IAES International Journal of Artificial Intelligence (IJ-AI)
Vol. 11, No. 3, September 2022, pp. 819~825
ISSN: 2252-8938, DOI: 10.11591/ijai.v11.i3.pp819-825

Four inputs-one output fuzzy logic system for washing machine

Nurain Zulaikha Husin[1], Muhammad Zaini Ahmad[1,2], Mustafa Mamat[3]
[1]Institute of Engineering Mathematics, Faculty of Applied and Human Sciences, Universiti Malaysia Perlis, Perlis, Malaysia
[2]Centre of Excellence for Social Innovation & Sustainability (CoESIS), Universiti Malaysia Perlis, Perlis, Malaysia
[3]Faculty of Informatics and Computing, Universiti Sultan Zainal Abidin, Terengganu, Malaysia

Article Info

Article history:

Received Dec 31, 2021
Revised May 24, 2022
Accepted Jun 2, 2022

Keywords:

Fuzzy logic system
Mamdani method
Washing time

ABSTRACT

The presence of a fuzzy logic system on the washing machines becomes a demand in every home as it simplifies human work. The uses of washing machine will facilitate the user, reduce electricity consumption, washing time, and water intake. Thus, in this paper, the fuzzy logic system is used to determine the washing time by considering four different inputs, which are type of fabric, type of dirt, dirtiness of fabric and weight of load. The possible rules from the input variables are developed by combining all the variables using fuzzy IF-THEN rule. Referring to the Mamdani inference engine, a minimum membership function from input parts is truncated to the output for each of the rules. Next, the maximum membership function from the output is aggregated and the washing time can be calculated by using centroid method. The comparison is done by comparing the washing time of four input variables with three input variables.

Corresponding Author:

Muhammad Zaini Ahmad
Institute of Engineering Mathematics, Faculty of Applied and Human Sciences, Universiti Malaysia Perlis
Pauh Putra Main Campus, 02600 Arau, Perlis, Malaysia
Email: mzaini@unimap.edu.my

1. INTRODUCTION

Fifty-five years ago, the concept of fuzzy logic was introduced in [1]. Fuzzy logic was used as a part of artificial intelligence which resembles human behaviour that helps computer in making decisions. In recent years, the use of fuzzy logic techniques has increased significantly [2]. The emergence of fuzzy logic can be seen in pattern recognition, controller design, economy management and decision making, communications and networking, aerospace applications and also in engineering sectors. The researchers stated that there were a great number of researchers that interested in dealing with fuzzy logic to solve real-world issues [3]. This may lead to the innovation and industrialization in technologies, such as air conditioners, washing machine, antiskid braking systems and weather forecasting systems [4]. In 1974, the first study of fuzzy logic was conducted by using a model of a steam engine [5]. The fuzzy logic enables designers to control complex systems effectively because it was proven that proportional, integral and differential (PID) controllers were less capable [6]–[8].

Today, the study of washing machine with fuzzy logic has gained attention among researchers. The implementation fuzzy logic in the washing machine will provide many benefits to the users, such as time-saving, low cost and it also results in better performance and productivity. This washing machine also promotes 'one-touch control' to the users [9]. Therefore, the researchers conducted the research on how the input variables affect the output variables by considering several factors of the variables. In 2013, a group of researchers introduced the degree of dirt and type of dirt as input variables [10]. The authors described the concept of base ten minutes to decide the best washing time based on the input variables. Next, the amount of dirt, type of dirt, sensitivity of cloth and amount of cloth are studied to determine how these inputs will respond to different output

variables [11]. Another studies presented the type of cloth, type of dirt and dirtiness of cloth as input variables in determining the washing time [12].

Besides, the fuzzy logic controllers use a Mamdani type to observe how five inputs and outputs variable responds to different conditions [13]. The input variables involved are type of dirt, turbidity of cloth, mass of cloth, sensitivity of cloth and water hardness while the output variables are washing time, wash speed, amount of water, amount of detergent and water hotness. In 2016, the fuzzy logic controller was designed for washing machine by incorporating five input and three output variables [14]. A study on the washing time is also done when the amount of grease and dirtiness of cloth is put in the washing machine [15]. A relationship between four inputs and five outputs has been studied by other researchers [16].

Other than that, a study was carried out by presenting four input variables which are type of cloths, dirtiness of cloths, amount of detergent and water [17]. This study proposed a neuro-fuzzy controller where the controllers helped the system to take its own decisions. Wang and Ren [18] investigated another neural network fuzzy control. Hatagar and Halase provided the input variables of turbidity and turbidity change rate, as well as the output variable of washing time. Next, the spin time is studied as the output variable and the input variables are types of dirt, dirtiness of cloths and mass of cloths [19]. The fuzzy logic controller can be used to determine the washing speed when four inputs are considered [20]. Four input and output variables are studied in [21], where the inputs are dirtiness of cloths, type of fabric, type of dirt and volume of cloths. Whilst the outputs are water intake, water temperature, wash time and washing speed. Hence, to make the output of washing machine more efficient, the washing time is necessary to define as well as the users can estimate the total washing process. From the previous research, the authors used a few inputs related to the washing machine, but it can be seen that not many papers use weight of load as an input parameter in their study.

Therefore, the main goal of this research is to present the fuzzy logic system for washing machine by considering four input variables and one output variable. Different from the previous research, one new parameter is considered, namely the weight of the load. The weight of the load is needed as the washer can weigh the cloths before starting the washing process in order to determine the best washing time. By considering the result of four input variables, we will make a time comparison with previous research. This new parameter will produce new results to identify the best washing time.

2. METHOD

In this paper, a simulation package in MATLAB which is fuzzy logic toolbox is used. This toolbox allows a few things to be done easily. Figure 1 shows the process of the fuzzy logic system [22]. Several processes need to be considered before using a fuzzy logic toolbox. Fuzzy logic system is an alternative approach to control the process that involved a complex work that not easy to study manually [23]. The first step to build the fuzzy logic controller is to define the input and output variables. Since the boundaries of fuzzy sets may be vague, thus, there are no rules in generating the variables [24]. From Figure 2, four input variables are chosen, namely type of fabric, type of dirt, dirtiness of fabric and weight of load. As for the output variable, it is clear that washing time is the main component in developing a washing machine.

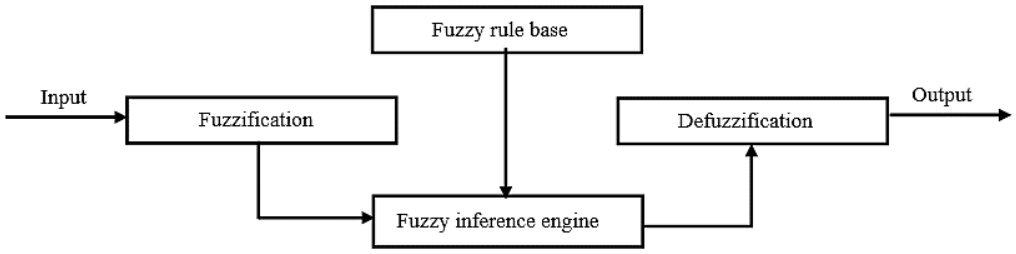

Figure 1. Fuzzy logic system process

For each of the input and output variables, there exist a linguistic variable that allowed to take natural language as its values [25]. There are 14 linguistic variables for input and output variables, namely: silk (S), woolen (W), cotton (C), non-greasy (NG), medium (M), greasy (G), small (Sm), large (La), light (Li), heavy (H), very short (VSh), short (Sh), long (Lo) and very long (VLo). The membership functions for each of the input and output variables are shown in Figure 3.

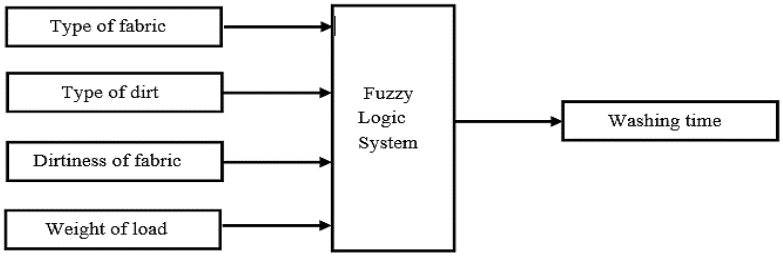

Figure 2. The input and output variables in fuzzy logic system

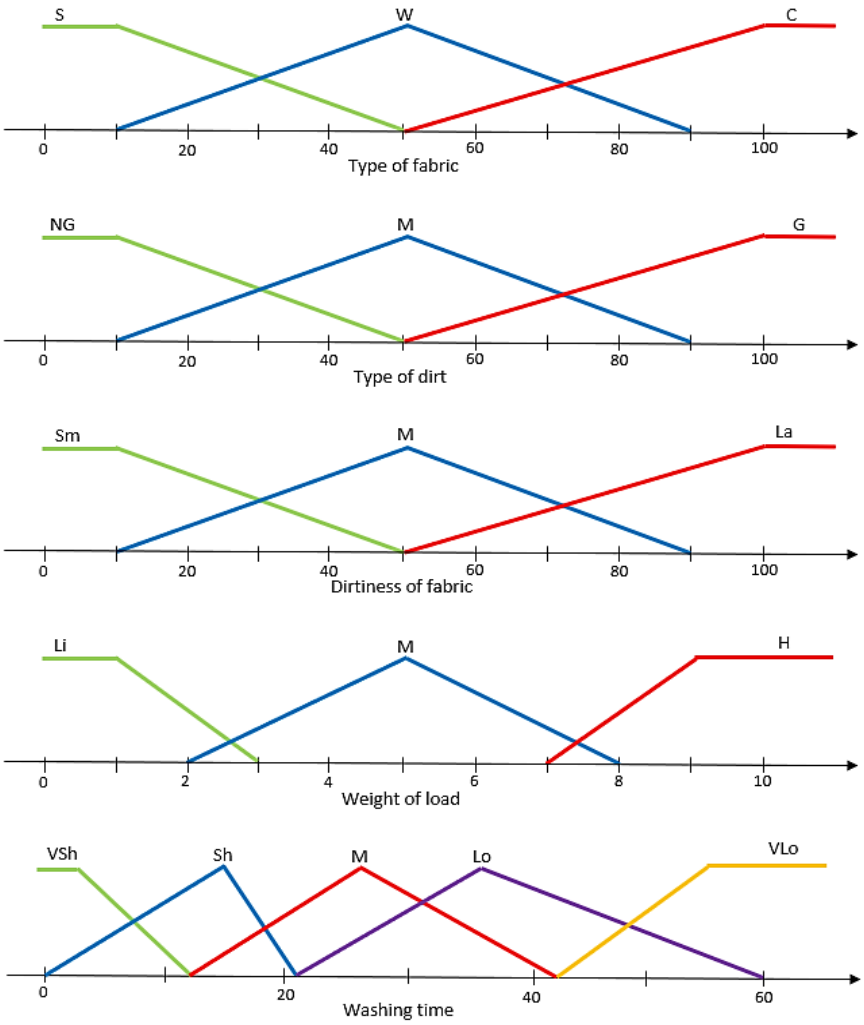

Figure 3. The membership functions of the input and output variables

For type of fabric, it can be classified as silk, woolen and cotton. So, the user can choose from the selector whether it is a heavy or normal task, depending on the type of fabric they have. As for dirtiness of fabric, the sensor will determine it by looking the water transparency. The sensor also will detect the type of dirt through the time saturation, where there is no change of wash water at certain time. Besides, the load sensor that has been installed in washing machine will weigh the load placed by the user. To ensure the clothes are washed thoroughly, the user can estimate the weight of load put into washing machine is less than the washer capacity.

The second step in fuzzy logic system is fuzzification. Fuzzification is the process involving the transformation of crisp input into fuzzy input. The exact value of crisp inputs is measured by sensors in the machine and passed to the controller for processing. Figure 4 represents the crisp input (see red line) and the blue line represents the membership function of fuzzy input values for the input variables involved.

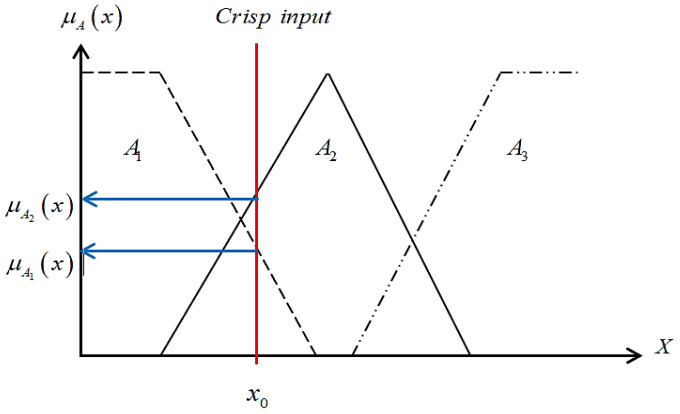

Figure 4. An illustration of fuzzification process

Then, the third step is to develop a fuzzy rule-based on linguistic variables. A fuzzy rule base is a collection of linguistic statement that explain how the fuzzy inference system decides by classifying the input or controlling the output. Since we have the input and output variables, we then combine all the variables using fuzzy IF-THEN rule. This rule can be obtained from the knowledge of experts. Table 1 shows fuzzy inference rule and the total number of rules involved is 81.

Table 1. Fuzzy logic rules for washing machine

No of rules	Type of fabric	Type of dirt	Dirtiness of fabric	Weight of load	Washing time
1	S	NG	Sm	Li	VSh
2	S	NG	Sm	M	Sh
3	S	NG	Sm	H	M
4	S	NG	M	Li	Sh
5	S	NG	M	M	M
6	S	NG	M	H	M
7	S	NG	La	Li	M
⋮					
81	C	La	La	H	VLo

The rules declared above are not crisp but have fuzzy values. Therefore, the fuzzy inputs need to be converted into a single fuzzy output by employing fuzzy implication which is Mamdani inference engine. Then, the AND operator is used to connect the fuzzy input variables for each of the rules. The function of this operator is to take a minimum value of membership functions from the fuzzy input variables. The fuzzy output variable is truncated using the value obtain from the input part. Thus, the entire truncated output is aggregated in one graph by taking the maximum value of membership degree and this will be used in the last step of fuzzy logic system.

The last step in fuzzy logic system is defuzzification process. Defuzzification is the process of converting the fuzzy output into crisp output. In order to find the crisp output, the centroid method is used where this method evaluates the center of area under the curve. The formula of this method is:

$$\text{Centroidmethod} = y* = \frac{\int_y \mu(y).ydy}{\int_y \mu(y)dy}. \quad (1)$$

3. RESULTS AND DISCUSSION

In this section, the relationship between the input and output variables are analysed by using fuzzy logic system and the data will be run by fuzzy logic toolbox for the purpose of obtaining the washing time. In order to obtain the washing time, the crisp inputs need to be chosen first. In this study, the chosen crisp inputs for type of fabric, type of dirt, dirtiness of fabric and weight of load are 32, 55, 48 and 7, respectively. The crisp inputs are imposed to the possible rules as shown in Figure 4. Then, the minimum value from fuzzy inputs is truncated to fuzzy output for each of the rules. Figure 5 shows how the maximum value of fuzzy outputs is aggerated in a single graph.

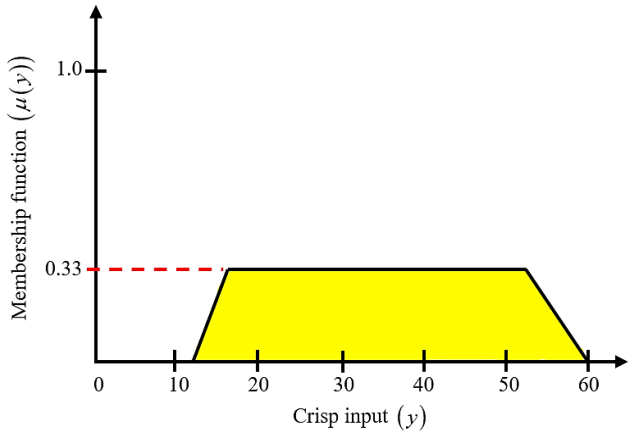

Figure 5. An aggregation of output for four input variables

Based on Figure 5, the membership function is obtained as:

$$\mu_{\text{4-inputs}}(y) = \begin{cases} 0.0733y - 0.8795, 12.0 \le y < 16.5 \\ 0.33, 16.5 \le y < 52.5 \\ -0.0440y + 2.64, 52.5 \le y \le 60 \\ 0, \text{otherwise} \end{cases} . \quad (2)$$

By substituting (2) into (1), the washing time is calculated as in (3). The time required to wash the clothes for four input variables is 35.3 minutes. This answer coincides with the answer obtained from fuzzy logic toolbox.

$$\begin{aligned} \text{Washingtime} &= \frac{\int \mu(y).ydy}{\int \mu(y)dy} \\ &= \frac{\int_{12}^{16.5}(0.0733y - 0.8795)\,ydy + \int_{16.5}^{52.5} 0.33ydy + \int_{52.5}^{60}(-0.0440y + 2.64)ydy}{\int_{12}^{16.5}(0.0733y - 0.8795)\,dy + \int_{16.5}^{52.5} 0.33dy + \int_{52.5}^{60}(-0.0440y + 2.64)dy} \\ &= 35.3\text{minutes} \end{aligned} \quad (3)$$

Next, the study of four input variables is compared with three input variables where the weight of load is excluded. Thus, the input variables involved are type of fabric, type of dirt and dirtiness of fabric. By using the same steps as stated in section 2, the crisp inputs are applied to each input involved and imposed on the possible rules. By considering the same process as in Figure 4, the minimum value of membership functions from fuzzy input variables is truncated onto a fuzzy output variable. Hence, the maximum value from fuzzy output is aggregated into one graph as shown in Figure 6.

As shown in (4), the membership functions for three input variables are obtained by extracting all the information from Figure 6.

$$\mu_{\text{3-inputs}}(y) = \begin{cases} 0.0647y - 0.7764, 12.0 \le y < 20.5 \\ 0.55, 20.5 \le y < 34.0 \\ -0.0667y + 2.8179, 34.0 \le y < 35.5 \\ 0.45, 35.5 \le y < 49.0 \\ -0.0409y + 2.454, 49.0 \le y \le 60.0 \\ 0, \text{otherwise} \end{cases} . \quad (4)$$

Referring to (4), the washing time for three input variables is 34.45 minutes and details of the calculation are shown in (5).

$$\text{Washingtime} = \frac{\int \mu(y).ydy}{\int \mu(y)dy}$$

$$= \frac{\int_{12}^{20.5}(0.0647y - 0.7764)ydy + \int_{20.5}^{34} 0.55ydy + \int_{34}^{35.5}(-0.0667y + 2.8179)ydy + \int_{35.5}^{49} 0.45ydy + \int_{49}^{60}(-0.0409y + 2.454)ydy}{\int_{12}^{20.5}(0.0647y - 0.7764)dy + \int_{20.5}^{34} 0.55dy + \int_{34}^{35.5}(-0.0667y + 2.8179)dy + \int_{35.5}^{49} 0.45dy + \int_{49}^{60}(-0.0409y + 2.454)dy}$$

$$= 34.45\text{minutes} \quad (5)$$

Thus, by comparing these two results, it can be concluded that there is a slightly difference in time between these two studies. The comparison shows that there is a superior timing between four and three inputs variable because the number of possible rules also varies. As the weight of the load is considered, the controller can function smoothly and efficiently in ensuring that the clothes are washed properly. If we change the value of the crisp input, then the result will also be different. To conclude this point, the washing time depends on the crisp input value as all the rules involved need to be considered.

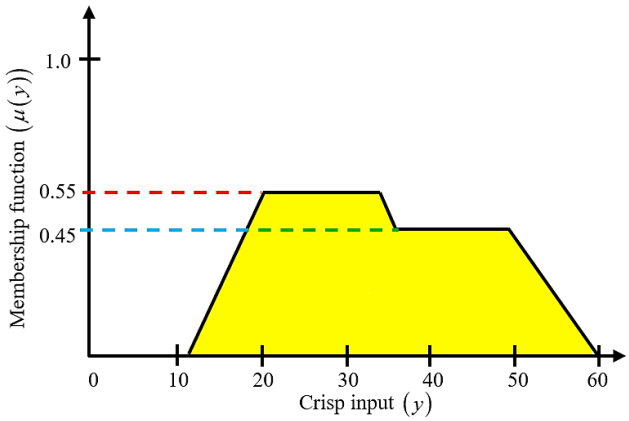

Figure 6. An aggregation of output for three input variables

4. CONCLUSION

In this paper, the analysis clearly states the advantages of fuzzy logic in solving washing machine problem. By adding some of the intelligence, the users do not have to worry about their washing process. Four input variables were successfully studied in order to achieve optimal washing time. The result of four input variables was compared with three input variables and there is a slight time difference between these two studies. Therefore, the washing machine with four input variables can be classified as comparable controller with human behaviour as the washed clothes becomes cleaner and the time taken is suitable in accordance with the proposed input compared to washing machine with three inputs. It can be said that the washing machine with fuzzy logic controller is a great combination of technology and intelligence. For future work, to make the controller of washing machine works smoothly, more input variables can be implemented in washing machine in order to estimate the best washing time. Other than that, for future research, the researchers can use another method, namely the Sugeno method, to analyse the washing time and compare the result with existing research.

REFERENCES

[1] L. A. Zadeh, "Fuzzy sets," *Inf. Control*, vol. 8, no. 3, pp. 338–353, 1965, doi: 10.1016/S0019-9958(65)90241-X.
[2] M. R. S. Emami, "Fuzzy Logic Applications In Chemical Processes," *J. Math. Comput. Sci.*, vol. 1, no. 4, pp. 339–348, 2010, doi: 10.22436/jmcs.001.04.11.
[3] R. Kumari, V. K. Sharma, and S. Kumar, "Design and Implementation of Modified Fuzzy based CPU Scheduling Algorithm," *Int. J. Comput. Appl.*, vol. 77, no. 17, pp. 1–6, 2013, doi: 10.5120/13612-1323.
[4] H. Singh *et al.*, "Real-life Applications of Fuzzy Logic," *Adv. Fuzzy Syst.*, vol. 2013, pp. 1–3, 2013, doi: 10.1155/2013/581879.
[5] E. H. Mamdani, "Application of Fuzzy Algorithms for Control of Simple Dynamic Plant," in *Proceedings of the Institution of Electrical Engineers*, 1974, vol. 121, no. 12, pp. 1585–1588, doi: 10.1049/piee.1974.0328.
[6] M. M. Gouda, S. Danaher, and C. P. Underwood, "Fuzzy Logic Control Versus Conventional PID Control for Controlling Indoor Temperature of a Building Space," *IFAC Proc. Vol.*, vol. 33, no. 24, pp. 249–254, 2000, doi: 10.1016/s1474-6670(17)36900-8.
[7] M. J. Yusoff, N. F. N. Ismail, I. Musirin, N. Hashim, and D. Johari, "Comparative study of Fuzzy Logic controller and Proportional Integral Derivative controller on {DC}-{DC} Buck Converter," Jun. 2010, doi: 10.1109/peoco.2010.5559170.

[8] T. Ahmed and A. Toki, "A Review on Washing Machine Using Fuzzy Logic Controller," vol. 4, no. 7, pp. 64–67, 2016.
[9] K. Raja and S. Ramathilagam, "Washing machine using fuzzy logic controller to provide wash quality," *Soft Comput.*, vol. 25, no. 15, pp. 9957–9965, 2021, doi: 10.1007/s00500-020-05477-4.
[10] M. Alhanjouri and A. A. Alhaddad, "Optimize wash time of washing machine using fuzzy logic," in *The 7th International Conference on Information and Communication Technology and Systems (ICTS 2013)*, 2013, pp. 77–80.
[11] M. Demetgul, O. Ulkir, and T. Waqar, "Washing Machine Using Fuzzy Logic," *Autom. Control Intell. Syst.*, vol. 2, no. 3, pp. 27–32, 2014, doi: 10.11648/j.acis.20140203.11.
[12] S. Hatagar and S. V. Halase, "Three Input – One Output Fuzzy logic control of Washing Machine," *Int. J. Sci. Res. Eng. Technol.*, vol. 4, no. 1, pp. 57–62, 2015.
[13] M. Agarwal, A. Mishra, and A. Dixit, "Design of an Improved Fuzzy Logic based Control System for Washing Machines," *Int. J. Comput. Appl.*, vol. 151, no. 8, pp. 5–10, 2016.
[14] T. Ahmed and A. Ahmad, "Fuzzy logic controller for washing machine with five input and three output," *Int. J. Latest Trends Eng. Technol.*, vol. 7, no. 2, pp. 136–143, 2016, doi: 10.21172/1.72.523.
[15] M. A. Islam and M. S. Hossain, "Optimizing the wash time of the washing machine using several types of fuzzy numbers," *J. Bangladesh Acad. Sci.*, vol. 45, no. 1, pp. 105–116, 2021, doi: 10.3329/jbas.v45i1.54432.
[16] K. A. Kareem and W. H. Ali, "Implementation of Washing Machine System Via Utilization of Fuzzy Logic Algorithms," in *Proceedings - ISAMSR 2021: 4th International Symposium on Agents, Multi-Agents Systems and Robotics*, 2021, pp. 45–50, doi: 10.1109/ISAMSR53229.2021.9567796.
[17] M. N. Virkhare and P. R. W. Jasutkar, "Neuro-Fuzzy Controller Based Washing Machine," *Int. J. Eng. Sci. Invent.*, vol. 3, no. 1, pp. 48–51, 2014.
[18] A. Z. Wang and G. F. Ren, "The design of neural network fuzzy controller in washing machine," in *Proceedings - 2012 International Conference on Computing, Measurement, Control and Sensor Network, CMCSN 2012*, 2012, pp. 136–139, doi: 10.1109/CMCSN.2012.35.
[19] S. S. Hatagar and S. S. V Halase, "Simulating Matlab Rules in Fuzzy Controller Based Washing Machine," *Int. J. Emerg. Trends Sci. Technol.*, vol. 2, no. 7, pp. 2796–2802, 2015.
[20] N. Wulandari and A. G. Abdullah, "Design and Simulation of Washing Machine using Fuzzy Logic Controller (FLC)," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 384, pp. 1–8, 2018, doi: 10.1088/1757-899X/384/1/012044.
[21] I. Iancu and M. Gabroveanu, "Fuzzy Logic Controller Based on Association Rules," *Math. Comput. Sci. Ser.*, vol. 37, no. 3, pp. 12–21, 2010.
[22] S. S. Jamsandekar and R. R. Mudholkar, "Performance Evaluation by Fuzzy Inference Technique," *Int. J. Soft Comput. Eng.*, vol. 3, no. 2, pp. 158–164, 2013.
[23] L. A. Q. Aranibar, "Learning fuzzy logic from examples," Ohio University, 1994.
[24] J. F. Silva and S. F. Pinto, *Linear and Nonlinear Control of Switching Power Converters*. 2018.
[25] L. A. Zadeh, "The concept of a linguistic variable and its application to approximate reasoning—I," *Inf. Sci.*, vol. 8, no. 3, pp. 199–249, 1975, doi: 10.1016/0020-0255(75)90036-5.

BIOGRAPHIES OF AUTHORS

Nurain Zulaikha Husin completed her bachelor degree of Mathematics in 2017 from Universiti Teknologi MARA (UiTM) Kelantan, Malaysia. She received a master degree in Engineering Mathematics from Universiti Malaysia Perlis in 2018. She can be contacted at email: nuhazulaikha94@gmail.com.

Muhammad Zaini Ahmad is currently an associate professor at the Institute of Engineering Mathematics, Faculty of Applied and Human Sciences, Universiti Malaysia Perlis, from 2003 till date. He obtained Ph.D. from Universiti Kebangsaan Malaysia in 2012, specialising in the field of Industrial Computing. He has published research papers in various international journals. His research interest includes fuzzy set theory, differential equations and mathematics for decision making. He can be contacted at email: mzaini@unimap.edu.my.

Mustafa Mamat is currently a Professor in the Faculty of Informatics and Computing at the Universiti Sultan Zainal Abidin (UniSZA) Malaysia since 2013. He was first appointed as a Lecturer at the Universiti Malaysia Terengganu (UMT), in 1999. He obtained his Ph.D. from the UMT in 2007 with a specialization in optimization. He was appointed as a Senior Lecturer in 2008 and as an Associate Professor in 2010 also the UMT. To date, he has published more than 380 research papers in various international journals and conferences. His research interest in applied mathematics, with a field of concentration of optimization, includes conjugate gradient methods, steepest descent methods, Broyden's family, and quasi-Newton methods. He can be contacted at email: must@unisza.edu.my.