Washing Machine Control Using Fuzzy Logic

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Abstract

Fuzzy logic allows developers to more efficiently control complex systems than traditional methods. It offers an easy way for unclear, imprecise or noisy data to reach a definite conclusion. I have suggested in this document the design of a fuzzy logic controller with two inputs to give the washing machine the right wash time. The goal is to save a lot of time, power and water during the washing of different cloths. This paper defines the operation that can be used to give various types of cloths an appropriate washing time. The method is completely based on the concept of taking non-precise inputs from sensors and applying fuzzy logic to achieve a crisp washing time value.

Keywords: fuzzy logic, wash time, Mamdani Inference System, Triangular MF, Centre of Gravity

1. Introduction

Fuzzy logic is a type of multi-evaluated logic in which variable truth values can be any real number between 0 and 1 inclusive. It is used to handle the concept of partial truth, where the value of truth can vary between totally true and totally false [1]. In Boolean logic on the other hand, the value of truth of variables can be only integer values 0 or 1. The term fuzzy logic was introduced with Lotfi Zadeh's 1965 proposal for fuzzy set theory [2]. It is based on the observation that people make decisions based on imprecise and non-numerical information, fuzzy models or sets are mathematical means of representing vagueness and imprecise information, hence the term fuzzy. These models have the capability of recognizing, representing, manipulating, interpreting, and utilizing data and information that are vague and lack certainty.

In Japan, many of the early effective Fuzzy logic apps have been introduced. The first remarkable implementation was on the Sendai subway train, where fuzzy logic was able to enhance the ride's economy, convenience, and accuracy [3]. It was also used to recognize hand-written symbols in Sony pocket computers, flight aid for helicopters, control of subway systems to enhance driving comfort, accuracy of stopping and energy economy, enhanced fuel consumption for cars and automatic motor control for vacuum cleaners with surface condition recognition and degradation.

Fuzzy logic can also be used to control different aspects of a washing machine [4] [5]. When using a washing machine, people usually select the duration of the wash based on their estimation of the amount of clothes to wash, the type of dirt and the degree of dirtiness of the clothes. This estimation is made generally on the basis of trial and error methods. We can use sensors to detect these parameters (i.e. clothing volume, degree and type of dirt) to automate this process. From this information, the wash time can then be determined.

Unfortunately, there is no easy way to formulate an accurate mathematical relationship between the volume of clothes and dirt and the time required for washing. This is why a washing machines controller design in the past has not loaned itself to traditional control design methods. Using fuzzy logic, it is possible to tackle this design issue. Fuzzy logic is used because a fuzzy logic regulated washing machine controller provides the right washing time even though there is no precise model of the input / output relationship.

2. Principles of Washing Machines

Inside a washing machine, there are many components which work together to help wash the clothes [6]. These components are water inlet control valve, water pump, tube (washer drum), agitator, motor, door safety sensor, detergent drawer, drain pipe, controller, mechanical programmer. There is also a component called the wash sensor or optical sensor. An optical sensor is a device that converts light rays into electronic signals. It measures the physical quantity of light and translates it into a form read by the instrument. The features of an optical sensor are its ability to measure the changes from one or more light beams. A washing machine includes an optical sensor for detecting a light permeability of detergent solution and rinse water in a washer tank. The optical sensor includes a light emitting element and a light receiving element. The optical sensor is responsible for collecting the data about different aspects of the clothes like the type of dirt and the degree of dirtiness.

- **Degree of dirt** is determined by the transparency of the wash water. The dirtier the clothes, less transparent the water being analyzed by the sensors is.
- **Type of dirt** determines the quality of dirt. Greasy cloths for example take longer for water to reach full transparency because grease is less soluble in water than other forms of dirt. Type of dirt is determined by the time of saturation.

In my research, i am not concerned with the workings of the optical sensor. I am assuming that i will have the inputs for my fuzzy controller available from the optical sensor.

3. Proposed Design

The proposed Fuzzy Logic Controller for washing machine consists of 3 variables. Among the 3 variables, 2 of them are input variables and 1 is the output variable. Input variables are type of dirt and the degree of dirtiness the clothes have. One output variable is wash time. The uncertainty that is captured using fuzzy logic for the variables are:

- **Type of dirt**: "Not Greasy", "Moderately Greasy", "Extremely Greasy"
- **Degree of dirt**: "Low", "Medium", "High
- **Wash time**: "Very Short", "Short", "Medium", "Long", "Very Long"

So for the type of dirt, it is difficult to say that if the dirt is moderately greasy, extremely greasy or not greasy at all. For degree of dirt, it is difficult to say that if the degree/amount of dirt is considered to be low, medium or high. It is not possible to put any fixed boundaries. Using fuzzy logic, the boundaries can be made "fuzzy." Something that is not in or out, for example. It sits somewhere on the continuum between in and out. Hence fuzzy logic allows us to model this uncertainty by determining an interval using fuzzy sets.

The proposed Fuzzy Logic Controller inference engine is designed using 9 rules for Wash Time. The rules formed in this research are derived mostly from references taken from the internet [5][6]. Some of the rules are also defined using common sense. Every Linguistic inputs and outputs has a set of membership functions (MF). Triangular membership function is used for all the variables. The mathematical representation of the triangular function is shown below:

$$f(x;a,b,c) = \begin{cases} 0, & \text{if } x \leq a \\ \frac{x-a}{b-a}, & \text{if } a \leq x \leq b \\ \frac{c-x}{c-b}, & \text{if } b \leq x \leq c \\ 0, & \text{if } c \leq x \end{cases} \tag{1}$$

The graphical representation of the triangular membership function is much easier to understand compared to the mathematical representation. For example if we set $a = 3$, $b = 6$ and $c = 8$, we get the following graph:

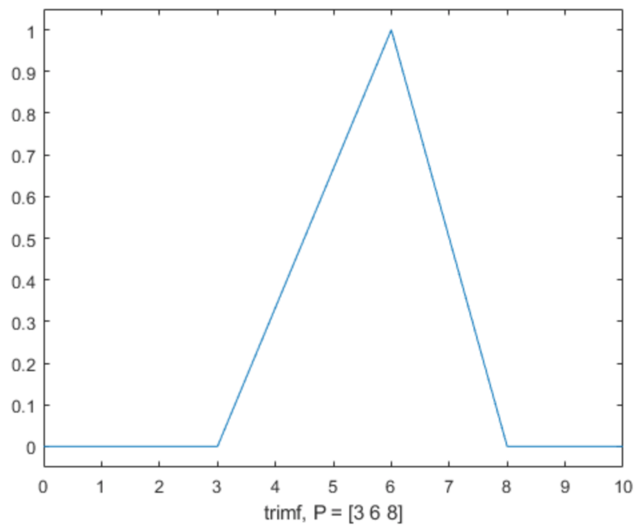

Figure 1: Triangular membership function ($a = 3$, $b = 6$, $c = 8$)

The X-axis of the input variable's MF graphs represents the values which are obtained from the sensors and it ranges from 0 to 100 in my research. The X-axis of the output variables MF graph ranges from 0 to 60 in my research. The Y-axis of all the MF graphs denotes the degree of the membership function which ranges from 0 to 1. The fuzzy inference system that is being used in this research is known as the "Mamdani-style fuzzy inference". The Mamdani-style fuzzy inference process is performed in four steps: 1) Fuzzification of the input variables, 2) Rule evaluation 3) Aggregation of the rule outputs, and finally 4) Defuzzification.

3.0.1. Fuzzification

Let "type of dirt" input variable be represented as x and "degree of dirtiness" input variable be represented as y. In the fuzzification process, the crisp inputs x and y (these values are assumed to be available from the sensor inside the washing machine) are applied to the MF's of each of the appropriate fuzzy set to determine the degree of membership. For input variable x, the fuzzy sets are "Not Greasy", "Moderately Greasy" and "Extremely Greasy". For input variable y, the fuzzy sets are "Low", "Medium" and "High". The following graphs show the membership function used for each fuzzy set:

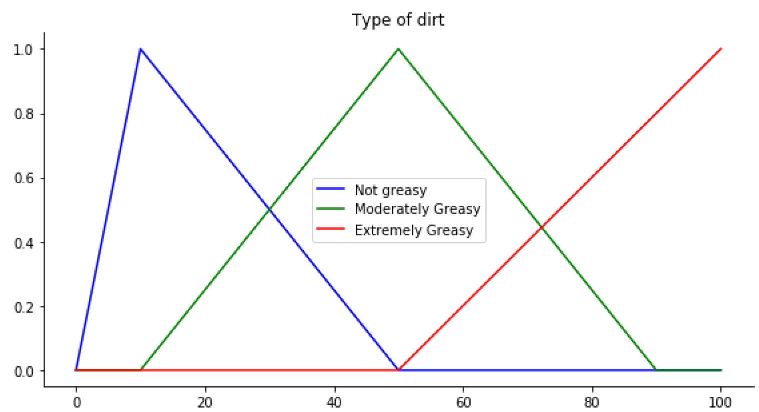

Figure 2: Type of Dirt

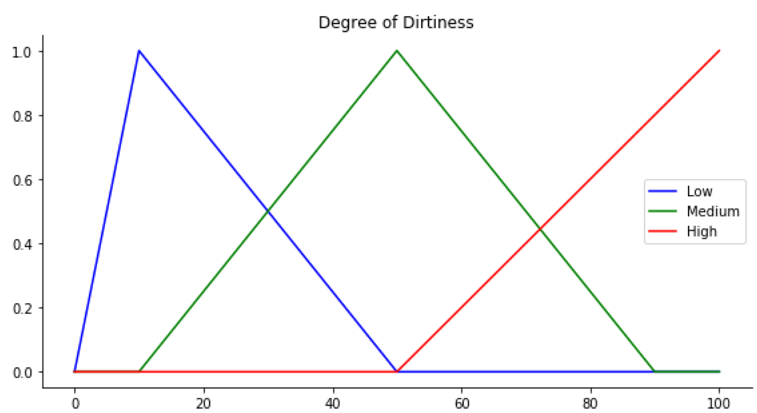

Figure 3: Degree of Dirtiness

So the input variable x is first applied to each of the membership functions of the fuzzy sets "Not Greasy", "Moderately Greasy" and "Extremely Greasy" to output the degree values α_1, α_2 and α_3. Then the input variable y is applied to each of the membership functions of the fuzzy sets "Low", "Medium" and "High" to output the degree values β_1, β_2 and β_3.

3.0.2. Rule Evaluation

Before discussing what happens in the rule evaluation process, the rules that are used for the fuzzy logic controller of the washing machine are shown as a table below:

Rule Number	*Linguistic Input*		*Linguistic Output*
	Type of Dirt	**Degree of Dirtiness**	**Wash Time**
1	Not Greasy	Low	Very Short
2	Not Greasy	Medium	Short
3	Not Greasy	High	Medium
4	Moderately Greasy	Low	Medium
5	Moderately Greasy	Medium	Long
6	Moderately Greasy	High	Long
7	Extremely Greasy	Low	Medium
8	Extremely Greasy	Medium	Long
9	Extremely Greasy	High	Very Long

Table 1: Rules used for the Fuzzy Logic Controller

The rules shown in the above Table can be read in terms of IF and THEN statements and each of the rules have exactly 2 antecedents which are joined using the AND operator. The rules expressed as IF and THEN form are shown below.

Rule 1:
IF (Type of Dirt is Not Greasy) and (Degree of Dirtiness is Low) THEN (Wash time is Very Short)
Rule 2:
IF (Type of Dirt is Not Greasy) and (Degree of Dirtiness is Medium) THEN (Wash time is Short)
....

Rule 9:

IF (Type of Dirt is Extremely Greasy) and (Degree of Dirtiness is High) THEN (Wash time is Very Long)

In the rule evaluation process, the fuzzified inputs α_1, α_2, α_3, β_1, β_2 and β_3 are applied to the antecedents of the fuzzy rules. As there are multiple antecedents for each rule, the fuzzy operator (AND) is used to obtain a single number that represents the result of the antecedent evaluation. The fuzzy operator AND outputs a single number which actually is the minimum of all the fuzzified inputs for each rule. This single number (the truth value) is then applied to the consequent membership function of the wash time output variable. The following graph shows the membership function used for each fuzzy set of the wash time output variable:

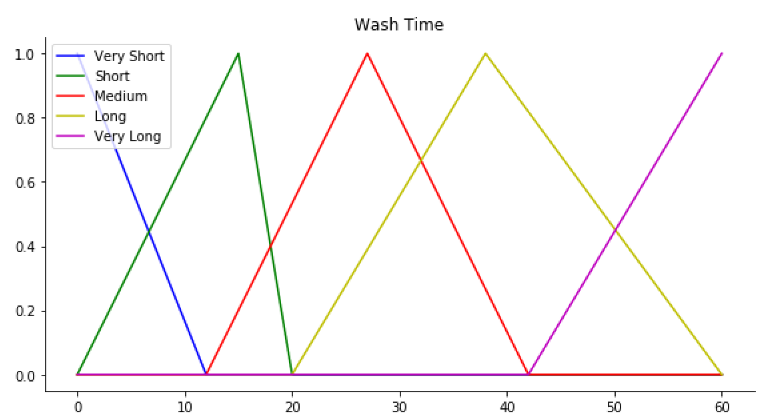

Figure 4: Wash time

To correlate the rule consequent with the truth value of the rule antecedent, the clipping method is used. In this method, consequent membership function is cut at the level of the antecedent truth. Since the top of the membership function is sliced, the clipped fuzzy set loses some information. However, clipping is still often preferred because it involves less complex and faster mathematics, and generates an aggregated output surface that is easier to defuzzify. The graphical representation below shows an example of a trapezoidal fuzzy membership function for a fuzzy set C2 which is clipped at the degree value of 0.2:

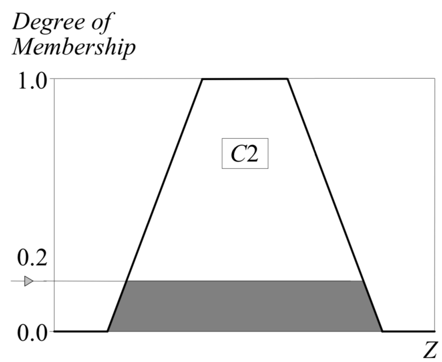

Figure 5: Clipping Method

3.0.3. Aggregation of the rule outputs

In this process, outputs of all the rules are combined together. Membership functions of all the 9 rule consequents previously clipped are combined into a single fuzzy set. The graphical representation below shows an example of aggregation where outputs from 3 rules are combined together into a single fuzzy set. Note this is just an example to demonstrate the process of aggregation and does not represent the output from my research:

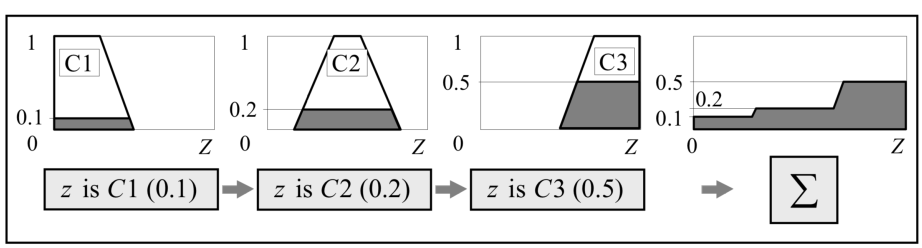

Figure 6: Aggregation of MF's of rule consequents

3.0.4. Defuzzification

The last step in the fuzzy inference process is defuzzification. Fuzziness helps us to evaluate the rules, but the final output of a fuzzy system has to be a crisp number. The input for the defuzzification process is the aggregate output fuzzy set and the output is a single number. This output basically represents the wash time in my research. There are several defuzzification methods, but centroid technique is used in this research. It finds the point where a vertical line would slice the aggregate set into two equal masses. Mathematically this centre of gravity (COG) can be expressed as:

$$COG = \frac{\int_a^b \mu_A(x)x \ dx}{\int_a^b \mu_A(x)dx} \tag{1}$$

This equation basically finds a point representing the centre of gravity of the fuzzy set, A, on the interval, ab. The graphical representation below shows an example of the center of gravity calculation of an aggregated fuzzy set:

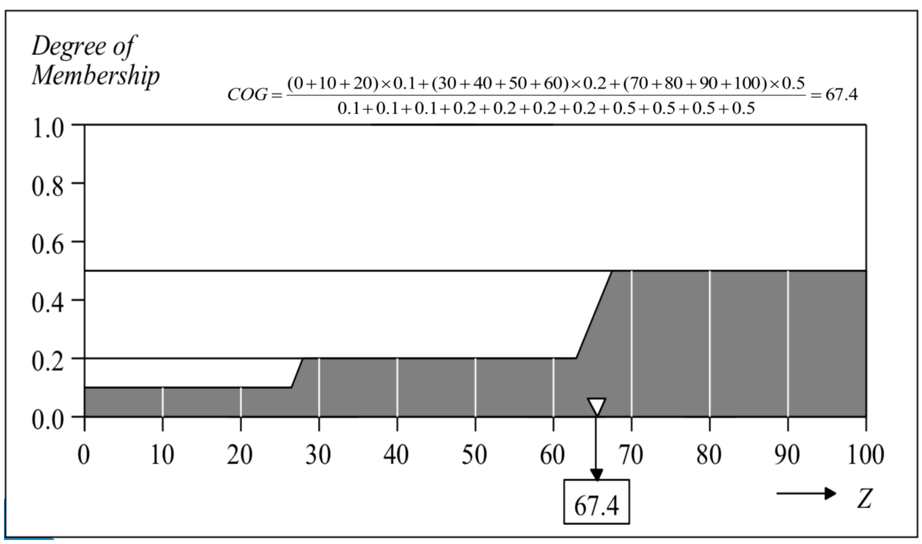

Figure 7: Calculation of COG

4. Results and discussion

Using four example inputs, i have tested out my fuzzy logic controller for washing machine. Inputs used are:

1. (Type of dirt, Degree of Dirtiness) = (5,5)
2. (Type of dirt, Degree of Dirtiness) = (35,35)
3. (Type of dirt, Degree of Dirtiness) = (65,65)
4. (Type of dirt, Degree of Dirtiness) = (90,90)

Each of the inputs are processed using the Mamdani Fuzzy Inference system as described in the previous section. The outputs for each of the set of inputs are shown below:

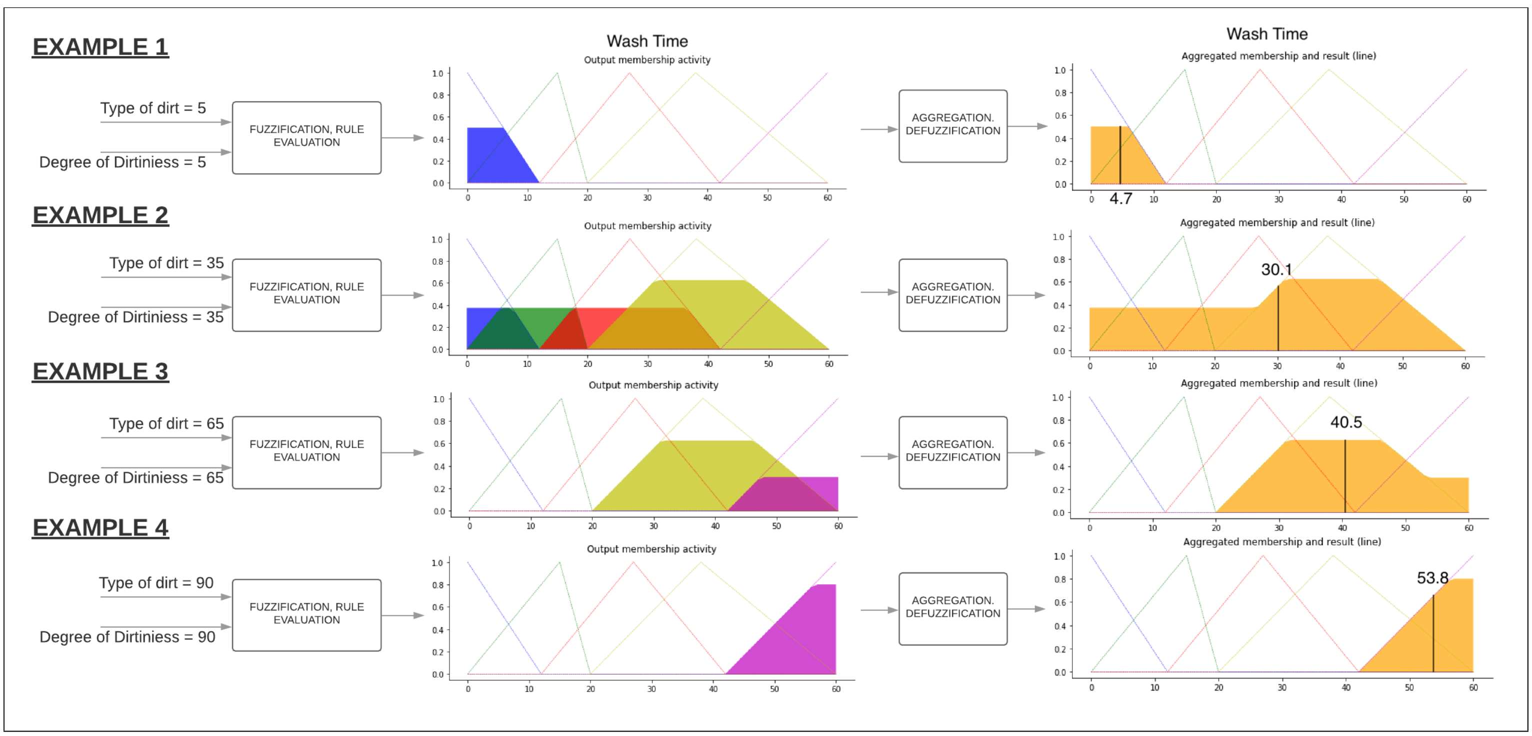

Figure 8: Example outputs for different input combinations

As seen from the above graph, each pair of inputs are first fuzzified and then the fuzzified inputs are evaluated using the 9 rules. The activations that occur for each fuzzy set for the output variable wash time are also shown in the figure. After the rule evaluation stage, the individual fuzzy sets are aggregated and finally defuzzified using the centroid method. A vertical line is used to slice the aggregate set into two equal masses and denote the crisp value of wash time. Increasing both the input values of "Type of dirt" and "Degree of Dirtiness" for each subsequent input, it is seen that there is an increase in the wash time. For example 1 to example 2, there is seen an increase in wash time of 25.4. This increase is quite logical because as the clothes become more dirty, the clothes need to be washed more to get rid of the dirt. In example 1, the wash time is seen to be the shortest (4.7) because the "type of dirt" and "degree of dirtiness" is the lowest. In contrast, the wash time in example 4 is the highest (53.8) because the "type of dirt" and "degree of dirtiness" is the highest.

There are many advantages of using fuzzy logic controllers over conventional controllers in washing machines and in general also. Firstly, fuzzy logic regulated washing machine controller provides the right washing time even though there is no precise model of the input / output relationship. Secondly, the fuzzy logic system is very flexible. We can easily modify the rules if we want, we can add more rules also whenever needed. Even imprecise, distorted and error input information is also accepted by the system. Also as it uses if-then rules, it is very easy for humans to understand and also analogous to how human think and reason. This leads to a very convenient end-user interface where it is easier for an end-user interpretation even when the final user is not a control engineer. Fuzzy logic controller's are also cheaper to develop. But I think the biggest advantage of fuzzy logic is that it can model uncertainty. Fuzzy logic provides a systematic framework for dealing with fuzzy quantifiers, e.g., most, many, few, not very many, almost all, infrequently, about 0.8, etc. In this way, fuzzy logic subsumes both predicate logic and probability theory, and makes it possible to deal with different types of uncertainty within a single conceptual framework.

In this research, only two input parameters are used to predict the crisp value of wash time. But in reality, the wash time depends on many more factors. One of the factors is mass of clothes put inside the washing machine. In general, the washing time should increase with more amount clothes in the washing machine. Also the interval that is defined for each fuzzy set in this research are taken from few references from the web. Furthermore, different references have different intervals defined. So to tackle this issue, we could use type-2 fuzzy set which lets us incorporate uncertainty about the membership function into fuzzy set theory. Alternatively, we can use a neuro-fuzzy approach where neural networks can be used to automatically find the appropriate interval range and the fuzzy rules assuming we have enough data available. The aforementioned points are basically the limitations of my research and similarly are the future research directions to be explored.

5. Conclusion

In this paper, a fuzzy logic system is developed for washing machines which can help improve automation systems in washing machines and reduce electricity, water and time consumption. Based on the "type of dirt" and "degree of dirtiness" input parameters which are assumed to be collected from the sensors, the appropriate washing time can be determined. System was tested with increasing values of both the input parameters and the wash time was seen to increase as both "type of dirt" and "degree of dirtiness" increases. As mentioned earlier, this increase is quite logical because as the clothes become more dirty, the clothes need to be washed more to get rid of the dirt. Hence, using a fuzzy logic system is easier to implement into complex systems than using conventional controls.

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