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Research Article

Fuzzy Controller for Optimization of Operation Time in Washing in Machine

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Abstract

The washing machine is one of the important home appliance. Most of today's common washing machines do not yet have smart features. Smart white goods have some decision-making functions instead of users. Smart washing machines can collect some data through their different sensors and use this data in appropriate actions. In this paper, it is aimed to suggest the most suitable program duration to the user and save energy, water and time by using a fuzzy controller system with three inputs and one output. Three different inputs are used; the dirt level of the laundry, the amount of oil and the amount of load. These input values can be obtained through related sensors. Washing time will be obtained as a single output. It is aimed to obtain optimum washing time by trying different methods in fuzzy controller. Two different types of fuzzification methods, triangular and trapezoidal, are applied as membership functions. As the fuzzy inference engine methods, product and minimum inference engine are used comparatively. This study also analyze the effects of the application of different defuzzification methods. We deployed five defuzzification methods: center of gravity, bisector, largest of maximum, smallest of maximum, and mean of maximum. The codes are written using Python programming language. For the evaluation, the results obtained from different methods were compared with each other. According to results, most suitable washing time can be obtained by using the methods of trapezoidal membership function for fuzzification, minimum inference engine and center of gravity for defuzzification.

Keywords: Fuzzy Controller, Inference Engine, Membership Function, Defuzzifier, Smart White Goods.

Çamaşır Makinesinde Çalışma Süresinin Optimizasyonu için Bulanık Kontrolör

Öz

Çamaşır makinesi önemli ev aletlerinden biridir. Günümüzün yaygın çamaşır makinelerinin çoğu henüz akıllı özelliklere sahip değildir. Akıllı beyaz eşyalar, kullanıcılar yerine bazı karar verme işlevlerine sahiptir. Akıllı çamaşır makineleri, farklı sensörleri aracılığıyla bazı veriler toplayabilir ve bu verileri uygun eylemlerde kullanabilir. Bu bildiride, üç girişli ve bir çıkışlı bir bulanık kontrol sistemi kullanılarak kullanıcıya en uygun program süresinin önerilmesi ve enerji, su ve zamandan tasarruf edilmesi amaçlanmaktadır. Çamaşırların kir seviyesi, yağ miktarı ve yük miktarı olacak şekilde üç farklı giriş kullanılmaktadır. Bu giriş değerleri ilgili sensörler aracılığıyla elde edilir. Yıkama süresi tek çıkış olarak elde edilecektir. Bulanık denetleyicide farklı yöntemler denenerek optimum yıkama süresinin elde edilmesi amaçlanmaktadır. Üyelik fonksiyonu olarak üçgen ve yamuk olmak üzere iki farklı bulanıklaştırma yöntemi uygulanmaktadır. Bulanık çıkarım motoru yöntemleri olarak çarpım ve minimum çıkarım motoru karşılaştırmalı olarak kullanılmıştır. Bu çalışma aynı zamanda farklı durulaştırma yöntemlerinin uygulanmasının etkilerini de analiz etmektedir. Ağırlık merkezi, açıortay, maksimumun en büyüğü, maksimumun en küçüğü ve maksimumun ortalaması olmak üzere beş farklı durulaştırma yöntemi kullanılmıştır. Kodlar Python programlama dili kullanılarak yazılmıştır. Değerlendirme için farklı yöntemlerden elde edilen sonuçlar birbirleriyle karşılaştırılmıştır. Sonuçlara göre, bulanıklaştırma için yamuk üyelik fonksiyonu, çıkarım motoru için minimum çıkarım motoru ve durulaştırma için ağırlık merkezi yöntemleri kullanılarak en uygun yıkama süresi elde edilmiştir.

Anahtar Kelimeler: Bulanık Kontrolör, Çıkarım Motoru, Üyelik Fonksiyonu, Durulaştırıcı, Akıllı Beyaz Eşyalar.

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1. Introduction

The washing machine saves people from the hassle of washing laundry and creates time for people to use it more efficiently. In a conventional washing machine, the user has to make settings such as program selection, time, spin and temperature [1].

On the smart washing machines, smart features enable users to think and make decisions instead. Smart machines collects some data through different sensors and uses this information in some operations. These machines offer many different features that make the user's job easier. Some of these features provide the user with a suitable program time by performing the necessary operations on the processor with the data collected by sensors such as turbidity sensor and load sensor [2].

Washing machine manufacturers produce machines with sensors that detect the type of laundry and the amount of dirt in order to better ensure the cleanliness of the laundry. The turbidity sensor used in washing machines may be a simple optical sensor that measures the amount of light that passes through a glass tube and can then be converted into electrical signals to estimate the amount of dirt [3].

The turbidity sensor sends a beam of light through the water and measures how much of it reaches the other side. The dirtier the water, the less light crosses. The turbidity sensor can also tell how oily the dirt is. The oily the laundry, the slower it will dissolve. If the light readings quickly reach a minimum, the dirt is low on oil. If the decline is slow, laundry has high oil. The machine may have also a load sensor that registers the volume of clothes. The more volume of the clothes, the more washing time is needed [4].

Washing machine users choose different programs and options on the machine while determining the washing time. These selections may not automatically adjust the washing time in the most accurate way according to the type of laundry, the type of soiling, the dirtiness of the laundry and the amount of laundry. This problem can be overcome with fully automatic washing machines based on fuzzy logic. It also offers performance, simplicity and less cost advantages [5].

Fuzzy Logic is the evaluation of mathematics as any input is converted into output for any problem based on the degree of truth. In the fuzzy control system, degree of truth differs from the classical method. While there are only true or false in the classical method; fuzzy logic gives the shades of truth and false in the same statement. Thus, more convenient results are offered to the user in the control system. This ensures that the controlled machine works at optimum values [2].

Fuzzy logic is a concept that allows computers to make decisions in a similar way to humans. It provides a simple way to arrive at a definitive conclusion based on input information such as vague, noisy, or incomplete [6].

In control systems there are two main types which are widely applied in the fields of engineering activities; these are proportional-integrated-derivative (PID) and fuzzy logic control systems (FLCSs) [20]. PID controllers are universally used in the control operations mechanism. However, it may show poor performance for nonlinear systems due to insufficient information about the parameters. The FLCS is an efficient model with several attributes such as reduced oscillations, better stability, smaller overshoot and faster settling time [7].

Fuzzy control is a control method based on fuzzy logic. Fuzzy logic can be defined as calculation with words instead of numbers, fuzzy control can be defined as control with sentences instead of equations. The Mamdani (linguistic) controller, which is usually used as a direct closed-loop controller, and the Takagi-Sugeno controller, which is typically used as a supervisory controller, are the most commonly used fuzzy logic controllers. Fuzzy controllers are used in consumer products such as washing machines, video cameras and rice cookers. It is also used to control industrial processes, including cement kilns, underground trains and robots [8].

Fuzzy control can be used for different purposes in washing machines. Different manufacturers collect data from the machine through different sensors and give the desired results without tiring the user. In these machines, more appropriate choices can be made than the choices made by the user. Systems that suggest the most suitable washing time for the laundry to be washed in the machine can be given as an example [9].

Making the washing time control of washing machines with fuzzy logic saves electricity and water resources. At the same time, it will also provide financial savings to the user in the commercial solutions offered in the market. The application areas of fuzzy logic controllers are more dynamic compared to traditional PID controllers [6].

Fuzzy Logic controllers are capable of solving problems in complex systems which can not be done by traditional PID controllers [10]. The structure of the Fuzzy Controller structure is shown in Figure (1).

The concept of fuzzy logic was first introduced by Professor Lotfi A. Zadeh University of California Berkeley in 1965 [11]. Fuzzy control did not receive much attention for a long time after it was first introduced. It was only in the 1990s that interest in fuzzy control increased due to the advertisements and successes of applications in Japanese consumer products such as washing machines and video cameras. After this increase in interest, contributions were made in conferences and control literature on fuzzy logic [12].

Fuzzy logic is a powerful design technology used to develop the control system and facilitate the implementation of complex systems [19]. Fuzzy Logic accepts input with varying degrees of accuracy and allows the system to be further developed over classical logic [13].

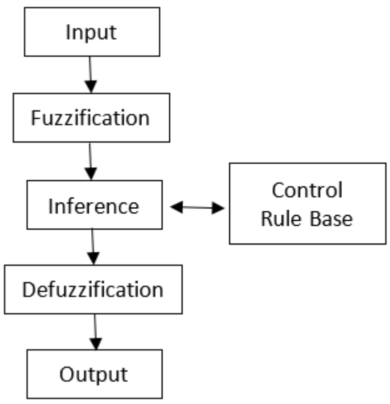

Figure 1. Fuzzy Controller structure [10]

A controller "Developed Control Microchip for Washing Machine" is proposed. FLC is created as 25 rules. There are three inputs as soil type, clothing type and soil level, and an output as washing time [14]. A fuzzy logic control for a two-input and one-output washing machine with a 9-rule fuzzy inference engine is presented in[15]. A Sugeno type FLC structure to achieve the controller output is provided in [16]. A FLC washing machine with two inputs which are the type of soiling and the degree of contamination, and the output of the system is the washing time is proposed in [17]. A fuzzy logic controller with three input and one output system in the washing machine is constructed in [18]. In the system there are 21 rules for FLC. The inputs are the type of soil, the type of clothing and the degree of soiling, and the output is the washing time [18].

In this study, it is aimed to find the most suitable program duration in the washing machine by comparing different methods of fuzzy control. Two different membership functions, triangular and trapezoidal, were compared. Two different inference engines, minimum and product, were compared. In addition, five different defuzzification methods were used; center of gravity, bisector, largest of maximum, smallest of maximum, and mean of maximum.

It has been observed that the combination of trapezoidal fuzzification, minimum inference engine and center of gravity defuzzification method gives the most suitable results for the washing time. By these methods, the system can provide the optimum value in the calculation of washing time. For this reason, it was decided to conduct a washing machine study that optimizes the fuzzy controlled washing time by using these methods.

This paper aims to design and simulate cycle time control system of a washing machine using fuzzy logic. It provides a fuzzy controller for a washing machine that processes the sensor inputs and produces optimized washing time.

Section 2 of the paper includes the design of the fuzzy controller and its parameters. The results obtained for different fuzzifiers, inference engines and defuzzifiers are presented in Section 3. The obtained results are discussed in Section 4 and Section 5 presents the best combination for design of the controller and future works.

2. Material and Method

The proposed Fuzzy Logic Controller for washing machine consists of three Linguistic Inputs i.e.

- Dirt level
- Oil Level
- Load Size

and one Linguistic output i.e.

- Washing Time.

In the fuzzy controller, different methods are used comparatively. Triangular and trapezoidal fuzzification methods are applied to obtain fuzzy values of crisp inputs. Minimum and product fuzzy inference engine methods are applied to obtain fuzzy output. Centroid, bisector, largest of maximum, smallest of maximum, and mean of maximum methods are used for defuzzification to obtain crisp value of fuzzy output. In Figure (2), the schematic of fuzzy logic controller for washing machine is represented.

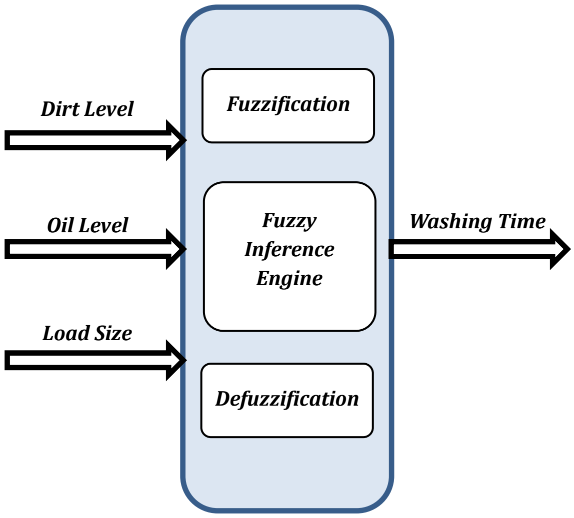

Figure 2. Fuzzy logic controller for washing machine

The process which converts crisp value in fuzzy value is known as fuzzification. Triangular and trapezoidal methods are used for the fuzzification. The triangular and trapezoidal forms were used to obtain the membership values from the input data. According to simulation results it is observed that better washing time can be obtained in the use of a trapezoidal membership function, compared to the use of a triangular membership function.

In Figure (3), the dirt levels of membership functions are represented in trapezoidal form. The dirt level is defined in the range of 0 to 100 percentage and has been classified into three sub levels (Low, Medium and High).

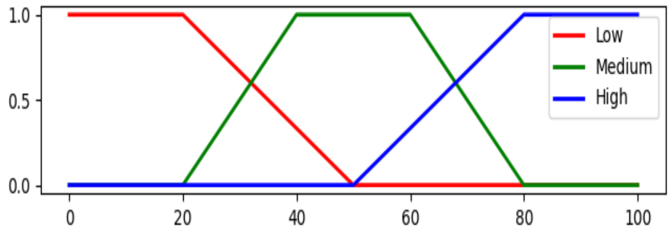

Figure 3. Dirt levels membership functions

In Figure (4), the oil levels of membership function graphs are shown. The oil dissolving time is defined in the range of 0 to 60 minutes and has been classified into three sub levels (Low, Medium and High).

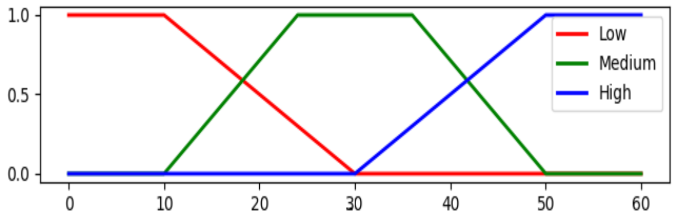

Figure 4. Oil levels membership functions

In Figure (5), the load size membership function graphs are shown. The load size level is defined in the range of 0 to 100 percentage and has been classified into two sub levels (Low and High).

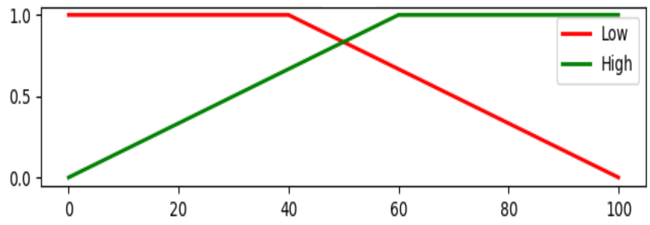

Figure 5. Load Sizes membership functions

The washing time is defined in the range from 0 to 120 minutes, based on the fuzzification of above mentioned inputs (dirt level, oil level, load size). Further, scaling has been done into five sub levels (Very Small, Small, Medium, Large, Very Large). The output is defined by the suzzy subsets as shown in Figure (6).

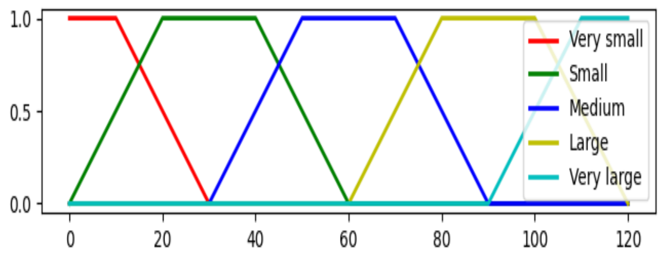

Figure 6. Washing time membership functions

Minimum and product fuzzy inference engine methods are applied for fuzzy control of the system. In minimum inference engine, individual-rule based inference with union combination, Mamdani's minimum implication and minimum for all the t-norm operators and maximum for all the s-norm operators are used. In product inference engine, individual-rule based inference with union combination, Mamdani's product implication and algebraic product for all the t-norm operators and maximum for all the s-norm operators are used. It has been observed that when the minimum inference engine is used, more suitable and advantageous washing times are obtained than the product inference engine

In order to find crisp output value from the fuzzy output; centroid, bisector, largest of maximum, smallest of maximum, and mean of maximum methods are used for defuzzification. When the defuzzification methods are compared, it is seen that the center of gravity defuzzification method gives values closer to the optimum than other methods. The order of the other defuzzification methods from better to worse is as follows: bisector, mean of maximum, smallest of maximum, largest of maximum.

3. Results and Discussion

To simulate the system, codes are written in Python programming language. By using minimum inference engine, the minimum value of the membership degrees of fuzzy propositions for each rule is determined. Then, the maximum values of the washing time outputs will give us the fuzzy outputs.

The decisions made by fuzzy logic controller are derived from the fuzzy rules. The 18 rules are formed using dirt level, oil level, and load size inputs and washing time output is discussed in terms of IF and THEN statements. Fuzzy linguistic input and output variables are shown in Table (1)

Table 1. Fuzzy linguistic input and output variables

Rule No:	IF			THEN
	Dirty	Oil	Load	Washing Time
1	LOW	LOW	LOW	VSMALL
2	LOW	LOW	HIGH	SMALL
3	LOW	MEDIUM	LOW	VSMALL
4	LOW	MEDIUM	HIGH	MEDIUM
5	LOW	HIGH	LOW	SMALL
6	LOW	HIGH	HIGH	LARGE
7	MEDIUM	LOW	LOW	SMALL
8	MEDIUM	LOW	HIGH	MEDIUM
9	MEDIUM	MEDIUM	LOW	SMALL
10	MEDIUM	MEDIUM	HIGH	MEDIUM
11	MEDIUM	HIGH	LOW	LARGE
12	MEDIUM	HIGH	HIGH	VLARGE
13	HIGH	LOW	LOW	LARGE
14	HIGH	LOW	HIGH	VLARGE
15	HIGH	MEDIUM	LOW	MEDIUM
16	HIGH	MEDIUM	HIGH	VLARGE
17	HIGH	HIGH	LOW	LARGE
18	HIGH	HIGH	HIGH	VLARGE

On the developed system, it is assumed that the crisp inputs are;

- Dirt level = 65%
- Oil dissolving time = 25 minutes
- Load Size = 50%

By using trapezoidal fuzzification formulas, the membership degrees of each level of inputs can be calculated. For our assumption, these values are shown in the Table (2).

Table 2. membership degrees of each level of inputs

Dirt level membership functions	Oil level membership functions	Load Size membership functions
$\mu'_{LD}(x) = 0$	$\mu'_{LO}(x) = 0.25$	$\mu'_{LL}(x) = 0.83$
$\mu'_{MD}(x) = 0.75$	$\mu'_{MO}(x) = 1.0$	$\mu'_{HL}(x) = 0.83$
$\mu'_{HD}(x) = 0.5$	$\mu'_{HD}(x) = 0$	

Table 3. Comparison of fuzzification methods

Inputs	*Dirt level [0-100]*	*0*	*10*	*20*	*30*	*40*	*50*	*60*	*70*	*80*	*90*	*100*
	Oil level [0-60]	*0*	*6*	*12*	*18*	*24*	*30*	*36*	*42*	*48*	*54*	*60*

	Load size [0-100]	0	10	20	30	40	50	60	70	80	90	100
Output	Using Trapezoidal Fuzzification Method	11	16	25	36	41	45	60	69	95	104	109
	Using Triangular Fuzzification Method	10	27	34	38	42	45	56	64	70	81	110

Fuzzy linguistic input and output variables and their membership degrees are shown in Table (2). As indicated in the table, except Very Small linguistic variable, all other variables have nonzero washing time membership value. The nonzero values for Medium, Large, and Very Large Washing Times shown in Table (3) are obtained from these comparison.

When the trapezoidal and triangular fuzzification methods are compared, it has been observed that trapezoid fuzzification results are more suitable for washing time output. In the Table (3), different output values are shown for each methods.

Table 4. Fuzzy linguistic input and output variables and their membership degrees

Rule No:	Dirt Level Membership Value:	Oil Level Membership Value:	Load Size Membership Value:	Washing Time Membership Value (Min of the Inputs):
1	Low: 0	Low: 0.25	Low: 0.83	V.small: 0
2	Low: 0	Low: 0.25	High: 0.83	Small: 0
3	Low: 0	Mid: 1.0	Low: 0.83	V.small: 0
4	Low: 0	Mid: 1.0	High: 0.83	Medium: 0
5	Low: 0	High: 0	Low: 0.83	Small: 0
6	Low: 0	High: 0	High: 0.83	Large: 0
7	Mid: 0.75	Low: 0.25	Low: 0.83	Small: 0.25
8	Mid: 0.75	Low: 0.25	High: 0.83	Medium: 0.25
9	Mid: 0.75	Mid: 1.0	Low: 0.83	Small: 0.75
10	Mid: 0.75	Mid: 1.0	High: 0.83	Medium: 0.75
11	Mid: 0.75	High: 0	Low: 0.83	Large: 0
12	Mid: 0.75	High: 0	High: 0.83	V. Large: 0
13	High: 0.5	Low: 0.25	Low: 0.83	Large: 0.25
14	High: 0.5	Low: 0.25	High: 0.83	V. Large: 0.25
15	High: 0.5	Mid: 1.0	Low: 0.83	Medium: 0.5
16	High: 0.5	Mid: 1.0	High: 0.83	V. Large: 0.5
17	High: 0.5	High: 0	Low: 0.83	Large: 0
18	High: 0.5	High: 0	High: 0.83	V. Large: 0

By finding maximum of each values of linguistic variable we obtain membership values of the fuzzy output as following;

$\mu_{VS}(x) = 0, \quad \mu_S(x) = 0.75, \quad \mu_M(x) = 0.75, \quad \mu_L(x) = 0.25, \quad \mu_{VL}(x) = 0.5.$

Table (4) shows the memebership degrees of the linguistic variables for inputs and output in each rule. Table (5) includes the degrees of membership functions for output obtained from the rules.

Table 5. Nonzero values of fuzzy output variables

Rule no:	THEN	Washing Time Membership Value:
7	Small	0.25
8	Medium	0.25
9	Small	0.75
10	Medium	0.75
13	Large	0.25
14	Very Large	0.25
15	Medium	0.5
16	Very Large	0.5

When the minimum and product inference engine methods are compared, it has been observed that minimum inference engine results are more suitable for washing time output. In the Table (6), different output values are shown for each methods.

The combination of membership funtions for fuzzy output linguistic variables is shown in the Figure (7).

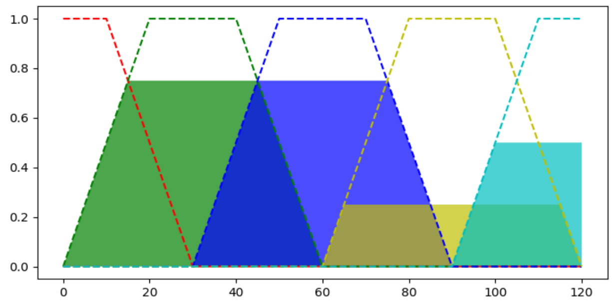

Figure 7. Gravity of each fuzzy outputs

By finding center of gravity of the output membership functions, we obtain crisp output value of washing time. The center of gravity graph is shown in Figure (8).

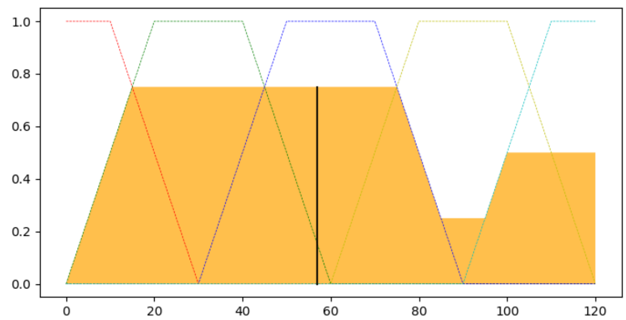

Figure 8. Center of gravity for defuzzification of fuzzy outputs

Table 6. Comparison of Inference Engine Methods

Inputs	*Dirt Level [0-100]*	*0*	*10*	*20*	*30*	*40*	*50*	*60*	*70*	*80*	*90*	*100*
	Oil Level [0-60]	*0*	*6*	*12*	*18*	*24*	*30*	*36*	*42*	*48*	*54*	*60*
	Load Size [0-100]	*0*	*10*	*20*	*30*	*40*	*50*	*60*	*70*	*80*	*90*	*100*
Output	*Using Minimum Inference Engine Method*	*11*	*16*	*25*	*36*	*41*	*45*	*60*	*69*	*95*	*104*	*109*
	Using Product Inference Engine Method	*11*	*13*	*17*	*27*	*39*	*45*	*61*	*87*	*103*	*107*	*109*

Table 7. Comparison of Defuzzification Methods

Inputs	*Dirt Level [0-100]*	*0*	*10*	*20*	*30*	*40*	*50*	*60*	*70*	*80*	*90*	*100*
	Oil Level [0-60]	*0*	*6*	*12*	*18*	*24*	*30*	*36*	*42*	*48*	*54*	*60*
	Load Size [0-100]	*0*	*10*	*20*	*30*	*40*	*50*	*60*	*70*	*80*	*90*	*100*
Output	*Using Center of Gravity Defuzzification*	*11*	*16*	*25*	*36*	*41*	*45*	*60*	*69*	*95*	*104*	*109*
	Using Mean of Maximum Defuzzification	*5*	*6*	*7*	*9*	*30*	*45*	*60*	*111*	*113*	*114*	*115*
	Using Bisector Defuzzification	*10*	*12*	*17*	*33*	*39*	*45*	*59*	*71*	*103*	*108*	*110*
	Using smallestof maximum Defuzzification	*0*	*0*	*0*	*0*	*18*	*15*	*48*	*102*	*106*	*108*	*110*
	Using largest of maximum Defuzzification	*10*	*12*	*14*	*18*	*42*	*75*	*72*	*120*	*120*	*120*	*120*

By using center of gravity defuzzification method the crisp output value is found 56 minutes as optimized washing time for fuzzy controlled washing machine.

In order to compare the defuzzification methods, we calculate the crisp output washing time value for different input values. The results are shown for each defuzzification method in the Table (7).

When the defuzzification methods are compared, it is seen that the center of gravity method gives more suitable output value than other methods.

4. Conclusions and Recommendations

In order to reach the optimum time in the washing machine, it has been seen that designing a fuzzy controller with trapezoidal membership function, minimum inference engine and center of gravity defuzzification can reach the most optimum time compared to other methods.

Fuzzy logic applications have become popular because they provide unlimited processing possibilities. This paper provides a fuzzy control method, allowing users to spend less time in the washing machine and use it more efficiently.

Using trapezoidal fuzzification, minimum fuzzy inference engine, center of gravity (CoG) defuzzification methods, it has been developed successfully a fuzzy washing machine with optimum washing time. Based on the successful conclusion of this study, it would be appropriate to use these methods in the fuzzy control of washing time calculations.

The number of input and out parameters and the number of rules can be increased to obtaine a better performance in controller design as a future work.

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