on low to get the MF delta value error ($\mu$) is using the formula:

$$
\mu_{MF\ lower} = \begin{cases} 
1; & x \leq a \\
(b - x)/(b - a); & a \leq x \leq b \\
0; & x \geq b
\end{cases}
$$

As for the $x, b, a$ for ultrasonic sensor are input variable of ultrasonic sensor, upper and lower bounds respectively. So, if MF day is given $x = 50, a = 0$ and $b = 40$, will be got $\mu_{lower} = 0$

As for the determination of fuzzification with the Sugeno model on medium to get the MF delta value error ($\mu$) is using the formula:

$$
\mu_{MF\ medium} = \begin{cases} 
0; & x \leq a \ or \ x \geq c \\
(x - a)/(b - a); & a \leq x \leq b \\
(c - x)/(c - b); & b \leq x \leq c
\end{cases}
$$

As for the $x, a, b, c$ for ultrasonic sensor are input variable of ultrasonic sensor, lower, medium and upper bounds respectively. So, if MF night is given $x = 50, a = 0, b = 40$ and $c = 80$, will be got $\mu_{medium} = 0.75$.

While the fuzzification determination with Sugeno model on the high MF to get the value of the error ($\mu$) is by using the formula:

$$
\mu_{MF\ high} = \begin{cases} 
0; & x \leq a \\
(x - a)/(b - a); & a \leq x \leq b \\
1; & x \geq b
\end{cases}
$$

As for the MF high, $x, b, a$ for ultrasonic sensor are input variable of ultrasonic sensor, upper and lower bounds respectively. So, if MF day is given $x = 50, a = 0$, and $b = 80$, will be got $\mu_{high} = 0.25$

Determination of RULES by using logic AND operation. $\alpha$-predicate as a result of operations by using logic AND operation obtained with the smallest membership value between elements on the set correlation.

3. Results and Discussions

As for the RULE determination can be seen in Table 1 below.

| No | Rules |
|----|-------|
| [R1] | If water LOW and LDR NOON then MOTOR FAST |
| [R2] | If water MEDIUM and LDR NOON then MOTOR MEDIUM |
| [R3] | If water HIGH and LDR NOON then MOTOR OFF |
| [R4] | If water LOW and LDR NIGHT then MOTOR MEDIUM |
| [R5] | If water MEDIUM and LDR NIGHT then MOTOR MEDIUM |
[R6]  If water HIGH and LDR NIGHT then
   MOTOR OFF

The next step in determining rules on the preparation of FLC is the implementation of the rules in programming. Table 2 shows the equation process on implementation rules.

**Table 2.** Rules implementation of the FLC for WLC system

| No | Rules |
|----|-------|
| [R1] | $\alpha -\text{predicate}_1 = \mu/LTRAlow \land LDRnoon$ |
| [R2] | $\alpha -\text{predicate}_2 = \mu/LTRAmedium \land LDRnoon$ |
| [R3] | $\alpha -\text{predicate}_3 = \mu/LTRAhigh \land LDRnoon$ |
| [R4] | $\alpha -\text{predicate}_4 = \mu/LTRAlow \land LDRnight$ |
| [R5] | $\alpha -\text{predicate}_5 = \mu/LTRAmedium \land LDRnight$ |
| [R6] | $\alpha -\text{predicate}_6 = \mu/LTRAhigh \land LDRnight$ |

After the process of determining the rules finished then continued with the process of defuzifikasi so that it can determine the value of the output ($Z$) using the following formula,

$$Z = \frac{apred_1 \cdot z_1 + apred_2 \cdot z_2 + apred_3 \cdot z_3 + apred_4 \cdot z_4 + apred_5 \cdot z_5}{apred_1 + apred_2 + apred_3 + apred_4 + apred_5 + apred_6}$$

(6)

So that the output value of the amount obtained ($Z$) of 90.3125 that will be used to set the pulse width of PWM on the motor. Meanwhile, after the completion of the design and simulation of FLC then continued with experimental works.

In the experimental works, the hardware component namely input needed the form of 1 piece sensor LDR and 1 fruit ultrasonic sensors as well as an electric motor as the output. Voltage source Vcc and ground on the sensor are mounted by using the socket resources (+) and (-).

Preparation of auto-control system of water pump using the FLC was designed using an application CV AVR. With block diagram can be seen in Figure 3.

![Figure 3. The schematic diagram of WLC](image)

In this study has been conducted simulation and experimental works. In experimental work, the sensors are used namely SRF04 ultrasonic has 4 legs i.e., GND, VCC, ECHO and TRIGGER. ECHO is set as the input on the PIN ADC (0)/PINA. 0 and TRIGGER are set as the output on PIN ADC (1) or PINA. 1.
While the output that is a Motor Driver of L293D mounted in PIND. 0 and the PINB. 1 for input and Enable on PINB. 3. With the output, driver motor is connected to the Motor. It is necessary for connecting the ground terminal of the motor to the socket (s).

As for Pulse Width Modulation (PWM) used as Motor speed regulator. When the characters smaller than PWM, then PORTD.0=1 (motor output PINB.0 value 1 or active) and when over PWM, then PORTD.0=0 or motor is off.

Before the test is done on the hardware, the first performed testing using simulation software Matlab and Proteus. Figure 4 shows the electronics circuits of WLC using Proteus.

![Figure 4. The electronics circuits of WLC](image)

PWM used as a speed regulator Motor. When the characters smaller than PWM then PORTD.0=1 (output motor PINB.0 value 1 or active) and when over PWM then PORTD.0=0 or the motor is off. While the sensor ultrasonic used to measure three distance i.e. low, medium, and high. To find out the limitations, looked for $\mu$ with MIN-MAX method. LDR is used as a determinant of night and day. $\mu$ night or u night have 1 value if LDR 0 and have 0 value if LDR 1000. The performance measurement results on the experimental work results can be presented at Table 3.

| No. | INPUT Ultrasonic (volt) | LDR (lux) | Output of PWM Motor | Simulation Using Matlab | Simulation Using Proteus |
|-----|-------------------------|-----------|---------------------|------------------------|--------------------------|
| 1   | 5                       | 24        | 130                 | 130.42                 | 130                      |
| 2   | 5                       | 128       | 128.01              | 128                    | 128                      |
| 3   | 0                       | 129       | 129.03              | 129                    | 129                      |
| 4   | 5                       | 170       | 170.34              | 170                    | 170                      |
| 5   | 5                       | 148       | 148.31              | 148                    | 148                      |
| 6   | 5                       | 133       | 133.60              | 133                    | 133                      |

The results show that in the lighter outdoors and high water is low then water-pumping Motor speed is the faster or maximal. When the high water is medium and a bright light or daylight then the motor rotation speed is medium and the water is maximal then the motor will die. Conversely, if the outdoor light is darker or at night and the water levels are low or medium, Motor rotation speed will medium too.
Based on Table 3, it is noted that the comparison between the calculation results of the output with the results of experimental work is having similarity and only a very small error occurs. As for the error value between experimental results and calculation, works can be presented with Mean Square Error (MSE) of 0.278. It is noted that performance of experimental work is closer with simulation work.

It is also shown with simulation work based on Matlab and Proteus, the performance of experimental work is similar to simulation work. On Table 3 also shows numerous different variations of outdoor light conditions and water levels that detected by ultrasonic and LDR respectively. The results show that although with different variations of the input value of LDR and ultrasonic then keep producing performances similarities between simulation and experimental works.

4. Conclusion

In this study has developed WLC system based on FLC with Sugeno technique. The FLC has input two input and single output namely LDR, ultrasonic and motor respectively. In this study presented simulation work within Matlab and Proteus and then validated through experimental work. The result shows that the simulation work is much closer to experimental work. Only a few errors between calculation method and experimental work. The FLC smoothly can the WLC. The FLC performance between experimental and simulation show similar.

5. References

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