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Water Distribution Control Using Arduino with Fuzzy Logic Algorithm Method: A Prototype Design

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***Abstract* – The pipe distribution network is a complex matter for the water distribution system. Meanwhile, the needs of clean water have grown rapidly. This has become a problem for water distribution in many cities, including Palembang since the clean water is not distributed equally. Consequently, every household does not get the flow rate based on their needs yet. Thus, this paper proposes a clean water distribution control system which utilizes Arduino based on the fuzzy method. This control system is built in a prototype design and uses 3 sensor flows as input and 3 servo outputs which control the valve of the servo. Meanwhile, the fuzzy logic program uses Arduino Mega microcontroller as a process regulator at the input and output. Each distribution area is controlled by a servo value as the output of Pulse Width Modulation (PWM) from the Arduino Mega. The results show that PWM will control the opening of the valve according to the needs so the water flow will be distributed and received by the costumers at the same time.**

Keywords - water flow sensor. servo motor, Arduino Mega, fuzzy logic

I. INTRODUCTION

Water is an important aspect of our daily life. Regional water supply company (known as Perusahaan Daerah Air Minum (PDAM)) has to fulfill such needs by distributing clean water from the river as the source for water treatment systems to comply domestic and non-domestic water needs. As the population grows, the water needs may increase as well. Hence, it is essential to have a good plan for water system based on the growth of population.

Some papers have discussed the importance of water distribution. [1] discussed the effect of water flow increasing demand in the water service zone of PDAM Tirta Mawar. Based on this research, the piping network is complex and the need for clean water increases in line with the development of the city and population growth, while the planning is not optimally carried out. The results of the research conducted at PDAM Tirta Mawar showed that it has not been fully optimal because it did not use a method for water distribution [1].

Chakchouk et al. implemented an algorithm to detect leak locations by reading sensors which were placed in pipes from a certain distance. The leak location was then sent to the operator [2]. However, this method was not able to control the water distribution in an area, especially when there was an error in the sensor reading. Other studies that discussed the control system of water distribution were performed by [3-4]. .

The problem of clean water distribution also occurs in Palembang since it is not distributed equally to every region based on the needs. Besides, the difference in water flow may be due to a leak in the transmission pipe [2].

Some studies have discussed the water distribution problem. Ahmadullah and Dongshik proposed GIS and Espanet-based methodology to solve the closed-loop network problem in water distribution network [5]. Meanwhile, [6] introduced a clustering approach for a real-time decision support system in water distribution systems. Besides that, [7] implemented fuzzy logic control for irrigation systems. This study showed that fuzzy may provide an optimal distribution of water resources.

Thus, this study aims to propose a method for water distribution control based on fuzzy logic. It is expected that water flow can be distributed at the same time, based on the needs of customers.

II. RESEARCH METHODS

The prototype was designed to represent the condition of the water distribution system which can be seen in Fig. 1. As shown in the figure, the flow sensor and servo may control the valve for 3 distribution areas.

Flow sensor, as input, will provide data to the microcontroller and adjust the opening of the valve. A servo motor is applied as a regulator component which adjusts the opening of the valve. Control of servo motor on the valve will be regulated directly by the Arduino Mega 2560 From the data received by the flow sensor, the microcontroller will control the valve so that the water flow complies with the requirements read in each area. Before implementing fuzzy logic controller in Arduino, it is simulated in Matlab.

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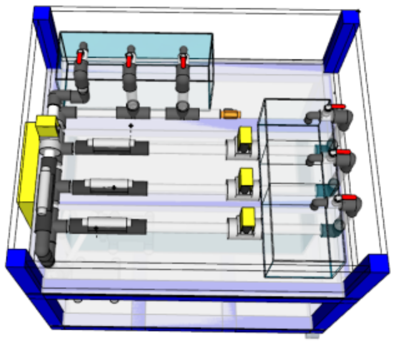

Fig. 1. Prototype Design of Water Distribution System.

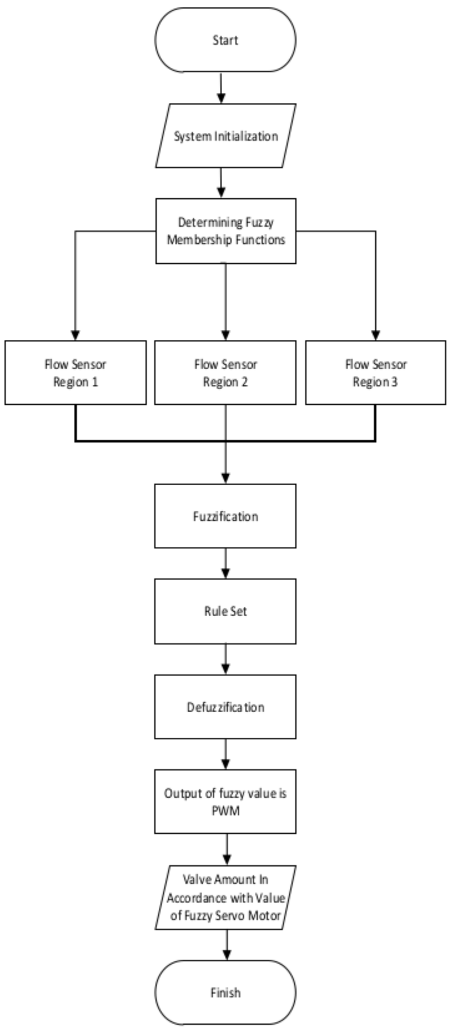

Fig.2. Flowchart System

Next, the fuzzy logic control system is designed to optimize the valve. A flowchart of the system can be seen in Fig. 2. Input parameters come from sensor flow. The value obtained from this input will be used by fuzzy to control the Pulse Width Modulation (PWM) of the servo motor. There are 3 servo motors used to distribute to three areas. Then, the PWM may control the opening of the valve.

As shown in Fig. 2, in the beginning, the device control system will be initialized by setting and determining fuzzy membership functions. Then, the sensor reads the water flow from 3 areas. Following this stage, the fuzzification is performed. Here, a non-fuzzy variable (numeric variable) from the sensor is changed into a fuzzy variable (linguistic variable) which will determine the output. Then, the rule set will be used to group fuzzy rules in relation to the state of the input and output signals. This rule evaluation is the basis for decision making or inference process to get the control signal output from input conditions based on predetermined rules. After the rule set is determined, the process is carried out on the defuzzification block. This process is the opposite of the Fuzzification process where the fuzzy variable (linguistic variable) is changed to a non-fuzzy variable (numeric variable) which produces all fuzzy output values specified with the PWM value in order to control the motor servo on the valve. From the PWM value output, all fuzzy output values will effectively change the valve quantity position in accordance with predetermined rules so the water flow is distributed based on the customers' needs. .

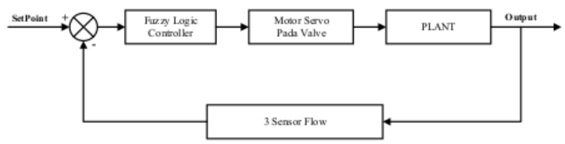

Fig. 3 Block System Diagram

The fuzzy logic controller (FLC) system which is implemented in the block diagram can be seen in Fig. 3. As seen in the figure, the FLC has 3 main input parameters from 3 flow sensors, and output is in the form of a servo motor. Water flow will be read by the sensor flow and this value will become the parameter for the PWM as the output of servo motor. PWM will adjust the opening valve based on the obtained parameter value. This value is adjusted until the steady-state error value is reached on the servo motor output graph. Thus, the distribution of water results water flows in accordance with the requirements of sensor readings.

III. Results and Discussion

TABLE I. INPUT AND OUTPUT VARIABLES.

No	Input			Output		
	Flow 1	Flow 2	Flow 3	Valve 1	Valve 2	Valve 3
1	slow	slow	slow	small open	small open	small open
2	mid	mid	mid	mid open	mid open	mid open
3	fast	fast	fast	big open	big open	big open

The membership function of fuzzy logic for the water distribution control system consists of 3 input variables and 3 output variables as presented in Table I. Input variables consist of input Flow1, Flow2, and Flow3 while output variables consist of output valve1, valve2, and valve3. Each variable has the same set and value of members. The input variable is divided into 3 Fuzzy Logic sets, which are slow, mid, and fast, respectively. Meanwhile, the output variable is divided into 3 fuzzy sets, namely, small open, mid open, dan big open.

TABLE II. VARIABLE FLOW PARAMETER VALUES AND VALVE

No	Flow in Milliliters			Valve in PWM value		
	Slow	Mid	Fast	Small Open	Mid Open	Big Open
1	0	5	20	0	10	35
2	0	15	30	0	25	50
3	5	20	35	10	35	60
4	15	30	35	25	50	60

In the initial stage of determining the fuzzy variable, water flow as the input variable is obtained from experimental reading of water flow to determine the maximum and minimum capacities before the application of fuzzy control with Arduino. Meanwhile, the size of the valve is determined by testing the Arduino control output in the form of a PWM value with a valve amount of 0-100%. All experiments get fuzzy sets of each input and output variable have the value range of 0 to 35 liters minutes for input and magnitude of PWM of 0-60 which represents the opening of servo according to degrees. Parameter values for the slow input membership is [0 0 5 15], [5 15 20 30] for the mid input membership, and [20 30 35 35] for the fast input membership . The trapezoidal curve type is used for all input membership parameters. The value of the small open output membership parameter is [0 0 10 25], the value of large open output is [10 25 35 50], and the value of open output is [35 50 60 60] with the trapezoidal curve type on all output membership parameters. These variables of input and output can be seen in Table II.

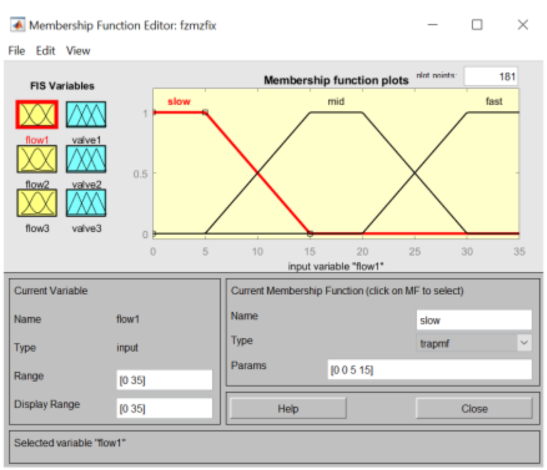

Fig. 4. Fuzzy Logic Input Settings in Matlab

Fuzzy logic implemented in water distribution has 27 rules to prescribe membership values so that the results are suitable for the distribution of water which will be controlled by servo. The rules of the proposed FLC is shown in Table III.

To test the proposed FLC, we use Matlab application using the same 3 variables for input and output. Fig. 4 shows the fuzzy logic input setting in Matlab.

TABLE III. FUZZY LOGIC RULES OF WATER DISTRIBUTION

No	Flow 1	Flow 2	Flow 3	Valve 1	Valve 2	Valve 3
1	Slow	Slow	Slow	Mid Open	Mid Open	Mid Open
2	Slow	Slow	Mid	Small Open	Small Open	Mid Open
3	Slow	Mid	Slow	Small Open	Mid Open	Small Open
4	Slow	Mid	Mid	Small Open	Mid Open	Mid Open
5	Slow	Mid	Fast	Small Open	Mid Open	Big Open
6	Slow	Fast	Mid	Small Open	Big Open	Mid Open
7	Slow	Fast	Fast	Small Open	Big Open	Big Open
8	Slow	Fast	Slow	Small Open	Big Open	Small Open
9	Slow	Slow	Fast	Small Open	Small Open	Big Open
10	Mid	Slow	Slow	Mid Open	Mid Open	Mid Open
11	Mid	Slow	Mid	Mid Open	Small Open	Mid Open
12	Mid	Mid	Slow	Mid Open	Mid Open	Small Open
13	Mid	Mid	Mid	Mid Open	Mid Open	Mid Open
14	Mid	Mid	Fast	Mid Open	Mid Open	Big Open
15	Mid	Fast	Mid	Mid Open	Big Open	Mid Open
16	Mid	Fast	Fast	Mid Open	Big Open	Big Open
17	Mid	Fast	Slow	Mid Open	Big Open	Small Open
18	Mid	Slow	Fast	Mid Open	Small Open	Big Open
19	Fast	Slow	Slow	Big Open	Mid Open	Mid Open
20	Fast	Slow	Mid	Big Open	Small Open	Mid Open
21	Fast	Mid	Slow	Big Open	Mid Open	Small Open
22	Fast	Mid	Mid	Big Open	Mid Open	Mid Open
23	Fast	Mid	Fast	Big Open	Mid Open	Big Open
24	Fast	Fast	Mid	Big Open	Big Open	Mid Open
25	Fast	Fast	Fast	Big Open	Big Open	Big Open
26	Fast	Fast	Slow	Big Open	Big Open	Small Open
27	Fast	Slow	Fast	Big Open	Small Open	Big Open

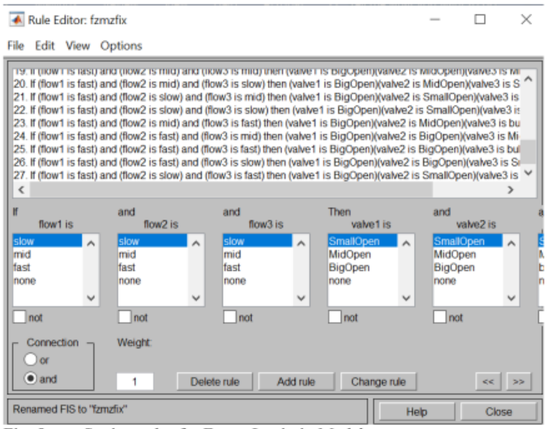

Fig. 5. Setting rules for Fuzzy Logic in Matlab

Then, the simulation of rules value which is divided into 27 groups using the Mamdani method can be seen in Fig. 5.

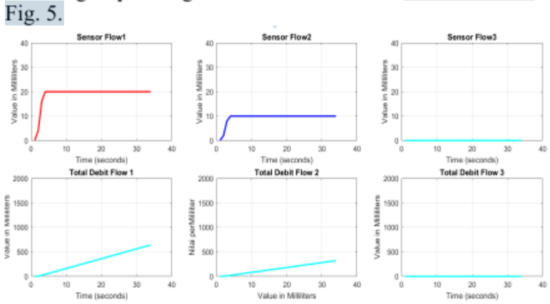

Fig. 6. Matlab graph in trial 1 without Fuzzy by setting Flow1 to 20 and Flow2 to 10.

To see the effectiveness of the proposed method, we compare two conditions; with and without Fuzzy using an Arduino controller. Arduino without fuzzy means that no control is applied. Fig. 6 shows the graph for the system without Fuzzy in trial 1. Here, Flowl is set at 20 ml/sec, Flow2 is set to 10 ml/sec, and Flow3 is set to 0 ml / sec. Total time to distribute the water is set to 17-seconds. As shown in the figure, the flow rate is around 10-20 ml/sec per area which is in accordance with input, and the water flows distributed at Flowl, Flow2, and Flow3 are 300, 150, and 0, respectively.

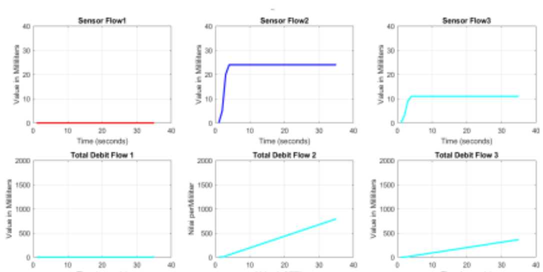

Fig. 7 Matlab graph in trial 2 without Fuzzy by setting Flow2 to 24 and Flow3 to 11.

Then, in the second trial, we change the set of flow to 0 ml/sec for Flowl, Flow2 is set to 24 ml / sec, and Flow3 is set to 11 ml/sec. The results are shown in Fig. 7. The total time flow water distribution maintains to 17-second test. As shown in the figure, the flow rate is around 11-24 ml/sec per area where the water flows are 0, 361, and 166 at Flowl, Flow2, and Flow3, respectively.

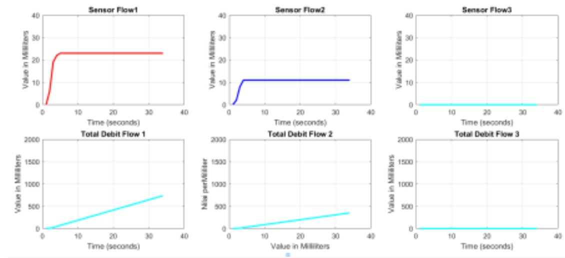

Fig. 8. Matlab graph in trial 1 with Fuzzy by changing Flowl reading to 23 and Flow2 to 11.

Fuzzy logic is then implemented to the system using the same duration of 17 seconds. The results in trial 1 are shown in Fig. 8. In this test, the flow rate of Flowl is 23 ml/sec, Flow2 is 11 ml/sec, and Flow3 is 0 ml/sec. Meanwhile, the amount of water flow is 346 milliliters in Flowl, 163 milliliters in Flow2, and 0 milliliters in Flow3.

Fig. 9 shows the result in trial 2 of implementing the fuzzy logic system. The same duration of 17 seconds is used. In this test, the flow rate of Flowl is 0 ml / sec, Flow 2 is 34 ml/sec,and Flow3 is 11 ml / sec. The number of water flows are 0, 512 and 166 at Flowl, Flow2, and Flow3, respectively.

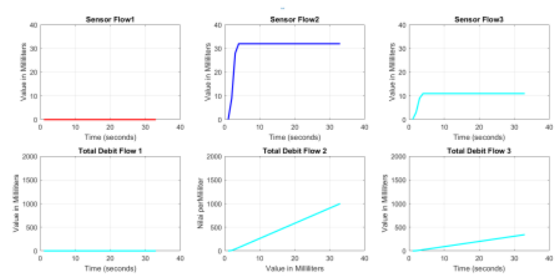

Fig. 9. Matlab graph in trial 2 with Fuzzy by changing Flow2 reading to 34 and Flow2 to 11

Fuzzy logic is also applied to Arduino. The results of fuzzy logic in Matlab is then compared to Arduino as shown in Table IV. From the table, we can see that the results for the tests which were carried out for the same input of Flowl [23, 0], Flow2 [11, 34] and Flow3 [0,11], may result the close output between Matlab and Arduino.

Table V shows the comparison of the water flow with and without fuzzy using Arduino in 17 seconds. As shown in the table, the water flow will adjust according to the needs for the first and second experiment.

TABLE IV. COMPARISON OF FUZZY LOGIC CONTROL RESULTS ON ARDUINO AND MATLAB

Test Simulation	Trial	Input			Output		
		Flow 1	Flow 2	Flow 3	Valve 1	Valve 2	Valve 3
Water Distribution Performance with Fuzzy Logic Control on Arduino	1	23	11	0	25	35	49
	2	0	34	11	49	10	35
Performance of water distribution with fuzzy logic controls in Matlab	1	23	11	0	26	35.2	49.7
	2	0	34	11	49.7	10.3	35.2

TABLE V. COMPARISON OF THE WATER FLOW WITH AND WITHOUT FUZZY LOGIC IN 17 SECONDS USING ARDUINO

Input	Experiment 1		Experiment 2	
	Without Fuzzy	With fuzzy	Without Fuzzy	With Fuzzy
Value of Flow	20	24	24	34
Flow 1	300	346	0	0
Flow 2	150	163	361	512
Flow 3	0	0	166	166

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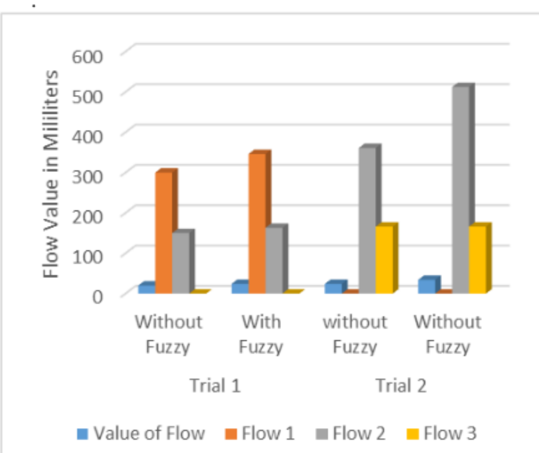

Fig. 10. Comparison chart of Fuzzy Logic and without Fuzzy Logic Using Arduino

Fig. 10 represents a graphical display of testing with and without fuzzy logic controls using Arduino as shown in Table V. From this figure, we can see that fuzzy logic may improve the water flow in Flow2 in trial 2. It is from 361 ml to 512 ml and Flow3 is fixed at 166 ml. Before implementing fuzzy, the water Flow2 was read as 24 ml/sec and Flow3 was 11 ml/sec in the initial condition. When the fuzzy was implemented, Flow2 changed to 34 ml/sec. On the output, the value of PWM was set equally to 45 before implementing the fuzzy logic. It indicates that the opening of the valve is the same even though the input is different. This condition may imply that the water supply is not distributed equally based on the needs. Once the fuzzy has been applied to the prototype, the PWM value for valve 1, valve 2, and valve 3 are 49, 10, and 34, respectively for Flow1 of 0 ml/sec, Flow2 of 34 ml/sec, and Flow3 of 11 ml/sec. These results may present that the implementation of fuzzy logic in the water distribution may control the opening of the valve based on the needs. Thus, the amount of water flow in Flow 2 is higher than Flow 3 which may imply that the need in area 2 is higher than 3 as shown in experiment 2 in Table V. Hence, implementing fuzzy may improve the distribution of the water based on the need. The fuzzy logic may control the water distribution for each area effectively than without fuzzy.

IV. CONCLUSIONS

In this study, a prototype of water distribution control was designed by using the Fuzzy Logic algorithm. The results showed that before implementing fuzzy logic, the distribution of the water flow becomes relatively small eventhough that area needs more water than other regions, the flow of water flow is only 361 ml. After implementing Fuzzy Logic Algorithm, Flow2 water flow increases to 512 ml which means that fuzzy logic can increase the water flow based on the water requirements so customers get the water flow based on their needs. It might also imply that fuzzy logic can be used as a controller for a water distribution system by dividing the flow of water with other regions.

The proposed system was first tested using Matlab and then implemented in Arduino.The experiments conducted in both program show that the values of fuzzy output between them are very close or not significantly different. Both Matlab and Arduino use 3 inputs, 3 outputs, and 27 rules. Thus, this structure may become optimal parameters for the proposed prototype.

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