**Name:** Jamie Cropley
**P Number:** P15188432
**Module:** IMAT3406 - Fuzzy Logic and Knowledge Based Systems (AI)
**For the attention of:** Dr. Archie Singh Khuman
**Date:** 17/12/2018

**Contents:**



# Fuzzy Logic System Report

## 1.0 Abstract

This report puts forward a hypothesis and a design of a Fuzzy Inference System for a Fuzzy Controller for a washing machine to improve its energy efficiency. The issue has been researched by means of a literature review, additionally by means of utilising the Internet to look for consumer products, mainly in respect of normal average use of a washing machine and how the water is being utilised within the machine. In an industrial setting the rates of electricity are better refined usually, I decided to focus on consumer washing machines only to that effect, because I believe energy efficiency is more relevant to people at home rather than a business.

## 1.1 Introduction

This report details a descriptive analysis of a developed Fuzzy Inference System (FIS). This FIS focuses on a washing machine, where a FIS they can be used in a washing machine. Regularly within this industry, the FIS I have created will encompass means of energy efficiency respective of how the washing machine operates and utilises the FIS therein. Therefore, the background research in this report encompasses proof as such and relating it to the implemented Fuzzy Logic design throughout this report.

## 2.0 Literature Review and background

Fuzzy logic, a branch off logic, deals primarily with vagueness, it can represent formations of knowledge in a way like that of human understanding and reasoning allowing for an adequate interpretation by a digital device. Most modern day washing machines utilise some degrees of vagueness whether interpreted by Fuzzy Logic or not. Many different environmental factors can cause many varying types of dirt (soiling) on clothing outside of a washing machine or washer. Therefore when put in a washing machine usually different settings are there for the user to use to get the best results regarding cleanliness, this is a form of vagueness without utilising Fuzzy Logic, the human eye can not accurately correlate for example the temperature needed to get rid of a stain with a high-efficiency rate.

Fuzzy Logic can detect with better precision along with using different types of sensors to work out how much staining is actually on an item of clothing, for example, a stain which is invisible to the human eye can be better detected using a particular sensor and Fuzzy Logic to ensure that it does not miss it. There are many other scenarios and factors to take into account with a washing machine as the components they are made up of are mostly different. By implementing fuzzy logic methods such as a Fuzzy Logic, the time taken, and resources used in the washing machine can be better calculated thus saving on energy costs and all-around general running regarding energy efficiency.

Fuzzy Inference Systems (FIS) are a fuzzy logic methodology used to map various inputs to one output, I believe this to be an ideal method to utilise in terms of fuzzy logic within a washing machine as it allows for Inputs and Rules to crossover and be manipulated respective of the overall zoutput, for the purpose of this literature review and report I will mainly focus on the Mamdani method where relevant as it is the most commonly utilised one and is less ambigious to detail and utilise in comparison to other methods in terms of mathematical complexity.

There is a strong history of FIS's of varying types being utilised in washing machines, again because the components throughout each washing machine the way they wash clothes can always be slightly different thus making the FIS they utilise different in each approach, more specifically one washing will have varying different inputs and outputs to another washing machine.

Sudha Hatagar and S.V. Halase [1] indicate that "Fuzzy logic enables designers to control complex systems more effectively than traditional approaches. As it provides a simple way to arrive at a definite conclusion upon the ambiguous, imprecise or noisy information." They then go on to detail in the paper how such an approach is capable of saving time and therefore electricity consumption. The fuzzy approach they detail can roughly be described as two inputs being that of the type of dirt and the dirtiness of clothes then concluding when put through the FIS as the output being wash time. This correlates to the vagueness of not being able to see a stain with the human eye as accurately but a system designed to deal with such vagueness yet accuracy and efficiency in terms of time. Their results and conclusions attribute to this specifically towards the factor of time.

The washing machine sensors alone play an important role aside from the factor of fuzzy logic methods, however when utilised in such methods they can improve accuracy of such sensors. Bogdan Spasojevic [2] indicates that for there fuzzy optical sensor that it can infer time throughout the process of the washing cycle, this concludes in the clothes being washed until they are clean thus more accurately calculating the time for the wash cycle. The sensor achieves this accuracy by utilising the Tyndall effect along with a fuzzy logic design which allows a logical flow of in terms of design of the optical sensor, the Tyndall effect scatters light (in a sense similar to that of something like fog or mist) in order to achieve more accuracy of detecting staining on the clothing being washed throughout the cycle. The degree of dirt and the type of dirt as inputs always affects the overall washing time through the fuzzy controller proposed in this paper.

A FIS can also have more than one output in some instances, for the purpose of a washing machine in terms of its energy usage time is the most common deciding factor here, however the power that the washing machine is utilising could also be easily overlooked when designing a FIS in this respect, although there would be a tiered limit depending on the washing machine, of its overall specific power output it still can be altered via different outputs on a FIS dependent on how that is designed.

Yu Zhen and Xu Fang indicate [3] Stream Compentence (Which basically means motor speed) as an additional output in there FIS design, they specifically state for this output along with the washing time that “the controlling process highly depends on the experiences of the operator and it is hard to formulate a precise mathematical model of the input/output relations, so it is very difficult to gain good performance with traditional control.” this follows on what was indicated in my initial hypothesis, where the user of the machine would not necessarily be as accurate as when a user (operator) indicates the settings on the machine relative to the staining on the clothing. Although not specifically mentioned in this paper, I would presume that more specific control over the motor speed would allow for more accurate energy consumption.

The possibilities are almost endless when it comes to designing a FIS (Fuzzy controller) for a washing machine, where other attributes can be used in conjunction with a fuzzy controller such as neural networks or genetic algorithms to improve efficiency even further. In conclusion I have found that most attributes in a FIS always greatly affect the overall time of the cycle and thus it always seems at the utmost significance and relevance to indicate an output of washing cycle time in the majority of FIS design’s. The less time a washing cycle is going for, the less electricity it utilises overall making the washing machine or washer more energy efficient. Additional outputs may help with stain removal, however sufficient evidence in such use cases was difficult to come by where time can be proved from a more common sense approach.

## 3.0 System Design

### Input - Variables:

As washing machines are generally quite big and powerful in terms of there function, they obviously use a lot of electricity.

To reduce the electricity usage as much as possible can prove very challenging as different types of wash cycles can be applied to different washing type situations. I concluded that water being the other main aspect of a washing machines function alongside electricity therefore I decided to do two of my inputs as water-based which are water hardness and water temperature to better and thus quickly wash the clothing for my FIS / Fuzzy Controller for the washing machine. As another main aspect of the washing machine function would actually be its moving parts of it, I decided to focus on the actual motor, the thing that turns the tumbler inside the washer as my third input, and with time being a relative factor in electricity usage I decided this would be my overall output.

Inputs and variables in detail:

- Water Temperature in Centigrade (Hot to cold in Degrees) :
    - 0 to 90 degrees, decided to do a range from 0 because this is the lowest temperature that washing machines usually wash at.
- Spin Speed (Revolutions Per Minute) (RPM)) : 0 to 1600 Revolutions Per Minute
- Water hardness (Calcium Carbonate Content) CaCO_3)

Outputs and variable in detail:

- Wash time (minutes) : 0 to 95 minutes

**Fuzzification - Input of Sets:**

The sets I used allowed me to figure out what type of membership function to use for each input and the output by means of aesthetical experimentation to where this fits into a outlay of a madami fuzzy system.

For Water temperature I decided to use Gaussian membership function, I believe this was best suited for water temperature because temperature will always go up and down to varying degrees, it is never always exactly one number, the flowing visual aesthetics of the Gaussian membership function allowed to visualise such a varying fluidity of temperature change in the easiest manner I believe. I then went onto to subjugate as simply as possible what the main temperatures were going to be called for each set as follows along with the initial value being [ 12 _ ] in each set, configured mainly from an aesthetical need :

- Very Cold - At most, will always be at 0 degrees centrigade therefore [12 0]
- Cold - At most, will always be at 10 degree centrigade therefore [12 10]
- Hot - At most, will always be at 40 degree centrigade therefore [12 40]
- Very Hot - At most, will always be at 90 degree centrigrade therefore [12 90]

For the spin speed I decided to use a mixture of the Triangular-shaped membership function and the Trapezoidal-shaped membership function, this is because most modern washing machines start their motor speeds at around 1200rpm as a optimal very fast speed, this type of membership function better illustrated such a transition from the lower speeds of a washing machine. The speeds were clearly illustrated in each set going from 0rpm to a maximum speed that a washing machine can currently go up to which is 1600rpm, the sets crossover slightly with some numbers as motors do not generally instantly slow down unless it is something like a motor vehicle, in a modern washing machine before a cycle ends my observations indicate the tumbler is always constantly transitioning in between speeds as well as when the cycle ends the washing machine usually gradually slows the tumbler down using the motor and does not usually do this instantly. Below are my overall decided sets based on rpm speeds:

- Very Slow - Starting from 0rpm to 400rpm therefore [0 0 400]
- Slow - Starting from 400rpm to 800rpm therefore [400 600 800]
- Fast - Starting from 600rpm to 1000rpm therefore [600 800 1000]
- Very Fast - Starting from 800rpm to 1600rpm therefore [800 1200 1600 1600]

For the water hardness, this was tricky to visualise as it is usually a chemical type of build up common in plumbing and water-based appliances such as washing machines. In my research, I found that water hardness testing kits are commonly used to figure out water hardness in plumbing and I believe appliances such as washing machines, (however, how such a kit is used in washing machine I could not work out as the user does not usually have access to the water, the water is only there when the washer is actually washing clothes and running, perhaps a sensor would be a more amicable solution however I would still need to work out the ranges for the sensor) the water testing kit led me to the following scale:

| **Calcium Hardness as CaCO3 (mg/L)** | |
|---|---|
| Soft | 0 – 20 |
| Moderately soft | 20 – 40 |
| Moderately hard | 40 – 80 |
| Hard | 80 – 120 |
| Very Hard | > 120 |

This then gave me adequate information for my sets, I decided to use only the Trapezoidal-shaped membership function for these plots, mainly because the above table indicated such Linearity more numerically than anything, that the numbers tended not to crossover, experimenting with other membership functions did not prove to be an adequate representation of the above table. Other factors can also make up water hardness as it is a chemical type of build up, and water varies a lot nationally and internationally, to keep things simple I decided to only focus on the Calcium Hardness (CaCO3, (mg/L)) in terms of the water hardness it can create in a washing machine. Overall I decided on the following sets.

- Soft - Ranging between 0 to 20 $CaCO_3$ (mg/L) therefore [0 0 20 20]
- Moderately soft - Ranging between 20 to 40 $CaCO_3$ (mg/L) therefore [20 20 40 40]
- Moderately hard - Ranging between 40 to 80 $CaCO_3$ (mg/L) therefore [40 40 80 80]
- Hard - Ranging between 80 to 120 $CaCO_3$ (mg/L) therefore [80 80 120 120]
- Very hard - Ranging of anything greater than 120 $CaCO_3$ (mg/L) therefore [120 120 120 120]

The wash time, I decided to indicate in minutes only, all washing machines I have come across and through my research online indicated dials in minutes only of an average of 0 minutes (obviously meaning machine off / idle) to 90 minutes, in terms of sets I felt a more binary approach was needed here especially in terms of conserving electricity, most wash times of the average user (based on my own experience washing clothes) seem to average at a maxium of 45 minutes in most weekly washes, then anything higher seems to apply more to specialist clothing and items, e.g. sportswear, curtains, whites etc… Overall I decided on the following sets: The Trapezoidal-shaped membership function was chosen for Not a long time to better illustrate how the motor would work in terms of effeciency (e.g. it starts to slow down towards 45 minutes to end the cycle.) where I utilised Gaussian curve membership function for A long time in order to better illustrate the time escalation necessary for more harsh washes in a washing cycle.

- Not a long time - Ranging from 0 minutes to 45 minutes therefore [0 10 25 45]
- A long time - Ranging from 65 to 95 minutes therefore [65 95]

**Fuzzy Inference - Rules:**

To construct the rules, I firstly crossed referenced everything within a matrix illustrated in the below table, based on my three inputs and my output:

| **Rule Number** | Water Temp | Spin Speed | Water Hardness | Wash Time |
|---|---|---|---|---|
| **Conjunction:** | **IF** | **AND** | **AND** | **THEN** |
| **1** | Very Cold | Very Slow | Soft | Not a long time |
| **2** | Cold | Slow | Moderately soft | Not a long time |
| **3** | Hot | Fast | Moderately hard | A long time |
| **4** | Very Hot | Very Fast | Hard OR Very Hard | A long time |
| **5** | Very Cold | Slow | Moderately soft | Not a long time |
| **6** | Cold | Fast | Moderately hard | Not a long time |
| **7** | Hot | Very Fast | Hard OR Very Hard | A long time |
| **8** | Very Hot | Very Slow | Soft | A long time |
| **9** | Very Cold | Fast | Moderately hard | Not a long time |
| **10** | Cold | Very Fast | Hard OR Very Hard | Not a long time |
| **11** | Hot | Very Slow | Soft | A long time |
| **12** | Very Hot | Slow | Moderately soft | A long time |
| **13** | Very Cold | Very Fast | Hard OR Very Hard | Not a long time |
| **14** | Cold | Very Slow | Soft | Not a long time |
| **15** | Hot | Slow | Moderately soft | A long time |
| **16** | Very Hot | Fast | Moderately hard | A long time |

The main varying factor in each cycle would be the temperature, as this is user controlled, so would be the most deciding factor depending on level of stains on clothes, amount of clothes / load in the washer etc…

**DeFuzzification - Output of sets:**

This part of the process would run through each set, and apply the rules mentioned in the previous two sections in order to produce a crisp set.

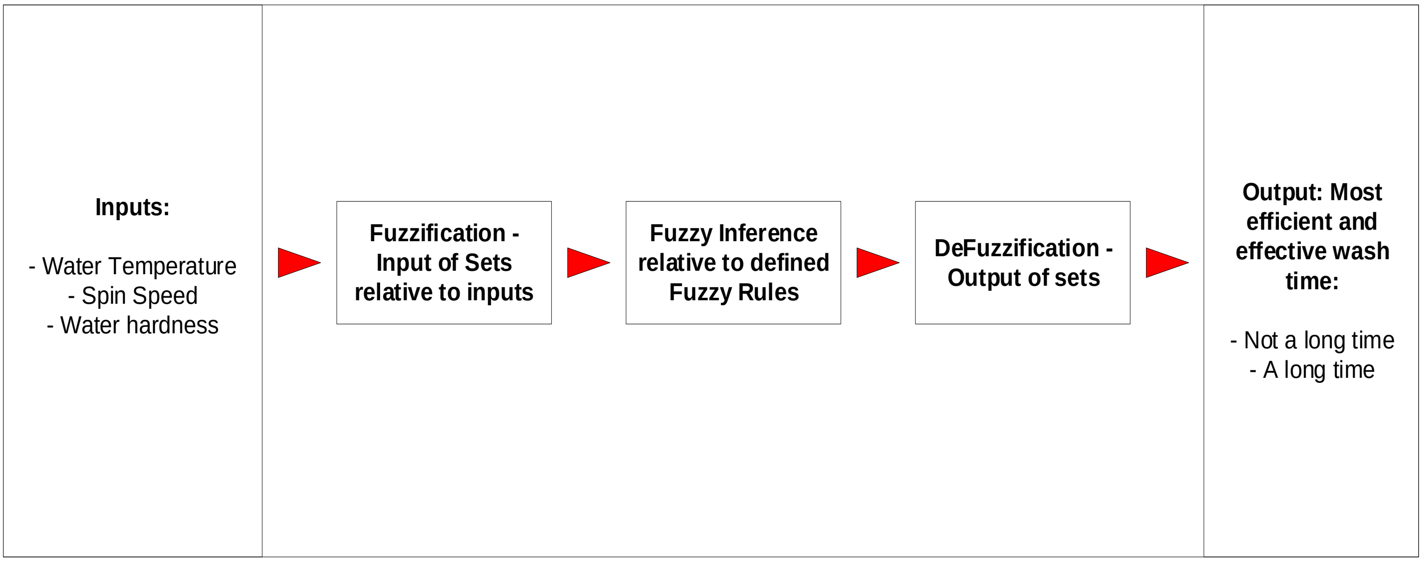
There are many different methods to achieve the best results in terms of utilising the utmost efficiency of a FIS or Fuzzy Logic Controller.

With my design as the temperature was the most fluid range of numbers, I could possibly apply the weighted average to temperature which would ordinate in reflection of the rules I implemented above. I could do this using Matlab code to plot it on the charts as generated as per below.

**Output - Result:**

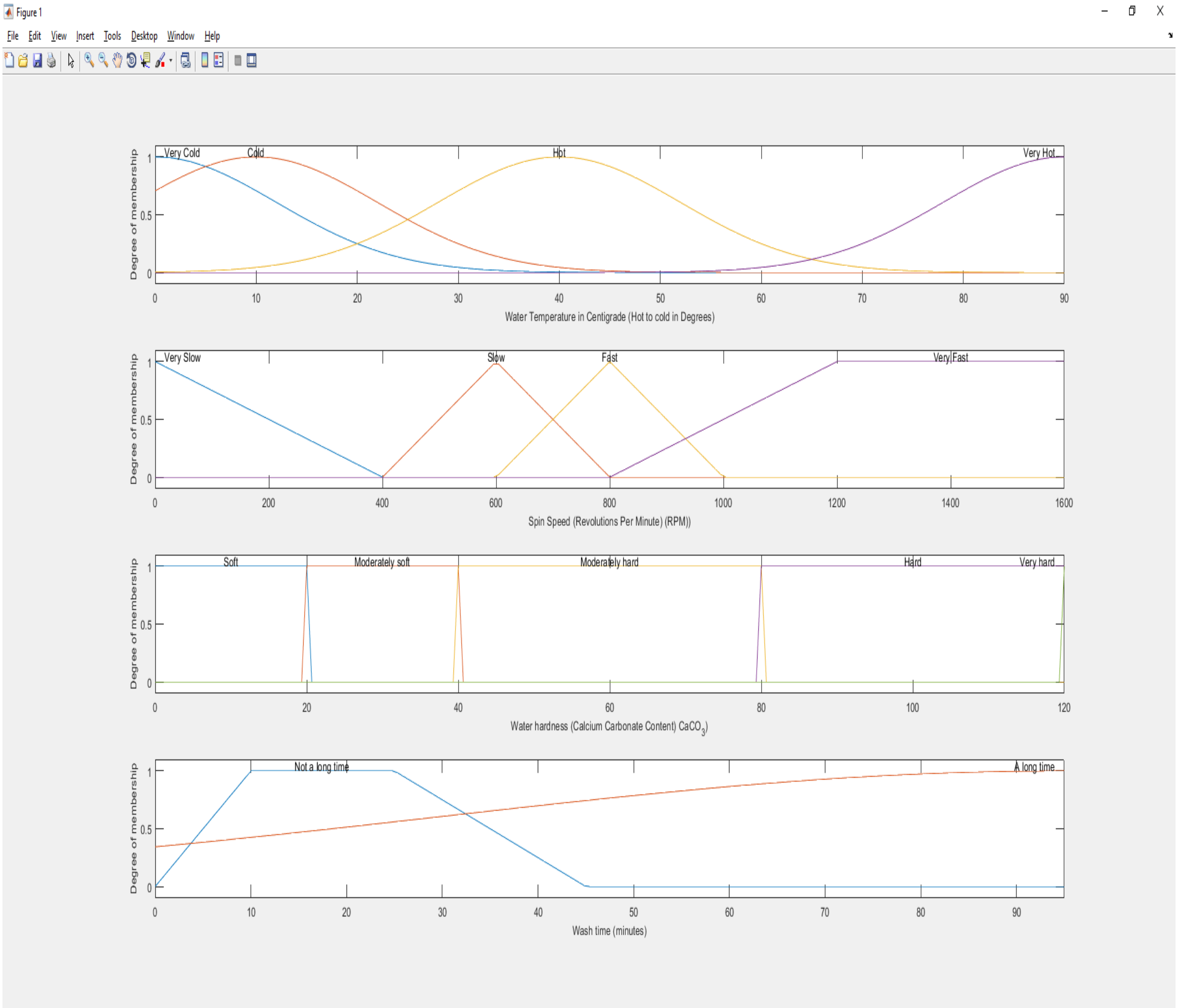
The overall output would be the best decided and most efficient wash time, this would therefore as initially indicated save on electricity, do a more efficient wash as the less time the washing machine is washing the clothes well, the less electricity the machine uses overall.

I decided to implement all of the above dynamics and attributes into a Mamdani fuzzy logic system like the one illustrated below:




*Based on image located at: https://fuzzy.ai/assets/i/fuzzy-control-diagram.png*

Additionally overall the output of my code resulted in:



## 4.0 Critical Reflection

I believe that the results by my design were perhaps to simplistic to come to any critical conclusions where little experimentation was done mathematically in order to prove on the overall output of my FIS, most of what I concluded I seemed to rely on my own logic and the general understandings and workings of how a washing machine works. Breaking the different parts of the design down further to that however:

Input - Variables:

I believe these were clearly defined, however if I had to go back and do them, I would make the ranges more dynamic and varied as I believe this would of created better results and more means for adequate experimentation overall. I would of also defined the same amount of variables for each input, I found this created a somewhat unnecessary complexity when I created my rules for my FIS.

Fuzzification - Input of Sets:

I believe these were well defined, however some points I believe I could of crossed over if I had specified the ranges they contained in a more concise manner relative to a washing machine. Some of them were mostly ok, as a washing machine is somewhat restricted sometimes, e.g. on the maximum temperature it can reach.

Fuzzy Inference - Rules:

Following on the from the variables, where having the same amount for each input I believe would of made these rules a lot less complex and easier to define, by this I mean there would have been an overall less amount of complication in the combinations of rules, thus I could of concluded on the efficiency of the output a lot easier. Additionally, following on from the complexity I created for myself, what I mean by this exactly, is that whilst one input can have more thresholds than another, so when working with say numbers in the set of another input this can make defining sets and thus the rules more complex than necessary therein.

Additionally, although I understood in the basic sense on how to produce the crisp set, more actual evidence and perhaps a visual representation of how this works would have been beneficial especially in terms of the next part, the overall results.

Output - Result:

I believe the overall result the FIS generates can be proved as effective by the means of the charts that Matlab produced from my code, you can clearly see how much more efficient in terms of time and energy it would be from the graphs, however more interpretation of the results I felt was needed in order to better prove this.

## 5.0 Conclusion

I believe I proved my initial hypothesis of utilising a FIS in order to improve efficiency and energy usage in terms of time on a washing machine. In regards to the literature review I believe this provided a adequate background in order to show a diverse range of how a Fuzzy Logic Controller / FIS can be utilised in a washing machine in order to improve it in many varying ways, common factors were easily identified from this literature review such as time of a cycle for example, which allowed me to reach conclusions easily and then go further to slightly prove such conclusions by means of my FIS design. Overall my FIS design, is effective in what it set out to achieve which was to improve energy efficiency of the washing machine by utilising a FIS containing inputs and a output of time as the common factor. The rule base I designed within my FIS allowed for the binary like output to be easily chosen when the FIS was run through. This allows for the user to simply select their selected temperature of the wash at the least, and thus the FIS decides the best time of the wash cycle based on water hardness and speed needed relative to the rules declared.

## 6.0 Bibliography


[1] Sudha Hatagar, S. H., 2015. Three Input – One Output Fuzzy logic control of Washing Machine. *International Journal of Scientific Research Engineering & Technology,* 4(1), pp. 57 - 62.

[2] Spasojevic, B., 2004. *FUZZY OPTICAL SENSOR FOR WASHING MACHINE.* University of Belgrade, Serbia and Montenegro, IEEE.

[3] Yu Zhen, X. F., 2011. *The Fuzzy Decision and Simulation of Washer Control.* SuperStar Virgo, Singapore, The 6th International Conference on Computer Science & Education (ICCSE).

[4] Jing Gu, D. Q., 2015. *The Design of Intelligent Washing Machine Controller Based on FPGA.* Fifth International Conference on Instrumentation and Measurement, Computer, Communication and Control, IEEE.

[5] Anon., 2007. Intelligent Washing Machine: A Bioinspired and Multi-objective Approach. *International Journal of Control, Automation, and Systems,* 5(4), pp. 436 - 443.

[6] Agarwal, M., Unknown. *Fuzzy Logic Control of Washing Machines,* Kharagpur, India: Department of Mechanical Engineering, Indian Institute of Technology.

[7] Amazon, 2018. *Amazon - Total Hardness Test Strip.* [Online]
Available at: http://a.co/2zD9JYb
[Accessed 12 December 2018].

[8] Currys, 2018. *Currys Washing Machine Search - Spin Speed in Left hand column.* [Online]
Available at: https://www.currys.co.uk/gbuk/household-appliances/laundry/washing-machines/332_3119_30206_xx_xx/xx-criteria.html
[Accessed 12 December 2018].

[9] fuzzyai, 2018. *fuzzyai.* [Online]
Available at: https://fuzzy.ai/docs
[Accessed 17 December 2018].

[10] Vernier, 2018. *Calcium and Water Hardness.* [Online]
Available at: http://www2.vernier.com/sample_labs/WQV-13-COMP-calcium_water_hardness.pdf
[Accessed 17 December 2018].

[11] Cropley, J. (2018) (*This report had no title initially).* Leicester, U.K.