Fuzzy logic CISC 490/870

Final project report

The Fuzzy Decision and simulation of Washer control

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ABSTRATCT

The fuzzy control method is a smart control method that is built of the fuzzy logic theory. It simply imitates the process of human being's decision in behavior. It is very suitable of complex non-linear systems that it is hard to solve using the traditional methods. By applying fuzzy logic, you can have a simple continuous output that has values between [0...1]. In this report, the controlling of the washing machine has been chosen to be the control object. Three inputs that may affect the washing process were chosen to build the experiment on them and by setting up the correct fuzzy rules we can end up with two outputs that can optimize the washing techniques. The MATLAB will be used to simulate the example.

Report Outlines:

- List of figures and Tables
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Fuzzy Control

The fuzzy control is an intelligent control method relying upon the fuzzy set theory, fuzzy variables, and logic deduction. It has been putted forward by professor L.A.Zadeh from California University in 1965. The induction of fuzzy sets can put the cognitive process of human in simple mathematical expression, therefore, it is possible to deal with the complex system conforming to the reality and closed to thinking of human. The fuzzy logic has a lot of significant advantages it is easy to catch on, has continuous outputs and high reliability and so on. Fuzzy Logic is applied to different complex control object and has developed rapidly over the last years.

Fuzzy systems are giving a very good promise in consumer goods, industrial and commercial systems, and decision maker systems. The term "fuzzy" refers to the ability of dealing with not well known or vague inputs. Instead of using all the complex mathematical equations, fuzzy logic instead uses linguistic descriptions to define the relationship between the input information that we have and the output action that we want. In engineering systems, fuzzy logic provides a simple and user friendly frontend to develop the control programs, helping designers and researchers to concentrate on the functional objectives, not on the mathematics only.

Fuzzy sets are described by Membership functions and relative membership grade is the cornerstone of the fuzzy set theory. Relative membership grade can expand the values of characteristic function from (0, 1) to [0, 1], then we can use a real number between zero and one to express the degree of element relative to a fuzzy set. [1]

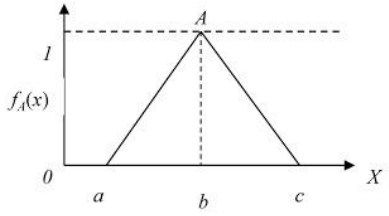
The scaling for the fuzzy sets is very important because the fuzzy system can be renewed with other devices or have different ranges of operation by just trying to change the scaling of the input and output. The decision-making idea figure out how the fuzzy logic operations are performed, and with the knowledge base figure out the outputs of each fuzzy IF-THEN rules that was created. Those at the end are joint and converted to crispy values with the Defuzzification block. The output crisp value can then be calculated by the center of gravity or the weighted average or any other Defuzzification method.

The Characteristic Feature of Membership Function

1. The value of membership function is a continuous value of a closed interval (range from zero to one). The value approaches one, the greater will be the RMG of element, otherwise, the value approaches zero, the smaller will be.
2. Membership function is the basic concept of fuzzy mathematics, and fully depicts the fuzzy sets.

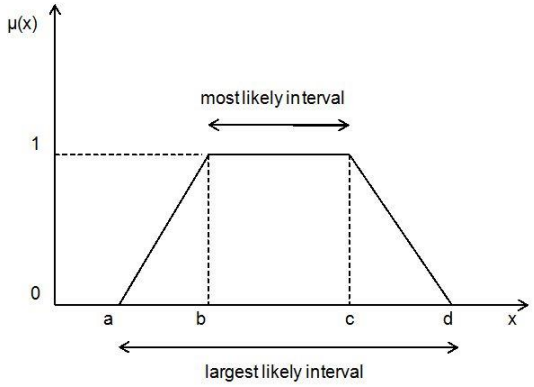
Classic Membership Function

1- Triangle Membership Function
The shape of the curve depends on three parameters a,b,c .



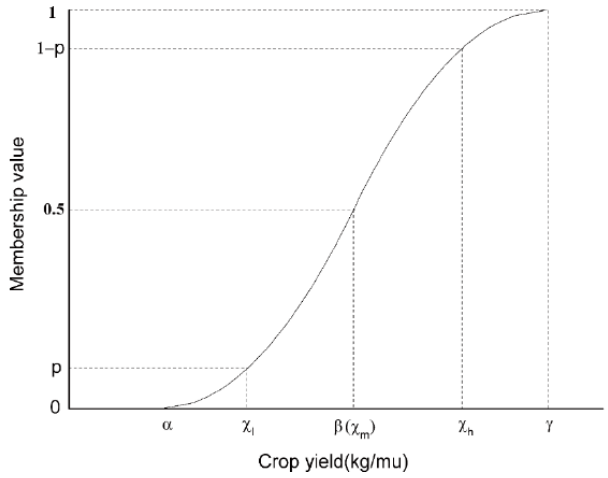
$$\text{triangle}(x; a, b, c) = \begin{cases} 0, & x \le a. \\ \frac{x-a}{b-a}, & a \le x \le b. \\ \frac{c-x}{c-b}, & b \le x \le c. \\ 0, & c \le x. \end{cases}$$

2- Trapezoid Membership function
The curve depends on four parameters a,b,c, d.



3- S Membership Function

Type S membership function depends on two parameters a and c .



The Steps of Fuzzy Controller Design

1- Determining the structure of the fuzzy controller and parameterize.
2- Getting the fuzzy knowledge and setting up rules library
3- Selecting the Fuzzification and Defuzzification methods.
4- Adjusting and improving control performance.
The Method of Setting up Fuzzy rules

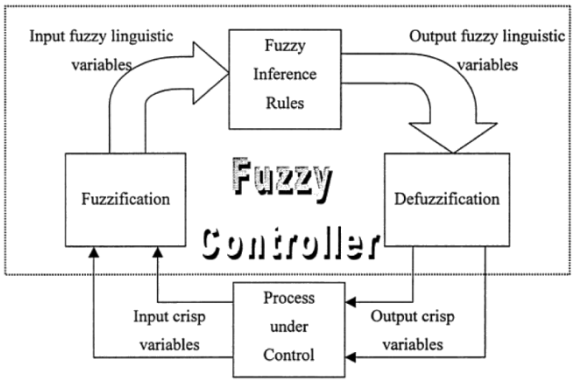


Figure1: Fuzzy Logic cycle

Fuzzy Compositional Rule of Inference

1- Inductive Method Based On Experience
The method based on experiences of the human to sum up the control experience and intuitive reasoning of human to set up the fuzzy rules, it is actually a huge jump from perceptual to traditional cognition.
2- Fuzzy Compositional Rule of Inference
In This method, The fuzzy compositional rule of inference is effective way to set up the fuzzy rules. It can build the fuzzy rules by compose fuzzy reasoning depending on the existing data of input and output.

Fuzzification

Fuzzification is well known as the process of decomposing a system input and output into multiple fuzzy sets. Many types of membership function can be used (as mention before), but triangular or trapezoidal membership functions are used the most because they are easier to represent in embedded controllers. Each fuzzy set take a specific region of input or output value that is well graphed with the membership. Any particular input or output is part from this fuzzy set and interpreted a degree of membership. The membership functions of the input or the output should overlap to allow better smooth mapping of the system. This process of fuzzification give the ability to the system inputs and outputs to be shown in linguistic terms so that the rules can be applied easily in a simple way to express a complex or hard system.

Defuzzification

After fuzzy logic, we have now a linguistic output variable that has to be translated into a crisp value again. The target of having a single crisp numeric value that can best represents the inferred fuzzy values of the linguistic output variable and it is easier for human and people to understand it easily. Defuzzification as from the word is the opposite of the fuzzification, it mainly works as inverse transformation which simply convert the output from the fuzzy domain back into the crisp domain. Defuzzification can work with two method one methods tend to produce an integral output by considering all the possible elements of the resulting fuzzy set with the right weights. Other methods take in consideration just the elements corresponding to the maximum points of the resulting membership functions.

Some of the Defuzzification methods could be:

1- The Maximum Membership Degree Method
   The maximum membership degree method is simplest and it selects the element having the maximum membership degree as the output in the fuzzy reasoning set.

2- COG (center of gravity) Method or Center of Area
   In order to get accurate controlling amount, the fuzzy method should well express the results of membership function. The results of fuzzy reasoning is the center of gravity of COG method.

3- Weighted Average Method
   The weighted average method is in wide use in the field of industrial control.

Fuzzy Control in the washing machines

The washing machine is one of the main machines in a modern household. In the recent years, users are mainly concerned about the capacity and the energy consumption of the machine, as it is well knowing that the washing machine is one of the top power consuming machines that uses very high amount of electricity, so there was always the need for trying to optimize and control its performance in an efficient way. There are many reasons that effect the performance of the washing machine, and each reason is important to some people respectively. Using the washing machines every time with the same options and same washing cycle is totally inefficient and can cause huge amount of waste in the electricity, the time and even could affect the clothes itself that might be ruined if it was washing for longer time that it should be and so on.
Due to the reasons mentioned above fuzzy logic controller could be very useful for trying to control the washing machine and improving its performance. Analyzing the running of the washing machine, we know that the main controlling amounts are the washing time and the stream competence (motor speed). [2]
There was a huge need to try and get the best of the washing process with higher efficiency and lower power, water and time.

The fuzzy logic has been already used in many washing machine lately as the company LG already realized lately its new virgin or washers that can estimate and work in getting performance in the washing cycle. “6.5KG TOP LOADING WASHING MACHINE T6511TDFV” is a new washer machine its mechanics uses built-in load sensors automatically detects the laundry load and a microprocessor uses the fuzzy logic to optimizes washing conditions such as ideal water level and washing time. You can set the Wash Program type at Fuzzy and it would sense the appropriate washing method to give you the best washing performance. [3]

In my report, I will focus on trying to estimate the washing time and the motor speed, the main factors influencing these outputs are the smudgy degree and nature of the laundry. These two factors can be expressed as the turbidity value and its changing rate in water. While the washing process it is known that the rate of oily smudge is less than that have mud. Due to the practical conditions of the system that contain a lot of unknown, the controlling process always depends on the experiences of the users or the companies and it is so hard to create an efficient mathematical model of the input/output relation, so it is quite difficult to get high performance with traditional control methods. I have chosen inputs that are quite fuzzy amounts for any washers so my input values are the Fiber Type, Washing Load, and as mentioned before the Smudge of the clothes, the fiber type and washing load are such fuzzy inputs, so we should sum up experience through a great deal of experiments to formulate fuzzy rules. Washing many times, after knowing fiber type and washing load with sensors and load transducer, the controller then will choose the right washing parameters, such as water level and motor rotate speed, and we can then use that to estimate the right time for the wash. The block diagram for the system can be shown in the figure below.

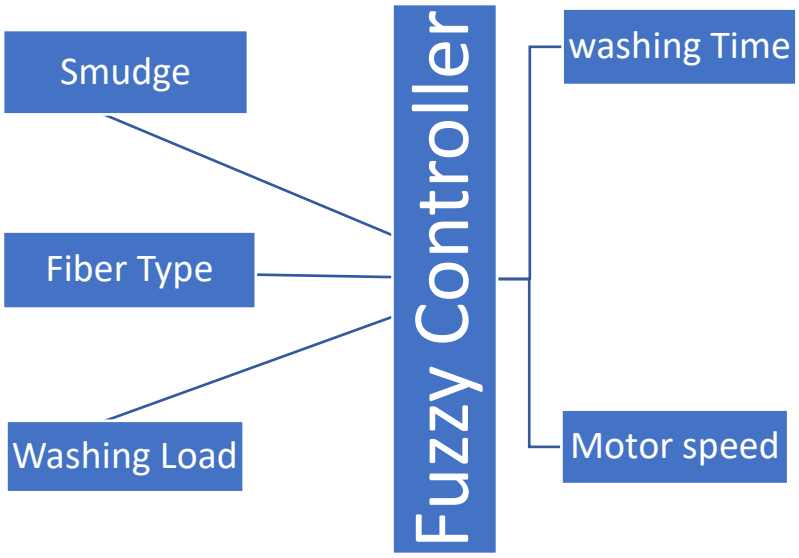


Figure2: System Strategy block diagram

Creating the fuzzy control on MATLAB

The fuzzy logic application on the MATLAB is quite smart and efficient, by choosing the right inputs and outputs it is easy then to create the fuzzy system and its fuzzy rules and see a very good output that will make us understand how it works and visualize the idea behind the system.

- First step is Determining the structure of the fuzzy controller

By selecting the fuzzy controller that has three inputs and two outputs. As mentioned before the inputs will be : Fiber Type, Washing load and smudge, the output will be: washing time and stream competence or motor speed.

- Second, we need to define the inputs and the outputs sets and define their verbs.

Smudge will be divided into seven sets as the following : Cleanest [CT], Cleaner [CR], Clean [C], Middle [M], Dirty [D], Dirtier [DR] , Dirtiest [DT] .

The Fiber Type will be divided into five sets as the following : Very Soft [VS], Soft [S], Middle [M], Hard [H}, Very hard [VH].

The washing load will be divided into five sets as well: Less [L], Little [LT], Middle [M], More [ME], Most [MT] .

For the output the washing time will be divided into five sets: Very Short [VS], Short [S], Middle [M], Long [L], Very Long [VL] .

Finally, the stream competence where also divided into five sets: Very Weak [VW], Weak [W], Middle[M], Strong [S], Very strong[VS]

- Defining the Membership Function

The triangle membership function will be used in this example to define the inputs and the outputs.
Starting with the inputs : Smudge, Fiber Type, Washing Load.

An important thing to mention is that the inputs and the outputs values are so fixable we can easily change what we want to put as the input and what we want to estimate to be the output. For instant, instead of having the fiber type we can make it to be the color of the clothes and according to the color we can estimate different outputs. Also for the output we can estimate different kind of output for example we can make one of the output be the water temperature, that we will give us how warm the water should be for this specific input we have.

SMUDGE

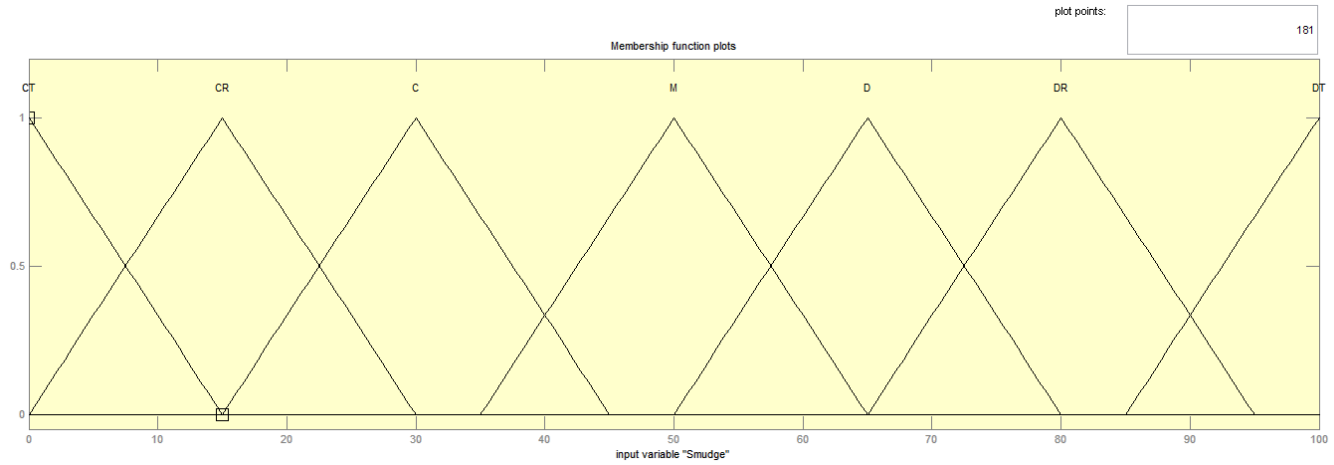


Figure3: Smudge Input Value

Putting the range between 0 and 100 for better vision.
Parameters for each set of the seven sets:
CT = [-15 0 15] , CR= [0 15 30], C=[15 30 45], M=[35 50 65], D=[50 65 80]
DR=[65 80 95], DT=[85 100 115]

FIBER TYPE

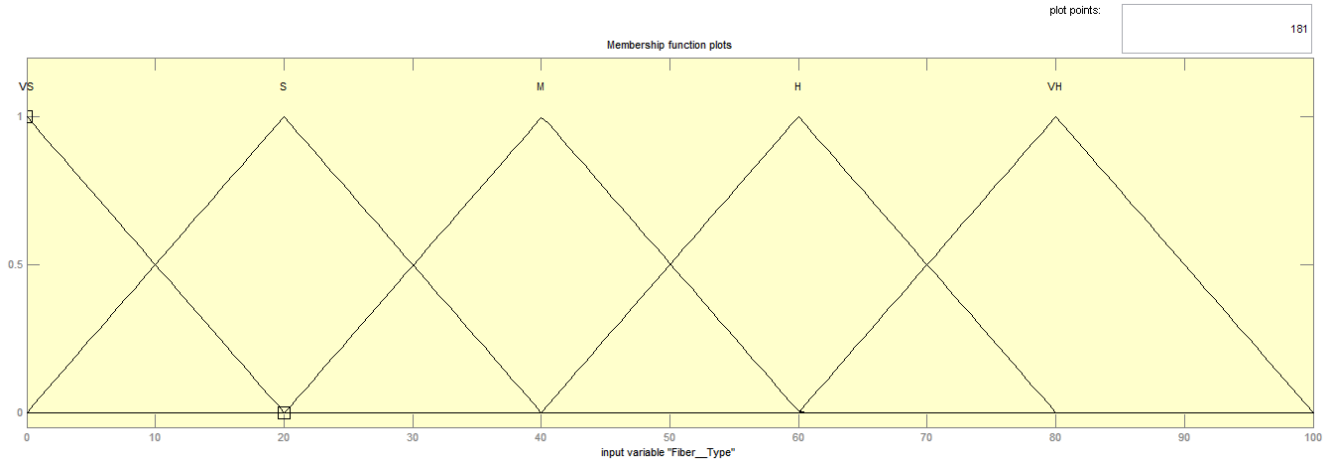


Figure4: Fiber Type Input value

Parameters for each set of the Five sets:
VS = [-20 0 20] , S= [0 20 40], M=[20 40 60], H=[40 60 80], VH=[60 80 100]

WASHING LOAD

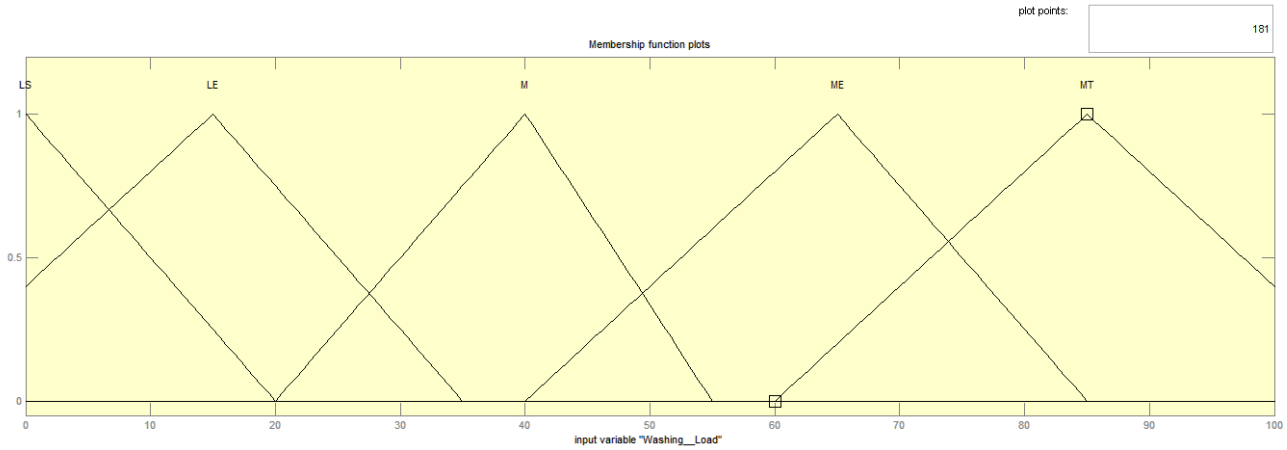


Figure5: Washing Load Input value

Parameters for each set of the Five sets:
LS = [-20 0 20] , LE= [-10 15 35], M=[20 40 55], ME=[40 65 85],
MT=[60 85 110]

Now we define the outputs: Washing Time, Motor Speed.

WASHING TIME

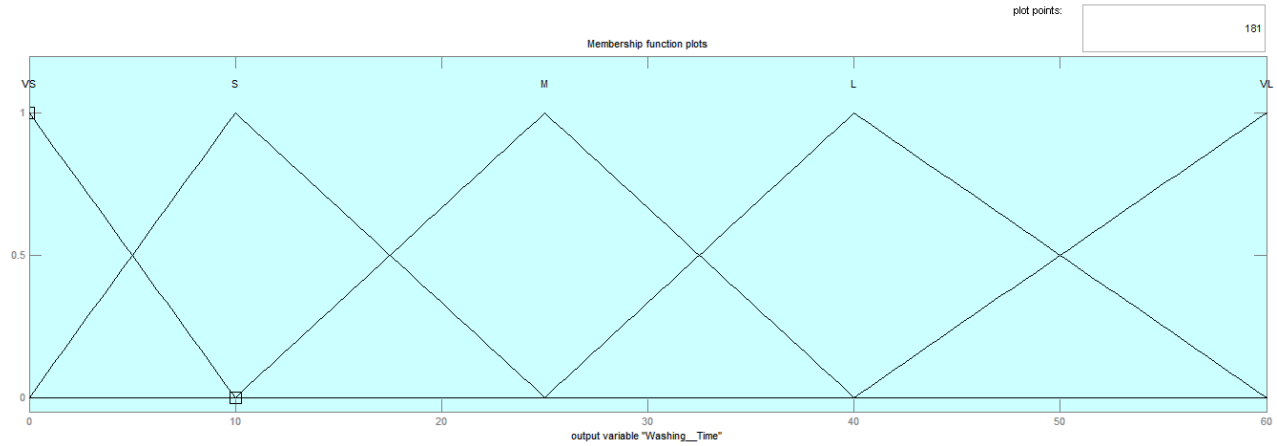


Figure6: Washing Time Output value

For the Output the range was setup to be between 0 and 60.

Parameters for each set of the Five sets:
VS = [-10 0 10] , S= [0 10 30], M=[10 25 40], L=[25 40 60], VL=[40 60 80]

Stream Competence (Motor Speed)

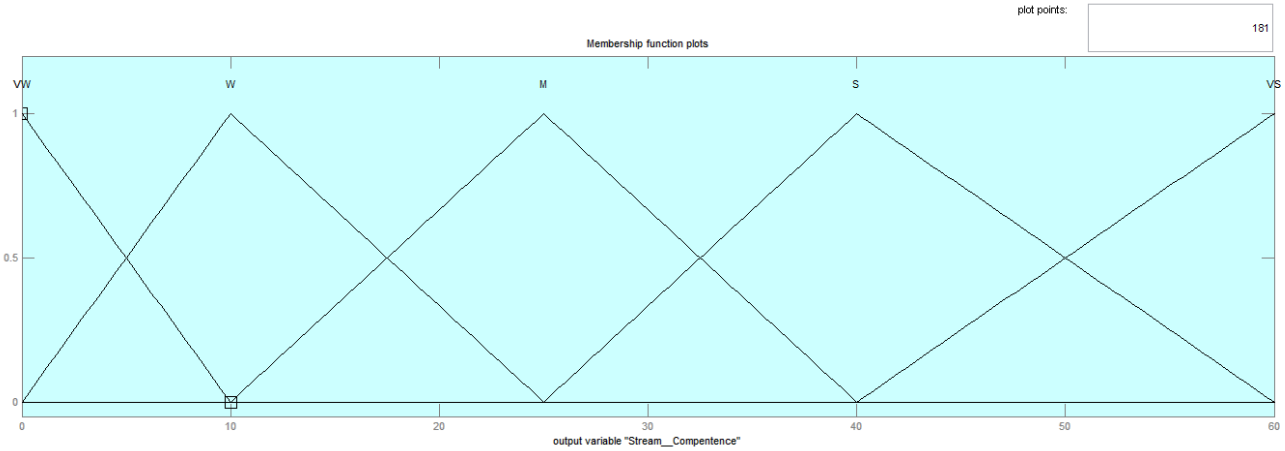


Figure7: Motor Speed Output value

Parameters for each set of the Five sets (Same like the previous definition) :
VW = [-10 0 10] , W= [0 10 30], M=[10 25 40],S=[25 40 60], VS=[40 60 80]

- Setting the Rules Table for the fuzzy controller

  As mentioned before the fuzzy rules are the “IF,Then” statements that control all the sets we defined for the Input and the Outputs. The following rules will be

build according to human experiences. IN this Experiment 35 Rules will be Defined as the following:

Smudge	Washing Load	Fiber Type	Washing Time	Stream Competence
CT	LS	VS	VS	VW
CR	LS	S	VS	W
C	LS	H	S	M
M	LS	VH	S	M
D	LS	VH	M	M
DR	LS	H	M	M
DT	LS	M	M	W
CT	LE	VS	VS	W
CR	LE	S	S	W
C	LE	M	S	M
M	LE	H	S	M
D	LE	VH	M	M
DR	LE	H	M	M
DT	LE	M	M	M
CT	M	VS	S	M
CR	M	S	S	M
C	M	M	M	M
M	M	H	M	S
D	M	VH	M	S
DR	M	H	M	S
DT	M	VH	L	S
CT	ME	VS	S	S
CR	ME	S	M	S
C	ME	M	M	S
M	ME	H	M	S
D	ME	VH	L	VS
DR	ME	H	L	S
DT	ME	M	L	S
CT	ME	VS	M	S
CR	MT	S	M	VS
C	MT	M	L	VS
M	MT	H	L	VS
D	MT	VH	VL	VS
DR	MT	H	VL	VS

DT	MT	M	VL	VS

Table: Fuzzy Rules Table

For instant, the last row of the table says, “IF the smudge level is VERY DIRTY and wash load is MOST and the Fiber type is Middle THEN the Washing time is VERY LONG and the motor speed is VERY STRONG”

An important Thing to mention is that “mamdani” Fuzzy logic type was used in the simulation of this example. Mamdani's fuzzy controller method is one of the most known seen fuzzy methodology. Mamdani's method was count as the first control systems built using the fuzzy set theory. If we want to go in how it works, In Mamdani’s model the fuzzy implication is designed by Mamdani’s minimum operator, which can be the conjunction operator is min, and the t-norm from compositional rule is min however, for the aggregation of the rules it is used the max operator.

Outputs and Results

After setting up our rules and defining the sets for the inputs and outputs we can go ahead and see our controller output by the Defuzzification method which is CENTROID in my example. Center of Area (COA) which is often referred to as the Center of Gravity (COG) method because it computes the centroid of the composite area representing the output fuzzy term. Following are some of the example outputs.

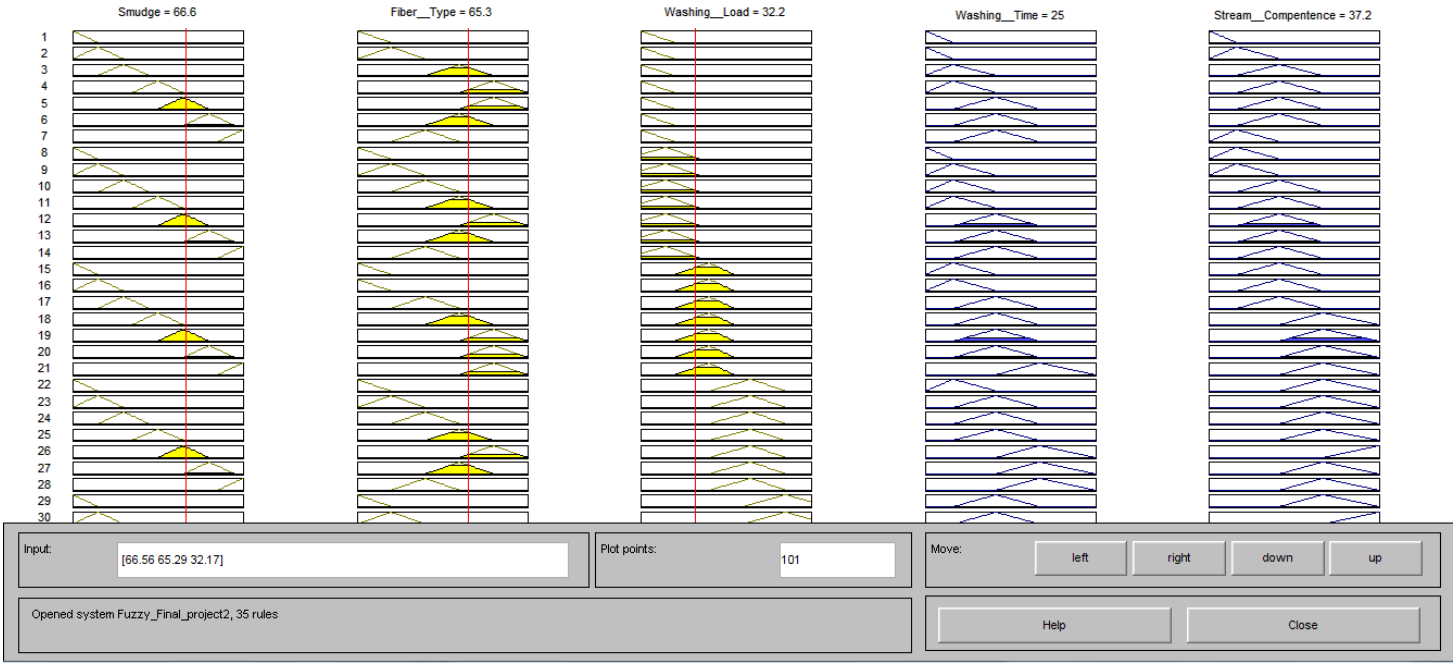


Figure8: Output value for the controller

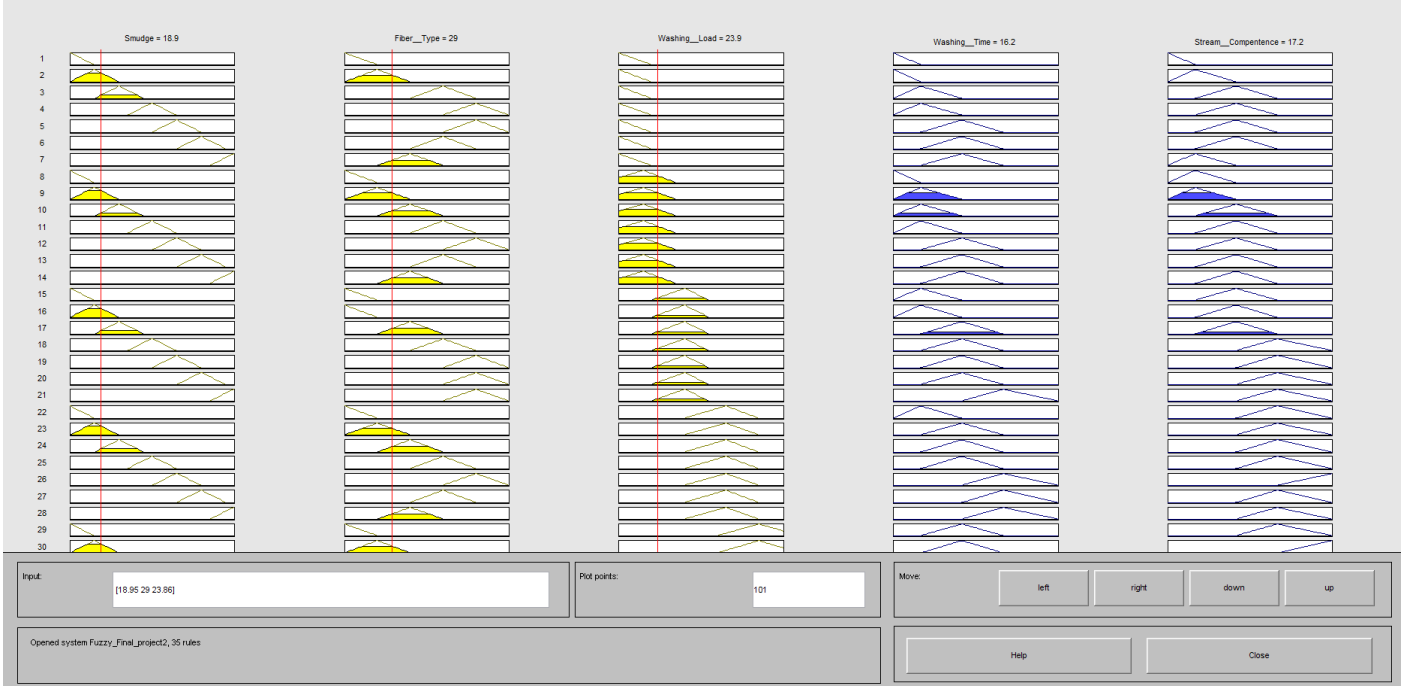


Figure9: Output value for the controller

The Defuzzification of the result of the fuzzy control are the expected controlled outputs. The first row is the smudge value, the second row is the load value, the third row is type value, the fourth and fifth rows are the output time and stream values.

Easily by moving the red line in the inputs to between the values we can see immediately the change in the output and the estimated washing time and the motor speed. We can find the value from 0 to 1 or from 0 to 100 or anything whatever we choose to put our range in setting up our controller. For instant, in this example the inputs range are from 0 to 100 so we will see them taking values from 0 to 1 and the outputs range have selected to be from 0 to 60 so simply the output value in the controller will take a number between 0 and 60.

Furth more, we can always see the 3D surface for any two inputs and one output in order to understand more the relation between each two inputs and one output and change them to get a better view of how it actually effect the output.

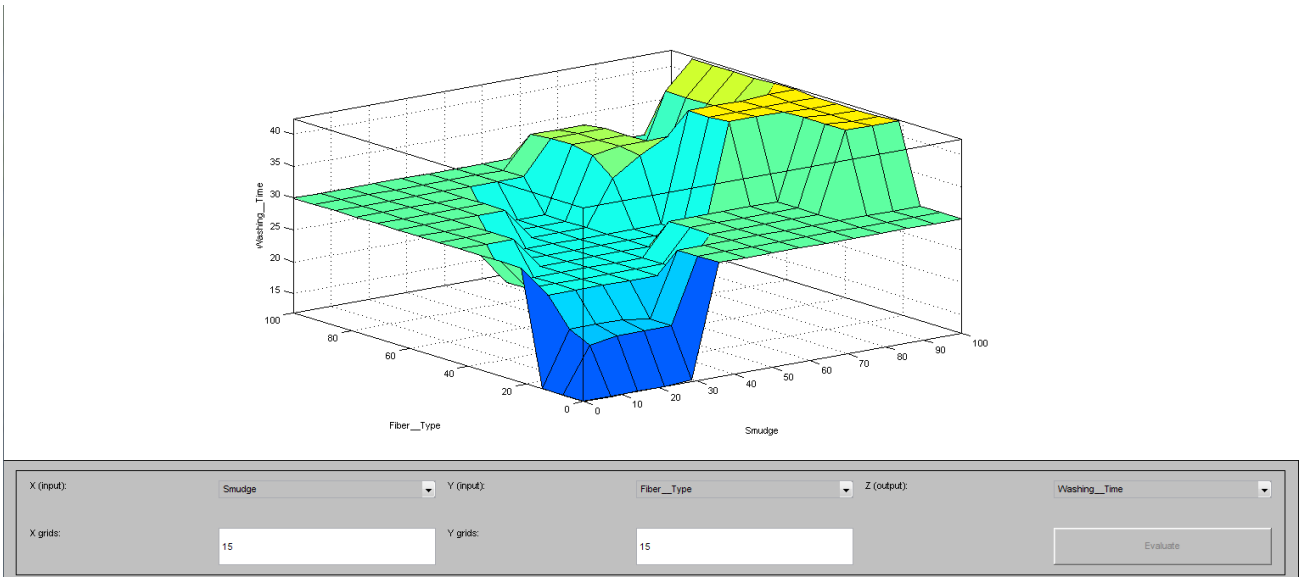


Figure10: 3D Output value

The figure above shows the 3D graph between Smudge, Fiber Type and washing time.

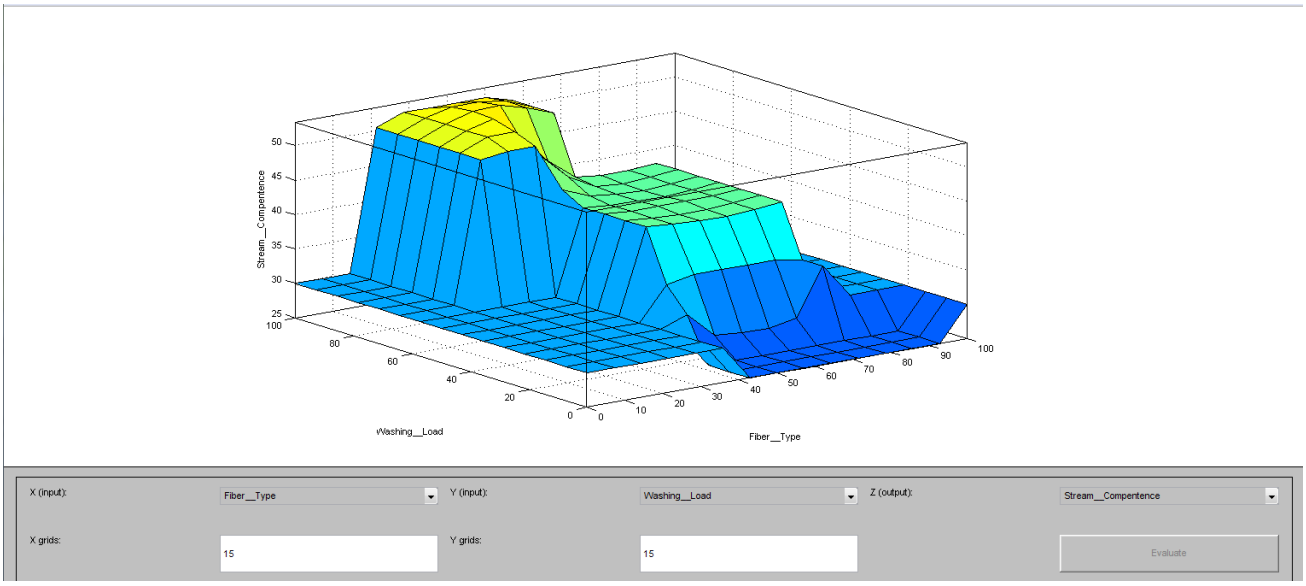


Figure11: 3D Output value

The figure above shows the 3D graph between Fiber Type, washing load and stream competence.

And so, as I mentioned before we can easily keep changing the variables for the inputs and the outputs to see the 3D graphs for any of them. Knowing how each inputs effect each output is important to understand the effect of each input on the system as all.

Important to mention that we always can go back and change or add the inputs sets, the output sets and even the fuzzy rules and go back to see the change caused by this editing.
For instant, In my example I started it with only two inputs and one output and I checked the results, then I added a third input while keeping only one output. After that I added one more output to end up with three inputs and two outputs.

Conclusion

The fuzzy controller with three inputs and two outputs basing on above fuzzy rules obtains good effect, it is sensitive to the inputs and is precise for the control after repeated experiments and contrasts. By using the system, we can now estimate a good time and speed for the wash in more efficient way and by this way we can optimize the washing cycle and saving time and power.

Future work

It will never be enough of satisfying for the users, so a very good way to extend this work and make it even better is by applying some kind of Artificial Intelligent to the system which can simply use some training data to be trained and then take a better action for specific situations. In addition, multiple sensor could be added inside in the washing machine to detect the whether the smudge or the fiber type or even the load, and by that way we simply don’t need an exact input for the users, but instead the input reading will be exported from the sensors going to the fuzzy controller to estimate the right output for the system.

References:

[1] 'The fuzzy decision and simulation of washer control' *Yu Zhen; Xu Fang 2011 6th International Conference on Computer Science & Education (ICCSE) Year: 2011*

[2] 'Estimation of Unbalanced Loads in Washing Machines Using Fuzzy Neural Networks' *Ahmet Yörükoğlu; Erdinç Altuğ IEEE/ASME Transactions on Mechatronics Year: 2013*

[3] http://www.lg.com/africa/washing-machines/lg-T6511TDFV

[4] "Mathematics of fuzzy sets and fuzzy logic" Barnabas Bede