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Developing an Intelligent Washing Machine with a Fuzzy Logic Controller

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Abstract

Nowadays, washing technologies are extensively used in every household. The purpose of this work is to create and develop a fuzzy logic-based system for improving the intelligence of washing machines. In complex control systems, fuzzy logic is more effective when compared to traditional procedures. The fuzzy technique combines machine precision as well as human intelligence to produce an adequate base for the future washing program. The entire method relies on the idea of using fuzzy logic to transform non-precise sensor inputs into a precise number representing the washing duration. Furthermore, using fuzzy logic conserves water, laundry detergent, and power, as well as saving time, which is a significant element in lowering process expenses. To improve the system, this proposed study includes three output variables and six input variables. Moreover, this paper explains, depending on the color and fabric type of the cloth, how a certain type of detergent and water temperature will be applied to existing inputs such as dirt type, dirt degree, and cloth quantity. As a result, an improved fuzzy logic controller-based washing machine system must be built to accommodate the color of clothes and the type of detergent. This proposed Fuzzy Logic Controller (FLC) is simulated using MATLAB's fuzzy logic toolkit.

Keywords: Fuzzy Logic Controller, Fuzzy Rules, MATLAB, Surface Rule Viewer, Washing Machine.

Introduction

A washing machine is one of the most commonly used household appliances, which is mostly used in all houses across the world (1). Most machines, including computers and cell phones, have been automated as a result of technological breakthroughs and no longer require human intervention to work. A mathematical notion known as fuzzy logic has been studied by numerous scholars over a variety of disciplines and periods. Fuzzy logic has resulted in a significant transition. Money, time, and energy have all been saved as a result of the increased ease of applying fuzzy logic in various areas. Zadeh (2) introduced fuzzy logic which is currently being used to modernize a lot of household equipment to save money and time. Due to its rule-based framework, fuzzy has been recognized as the most appropriate methodology. Numerous household equipment, including air conditioners, vacuum cleaners, and washing machines, use the fuzzy logic concept (3). Fuzzy logic-based fully automatic washing machines afford performance, easiness, and cost reductions to address these concerns.

The most significant advantage that a laundry machine may provide is that it accumulates the work of brushing, agitating, and washing clothes (4). Professional and manual user interaction is required with traditional washing machines (5). The idea of fuzzy logic enables machines to reach decisions that reflect human actions. It offers a straightforward method for drawing a conclusive result from ambiguous, unclear, or incomplete input data (6). It is a form of logic that can distinguish between correct and incorrect values. Most individuals are unaware of how long laundry takes to eliminate filth. FLC-based household appliances that offer greater functionality, and efficiency, and are relatively inexpensive must be invented in a bid to solve these issues (7, 8).

An intelligent lighting controller using fuzzy logic was presented by Ain *et al.,* (9) to optimize the luminance set points within a smart house. For expressing and implementing rules, Habib and Akram (10) developed an intuitionist fuzzy inference framework. They employed the Takagi-Sugeno method for defuzzification. Additionally, they unveiled a washing machine with an adaptive intuitive fuzzy neural network that reduces the

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wash time. Ibrahim *et al.,* (11) suggested a hybrid grid solar PV/battery power source with a fuzzy logic controller incorporated energy management system for commercial loads. Using neural networks, Kaler along with Gupta (12) presented two distinct models—the fuzzy interference system and the adaptive fuzzy system—for the development of smart washing machines. To reduce the use of water, electrical power, and laundry detergent for washing machines, Dheerawat *et al.,* (13) constructed 36 Mamdani fuzzy logic rules in Python. With a focus on optimizing the machine's operating algorithm, Salau and Takele (14) demonstrated the conceptualization and modelling of an Arduino fuzzy logic-based laundry machine control framework. Using an intuitionistic fuzzy logic rule, Akram *et al.,* (15) optimized the wash time by controlling the type along with the degree of dirt. Additionally, for defuzzification, the authors employed the Takagi-Sugeno technique.

Saqlain and Tariq (16) suggested the input of water pH on automatic washing machine fabric type, dirt type, and water pH were the input factors while washing time was the output variable. One output and three inputs are used in Menon *et al.,*'s (17) logical technique to calculate the wash duration of washing machines. To further minimize the wash duration, the writers established 27 guidelines. Agarwal (18) explained how to determine the ideal washing time for various types of clothing. Riaz *et al.,* (19) established 576 rules for reducing the washing duration and validated their findings using the TOPSIS approach. Using unlabeled data, Abaei *et al.,* (20) utilized a fuzzy logic system of experts to forecast the likelihood of module faults. Agarwal *et al.,* (21) optimized the wash time, wash velocity, and temperature of the water using five inputs and five outputs. Demetgul *et al.,* (22) optimized washing machine performance by creating 81 rules with a total of four inputs and five outputs. To optimize washing time, the degree of water, detergent quantity, and velocity, Karrem and Ali (23) established ten rules with inputs and outputs. To determine the wash time for a laundry machine, Islam and Hossian (24) used several kinds of fuzzy figures and, upon comparison, produced a variety of conclusions. Raja and Ramathilagam (25) proposed a better washing machine design with three and five outputs such as washing length, temperature, dry-out duration, RPM, and wash performance. By preventing garments from being overloaded and modifying the quantity of water needed, Hungilo *et al.,* (26) maximize the service life of the washing machine. An FLC was proposed by Wulandari and Abdullah (27) for the design and simulation of a washing machine. This study calculated the value of washing speed and the durability of the motor speed of the washing machine based on various inputs. Nagarajan *et al.,* (28) achieved automation of detergent consumption through the use of an interval type-2 fuzzy logic control. Four distinct defuzzification techniques were employed to analyze stability, with the most effective approach being determined. Nahar *et al.,* (29) built an intelligent washing machine using a fuzzy synthetic assessment method.

Based on the previous discussions, we added a new variable called detergent type to our study which did not exist in the literature. Fabric concern and electricity conservation are the paper's main objectives. The main contribution of this paper is as follows:

- We have presented six input variables such as dirt type, dirt degree, cloth color, the quantity of cloth, fabric type, and detergent type, and the output variables are washing time, detergent amount, and water temperature.
- To prevent bleach, we utilized liquid detergent for dark-colored and delicate clothing, as well as a consistent water temperature for fabric care to avoid bleach.
- After loading, if a user selects a specified cloth color and fabric type, the washing machine will select a specific detergent type and water temperature for fabric care.
- For linguistic terms, there is no specified wash time, amount of detergent, or water temperature in the literature. The primary benefit of this study is that it provides a particular value for linguistic terms of input and output parameters.
- To optimize the system, we developed 236 fuzzy logic rules.
- We used MATLAB tool software to assess the effectiveness and implementation of a simulation model.

The remaining sections are arranged as follows: discussion about fuzzy logic is in section 2, the recommended washing machine design is in section 3, the findings and analysis are in section 4, and the conclusion is in part 5.

Fuzzy Logic

Fuzzy logic is an extension of regular logic in which each assertion has a truth value of one or zero. Fuzzy logic allows statements to have partial truth values of 0.9, 0.5, or 0.2. The goal of fuzzy logic is to solve problems by taking into account all pertinent information and, based on the input, determining the optimal solution. Heuristic techniques like fuzzy logic allow for more complex decision-tree processing and improve rules-based programming. Example: Fuzzy logic computes the shades of gray between black and white. Fuzzy logic can be used as a component within AI systems to handle uncertainty and imprecision in decision-making processes. AI systems can benefit from fuzzy logic's ability to model human reasoning in situations where precise rules are difficult to define. Fuzzy Logic, coupled with technologies like Natural language processing and Artificial Intelligence, can enhance the capabilities of systems.

Fuzzy Logic Controller (FLC)

Fuzzy control, as used in technical applications, describes algorithms or programs that use fuzzy logic to let machines make decisions that correspond to the real-world experience of a human operator. The basic challenge of automatic control is identifying the optimal response of the system or industrial unit to any given set of variables. Traditionally, control strategies rely on precise mathematical representations of the system, usually in the form of a collection of differential equations with a limited number of variables. On the other hand, fuzzy control just needs the practical expertise of a skilled operator and does not require a precise theoretical model.

Features of FLC

Fuzzy logic has the following features:

It provides a flexible and easy way to use machine learning technology.

- It allows us to simulate human reasoning intelligently.
- Artificial Intelligence uses fuzzy logic to disseminate elastic limitations through inference.
- Building nonlinear functions with any level of complexity is made possible by fuzzy logic.
- It is simple to adjust to improve or increase system performance.
- Nonlinear systems that could be difficult to manage mathematically can be controlled via fuzzy logic.

Methodology

Proposed Structure of Washing Machine

The suggested washing machine design is shown in this section. Developing a system with a fuzzy inference engine is an appropriate approach in this investigation. In the case of applying a fuzzy system to a washing machine, it is mandatory to assign the membership function to describe all input and output variables using linguistic terms. The usage of fuzzy logic washing machines is increasing. These devices provide the benefits of ease of use, efficiency, and performance. Sensors continuously check the machine's internal conditions and modify operations to achieve the best possible wash. A sensor monitors the clarity of the water in a washing machine to evaluate the dirtiness. This indicates that if the water is less transparent, then the dirtier the garments are. The dirt level is determined by how long it would take to reach the saturation point. The term "saturation" refers to when the color of the water no longer changes considerably. The following steps are required for this suggested fuzzy logic controller design. The necessary stages are diagrammatically represented in Figure 1. The suggested structure of a fuzzy logic-based washing machine has six linguistic inputs, as follows:

- Dirt Type
- Filth Degree
- Cloth Colour
- Quantity of Cloth
- Fabric type
- Detergent Type

These inputs provide three linguistic outputs as follows:

- Wash duration
- Detergent Amount
- Water temperature

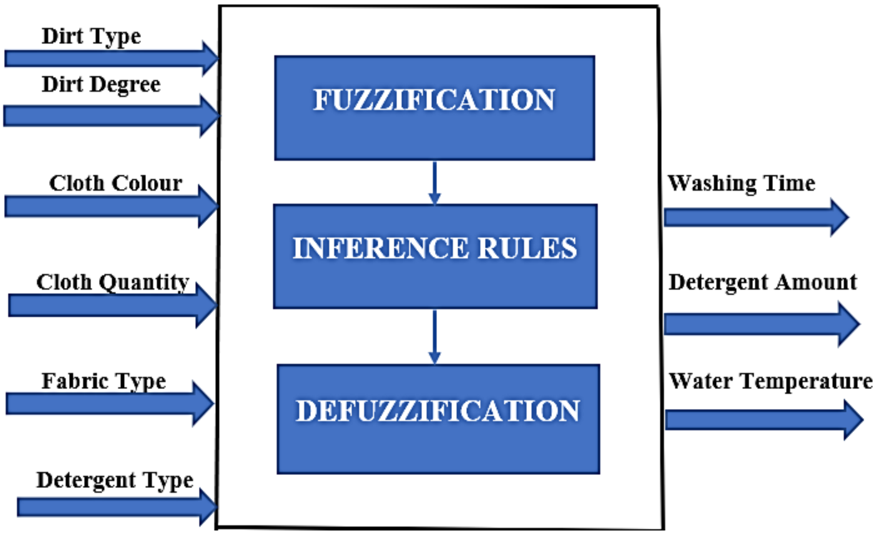

Figure 1: Proposed Design of Fuzzy Rule-Based System

Fuzzification of Input Variables

The process of changing a value of crisp into a value of fuzzy is named fuzzification, and to achieve fuzzification, a fuzzifier is used. The inputs and outputs are predetermined in terms of dealing with a fuzzy system controller. After converting the crisp input values to fuzzy values with a membership function, the relevant operation is applied. A triangular membership function (MF) is employed for all variables of inputs and outputs. The following Figure 2 to Figure 9 describe the membership function for each input and output variable.

Fuzzy Inference Rules

A process called inference involves concluding data already known. Inferencing is a crucial issue with expert systems. The inference engine outlines the method of developing a fuzzy logic-based matching from an input sequence set to a response. The mapping subsequently serves as a foundation for drawing conclusions and identifying patterns. Fuzzy logic controller decisions are based on fuzzy rules and the rules are made up of "If-Then" phrases. The fuzzy inference system manages the variables using fuzzy rules, which are a set of linguistic statements. The rule is implemented with the antecedent’s value and the consequent fuzzy set values as parameters to a fuzzy implication operator. Fuzzy rules are easy and simple to understand since it is in a natural or artificial language. To define the relationship between those input and output variables, a total of 236 rules have been established. The rules defined in this work are based on experience and from-home use. All possible input combinations and outputs are listed in Table 1 below.

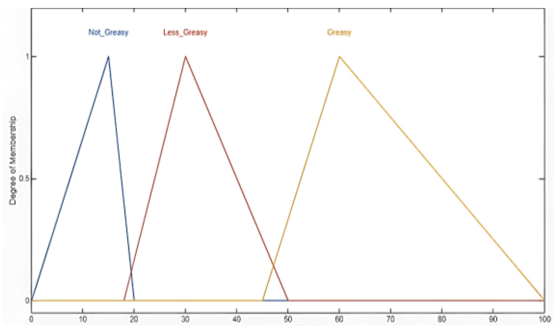

Figure 2: Fuzzy MF for Dirt Type

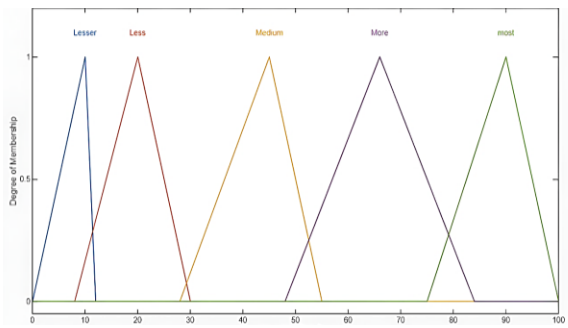

Figure 3: Fuzzy MF for Dirt Degree

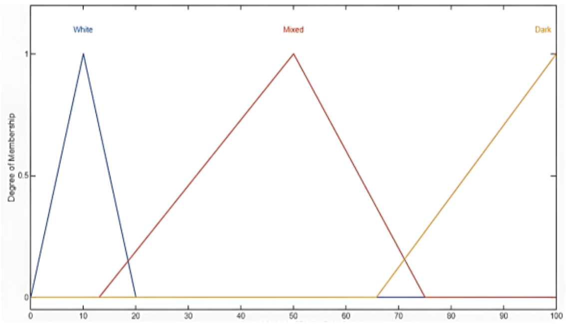

Figure 4: Fuzzy MF for Cloth Colour

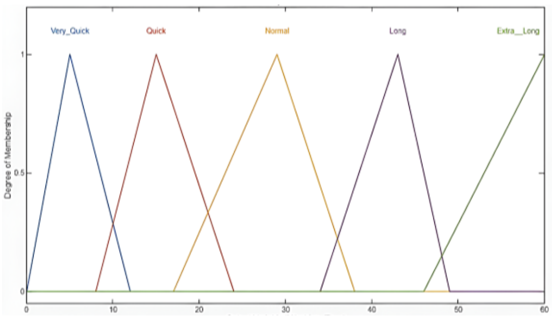

Figure 7: Fuzzy MF for Wash duration

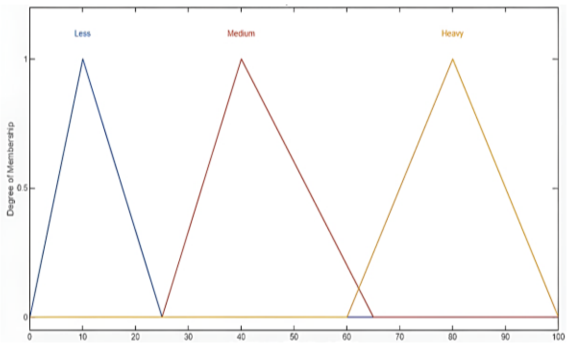

Figure 5: Fuzzy MF for Cloth Quantity

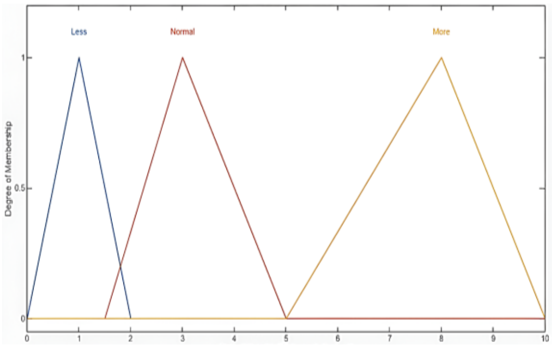

Figure 8: Fuzzy MF for Detergent Amount

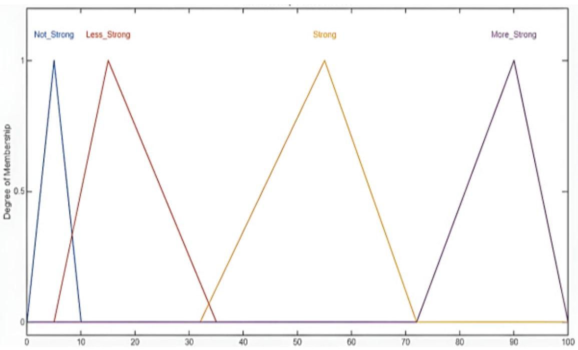

Figure 6: Fuzzy MF for Fabric Type

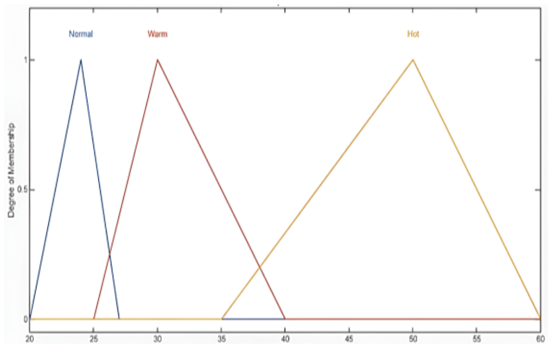

Figure 9: Fuzzy MF for Water Temperature

Table 1: Fuzzy Logic Rules

Fuzzy Rules	Linguistic Inputs						Linguistic Outputs		
	DIT	DD	FC	CQ	FQ	DET	WT	DA	WTE
1	NG	Lr	Wh	Mm	NS	T_1	VQ	Ls	N
2	NG	Lr	Wh	Hy	NS	T_1	VQ	Ls	N
3	NG	Lr	Wh	Mm	LS	T_1	VQ	Ls	N
4	NG	Lr	Wh	Hy	LS	T_2	VQ	Ls	N
5	NG	Lr	Wh	Mm	S	T_2	Q	N	N
6	NG	Lr	Wh	Hy	S	T_2	Q	N	N
7	NG	Lr	Wh	Mm	MS	T_2	Q	N	W
8	NG	Lr	Wh	Hy	MS	T_2	Q	N	W

9	NG	Lr	Wh	Mm	NS	T_1	VQ	Ls	N
10	NG	Lr	Wh	Hy	NS	T_1	VQ	Ls	N
...	...	...	...	...	...	...	...	...	...
234	G	Mt	D	Ls	MS	T_1	N	N	N
235	G	Mt	D	Mm	MS	T_1	L	Me	W
236	G	Mt	D	Hy	MS	T_1	EL	Me	W

Here T_1 represents liquid detergent for dark and delicate fabrics and T_2 represents powder detergent for white, mixed, and strong fabrics, DIT-Dirt Type, DD-Dirt Degree, FC- Fabric Colour, CQ- Cloth Quantity, DET-Detergent Type, WT- Washing Time, DA- Detergent Amount, WTE- Water Temperature, NG- Not Greasy, G- Greasy, Lr- Lesser, Mt- Most, Wh- White, D- Dark, Mm-Medium, Hy- Heavy, Ls-Less, NS- Not Strong, LS- Less Strong, MS- More Strong, VQ- Very Quick, Q- Quick, N- Normal, L- Long, EL- Extra Long, Me- More, W-Warm

Defuzzification

Defuzzification converts fuzzy values into crisp values. It is the inverse of the fuzzification process. The values received from the fuzzy inference rules are then utilized to form a computable outcome. In this study, the centroid method often referred to as the Centre of Gravity (COG), is applied to defuzzify the values of wash time, detergent amount, and water temperature. The formula for defuzzification is shown in equation [1]:

$$\underline{\dot{x}} = \frac{\int \dot{x}\mu_{\underline{G}}(\dot{x})\, d\dot{x}}{\int \mu_{\underline{G}}(\dot{x})\, d\dot{x}} \quad [1]$$

Results and Discussion

Based on Table 5, the suggested study appears to be better than the existing studies. The writers of the article (14) set their water temperature for clothes at 40 degrees Celsius, which is not suitable for their fabric types and colors. The design additionally requires more electricity. However, the proposed study has attained its optimal temperature for all types of fabrics and colors, as well as a minimal washing time. We can conclude that the suggested research achieves an ideal temperature to avoid bleach in darks, as well as appropriate detergent usage. Furthermore, the proposed study optimizes laundry time for filthy garments. Beyond that, the proposed system includes more inputs and regulations. Despite this, the suggested scheme requires the least amount of time to wash. The output values of washing time, detergent amount, and water temperature are shown in Tables 2, 3, and 4 for various inputs such as dirt type, dirt degree, and cloth colour. In this, we considered the linguistic term medium for dirt degree, cloth quantity, and fabric type. If the change occurs in the linguistic term, values of the output variables will fluctuate to the input variables. Therefore, the proposed study met its objectives. Figure 10 shows the surface view of the output variable washing time for two input variables of dirt type and dirt degree. Figure 11 shows the surface view of the output variable detergent amount for two input variables of dirt degree and cloth quantity. Figure 12 shows the surface view of the output variable water temperature for two input variables of cloth colour and fabric type.

Table 2: Washing Time for Different Dirt types

Dirt Type	Dirt Degree	Washing Time(O/P) in minutes
Not Greasy	Medium	15.9
Less Greasy	Medium	15.9
Greasy	Medium	30.4

Table 3: Detergent Amount for Different Dirt Degrees

Dirt Degree	Cloth Quantity	Detergent Amount(O/P) in units
Lesser	Medium	3.23
Less	Medium	3.68
Medium	Medium	4.72

More	Medium	5
Most	Medium	7.58

Table 4: Water Temperature for Different Cloth Colors

Cloth Color	Fabric Type	Water Temperature (O/P) in °C
White	Medium	40
Mixed	Medium	27.6
Dark	Medium	23.6

Table 5: Comparison with Existing Work

Authors	Rules defined	No. of inputs	No. of outputs	Detergent type	Water temperature °C	Washing time
(14)	9	2	1	-	40	9.26 minutes
(25)	27	3	5	-	48.3	28 minutes
(29)	10	3	1	-	-	24.775
Proposed	236	6	3	✓	27.6	15.9 minutes

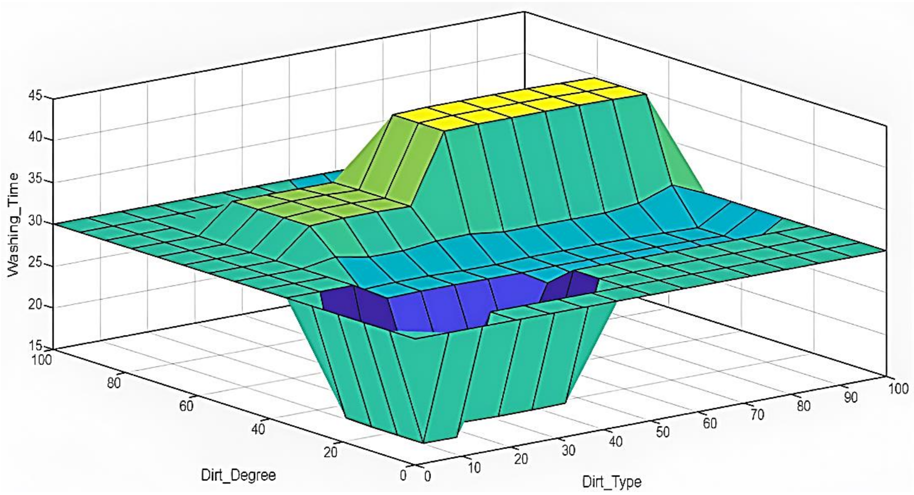

Figure 10: Surface View of the Relationship between Dirt Type, Dirt Degree, and Washing Time

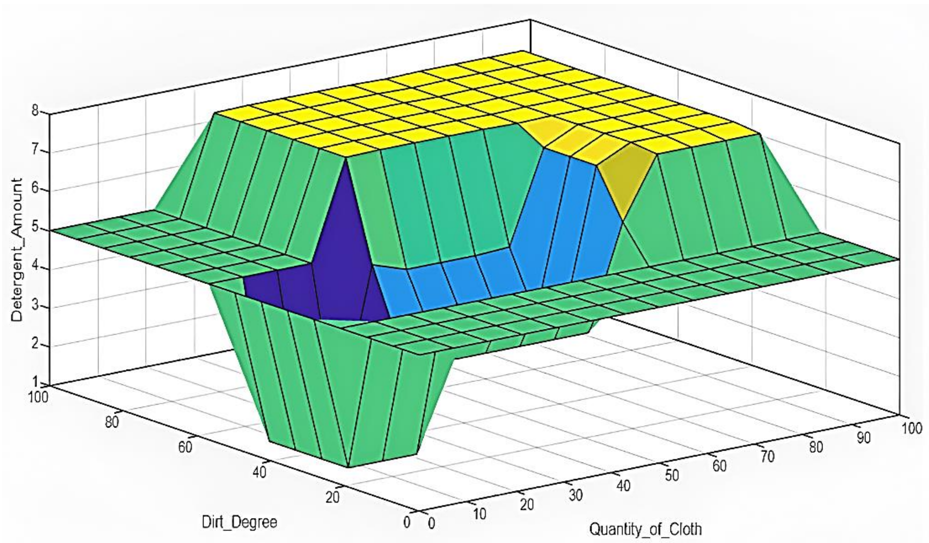

Figure 11: Surface View of the Relationship between Dirt Degree, Quantity of Cloth, and Detergent Amount

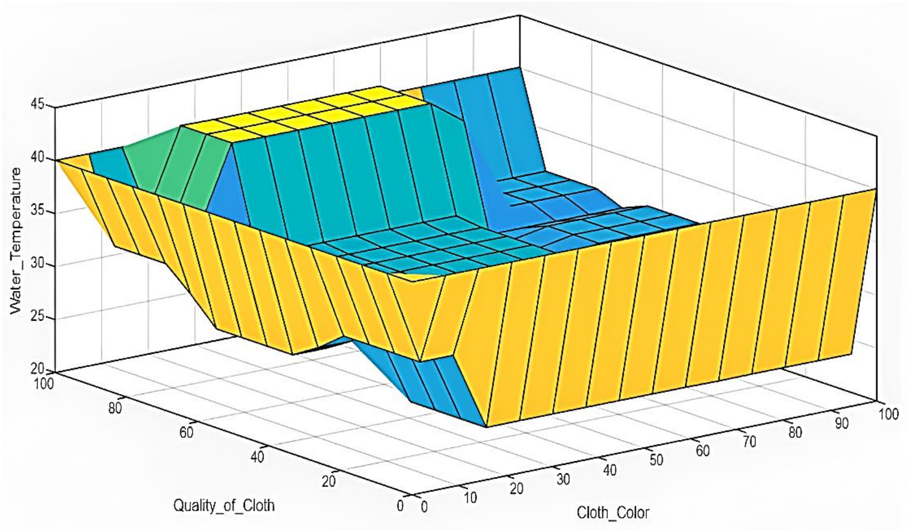

Figure 12: Surface View of the Relationship between Cloth Color, Cloth Quality, and Water Temperature

Benefits of FLC

- It is an easy-to-understand, robust system that doesn't require exact inputs.
- Numerous input formats, such as ambiguous, biased, or inaccurate data, can be handled by these systems.
- The feedback sensor can be reprogrammed to suit the circumstances if it stops functioning. System expenses can be reduced since these systems can handle inexpensive sensors.
- Since fewer data are needed to code the fuzzy logic methods, it doesn't require a lot of memory.
- The rules of these systems are modifiable, making them adaptable. Because of the flexibility of fuzzy logic, FLS may be more easily modified by simply adding or removing rules.
- Fuzzy controllers are real-time systems with experts that implement human experiences and expertise whereas PID cannot provide.
- To define any non-linear control system, one can use fuzzy controllers, which are heuristic modular controls. In PID, there is no such flexibility.
- With the help of a neural network and genetic algorithm, FLC can employ adequate system knowledge to utilize greater levels of automation and perform significantly better than any conventional controller.

Disadvantages of FLC

- Using fuzzy logic to solve an issue does not need the use of a single methodical technique. Consequently, numerous answers to a certain issue surface, creating uncertainty.
- For validation and verification, the systems need to be tested extensively.
- The rules of a fuzzy logic control system must be up-to-date.

Conclusion

Implementing a fuzzy approach to washing machines can greatly enhance automated efficiency also minimize electricity, water, and consumption of time in the laundry. It is observed that by applying fuzzy inference system technologies, an automated washing machine is simple to create. This improves the washing machine's intelligence and more reliable. The paper was carried out using the MATLAB/Fuzzy logic toolbox. The result of this study shows, how a washing machine reacts to various conditions. Moreover, in this proposed work if a user selects a specified cloth color and fabric type, the washing machine will select a specific detergent type and water temperature to avoid bleach of fabrics. By lowering the amount and temperature of water, detergent, and laundry time, the study demonstrates that the proposed fuzzy controller increases the washing machine's work efficiency. For instance, if all input variables are set to 50, then the washing duration will be 30.4 minutes. This would be very appealing and practical. It can be put into practice by applying mechanical and electronic engineering techniques. This work can also be extended in the future to create various output variables, such as rinse time and spin cycle.

Abbreviations

Nil.

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Author Contributions
K. Hemalatha: Conceptualization, Methodology, Investigation, Writing – original draft; Venkateswarlu. B: Supervision, Validation.

Conflict of interest
The authors of this paper declare that there are no competing interests.

Ethics Approval
Not applicable.

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