Indonesian Journal of Artificial Intelligence and Data Mining (IJAIDM)
Vol 7, No.1, March 2024, pp. 28 – 38
p-ISSN: 2614-3372 | e-ISSN: 2614-6150

Implementation of Fuzzy Logic Method to Get Estimation of Fluid Depletion on Smart Infusion

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Article Info

Article history:
Received Aug 10th, 2023
Revised Oct 19th, 2023
Accepted Dec 16th, 2023

Keyword:
Fuzzy Logic
Infusion Implementation
Infusion Estimation
Internet of Things
Smart Infusion

ABSTRACT

The importance of conducting research in the field of health because health is very important in human safety. The purpose of this research is to apply the fuzzy logic method to get an estimation of the infusion time out on smart infusion devices. The data used is data from sensor measurements made on the smart infusion device, namely the load cell sensor for weight measurement and the optocoupler sensor for measuring the speed of infusion drops, consisting of 10 data successfully measured to be applied to the fuzzy logic method. The results showed that the sensor devices made on the weight sensor and infusion drip speed sensor successfully read the received data with the highest error value of 5% on the weight sensor and 4% on the infusion drip speed sensor. The results of testing the fuzzy method obtained an accuracy value of 97.26% accuracy with the highest error rate of 9 minutes compared to the actual estimated data.

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DOI: http://dx.doi.org/10.24014/ijaidm.v7i1.25589

1. INTRODUCTION

With the continuous development of technology, many individuals are creating tools or systems to improve the efficiency of human performance in practical tasks, especially in the context of medical infusion use [1][2]. Medical infusion refers to the process of injecting fluids and electrolytes into the body to meet medical needs and provide nutrition [3][4]. To improve medical care, some hospital facilities have introduced infusion devices known as infusion pumps. This is the result of advances in medical equipment technology, especially in terms of infusion. Infusion pumps have the advantage of higher accuracy compared to conventional infusions, which helps reduce the risk of errors [5][6]. However, one of its main obstacles is its high cost, making its use limited to a few areas in the hospital [7].

Smart infusion is an advanced infusion technology that is more affordable than infusion pumps. The system has the ability to accurately detect and monitor the infusion process by checking infusion parameters according to established medical guidelines. This ensures that the infusion system does not exceed the recommended administration limit, so that the patient receives the correct and safe dose of fluid or medication [8][9].

The results of previous findings show that several studies have made the design of smart infusion tools, but there are still shortcomings, such as monitoring fluid in infusion tubes through digital image processing. One of the methods is thresholding, the system is only able to detect the presence of infusion fluid and has not been able to accurately count the number of liquid droplets [10].Although the development of an ATmega 8535 microcontroller-based infusion set monitoring tool has been carried out, this tool has a dependence on several electronic components, including IC comparators and ATmega 8535 microcontrollers.

Damage or failure of these components can negatively impact the performance of the device. Although the buzzer used is not considered harmful to nurses' hearing, the sound quality and capability of the buzzer in a noisy environment might affect the effectiveness of the alert provided [11]. Then, development continued by creating a device to collect information about the number of drips through the drip chamber. This device uses an optocoupler sensor. The results of this design showed an accuracy rate in calculating the number of drips per minute of 96.2%, based on the results of five sets of measurements taken [12].

The research [10][11][12] explains that one of the advantages of smart infusion technology is its ability to provide a quick response in emergency situations. When a patient experiences an emergency condition that requires periodic infusion, the smart infusion system is able to detect changes in the condition and regulate infusion as needed. As part of improving the capabilities and accuracy of the smart infusion system, further research has been carried out to improve the accuracy of the research [11], using optocoupler sensors and fuzzy logic on the labview-based microcontroller smart infusion device, the test results succeeded in achieving an accuracy rate of around 96.75% of the fifteen sets of experiments conducted [13].

The research [13], fuzzy logic methods have been a promising approach in addressing the problem of infusion fluid depletion estimation. Fuzzy logic enables the processing of uncertain data and ambiguities often associated with patient conditions and infusion parameters. With implementing fuzzy logic methods in intelligent infusion systems, we can improve the accuracy and responsiveness of the system to changes in the patient's condition[14].However, although fuzzy logic has shown great potential in the estimation of infusion fluid depletion, the practical implementation of this method in the context of intelligent infusion systems still requires further research. It is important to examine the optimal way to integrate fuzzy logic methods into intelligent infusion systems and to measure the extent of their accuracy and reliability in different medical situations [15], and also in research [13] although it has a good level of accuracy, making tools using labview-based microcontrollers is expensive and the distance to use must be close and still monitor using a computer.

Based on this background, this research focuses on developing a fuzzy logic method to obtain a more accurate estimation of the time the infusion runs out from the two sensor data used, namely the Loadcell sensor and the Optocoupler sensor, to measure the weight and number of liquid droplets in the infusion. By utilizing the more economical Internet of Things (IoT) technology, so that infusion fluid monitoring can be integrated through mobile devices.

2. RESEARCH METHOD

This study implements the fuzzy logic method to obtain a more accurate estimation of infusion fluid exhaustion in smart infusion. Smart infusion this study is designed by utilizing Internet of Things (IoT) technology, the use of Internet of Things (IoT) technology can provide significant advantages, including remote monitoring, rapid response to patient conditions, real-time monitoring, more affordable cost and integration of additional technologies [16].

The design of the infusion fluid depletion estimation tool made, using two sensor data, namely the loadcell sensor and the optocoupler sensor, to measure the weight and number of liquid droplets in the infusion using the fuzzy logic method. Furthermore, test results are carried out by comparing the results after using the fuzzy logic method on the tool sensor and by manual testing, so it will be found that the tool made can contribute to medical staff to make it easier to find out the patient's infusion fluid. The design flow of the intelligent infusion tool is shown in Figure 1.

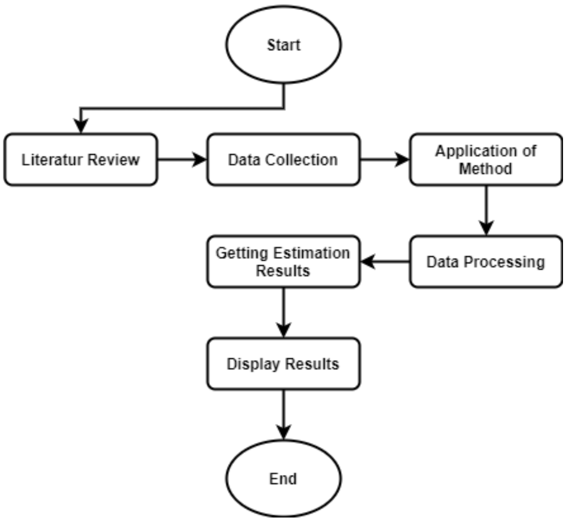

Figure 1. Research flow

Literature review is a step in research that involves extracting information from a variety of sources related to the research topic in order to gain a deep and broad understanding. This provides a solid foundation for planning and conducting research [17]. Data collection is obtained by reading the input value in the infusion fluid tube (drip chamber), which provides input values in the form of infusion fluid drip rate and infusion fluid weight. The loadcell sensor measures the weight of the fluid in the infusion, then the optocoupler sensor detects the presence of droplets in the drip chamber.

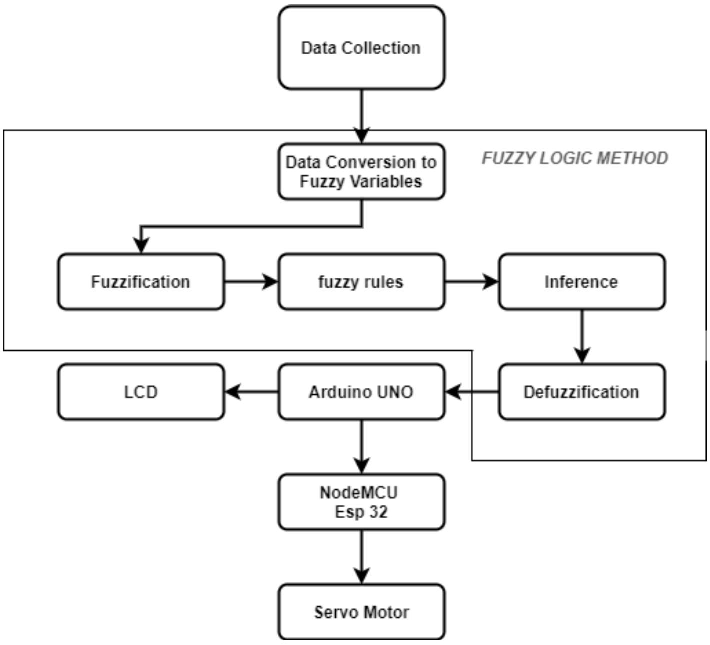

Figure 2. Data Processing With Fuzzy Methods

Figure 2 above is an in-depth step on the application of fuzzy logic methods. Fuzzy logic is used to model and solve problems involving uncertainty in various fields, such as control systems, decision making, pattern recognition, data analysis, artificial intelligence, and many more. Fuzzy logic also allows systems to operate in a more flexible manner[18]. The fuzzy control system has several stages as seen in Figure 2, namely, creating fuzzy variables, fuzzification, making fuzzy rules, inference, and defuzzification [19].

The first stage is to create fuzzy variables by converting the data generated by the load cell sensor and the optocoupler sensor into fuzzy variables, this is done so that data that is initially quantitative can be used in linguistic fuzzy logic. The data conversion to fuzzy variables is shown in Table 1.

Table 1. The Data Conversion to Fuzzy Variables

Data	Fuzzy Variables	Value Range	Fuzzy Set
Infusion Drip Speed	Fuzzy Drip Speed	[0,200] TPM	Slow, Medium, Fast
Infusion weight	Fuzzy weight	[0,500] ml	Under, Medium, Over
Time	Fuzzy Time	[0,>130] Minute	Short,Medium,Long

After converting the data into fuzzy variables, the next step is fuzzification. At this stage, the formed fuzzy variables are divided into fuzzy sets with appropriate membership functions. This membership function defines the extent to which a numerical data belongs to the fuzzy set. The results of membership function fuzzification are shown in Table 2.

Table 2. The Results of Membership Function Fuzzification

Function	Fuzzy Variables	Fuzzy Set	Value Range	Membership Functions
Inputs Variable	Infusion drip speed	Slow	[0,75]	Linear down
	Infusion drip speed	Medium	[20,180]	Triangle
	Infusion drip speed	Fast	[125,200]	Linear rise
	Infusion Weight	Over	[300,500]	Linear rise
	Infusion Weight	Medium	[50,450]	Triangle
	Infusion Weight	Under	[0,200]	Linear down
Output Variable	Time	Long	[>130]	Linier rise
	Time	Medium	[50-130]	Triangle
	Time	Short	[0-50]	Linier down

Table 2 above explains that the fuzzy variable "Infusion Drip Rate" has several fuzzy sets with different ranges and membership functions. When Infusion Drip Rate is in a slow state, the range of values is between 0 and 75 drops per minute (TPM) with a linear descending membership function. When the Infusion Drip Speed is in the Medium state, the range of values is between 20 and 180 TPM with a triangular membership function. On the other hand, when the Infusion Drip Speed is fast, the value is between 125 and 200 TPM with an ascending linear membership function.The graph of the Infusion Drip Speed membership function is shown in Figure 3.

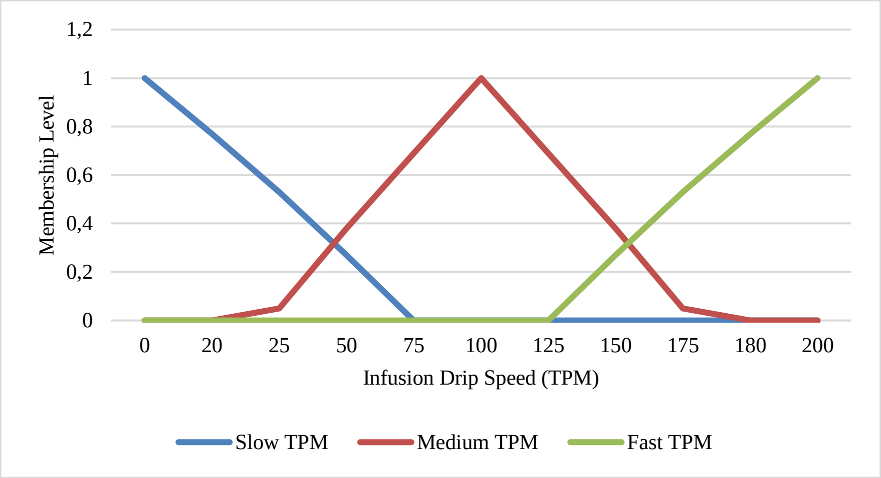

Figure 3. TPM Membership Function Chart

When the fuzzy variable "infusion weight" has many infusions, the range of values is between 300 and 500 milliliters (ml) with an ascending linear membership function. If the infusion weight is medium, the range of values is between 50 and 450 ml with a triangular membership function. Finally, if the fuzzy variable "infusion weight" has a small amount of infusion, then the range of values is between 0 and 200 ml with a linear descending membership function. The output of the fuzzy variable is the estimated time, if it has a long time the value is more than 30 minutes, the medium time is 50 to 130 minutes and the short time is 0 to 50 minutes.The graph of the weight membership function is shown in Figure 4 and the time membership function is shown in Figure 5.

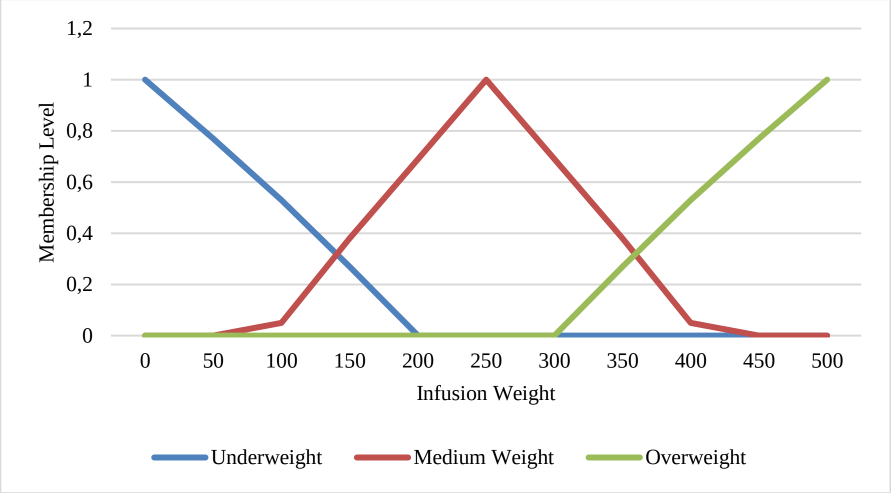

Figure 4. Infusion Weight Membership Function Chart

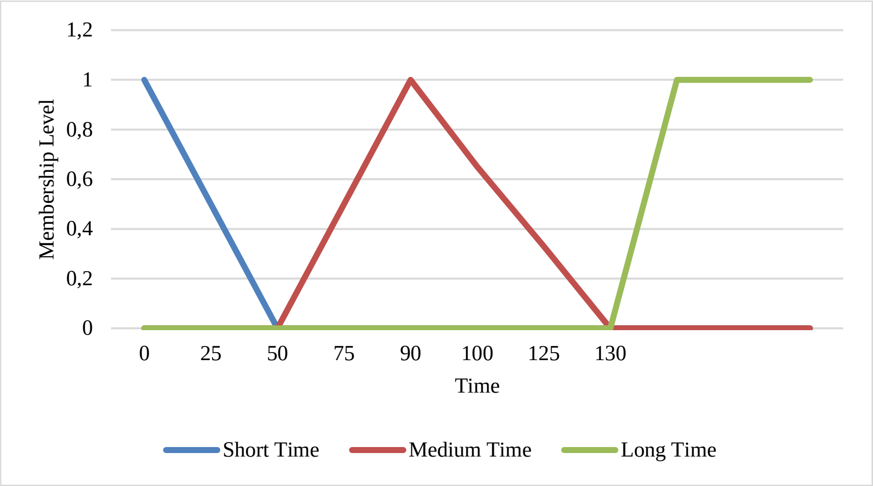

Figure 5. Infusion Time Membership Function Chart

After the membership function process in fuzzification, it will get a membership level, which is used to get the estimated infusion time-out results used in the next step, this membership level is calculated using equation (1), equation (2) and equation (2) for the membership level of infusion drip speed, for the infusion weight membership level using equation (4), equation (5) and equation (6) where the value "X" is input from how many drops or weight of infusion the sensor reads.

TPM Slow Level
$$[\chi] = \begin{cases} 1; 0 \leq \chi \leq 20 \\ \left(\frac{75-\chi}{55}\right); \quad 20 \leq \chi \leq 75 \\ 0\ ; \quad \chi \geq 75 \end{cases} \tag{1}$$

TPM Medium Level
$$[\chi] = \begin{cases} 0; \quad 0 \leq \chi \leq 20\ or\ 180 \\ \left(\frac{\chi-20}{55}\right); \quad 20\chi \leq 75 \\ 1; \quad 75 \leq \chi \leq 125 \\ \left(\frac{180-\chi}{55}\right); 125 \leq \chi \leq 180 \end{cases} \tag{2}$$

TPM Fast Level
$$[\chi] = \begin{cases} 0; \quad 0 \leq \chi \leq 125 \\ \left(\frac{\chi-125}{55}\right); 125 \leq \chi \leq 180 \\ 1; \quad \chi \geq 180 \end{cases} \tag{3}$$

Underweight Level
$$[\chi] = \begin{cases} 1; 0 \leq \chi \leq 50 \\ \left(\frac{200-\chi}{150}\right); 50 \leq \chi \leq 200 \\ 0; \quad \chi \geq 200 \end{cases} \tag{4}$$

Medium Weight Level
$$[\chi] = \begin{cases} 0; 0 \leq \chi \leq 50\ atau\ 450 \\ \left(\frac{\chi-50}{150}\right); 50 \leq \chi \leq 200 \\ 1; \quad 200 \leq \chi \leq 300 \\ \left(\frac{450-\chi}{150}\right); 300 \leq \chi \leq 450 \end{cases} \tag{5}$$

Overweight Level
$$[\chi] = \begin{cases} 0; 0 \leq \chi \leq 300 \\ \left(\frac{\chi-300}{150}\right); 300 \leq \chi \leq 450 \\ 1; \quad \chi \geq 450 \end{cases} \tag{6}$$

Long Time Level
$$[\chi] = \begin{cases} 0; 0 \leq \chi \leq 130 \\ \left(\frac{\chi-130}{130-130}\right); 130 \leq \chi \leq 130 \\ 1; \quad \chi \geq 130 \end{cases} \tag{7}$$

Medium Time Level
$$[\chi] = \begin{cases} 0;\, 0 \leq \chi \leq 50 \; or \; 130 \\ \left(\frac{\chi - 50}{50 - 50}\right);\, 50 \leq \chi \leq 50 \\ 1; \quad 50 \leq \chi \leq 130 \\ \left(\frac{130 - \chi}{130 - 130}\right); \quad 130 \leq \chi \leq 130 \end{cases} \tag{8}$$

Short Time Level
$$[\chi] = \begin{cases} 1;\, 0 \leq \chi \leq 50 \\ \left(\frac{50 - \chi}{50 - 50}\right);\, 50 \leq \chi \leq 50 \\ 0;\, \chi \geq 50 \end{cases} \tag{9}$$

The next step is the creation of fuzzy rules. Fuzzy rules are created based on fuzzy logic and connect fuzzy variables, fuzzy sets, functions and membership levels have been determined. These rules contain logical statements that describe the relationship between fuzzy variables. The fuzzy rules that have been created are shown in Table 3.

Table 3. The Fuzzy Rules

Infusion Weight	Infusion Drip Speed	Fuzzy Variables Time Estimation
Under	Slow	Medium
Medium	Medium	Medium
Over	Fast	Short
Under	Fast	Short
Medium	Slow	Long
Over	Medium	Long
Under	Medium	Short
Over	Slow	Long

After the rules are created, the next step is inference by determining membership values using implication functions. The implication function is a way to measure the extent to which inputs affect outputs in a fuzzy logic system.. Both work in synergy in the fuzzy inference process to make decisions based on uncertain knowledge in the data [20]. This process uses equation (10) for the implication function.

$$a \text{ −predicate}_i = \mu A1[\chi 1] \cap \mu A2[\chi 2] = \text{Min } \mu A1[\chi 1], \mu A2[\chi 2] \tag{10}$$

Where:
i = Value fuzzy to - i rule

The last step in the fuzzy logic system is the defuzzification process, which converts the results of the rule composition in the form of fuzzy sets into more concrete numerical values, in order to obtain results that are easier to interpret and use in real contexts. Defuzzification in this study uses the average method, namely by summing the results of multiplying a -predicate and z_i, the sum result is divided by the total a -predicate. Generally formulated in equation (12).

$$z^* = \frac{\sum_i^n a - apredicate_i * z_i}{\sum_i^n a - apredicate_i} \tag{11}$$

3. RESULTS AND ANALYSIS

3.1. Smart Infusion Tool Design Results

The results of designing a tool in the form of an IoT-based smart infusion device that can monitor and control the process of giving infusions to patients using two sensor data, namely the loadcell sensor and the optocoupler sensor to measure the weight and number of liquid droplets in the infusion, so that the sensor reading results can be used in determining the estimation of infusion runs out using the fuzzy logic method.The smart infusion device that has been made is shown in Figure 6.

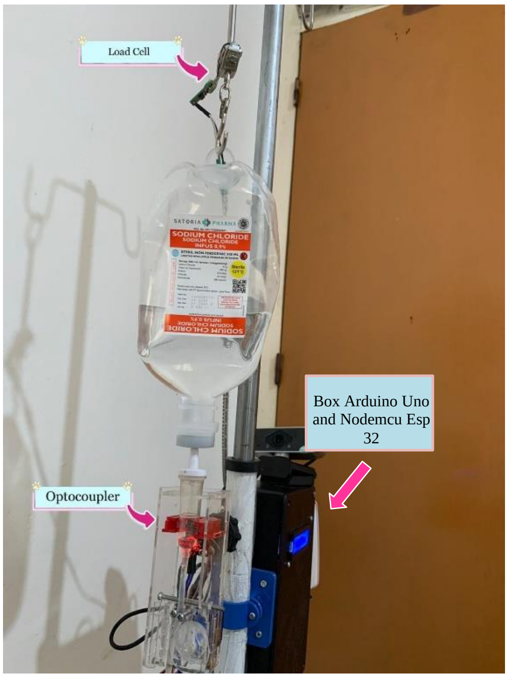

Figure 6. The Smart Infusion Device

3.2. Sensor Testing Results

The finished tool is then tested using digital scales with loadcell sensors and manual drip testing with optocopler sensors, aiming to find out whether the tool that has been designed has provided appropriate and efficient performance. The results of comparison of weight testing and comparison of infusion drip testing are shown in Table 4.

Table 4. The Results of Comparison Weight Testing And Comparison of Infusion Drip Testing

Manual Weight (ml)	Loadcell Sensor (ml)	Error (%)	Manual Infusion Drip (TPM)	Optocopler Sensor (TPM)	Error (%)	Infusion Time-out Estimataion Manual
437	432	5%	83	83	0%	140 Minute
335	332	3%	77	79	2%	137 Minute
250	248	2%	73	73	0%	134 Minute
238	236	2%	71	71	0%	132 Minute
182	178	4%	55	59	4%	125 Minute
169	165	4%	55	55	0%	119 Minute
150	150	0%	45	48	3%	112 Minute
300	300	0%	75	75	0%	127 Minute
255	250	5%	100	100	0%	130 Minute
400	395	5%	20	20	0%	139 Minute

3.3. Infusion Consumption Estimation Results Using Fuzzy Method

The method process involves the formation of fuzzy membership sets and levels. Next, the value of the sensor test results is entered to generate the infusion fluid estimation using the fuzzy method. The first step is to fuzzifize the intelligent infusion input data in the form of load cell sensor data and optocoupler sensors in Table 4, the data taken as a test sample is a weight value of 432 ml and an infusion drip value of 83 TPM. Based on the fuzzy variable data in Table 2, the weight of 432 ml is in the medium and large categories, and using equations (5) and (6), the membership level is obtained:

$$\text{Medium Weight Level} \quad [432] = \left(\frac{450-432}{450-300}\right) = \left(\frac{18}{150}\right) = 0{,}12$$

$$\text{Overweight Level} \quad [432] = \left(\frac{432-300}{450-300}\right) = \left(\frac{132}{150}\right) = 0{,}88$$

The infusion drip speed of 83 TPM belongs to the medium category, using equation (2) to obtain the membership level:

$$\text{TPM Medium Level} \qquad [83] = \left(\frac{83-20}{75-20}\right) = \left(\frac{63}{55}\right) = 1{,}145$$

Furthermore, the implication process is carried out, where rules are created that will later be used as rules to determine the output of the fuzzy system. The rule in question is in the form of an If ... Then ... Then ... rule, which is a combination of 3 variables (2 input variables and 1 output variable), from the above fuzzification results, two rules were obtained about 432 infusion weight and 83 infusion drip speed, which are assumed to be (R1), and (R2).

R1 If the weight is medium and the infusion drip rate is medium, the time estimation is medium.
R2 If the weight is excessive and the drip rate is medium then the time estimate is long.

From the obtained rules, the implication process can be calculated by finding the predicate value using equation (10), and also calculating the zi value using equations (8) and (9), the results of the implication process are shown in Table 5.

$$\begin{aligned} a-\text{predicate}_{R1} &= \text{Min } \mu\text{Medium Weight} \cap \mu\text{Medium Infusion Drip}\\ &= \text{Min } \ (432), (83)\\ &= \text{Min } (0{,}12;1{,}14)\\ &= 0{,}12 \end{aligned}$$

$$\begin{aligned} 130 - z_{R1} &= 0{,}12\\ z_{R1} &= 130 - 0{,}12\\ z_{R1} &= 129{,}88 \end{aligned}$$

$$\begin{aligned} \text{a } -\text{predicate}_{R2} &= \text{Min } \mu\text{Overweight} \cap \mu\text{Medium Infusion Drip}\\ &= \text{Min } \mu\text{Overweight } 432, \mu\text{Medium Infusion Drip } 83,\\ &= \text{Min } (0{,}88;1{,}14)\\ &= 0{,}88 \end{aligned}$$

$$\begin{aligned} z_{R2} - 130 &= 0{,}12\\ z_{R2} &= 130 + 0{,}88\\ z_{R2} &= 130{,}88 \end{aligned}$$

Table 5. Process Function Implication Infusion Weight 432 ml and Drip Speed 83 TPM

Fuzzy Rules	a – Predicate	Z_i
R1	0,12	129,88
R2	1,14	131,14

After obtaining the value from the fuzification and inference process, the last step will be defuzification, which is the transformation of fuzzy data into crisp data in order to get the estimated infusion time-out results, this process uses the average defuzification method using equation (11) previously explaisned.

$$z^* = \frac{[0{,}12(129{,}88) + 0{,}88(130{,}88)]}{0{,}12 + 0{,}88}$$

$$z^* = \frac{130{,}76}{1}$$

$$z^* = 130{,}76 \approx 131 \text{ Minute}$$

Thus, from the results of clouding using the average method, if the weight of the infusion is 432 ml and the infusion drip rate is 83 drops per minute, the estimated time to expiration is 131 minute.

3.4 Analysis of Testing

From the results of the research conducted, the design of a smart infusion device is made using Internet of Things (IoT) technology and Arduino uno by using two sensors as input values and time as an output value which will be calculated using the fuzzy method. The results of testing the tool are shown in Table 4 by comparing the results of the tool made with manual calculations, the highest error difference obtained reached

5% in measuring the weight of the infusion fluid and the highest error was 4% in measuring the droplet speed on the optocoupler sensor. In determining the estimated time out of infusion fluid using the fuzzy method with steps as shown in Figure 5, the calculation of the fuzzy method used one of the sample data in Table 3 to measure how the method used can be efficient with actual data, the estimated time obtained is 131 minutes when the weight of infusion fluid is 432 ml and the speed of infusion drops is 83 TPM, for 9 other samples the same calculation is performed by programming on Arduino Uno, so that the estimated time out of infusion is obtained from 10 data obtained by the smart infusion sensor. The results of the estimation of the infusion expiration time using the fuzzy method are shown in Table 6.

Table 6. Infusion Time Out Estimation Results Using Fuzzy

Estimated Actual Infusion Time-Out	Estimation of Infusion Time-Out Using Fuzzy	Difference
140 Minute	131 Minute	9 Minute
137 Minute	130 Minute	7 Minute
134 Minute	129 Minute	5 Minute
132 Minute	129 Mniute	3 Minute
125 Minute	121 Minute	4 Minute
119 Minute	117 Minute	2 Minute
112 Minute	114 Minute	2 Minute
127 Minute	129 Minute	2 Minute
130 Minute	129 Minute	1 Minute
139 Minute	131 Minute	8 Minute

The results of estimating the time out of infusion using the fuzzy logic method get the highest error difference of 9 minutes with the actual estimated time results, thus, the fuzzy logic method to get the estimated time out of infusion has been successfully carried out with an accuracy of 97.26%. The results to test the accuracy are applied using the formula equation (12) below.

$$\text{Accuracy (\%)} = \frac{\text{Total Value Successfully Measured}}{\text{Total Actual Value}}\ x\ 100\%$$

$$\text{Accuracy (\%)} = \frac{1260}{1295}\ x\ 100\%$$

$$\text{Accuracy (\%)} = 97{,}26\%$$

4. CONCLUSION

The use of fuzzy methods has proven effective in determining the estimation of infusion time-out on smart infusions. Smart infusions designed based on the internet of things with the use of two snsor, namely loadcell sensors and optocoupler sensors, have a fairly good test value because they can measure with the highest error rate of 5% so that the measured data can be processed using fuzzy methods. The findings show that the fuzzy method goes through several steps, namely creating fuzzy variables, fuzzification, making fuzzy rules, inference, and defuzzification, testing the fuzzy method is carried out by taking one of the samples from the smart infusion sensor, namely the weight of 432 and the speed of infusion drops 83 drops with an estimated time out of infusion obtained of 131 minutes. 9 other data were also carried out the same calculation so as to get the level of difference with the highest estimated infusion time-out of 9 minutes, by conducting the final test, namely the accuracy of the accuracy of the fuzzy method, the accuracy of the fuzzy method was obtained at 97.26%. The use of fuzzy methods carried out by this research is expected to contribute in the health sector to determine the estimated time out of infusion.

ACKNOWLEDGEMENTS

The authors thank the Sriwijaya State Polytechnic for providing the research facilities. All research lecturers and technicians at the Telecommunications Laboratory, Department of Electrical Engineering, Sriwijaya Polytechnic, who assisted and offered their knowledge, are also thanked. Finally, we would like to acknowledge the affection and support of our family and friends throughout the research process. We could only have completed this research with their encouragement and assistance.

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