IOSR Journal of Mathematics (IOSR-JM)
e-ISSN: 2278-5728, p-ISSN: 2319-765X. Volume 16, Issue 3 Ser. IV (May –June 2020), PP 01-08
www.iosrjournals.org

Application Of Fuzzy Logic On Washing Machine Decision Algorithms

Veysel Güney YILMAZ* and Emine CAN**
* *TEV Inanc High School, 41400, Kocaeli/Turkey*
** *Istanbul Medeniyet University, Department of Physics Engineering, 34700, Istanbul/Turkey*

Washing machines are parts of almost every house now, as they provide individuals with a fast and successful way to clean up clothes. However, they lack the automaticity which would save loads of time when thought of how much time is spent on determining the appropriate program. Standard washing machines also lack the number of choices in terms of temperature, washing cycle, etc. since such detailed input cannot be easily determined by non-professional washing machine users.This paper aims to suggest a washing machine algorithm that even non-professional washing machine users can use without trouble, which provides the optimal program according to the specified cloth types regarding their colours, delicacy levels and stain levels using "Fuzzy Logic" as a mathematical plane.The fuzzy approach provides a reasonable base for the resulting washing program by combining human intelligence and decision skills with machine precision. Another contribution of this mathematical system to the algorithm is its adaptability to various conditions in washing a cloth such as taking its colour, delicacy level, and stain level into consideration. As a result, the algorithm gives out three outputs namely "Washing Cycle", "Spin Cycle" and "Temperature" in which "Fuzzy Intersection" and "Fuzzy Weighted Average"methods are used to achieve.

Keywords: ***Color, Delicacy, Fuzzy Logic, Fuzzy Operator, Revolution per Minute,Stain Level, Temperature, Washing Machine Algorithm.***

Date of Submission: 20-05-2020 Date of Acceptance: 09-06-2020

I. Introduction

Fuzzy logic is a mathematical plane which allows us to convert lingual elements into parameters during any computation. On that sense, fuzzy logic fits perfectly in decision-making algorithms which requires acombination of the judgmental skills of a human and the precision of machines [1]. While applying fuzzy logic, the mathematician assigns membership functions for lingual variables in which every variable gives out an output value between 0 and 1. For example, the mathematician may define the age that is most appropriate for the word "young" as 20 years, and for every age from 20, the individual moves away from being young by 5%. In this case, the membership function for being young is defined as$\mu_{\tilde{A}} = \begin{cases} 1 - \left|\frac{20-x}{20}\right| & if 0 \leq x \leq 10 \\ 0 & if x > 40 \end{cases}$where the function defined on$[0, +\infty) \to [0,1]$. That way, "youngness" is given mathematical boundaries with membership values.

With the developing technology, most machines became automatic such as computers and cell phones which do not require human modifications to work. However, the applicationof the automaticity in cleaning industry was not as successful so far due to the abundance of variables such as extensive range of materials, colours, level of stain and amount of load in clothing. The quantity of parameters increases the risk of spoiling the clothes which discourages any attempt of automaticity in washing machines. Nonetheless, the main aim of this research is to encourage other researchers to offer new methods for Artificial Intelligence (AI) systems for washing machines as well as suggesting an intelligent decision algorithm with minimum possibility of spoiling the clothes and energy waste. So, the resulting optimum program will be determined upon the balanced aim of wrinkling and damaging the clothes as least as possible as well as providing cleanness to the highest degree.Toachieve this, the algorithm should include individual evaluation of the clothes' properties, combined with machine evaluation of the appropriate program. As a result, the determination of the algorithm will consist of 3 parts: fuzzification of the crisp set, assessment of the data in fuzzy form, and defuzzification[1]. That way, the fittest scenario will be decided according to 3 parameters namely "Delicacy of the Cloth", "Level of Stain on the Cloth" and "Color of the Cloth" where the output will be "Revolution per Minute of The Washing Cycle", "Revolution per Minute of The Spin Cycle", and "Temperature of Water".

Note: Washing Cycle and Spin Cycle are commonly mixed. The washing process consists of 2 parts: washing the cloth with water and extracting the moisture from the fabric by spinning it. In this paper, the washing cycle refers to the first part, and spine cycle refers to the second.

II. Methodology

Washing the clothes consists of 3 parts: separating according to colour, determining the delicacy, and determining the level of stain. The perfect scenario is where the clothes are categorized according to these properties and washed separately. However, this would require the machine to work too many rounds which results inan excessive waste of energy, money and efficiency. This research aims to suggest an algorithm that provides an optimal program for clothes from different categories to be cleaned up and stay undamaged as well as spending the least energy possible. To do this, the input variables must first be examined individually. The fuzzification of the parameters was determined upon their relations with the algorithm outputs.

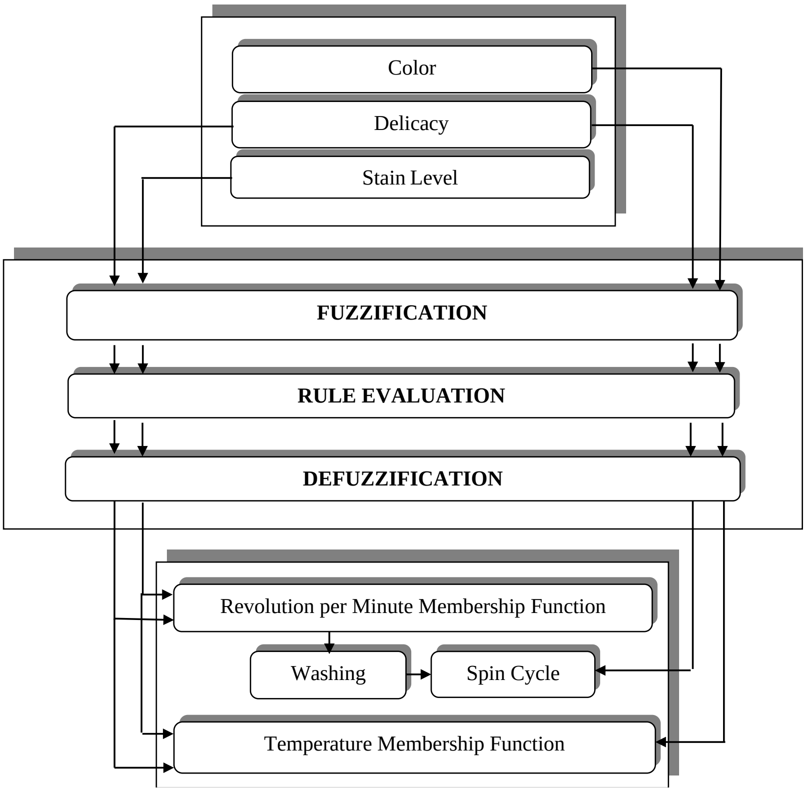
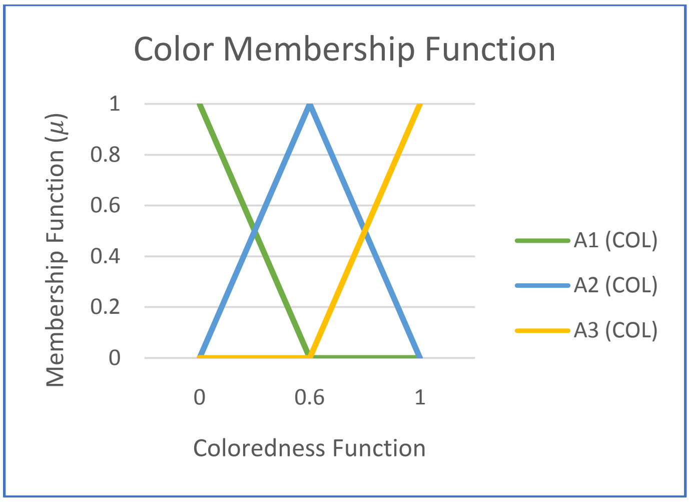


Figure1: Scheme of theMethodologythat is Suggested.

Parameter 1) Color (COL)

Colours of the clothes are essential due to two factors: optimal temperature and bleeding effect. Whilewhite clothes are suggested to be washed with hot water to eliminate the stains to a higher degree, when washedalong with coloured clothes, may get dyed with the colours of them in warm temperatures. In the fuzzy algorithm, it will be most reasonable to define "whiteness"as more active on the resulting washing program than "blackness" since even small amounts of dark colour may bleed on the whites. Therefore, the "whiteness" triangle in the "Color Membership Function" will be lower than "blackness" triangle. Besides, "coloureds" will be defined as a third fuzzy parameter to bring forth a membership function for coloured clothes as well.



Graph1: FuzzifiedGraph of ColorednessFunction

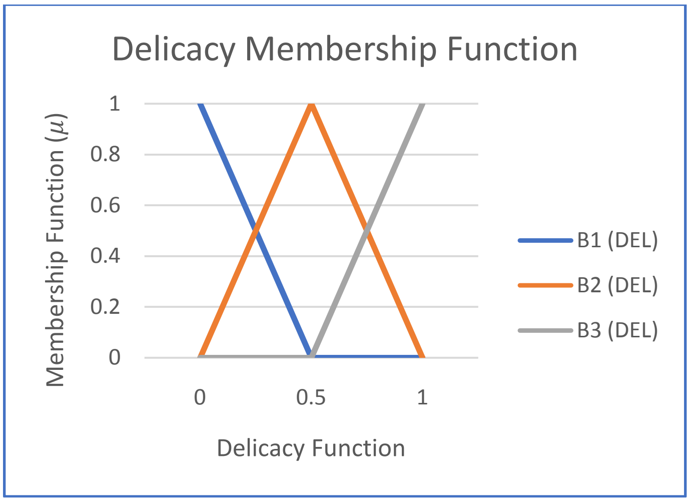
$$\mu_{A1}(COL) = 1 - \left(\frac{x}{0.6}\right), \; if \; 0 \le x \le 0.6 \quad (1)$$

$$\mu_{A2}(COL) = \begin{cases} \frac{x}{0.6} & , \quad if \; 0 \le x \le 0.6 \\ \frac{5}{2} - \left(\frac{x}{0.4}\right) & , \quad if \; 0.6 \le x \le 1 \end{cases} \quad (2)$$

$$\mu_{A3}(COL) = -\frac{3}{2} + \left(\frac{x}{0.4}\right), \; if \; 0.6 \le x \le 1 \; (3)$$

Parameter 2) Delicacy (DEL)

Clothes' delicacy levels are critical in deciding the washing program. When washed with faster spin cycles, delicate clothes may get damaged. Similarly, in high temperatures, delicate clothes easily wrinkle or even tear apart. Therefore, they will determine the "Revolution per Minute of The Washing Cycle", "Revolution per Minute of The Spin Cycle" and "Temperature" as it can be seen on the graph below.



Graph2:*FuzzifiedGraph of DelicacyFunction*

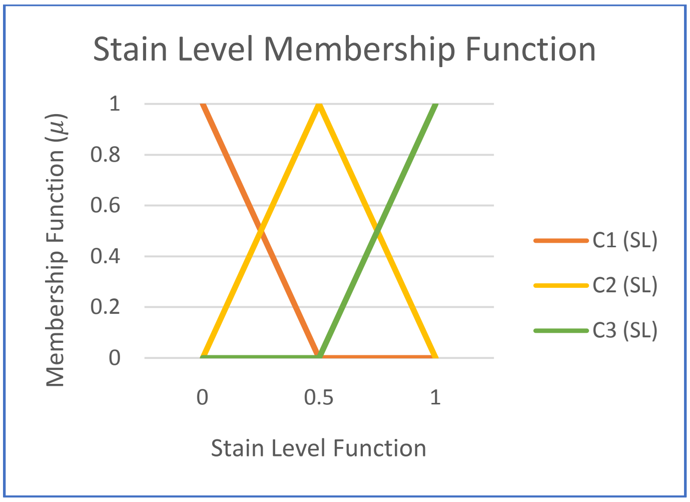
$$\mu_{B1}(DEL) = 1 - \left(\frac{x}{0.5}\right), \; if \; 0 \le x \le 0.5 \; (4)$$

$$\mu_{B2}(DEL) = \begin{cases} \frac{x}{0.5} & , \quad if \; 0 \le x \le 0.5 \\ 2 - \left(\frac{x}{0.5}\right) & , \quad if \; 0.5 \le x \le 1 \end{cases} \quad (5)$$

$$\mu_{B3}(DEL) = -1 + \left(\frac{x}{0.5}\right), \; if \; 0.5 \le x \le 1 \; (6)$$

Parameter 3) Stain Level (SL)

Stain level is another critical factor in determining the washing program. Longer washing cycles and higher temperature programs would be suitable for high-level stains as it can be deduced from the graph below.



Graph3:*FuzzifiedGraph of Stain Level Function*

$$\mu_{C1}(SL) = 1 - \left(\frac{x}{0.5}\right),\ if\ \ 0 \le x \le 0.5\ (7)$$

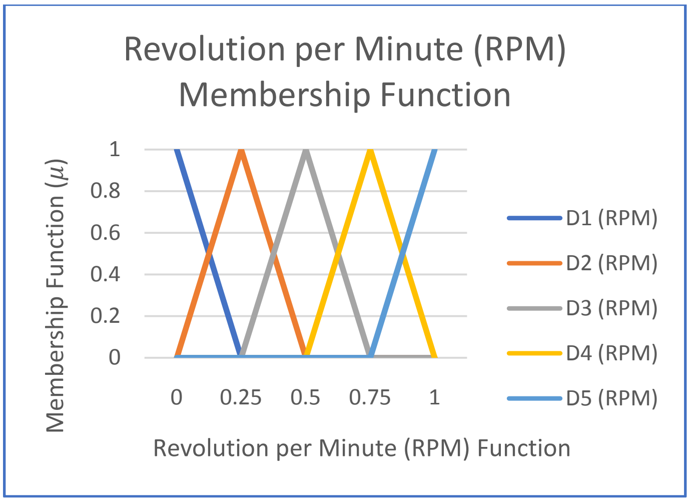
$$\mu_{C2}(SL) = \begin{cases} \frac{x}{0.5} & ,\quad if\ 0 \le x \le 0.5 \\ 2 - \left(\frac{x}{0.5}\right) & ,\quad if\ \ 0.5 \le x \le 1 \end{cases} (8)$$

$$\mu_{C3}(SL) = -1 + \left(\frac{x}{0.5}\right),\ if\ \ 0.5 \le x \le 1\ (9)$$

Now that the evaluation criteria for the properties of the clothes are determined, output values can be expressed in terms of the parameters. As it was mentioned in the introduction part, the main aim of this paper is to determine the “Revolution per Minute of The Washing Cycle”, “Revolution per Minute of The Spin Cycle”, and “Temperature of Water” according to the input values mentioned above. Different Fuzzy Methods will be applied to reach the optimum program. Therefore, every output will have respective Rule Base Tables.

Revolution per Minute (RPM) and Temperature (TEM) Functions

During the defuzzification process,two graphs will be used, one being the membership function of “Revolution per Minute” and “Temperature”. Revolution per Minute function is defined as following:



Graph4:*FuzzifiedGraph of Revolutionper Minute (RPM) Function*

$$\mu_{D1}(RPM) = 1 - \left(\frac{x}{0.25}\right),\ if\ \ 0 \le x \le 0.25\ (10)$$

$$\mu_{D2}(RPM) = \begin{cases} \frac{x}{0.25} & ,\quad if\ 0 \le x \le 0.25 \\ 2 - \left(\frac{x}{0.25}\right) & ,\quad if\ \ 0.25 \le x \le 0.5 \end{cases} (11)$$

$$\mu_{D3}(RPM)=\begin{cases}-1+\left(\frac{x}{0.25}\right) & , \quad if\ 0.25\le x\le 0.5\\ 3-\left(\frac{x}{0.25}\right) & , \quad if\ \ 0.5\le x\le 0.75\end{cases} \quad (12)$$

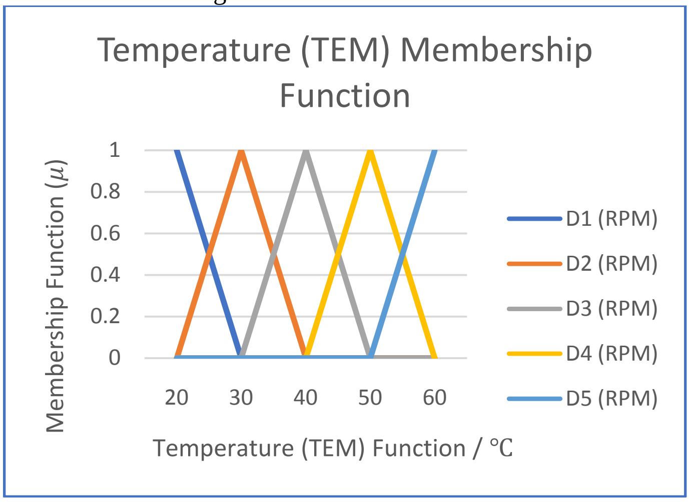
$$\mu_{D4}(RPM)=\begin{cases}-2+\left(\frac{x}{0.25}\right) & , \quad if\ 0.5\le x\le 0.75\\ 4-\left(\frac{x}{0.25}\right) & , \quad if\ \ 0.75\le x\le 1\end{cases} \quad (13)$$

$$\mu_{D5}(RPM)=-3+\left(\frac{x}{0.25}\right),\ if\ \ 0.75\le x\le 1 \ (14)$$

After finding the membership value, the defuzzification process will be conducted according to the following operation:

$$RPM=\frac{300\times\mu_{D1}(RPM)+600\times\mu_{D2}(RPM)+900\times\mu_{D3}(RPM)+1200\times\mu_{D4}(RPM)+1500\times\mu_{D5}(RPM)}{\mu_{D1}(RPM)+\mu_{D1}(RPM)+\mu_{D1}(RPM)+\mu_{D1}(RPM)+\mu_{D1}(RPM)} (15)$$

Temperature function is defined as following:



***Graph5**:FuzzifiedGraph of Temperature (TEM) Function*

$$\mu_{20\,°C}(TEM)=1-\left(\frac{x}{0.25}\right),\ if\ \ 0\le x\le 0.25\ (16)$$

$$\mu_{30\,°C}(TEM)=\begin{cases}\frac{x}{0.25} & , \quad if\ 0\le x\le 0.25\\ 2-\left(\frac{x}{0.25}\right) & , \quad if\ \ 0.25\le x\le 0.5\end{cases} \quad (17)$$

$$\mu_{40\,°C}(TEM)=\begin{cases}-1+\left(\frac{x}{0.25}\right) & , \quad if\ 0.25\le x\le 0.5\\ 3-\left(\frac{x}{0.25}\right) & , \quad if\ \ 0.5\le x\le 0.75\end{cases} \quad (18)$$

$$\mu_{50\,°C}(TEM)=\begin{cases}-2+\left(\frac{x}{0.25}\right) & , \quad if\ 0.5\le x\le 0.75\\ 4-\left(\frac{x}{0.25}\right) & , \quad if\ \ 0.75\le x\le 1\end{cases} \quad (19)$$

$$\mu_{60\,°C}(TEM)=-3+\left(\frac{x}{0.25}\right),\ if\ \ 0.75\le x\le 1\ (20)$$

$$FINAL\ TEM=\frac{20\times\mu_{20°C}(TEM)+30\times\mu_{30°C}(TEM)+40\times\mu_{40°C}(TEM)+50\times\mu_{50°C}(TEM)+60\times\mu_{60°C}(TEM)}{\mu_{20°C}(TEM)+\mu_{30°C}(TEM)+\mu_{40°C}(TEM)+\mu_{50°C}(TEM)+\mu_{60°C}(TEM)}\ (21)$$

Output 1) Revolution per Minute of The Washing Cycle (RPMWC)

Revolution per Minute of the Washing Cycle (RPMWC) is dependent upon the Delicacy (DEL) and the Stain Level (SL)of the clothes. The rule base table is accordingly:

***Table1:**Rule Base fortheDetermination of Revolutionper Minute of theWashingCycle (RPMWC)*

Rule 1	IF	DEL is B1	and	SL is C1	THEN	RPMWC is D1
Rule 2	IF	DEL is B2	and	SL is C1	THEN	RPMWC is D2
Rule 3	IF	DEL is B3	and	SL is C1	THEN	RPMWC is D3
Rule 4	IF	DEL is B1	and	SL is C2	THEN	RPMWC is D2
Rule 5	IF	DEL is B2	and	SL is C2	THEN	RPMWC is D3
Rule 6	IF	DEL is B3	and	SL is C2	THEN	RPMWC is D4
Rule 7	IF	DEL is B1	and	SL is C3	THEN	RPMWC is D3

Rule 8	IF	DEL is B2	and	SL is C3	THEN	RPMWC is D4
Rule 9	IF	DEL is B3	and	SL is C3	THEN	RPMWC is D5

**) 1: Revolutionper Minute of theWashingCycle (RPMWC): D1 (VerySlow), D2 (Slow), D3 (Medium), D4 (Fast), D5 (VeryFast)*

After the If-Then operation, μ_{Bi} and μ_{Ci} are obtained. Using the "intersection" operator of Fuzzy System, $\mu(RPMSC)$ is obtained. Suppose that $\mu_{B2} = 0.3$ and $\mu_{C2} = 0.7$ THEN D4, and $\mu_{B3} = 0.5$ and $\mu_{C3} = 0.6$ THEN D5. An example of the process is as follows:

Rule 5: If $\mu_{B2} = 0.3$ and $\mu_{C2} = 0.7$ THEN $\mu_{D3} = \mu_{B2} \wedge \mu_{C2}; \mu_{D3} = 0.3$

Rule 9: If $\mu_{B3} = 0.5$ and $\mu_{C3} = 0.6$ THEN $\mu_{D5} = \mu_{B3} \wedge \mu_{C3}; \mu_{D5} = 0.5$

For the next step, the values of both $\mu_{D3} = 0.3$ and $\mu_{D5} = 0.5$ will be taken an average of using the "Revolution per Minute" functions in the *Revolution per Minute (RPM)FunctionsSection*. Therefore:

$$\frac{(300 \times 0) + (600 \times 0) + (900 \times 0.3) + (1200 \times 0) + (1500 \times 0.5)}{0 + 0 + 0.3 + 0 + 0.5} = 1275\ rpm$$

According to the algorithm, 1275 revolutions per minute is found to be the optimal revolution speed for the washing cycle.

Output 2) Revolution per Minute of The Spin Cycle (RPMSC)

Revolution per Minute of the Spinning Cycle (RPMSC) is dependent upon only the Delicacy (DEL) of the cloth. However, since the cloth has already experienced a revolution speed in the washing cycle, it would be the most appropriate to consider $\mu(RPMWC)$ while determining RPMSC as well. The combination of DEL and RPMSC will be done using the fuzzy intersection operator. This way, delicate clothes will be less likely to get damaged, and water will be extracted from the clothes in the most optimum way.

Rule 0: $\mu(RPMSC) = \mu(RPMWC) \wedge \mu(DEL)$

After this process, the membership function $\mu(RPMSC)$ will be processed in the RPM operator in the *Revolution per Minute (RPM) FunctionsSection*in terms of D1, D2, D3, D4, D5 according to the following table.

Table 2:*Rule Base fortheDetermination of Revolutionper Minute of the Spin Cycle (RPMSC)*

IF	B1	and	D1	THEN	D1
IF	B1	and	D2	THEN	D2
IF	B1	and	D3	THEN	D3
IF	B1	and	D4	THEN	D4
IF	B1	and	D5	THEN	D5
IF	B2	and	D1	THEN	D1
IF	B2	and	D2	THEN	D2
IF	B2	and	D3	THEN	D3
IF	B2	and	D4	THEN	D4
IF	B2	and	D5	THEN	D5
IF	B3	and	D1	THEN	D1
IF	B3	and	D2	THEN	D2
IF	B3	and	D3	THEN	D3
IF	B3	and	D4	THEN	D4
IF	B3	and	D5	THEN	D5

**) 2: Revolutionper Minute of the Spin Cycle (RPMSC): D1 (VerySlow), D2 (Slow), D3 (Medium), D4 (Fast), D5 (VeryFast)*

Suppose $\mu_{D3}(RPMWC) = 0.3$ and $\mu_{B1}(DEL) = 0.2$; and also $\mu_{D5}(RPMWC) = 0.5$ and $\mu_{B2}(DEL) = 0.3$:

$$\mu(RPMSC) = \mu(RPMWC) \wedge \mu(DEL)$$
$$\mu_{D3}(RPMSC) = 0.2$$
$$\mu_{D5}(RPMSC) = 0.3$$

When the result is operated according to the membership function in *the Revolution per Minute (RPM) FunctionsSection*, the following result is obtained:

$$\frac{(300 \times 0) + (600 \times 0) + (900 \times 0.2) + (1200 \times 0) + (1500 \times 0.3)}{0 + 0 + 0.2 + 0 + 0.3} = 1260\ rpm$$

As a result, 1260 rpm is found to be the optimal value for "Revolution per Minute Spinning Cycle".

Output 3) Temperature (TEM)

Temperature is dependent on all the inputs, namely "Delicacy of the Cloth", "Level of Stain on the Cloth" and "Color of the Cloth". Washing Machines' programs differ from 20°C to 90°C; however, 70°C, 80°C and 90°C were neglected since they were neither common nor appropriate for daily washes.

Table3:*Rule Base fortheDetermination of Temperature (TEM)*

Rule 10	IF	COL is A1	and	DEL is B1	and	SL is C1	THEN	TEM is 20°C
Rule 11	IF	COL is A2	and	DEL is B1	and	SL is C1	THEN	TEM is 20°C
Rule 12	IF	COL is A3	and	DEL is B1	and	SL is C1	THEN	TEM is 30°C
Rule 13	IF	COL is A1	and	DEL is B2	and	SL is C1	THEN	TEM is 20°C
Rule 14	IF	COL is A2	and	DEL is B2	and	SL is C1	THEN	TEM is 30°C
Rule 15	IF	COL is A3	and	DEL is B2	and	SL is C1	THEN	TEM is 30°C
Rule 16	IF	COL is A1	and	DEL is B3	and	SL is C1	THEN	TEM is 20°C
Rule 17	IF	COL is A2	and	DEL is B3	and	SL is C1	THEN	TEM is 30°C
Rule 18	IF	COL is A3	and	DEL is B3	and	SL is C1	THEN	TEM is 40°C
Rule 19	IF	COL is A1	and	DEL is B1	and	SL is C2	THEN	TEM is 30°C
Rule 20	IF	COL is A2	and	DEL is B1	and	SL is C2	THEN	TEM is 30°C
Rule 21	IF	COL is A3	and	DEL is B1	and	SL is C2	THEN	TEM is 40°C
Rule 22	IF	COL is A1	and	DEL is B2	and	SL is C2	THEN	TEM is 30°C
Rule 23	IF	COL is A2	and	DEL is B2	and	SL is C2	THEN	TEM is 40°C
Rule 24	IF	COL is A3	and	DEL is B2	and	SL is C2	THEN	TEM is 40°C
Rule 25	IF	COL is A1	and	DEL is B3	and	SL is C2	THEN	TEM is 30°C
Rule 26	IF	COL is A2	and	DEL is B3	and	SL is C2	THEN	TEM is 40°C
Rule 27	IF	COL is A3	and	DEL is B3	and	SL is C2	THEN	TEM is 50°C
Rule 28	IF	COL is A1	and	DEL is B1	and	SL is C3	THEN	TEM is 40°C
Rule 29	IF	COL is A2	and	DEL is B1	and	SL is C3	THEN	TEM is 40°C
Rule 30	IF	COL is A3	and	DEL is B1	and	SL is C3	THEN	TEM is 50°C
Rule 31	IF	COL is A1	and	DEL is B2	and	SL is C3	THEN	TEM is 40°C
Rule 32	IF	COL is A2	and	DEL is B2	and	SL is C3	THEN	TEM is 50°C
Rule 33	IF	COL is A3	and	DEL is B2	and	SL is C3	THEN	TEM is 50°C
Rule 34	IF	COL is A1	and	DEL is B3	and	SL is C3	THEN	TEM is 40°C
Rule 35	IF	COL is A2	and	DEL is B3	and	SL is C3	THEN	TEM is 50°C
Rule 36	IF	COL is A3	and	DEL is B3	and	SL is C3	THEN	TEM is 60°C

**) 3: Temperature (TEM): 20°C, 30°C, 40°C, 50°C, 60°C*

To find the membership value of "Temperature", $\mu(TEM)$, "intersection" operator of "Fuzzy Systems" will be applied to prevent hot water from bleeding the colors and wrinkling the delicate clothes as well as waste less energy as much as possible. Therefore, the following process will be applied:

$$\mu_i(TEM) = \mu_{Ai}(COL) \wedge \mu_{Bi}(DEL) \wedge \mu_{Ci}(SL)$$

Similar with finding the RPM, the graph and membership function for "Temperature" value will be calculated according tothe*Temperature (TEM) Functions Section*. Suppose that as a result, we obtained$\mu_{20°C}(TEM) = 0.7$, $\mu_{30°C}(TEM) = 0.6$ and $\mu_{40°C}(TEM) = 0.3$. Then, the result would be as following:

$$FINAL\ TEM = \frac{20 \times 0.7 + 30 \times 0.6 + 40 \times 0.3 + 50 \times 0 + 60 \times 0}{0.7 + 0.6 + 0.3 + 0 + 0} = 27.5°C$$

According to the suggested algorithm, the optimum temperature for the washing process is 27.5°C.

III. Conclusion

Consequently, it was suggested in this paper that RPM of Washing Cycle, RPM of Spin Cycle and Temperature values in a washing machine must be determined upon the clothes' colour, delicacy level and stain level. The output values were expressed in terms of fuzzy functions correspondingly to the parameters. Based on the membership functions and fuzzy "IF-THEN" rules, the input values were fuzzified. Later, by using the "Fuzzy Weighted Average" method, the results were defuzzified. Like the product, the exact cycle revolutions and temperature values were obtained. The system allows one to wash clothes with the least possible damage to the cloth and most possible cleanness as well as allowing the person to set the program in a more precise way contrarily to primitive machines that enable the user to only choose specific applications and specific temperatures.

It must also be noted that this algorithm is only theoretical, and it suggests no exact methods to determine the clothes' properties. To use the algorithm in actual washing machines, help from other sources which imply methods to identify a cloth's properties or average properties of a pack of clothes must be gotten. Another improvement may be to add more factors such as mass and material of cloth. In this research, those variables were not noted since they would complicate the algorithm to the degree that it would not be suitable for daily use. However, they may be ideal for professional use.

References

[1]. Ahmed T., Toki A., (2016) A Review on Washing Machine Using Fuzzy Logic Controller, International Journal of Emerging Trends in Engineering Research 4, 64-67.

[2]. Bede B., (2013) Mathematics of Fuzzy Sets and Fuzzy Logic, *Springer Science+Business Media*, Heidelberg, Germany.

[3]. Hatagar S., HalaseS., (2015) Simulating Matlab Rules in Fuzzy Controller Based Washing Machine, *International Journal of Emerging Trends in Science and Technology* 2, 2796-2802.

[4]. Honisch M., Stamminger M., et Al. (2014) Impact of Wash Cycle Time, Temperature and Detergent Formulation on the Hygiene Effectiveness of Domestic Laundering, *Journal of Applied Microbiology* 117, 1787-1797.

[5]. Wulandari N., Abdullah A., (2017) Design and Simulation of Washing Machine using Fuzzy Logic Controller(FLC), *International Symposium on Materials and Electrical Engineering (ISMEE) 2018*, 012044, 16 November 2017, Bandung, Indonesia.

Veysel Güney YILMAZ, et al. "Application Of FuzzyLogic On Washing Machi DecisionAlgorithms." *IOSR Journal of Mathematics (IOSR-JM)*, 16(3), (2020): pp. 01-08.