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Research Article

Mathematical comparison of defuzzification of fuzzy logic controller for smart washing machine

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ARTICLE INFO	ABSTRACT
	This is the age of modern science where different kinds of gadgets are used for the betterment of humanity. Various electronic, intelligence systems are invented via modern technology where FLC (Fuzzy Logic Controller) is used to develop their intelligence systems. Nowadays, FLC is widely used in uncertainty and robust development systems. Two inputs and one output have been used in this paper. Also, various defuzzification methods are used to determine the washing time of a smart washing machine. Finally, the performance of the various defuzzification methods has been compared mathematically. This work has been simulated by using the MATLAB toolbox.

Introduction

The fundamental concept of Fuzzy Logic was first introduced by Zadeh in 1965 (Zadeh, 1965). After that, for the first time, Mamdani (Mamdani, 1974) demonstrated its application in 1974. Fuzzy logic helps to monitor nonlinear systems that are difficult to solve mathematically. Fuzzy logic and fuzzy set theory mention the non-probabilistic logic theory now augments substitute paths to solve automatic control problems (Mamdani and Assilian, 1975). According to fuzzy logic's basic ideas, Mamdani and Assilian submitted fuzzy controllers that describe human control in linguistic form. Therefore, the first applications of a fuzzy control replaced a human operator (Kilr and Yuan, 1965). Moreover, several researchers, namely Lohani and Hasan (2009), Aggarwal (2011), Alhanjouri and Alhaddad (2013), Akram et al. (2014), and Soparkar (2015), calculated wash time for the washing machine.

Further, many researchers, namely Amin et al. (2020), Mahbub et al. (2019), Amin and Rana (2018), Roshmi and Hossain (2019) and Khatun Fand Hossain (2022) are also working on fuzzy set.

The paper aims to develop a fuzzy logic Control System to make it automated by using triangular and trapezoidal fuzzy numbers. Here, we demonstrated a little bit about FIS in the introductory section, while the simulation results and graphical representation obtained by using MATLAB, are discussed afterward.

Proposed Design of an FLC of Washing Machine

In this paper, the Mamdani, the Center of Gravity (Centroid method), the Bisector, and the Mean of Maxima (MOM) methods are used to design and develop a washing machine. This FLC for consists of two linguistic inputs i.e.

(1) Present degree of dirt on the clothes.

(2) Present amount of grease on the clothes.

These two linguistic variables are used to achieve the wash time as an output. For all linguistic inputs and linguistic outputs, triangular and trapezoidal MF are used. Fuzzy arithmetic and criterion terms are applied to these variables and the outcome is a defuzzified term to get the following crisp results, as described by Ahmed and Toki (2016).

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Fuzzy Logic Controller (FLC)

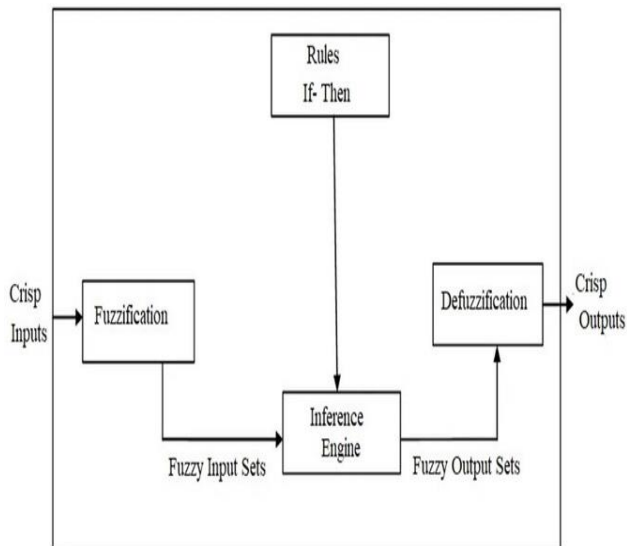If-Then rules-based format is solved by the fuzzy logic controller in four steps as follows in Fig. 1.

Fig. 1. Fuzzy logic controller system

Input Variables: Firstly, a set of MF of linguistic variables are taken as inputs where input variables are words or sentences. To take any fuzzy or crisp output by fuzzification is defuzzification respectably, fuzzy MF is used.

Fuzzification: Fuzzification is a process that provide a fuzzy output. Here, crisp values are fuzzified for fuzzy output.

Fuzzy Inference System: Fuzzy rule-based is applied here. For each antecedent, there is a consequent which is the resued output for every rule-base. Several operators like or, and, else, are not being used in rule-based system to connect multiple linguistic variables so that target output is obtained inside the inference system.

Defuzzification: The crisp output is obtained from a fuzzy set in the defuzzification process. Hardware applications are greatly dependent on defuzzification systems.

Defuzzification Techniques

Centroid Method

The "Centroid method", also known as the "Center of Gravity" or "Center of Area" method, is a technique that is most commonly employed and most familiar for defuzzification. It reduces the area to smaller regions, and a combined operation is performed to obtain the final output. It is stated by the expression below (Islam and Hossain, 2021).

$$x = \frac{\sum_{i=1}^{n} x_i \cdot \mu(x_i)}{\sum_{i=1}^{n} \mu(x_i)}$$

Here, n represents the number of elements in the sample, i.e., x_i are the elements and $\mu(x_i)$ are their corresponding membership functions.

Bisector Method

The Bisector method or Bisector of area splits the area into two states with the corresponding area, which can coincide or not with the centroid line of the particular area.

Mean of Maxima (MOM) method

The easiest way of defuzzification is to take the nearby crisp value with the highest MF. The arithmetic average of all mean values of the intervals containing fuzzy sets, including zero-length intervals, is the mean of the maxima method. The general equation of this method is given by Islam and Hossain (2021).

$$x = \frac{\sum_{x_i \in M} x_i}{|M|}$$

Where $M =$ height of the fuzzy set and $|M| =$ cardinality of the fuzzy set M.

Fuzzy Membership Functions

The membership function (MF) represents a fuzzy set graphically. Triangular and trapezoidal MF is used in FIS. This paper uses triangular and trapezoidal MF to develop a Fuzzy Logic Controller (FLC). Each input, and output, including their linguistic variable, are discussed below.

Fuzzy Input Variables

Usually, crisp inputs can be converted into fuzzy inputs in fuzzy mathematics, where MF represents crisp inputs based on their linguistic terms and ranges. Here, three

linguistic terms such as small (SD), medium (MD), and large (LD) for the present degree of dirt on the cloth are taken. Secondly, the present amount of grease on the clothes with three linguistic variables such as- amount of no grease (NG), medium amount of grease (MG) and a large amount of grease (LG) are taken. The universe of discourse for the present degree of dirt and the present amount of grease is [0, 100]. The MFs. Corresponding to the linguistic values are represented by the following TFN and TrFN The membership value and range are shown in Table 1 below.

Table 1. Show the membership value of input variables

Linguistic Value	Notation	Numerical Range (Normalized)
Linguistic Input Variable: Dirtiness of Clothes (Dirt)		
Small Dirt	SD	[0, 0, 20, 50]
Medium Dirt	MD	[0, 50, 100]
Large Dirt	LD	[50, 80, 100, 100]
Linguistic Input Variable: Type of Dirt (Grease)		
No Grease	NG	[0, 0, 20, 50]
Medium Grease	MG	[0, 50, 100]
Large Grease	LG	[50, 80, 100, 100]

Fuzzy Output Variable

The primary reason for this washing machine is to study the wash time of those inputs and additionally divide them into five linguistic variables consisting of very short time (VS), Short time (S), medium time (M), large time (L) and very large time (VL) that belong to the universe [0, 60]. The membership value and range are shown in Table 2 below.

Table 2. Show the membership value of output variables

Linguistic Value	Notation	Numerical Range (Normalized)
Linguistic Output Variable: Wash-Time		
Very Short	VS	[0, 0, 5, 10]
Short	S	[0, 10, 25]
Medium	M	[10, 20, 30, 40]
Large	L	[25, 40, 60]
Very Large	VL	[40, 50, 60, 60]

Here in Figs. 2 to 4, FLC inputs and output membership functions are shown.
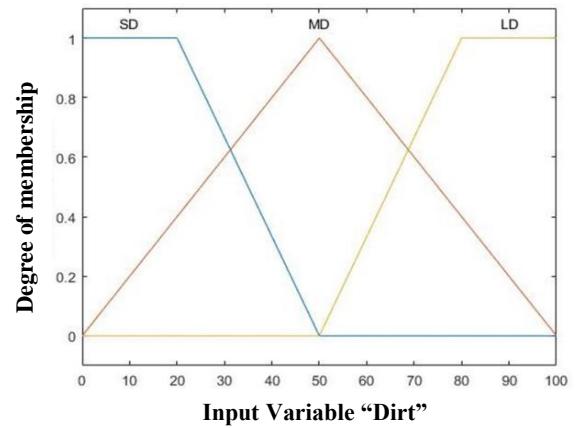

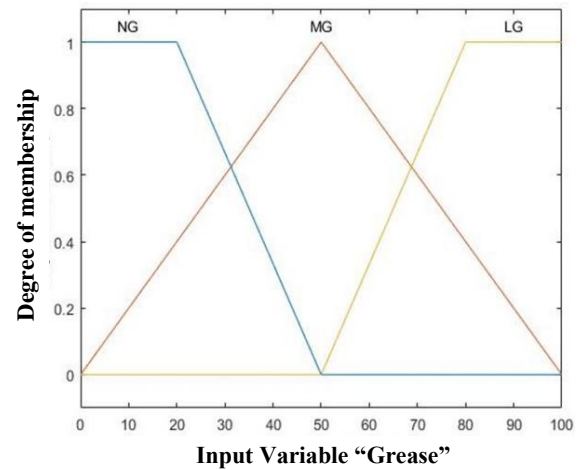**Fig. 2. Input variable of FLC "Dirt"**

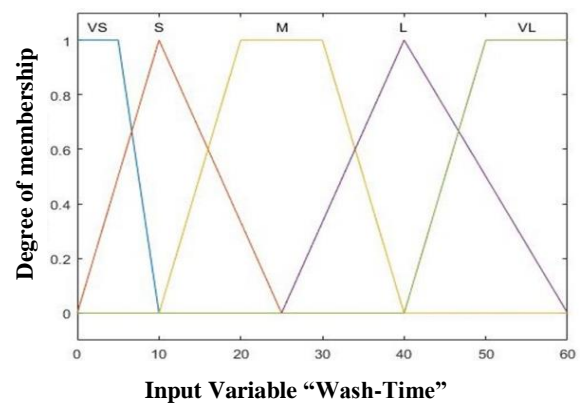**Fig. 3. Input variable of FLC "Grease"**

Fig. 4. Output variable of FLC "Wash-Time"

Fuzzy Rule Base

Fuzzy Rules-based are applied in the FLC by selecting the appropriate sequence in the If-Then rules, which are based on natural language. It is designed to make any automated decision, and formed by keeping the relationship between input and output in mind. The input variables (Dirt, Grease) make a total of 3*3=9 rules, as shown in the followings:

Rule 1: If (Type-Dirt is SD) and (Amount-Grease is NG), then (Wash-Time is VS).

Rule 2: If (Type-Dirt is SD) and (Amount-Grease is MG), then (Wash-Time is S).

Rule 3: If (Type-Dirt is SD) and (Amount-Grease is LG), then (Wash-Time is M).

Rule 4: If (Type-Dirt is MD) and (Amount-Grease is NG), then (Wash-Time is S).

Rule 5: If (Type-Dirt is MD) and (Amount-Grease is MG), then (Wash-Time is M).

Rule 6: If (Type-Dirt is MD) and (Amount-Grease is LG), then (Wash-Time is L).

Rule 7: If (Type-Dirt is LD) and (Amount-Grease is NG), then (Wash-Time is M).

Rule 8: If (Type-Dirt is LD) and (Amount-Grease is MG), then (Wash-Time is L).

Rule 9: If (Type-Dirt is LD) and (Amount-Grease is LG), then (Wash-Time is VL).

Fuzzy Logic Controller (FLC) Implementation in Smart Washing Machine

Fuzzy Base Class

Mamdani method is used to create system control rules obtained from experienced human operators (Kilr and Yuan, 1995). This paper uses the Mamdani method to illustrate, and the centroid method for defuzzification. Here, FIS editor FIS Editor defines the Fuzzy Base Class, the various inputs, i.e., dirt and grease, and the output variable like wash time (Zadeh and Berkeley, 1995), as shown in Fig. 5.
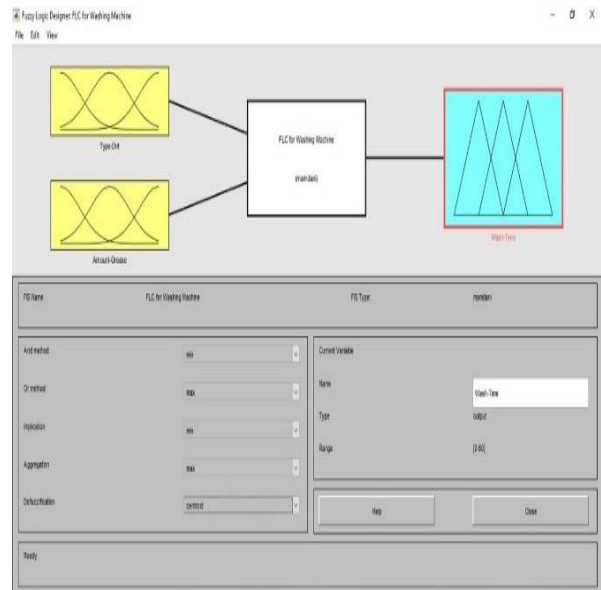

Fig. 5. Show the simulated washing machine on MATLAB

Fuzzy Rule Base

The users can design Fuzzy rules automatically or manually, i.e., some rules produced by the rules Editor for all combinations of selected input variables and a user fills consequent fuzzy term. The fuzzy outputs subsequently come from inputs (Zadeh and Berkeley, 1995), as shown in Fig. 6.
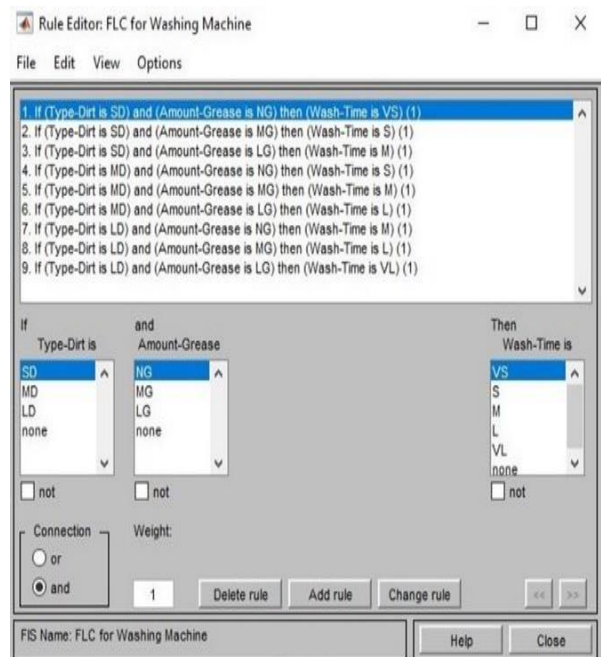

Fig. 6. Fuzzy base rules

Surface Plots

By applying three defuzzification methods like-COG, bisector, and MOM methods. We get the surface plots shown in Figs. 7 to 9 based on the above effectuation (Naaz et al., 2011).
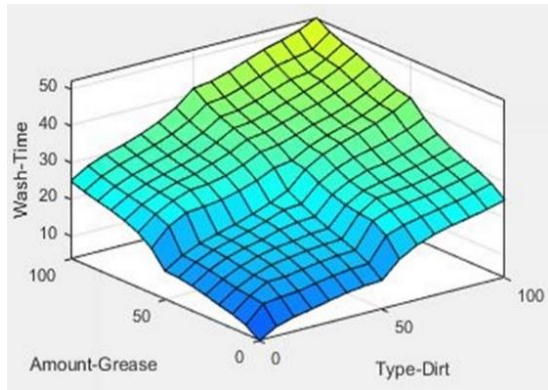

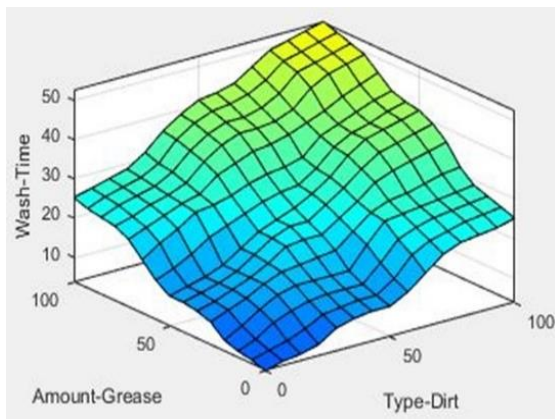**Fig. 7. Input/Output response surface for FLC using COG method**

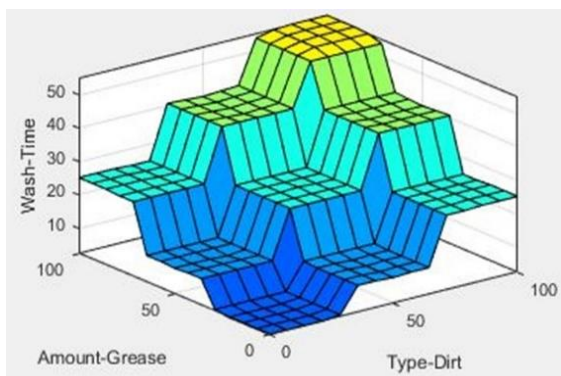**Fig. 8. Input/Output response surface for FLC using bisector method**

Fig. 9. Input/Output response surface for FLC using the MOM method

Result and Discussion

Based on the present degree of dirt and the present amount of grease on the clothes, it can be said that this method will have a different wash time. Here, a large number of values for dirt and grease can be used to evaluate the difference between these methods. Clearly, it can be said that these three techniques are shown in Table 3, which is used for comparison and provide wash time as an output. Hence, by using "If-Then" rules during the defuzzification of the washing machine, its output can be modified and verified simultaneously. Any amendment in the guidelines of the thumb base version would require you to alter the "If-Then" regulations to get the accurate output.

Table 3. Wash-Time output for varying input parameters

Type-Dirt (%)	Amount-Grease (%)	Wash-Time		
		COG	Bisector	MOM
25	40	18.3	16.8	10.5
30	50	19.7	19.2	11.1
40	60	27.8	27	24.9
50	50	25	25.2	25.2
60	70	34.9	35.4	40.8
70	90	41.6	43.2	53.4
90	40	33.9	37.2	40.5
80	50	35.9	37.8	40.2
60	20	25.4	22.8	10.5
40	30	19.2	19.2	11.1

Table 3 shows how the machine will respond to different situations. For example, if the type of dirt and the amount of grease are 60 and 70, respectively, according to the quality of the fabric, then the washing time for the models of COG, bisection, and MOM is equal to 34.30 minutes, 35.40 minutes, and 40.08 minutes respectively. It is quite believable and justifiable.

Mathematicians use the most effective triangular or trapezoidal fuzzy number in the models used to

locate the wash time of the washing machine. In our mathematical research, we have calculated the wash time using the Center of Gravity (COG), the Bisector, and the Mean of Maxima (MOM) models with the assistance of triangular and trapezoidal fuzzy numbers and mentioned their comparison.

The results in Figs 10 to 12 shows that when dirt and grease increase, the wash time of the washing machine for the COG method increases a bit slower than the bisector method and MOM method. Hence, if we use centroid, it will decrease the cost of electricity. So, it is more logical to use the COG method for our preferable
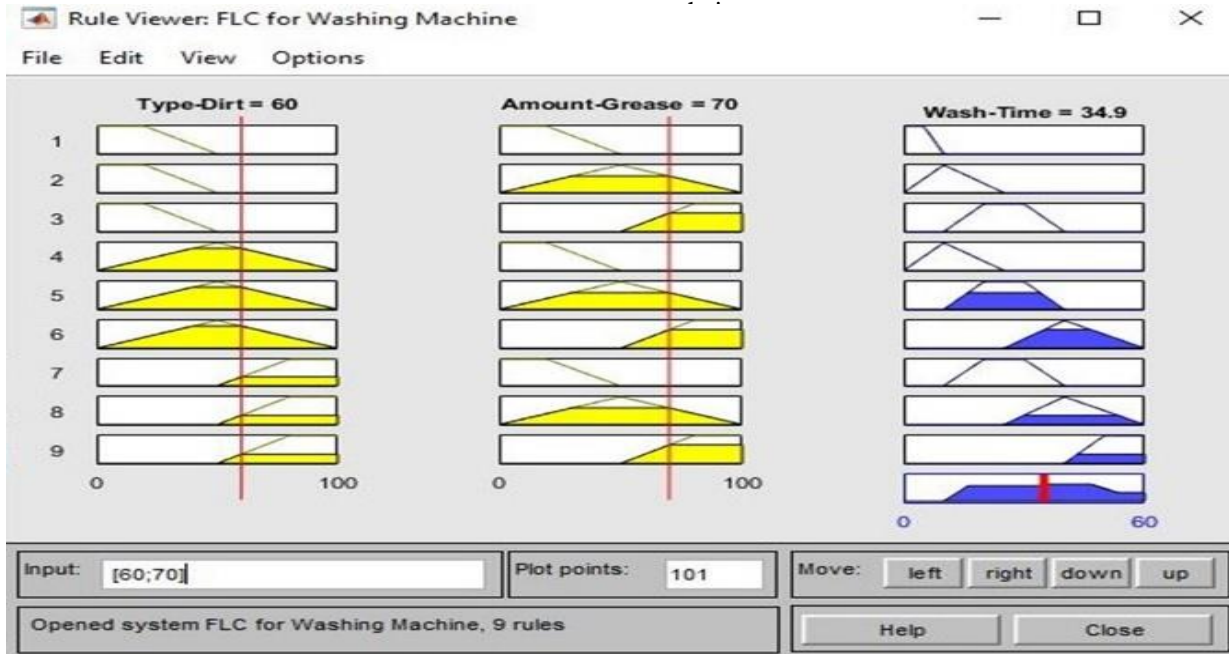

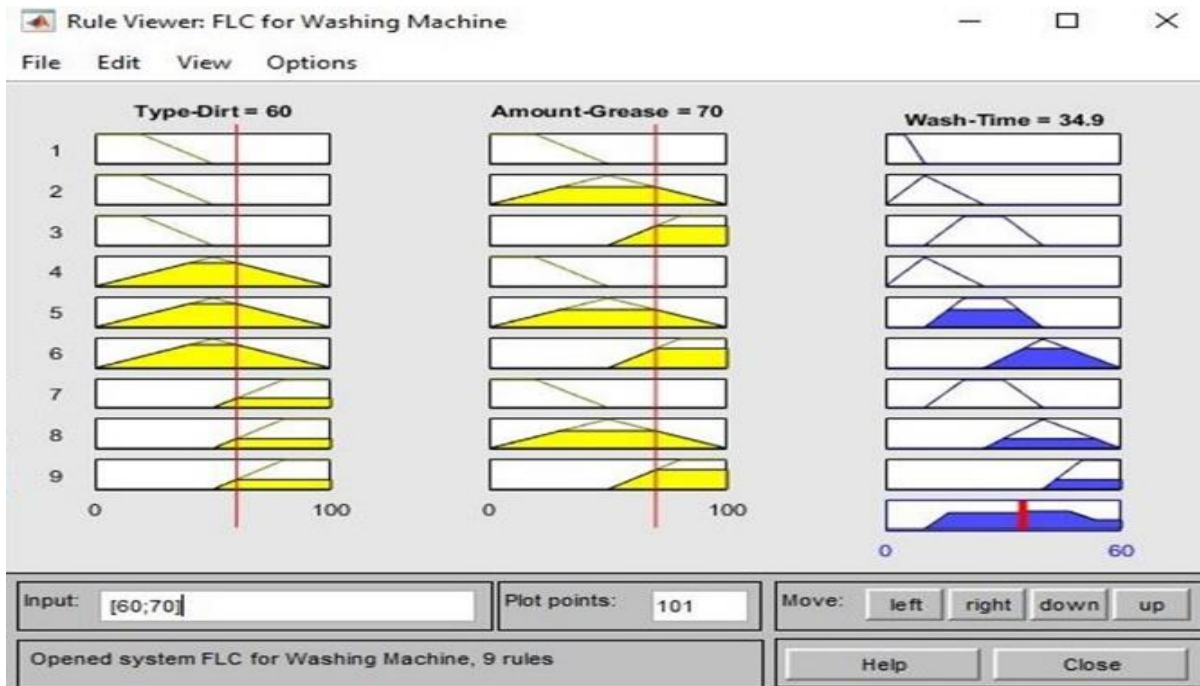**Fig. 10. Rule viewer of wash-time for FLC using the centroid method**

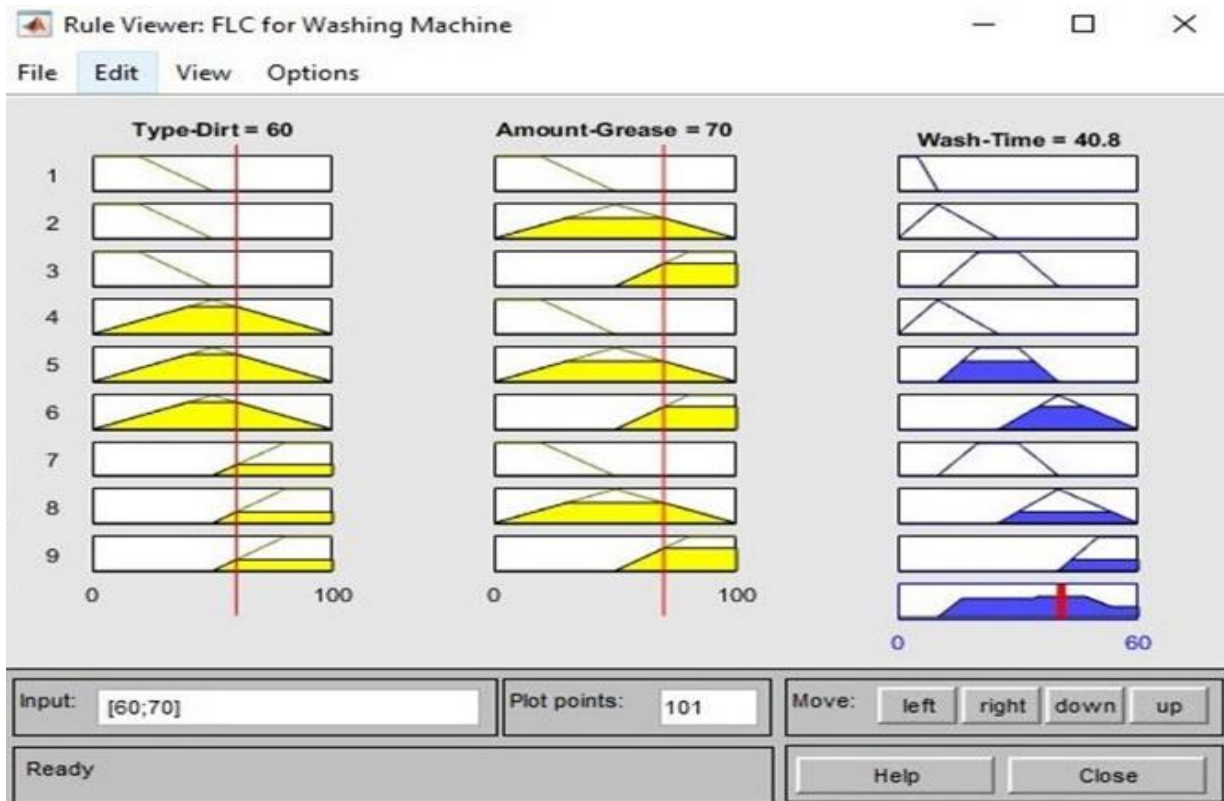**Fig. 11. Rule viewer of wash-time for FLC using the bisector method**

Fig. 12. Rule viewer of wash-time for FLC using the MOM method

The above work is done only mathematically using a Fuzzy Logic Controller. This model has not been used in the washing machine yet but has been successfully MATLAB simulated with the fuzzy toolbox. Hopefully, future researchers will get the same result if they use the above model in the washing machine.

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Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this article.

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