



## A Comprehensive Review of Multi-Valued Logic System in a Hybrid Washing Machine Controller Model

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### ABSTRACT

A measure of the efficiency and wide acceptability of programmed devices is their ability to exhibit some substantial intelligent behavior. Their control systems must be able to emulate the reasoning process which, largely centers on vagueness and complexity. The controller design for Washing Machine is a multi-objective problem. Energy consumption, the economy of materials, fabric quality retention, and the effectiveness of the washing process, being the main issues in this study all form contrasting objectives. Typically, intelligent control techniques employed in washing machines are capable of providing useful means for both energy and water conservation, and easier use. This work aims to broaden this intelligence by the integration of neural network and fuzzy logic to produce a hybrid control system that would aid the maintenance of cloth quality in addition to clean washing in record time, as well as the economy of materials. Neuro-fuzzy computing combines the system identification and interpretability of fuzzy models and the learning capability of neural networks in a single system. The fuzzy and neuro-fuzzy techniques will aid the system to detect the fabric, measure its quality, and take its own decisions such as the release of water and washing powder relative to the need for cloth, and determine the cleanliness of cloth at the end of the wash, all in record time.

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### INTRODUCTION

Intelligent control of home appliances has attracted much theoretical attention in recent years, as well as becoming a major factor for industrial and economic success and rapid market penetration. Automation has placed a high demand on these appliances to exhibit some substantial intelligent behavior as proof of their distinguishing efficiency and for wide acceptability and marketability. Washing machines represent an important market. Intelligent control techniques are capable of providing

useful means for both easier use and conservation of energy and water. Their control systems must emulate the reasoning process using many variables, which largely possess vagueness and uncertainty attributed to humans.

Binary logic, on which many digital systems are traditionally built due to its design simplicity, is incapable of handling the non-linearity of complex systems. For instance, higher order arithmetic circuits like adders and multipliers built using binary logic suffer from increased carry

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propagation levels that result in increases in delay and the chip area. With the growth in diversity and complexity of computing needs, researchers began to find the development in binary logic cumbersome, complex and difficult to understand (Sharma, *et al.*).

Multi-valued logic presents a grand solution to the development of complex control systems due to its multifaceted advantages. It enables more information to be packed in a single digit. Researchers therefore found it a key substitute and have been working on multi-valued logic for many years (Sandhie, 2021).

Multi-valued logic (or nonbinary logic) refers to digital logic used in logic circuits that are designed to handle more than two voltage levels. In  $n$ -valued logic there are  $n$  levels and each memory element (flip-flops, etc) can exist in  $n$  different states. According to Karmakar, (2019 & 2020), the rapid development of Very Large Scale Integration (VLSI) technologies has made the possibilities and reasons for implementation of multiple valued digital systems and devices to become real and applicable. Over the last couple of decades, the use of multiple-valued logic circuits (circuits with more than two logic levels) has been offered as a solution to the interconnection (both on chip and between chips) and routing problems of the exponentially growing IC industry (Li, *et al.*, 2019 & Sandhie, *et al.*, 2021). Systems built from multi-valued logic has outstanding advantages such as realization of greater speed of arithmetic operations, decreased interconnections complexity and interconnections area resulting in reduced chip size, reduction of pin number of integrated circuits and printed boards, greater data storage capabilities, better usage of

transmission paths, and possibilities for easier testing.

Applications of MVL include arithmetic circuits such as multipliers and adders (Salama, *et al.*, 2022 & Jain, *et al.*, 2019), and memories such as Flash memories, Dynamic RAM (DRAM) memories, CAM and optical memory designs (Wang, *et al.*, 2020). Despite their potential advantages, developments in multi-valued systems have been plagued with implementation issues. For example, many novel electronic devices and optical devices are capable of dealing with more than two logic states but according to Roscoe, *et al.*, (2020) it is still a complicated task to design a system for processing a signal in a multi-valued manner despite considerable effort. Some multi-valued logic systems such as ternary and quaternary logic schemes have been developed but successful implementation is yet to become available (Sandhie, *et al.*, 2021 & Cusveller, 2021). This work however engages multi-valued logic as a contributor to the field of Artificial Intelligence. Among the principal concerns of Artificial Intelligence, the areas of Knowledge Representation, Management of Uncertainty and Approximate Reasoning constitute relevant closely related research areas where logic plays a very important role. According to Méndez (2015), the very early work of Lukasiewicz in 1923 on a Logic with three truth values {true, false, unknown} and an appropriate concept of negation ( $\neg$ true = false;  $\neg$ false = true;  $\neg$ unknown = unknown) could be considered as the first step towards a consistent generalization of classical logic allowing a more realistic modeling of reasoning by including uncertainty. Lotfi A. Zadeh in his seminal paper in 1965 wrote:

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*"If the values of  $\mu A(x)$  are interpreted as truth values, the latter case corresponds to a multiple-valued logic with a continuum of truth values in the interval  $[0,1]$ ".*

Consequently, he presented Fuzzy logic as one of the most appropriated formalisms to work with uncertainty (Zadeh, 1965; Méndez, 2015). Fuzzy logic refers to a family of many-valued logics. It is a form of multi-valued logic obtained from fuzzy set theory which was introduced by Zadeh & Aliev, (2018) to deal with reasoning that is approximate rather than precise (Kabadayi and Dag 2020). Fuzzy logic stipulates that the truth value (which, in this case amounts to a degree of truth) of a logically compound proposition, like "Okon is fat and Bose is tall", is determined by the truth value of its components. That is, as it is in classical logic, one imposes truth-functionality. A fuzzy set assigns a degree of membership, typically a real number from the interval  $[0,1]$ , to elements of a universe. Fuzzy logic arises by assigning degrees of truth to propositions. The standard set of truth values (degrees) is  $[0,1]$ , where 0 represents "totally false", 1 represents "totally true", and the other numbers refer to partial truth, i.e., intermediate degrees of truth (Cintula, *et al.*, 2016).

"Fuzzy logic" is often understood in a very wide sense which includes all kinds of formalisms and techniques referring to the systematic handling of *degrees* of some kind (Nguyen & Walker 2018). It is aimed at efficient computational methods that are tolerant to sub-optimality and imprecision especially in engineering contexts such as fuzzy control, fuzzy classification, and soft computing (Twaisan & Barışçı, 2022). This work applies fuzzy logic as a multi-valued logic paradigm in the design of a

hybrid model of washing machine controller.

Many research work has been carried out on this area, the most recently published one are as follows among others. In Masood, (2017 ); Gu & Qiang, (2015); Chinenye & Obiageli (2018), and Fadel, *et al.*, (2019) these paper discusses an intelligent washing machine controller based on FPGA parallel processing technology combined with fuzzy and neural network and genetic algorithm. In fuzzy logic, the following authors present and discussed extensively on the important of logic control to design and simulation of fuzzy logic control system in washing machine (Masood, 2017; Kaarthik & Sridevi, 2017; Wulandari & Abdullah 2018; Saqlain & Tariq 2018 and Nagarajan, 2019) respectively. Likewise the following authors present and discussed extensively on the ANN techniques on the washing machine control system (Ahmed, *et al.*, 2016; Kim 2018; Kamruzzaman *et al.*, 2018 and Zhou *et al.*, 2020) respectively. Other researcher presented paper on general approach on washing machine, (Raja & Ramathilagam, 2021); (Ishaan, 2021); (Qiao, *et al.*, 2019) and (Riaz, *et al.*, 2019) with various techniques respectively.

## FUZZY CONTROL LOGIC

Fuzzy systems are currently being used in a wide field of industrial and scientific applications. Although classic control has for a long time proven to be good enough to handle control tasks on system control, its implementation relies on an exact mathematical model of the plant to be controlled and not simple mathematical operations (Melo, *et al.*, 2022). Fuzzy control emerged as one of the most active and fruitful areas for research in the application of fuzzy set theory (Zadeh & Aliev, 2018). As

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accurate control is crucial to every automated process, various types of controllers are being widely used in process industries though with some difficulties, the major one being that of tuning. To overcome these difficulties, three basic approaches are being applied to intelligent control, namely: knowledge based expert systems, fuzzy logic, and neural networks. All three approaches are interesting and very promising areas of research and development (Rahman, 2017).

Intelligent, self-learning or self-organizing controls using expert systems, artificial intelligence, fuzzy logic, neural networks, hybrid networks, and genetic algorithms, have been recently recognized as important tools to improve the performance of the systems in the industrial sectors. Nowadays, the combination of these intelligent controls with their adaptiveness appears as the most promising research area in the practical implementation and control of automated devices.

As previously stated, fuzzy-logic control emerged as one of the most active and fruitful approaches to controlling complex systems, motivated by the fact that the system knowledge and dynamic behavior are qualitative and uncertain. However, fuzzy controller design has its own challenges, the main ones being the construction of an initial rule base and in particular the optimization of an existing rule base, that is, where one exists. The methods presented in this thesis have been developed to support a user in both of these cases. Since the design and especially the optimization process of fuzzy systems can be very time consuming, the practical thing is to have algorithms which construct and optimize them automatically. One popular approach is to combine fuzzy

systems with learning techniques derived from neural networks.

### *Use of Fuzzy Logic*

Fuzzy Logic, a multi-valued system, provides a prominent way to perceive our solutions beyond the classical two-valued binary system. The degree of truth of the statement is evaluated as a continuous function, rather than explicitly true or false. Fuzzy logic, hence provides a way to map the practical decision making of the human mind into machines (Nagarajan, *et al*, 2019). Washing machines use different sensors to measure different inputs, like amount of clothes, temperature of water, etc. From here, manual input needs to be provided in different steps, like determining wash cycles, wash time, detergent amount, etc. This happens because of a lack of well-defined relation between the input and output, which can be converted to a mathematical equation. With the concept of smart washing machines, and use of fuzzy logic based sensors, one can view this problem differently.

The different input parameters which are converted to input signals using sensors are sent to the inference engine of the control system, where using a predefined rule base, it determines an approximate set of outputs. The use of fuzzy logic over conventional logic provides a degree of freedom in determining the outcomes than a conventional model. In issues like smart washing machines and smart air-conditioners, this leads to providing an approximate yet adequate solution to the problem statement because of the loosely bound relation between input and output parameter.

### *Type-1 Fuzzy sets*

A fuzzy set describes the degree to which an element belongs to

a set. If we consider  $X$  as a collection of objects ( $x \in X$ ), then a type-1 fuzzy set  $A$  in  $X$  is a set of ordered pairs:

$$A = \{(x, \mu_A(x)) \mid x \in X\} \quad \mu_A : X \rightarrow [0,1] \quad (1)$$

In equations (1-5)  $\mu_A$  is called membership function and maps elements of  $X$  into their membership in the fuzzy set  $A$  (Zadeh & Aliev, 2018).  $X$  usually is considered as universe of discourse and it may contain continuous or discrete space. The basic operations on fuzzy sets are union, intersection, containment and complement. The maximum and minimum is classical fuzzy operator for union and intersection on fuzzy sets. Standard fuzzy logic defines these operations as follows:

1. Union (Disjunction): Union of two fuzzy sets  $A$  and  $B$  generate another fuzzy set  $C$  whose membership function is derived from membership function of  $A$  and  $B$ :

$$\mu_C(x) = \mu_{A \cup B}(x) = \max(\mu_A(x), \mu_B(x)), x \in X \quad (2)$$

The equivalent definition of Union is the smallest fuzzy set which contains both  $A$  and  $B$

2. Intersection (Conjunction): Intersection of two fuzzy set  $A$  and fuzzy set  $B$  generate another fuzzy set  $C$  whose membership function is derived from membership function of  $A$  and  $B$ :

$$\mu_C(x) = \mu_{A \cap B}(x) = \min(\mu_A(x), \mu_B(x)), x \in X \quad (3)$$

$C$  is the largest fuzzy set which is enclosed in both  $A$  and  $B$

3. Containment (Subset): Fuzzy set  $A$  is contained in fuzzy set  $B$  ( $A$  is a subset of  $B$ ) or fuzzy set  $B$  contains fuzzy set  $A$  when:

$$A \subseteq B \Rightarrow \mu_A(x) \leq \mu_B(x), x \in X \quad (4)$$

4. Complement (negation): Complement of fuzzy set  $A$  represents with  $\bar{A}$ .

Membership of  $\bar{A}$  ( $\mu_{\bar{A}}(x)$ ) means the degree to which  $x$  does not belong to  $\bar{A}$

The membership function is represented as:

$$\mu_{\bar{A}}(x) = 1 - \mu_A(x), x \in X \quad (5)$$

### Input and Output Parameters

Analyzing the factors affecting the output, will lead us to the deciding input factors. Parameters can be decided while judging how the primary output, wash time are affected by different constraints. Other output factors which are considered are water level and amount of detergent. The most basic factor in deciding the washing time is the amount of dirt, or if simply put, the amount of clothes. Wash time will also depend on the temperature of water, type of fabric and type of dirt of clothes. The input parameters are discussed in detail as follows:

1. Amount of Dirt: Amount of dirt is directly proportional to the time taken to wash clothes. To measure the amount of dirt, we can simply measure the weight of the clothes put in the washing machine, assuming that practically only dirty clothes would be put in the machine. A simple sensor acting as a weighing machine can quantify the parameter and send it as an input signal.
2. Type of Dirt: Grease based dirt takes significantly higher time in cleaning, and a higher quantity of detergent as compared to non-grease based dirt. The former takes longer time to saturate water as compared to the later one. Saturation time of dirt can be



defined as the time taken to saturate the water with dirt. For this purpose, we will use an optical sensor (Masood, 2017). The sensor will repeatedly check the opaqueness of water in the machine to match with a fixed value. The time taken in achieving the mark, will determine the time of saturation.

3. Temperature of Water: This factor can be measured by a temperature based sensor. Higher temperature of water significantly affects the rate of washing clothes. Higher temperature speeds up the process of soaking the dirt particles from the clothes, and hence speeds up the cleaning process. On the other hand, higher temperature of water weakens the fabric strength. Since one of the objectives of this study is the possible retention of fabric quality, we need to find a trade-off between these two factors i.e. obtaining a fast and clean wash with the resultant weakening of the fabric quality against obtaining a relatively fast and clean wash along with maintaining fabric longevity.
4. Type of Fabric: For the purpose of simplicity, we have classified the types of fabric into cotton-based and non-cotton based; fast-color and non-fast-color. A cotton based fabric needs higher time for cleaning than a non-cotton based fabric. Also, a fast-color fabric needs a milder cleaning agent or less detergent than a non-fast-color fabric.

The output parameters are elaborated below:  
Wash Time, Level of water, Amount and/or type of detergent and color of water are as stated. Other factors are considered constant for this research. This model can accommodate other input (or output) parameters after finding an approximate relation

between the output and the input respectively.

### *Membership Functions of Parameters*

The input and output parameters have to be converted to a fuzzy set. For this, we will find the membership function of each parameter which will give us the fuzziness of the output. For simplicity, triangular membership functions and predefined range are used, but any shape or range is suitable for practical purposes (Masood, 2017). A triangular membership function representing  $[a \ b \ c]$  represents X-coordinates of the three corners of the underlying triangular MF. Membership Functions for Input Parameters -

1. Amount of Dirt - As amount of dirt is measured from the amount of clothes, the weight of clothes is the deciding factor for this parameter. It is assumed an average washing machine has the maximum capacity of 9kgs of clothes, hence making the range 0 to 9. Three membership functions are defined as low  $[0 \ 0 \ 3]$ , average  $[2 \ 4.5 \ 7]$  and large  $[6 \ 9 \ 9]$ .
2. Type of Dirt - Assuming maximum time taken to saturate as 10 minutes, two membership functions can be defined as non-greasy  $[0 \ 0 \ 2]$ , and greasy  $[1 \ 10 \ 10]$ . Here the greasy membership function starts from 1 minute because in a mix of greasy and non-greasy dirt, greasy dirt would be a deciding factor in attaining saturation time.
3. Temperature - Three membership functions are defined as - low  $[30 \ 30 \ 40]$ , medium  $[35 \ 50 \ 65]$  and high  $[55 \ 70 \ 70]$ , with the range of temperature being 30 to 70 degree Celsius.
4. Type of Fabric - A binary classification for cotton and non-

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cotton based fabric is used, hence two membership functions, non-cotton based [0 0 0.5] and cotton based [0.5 1 1] are defined, with 0 to 1 showing the percentage of cotton in the fabric.

#### **Membership Functions for Output Parameters:**

1. Wash Time - Here, wash time includes washing, rinsing and spin time for the sake of unambiguity. Five membership functions are used to define wash time between range 0 to 60 minutes - very quick [0 0 15], quick [0 15 30], medium [15 30 45], long [30 45 60] and very long [45 60 60].
2. Level of Water - The range of water is between 3 to 15 litres, based on maximum average washing machine capacity. Three membership functions defined are low [3 8 8], medium [5.4 9 12.6] and high [10 15 15].
3. Amount of Detergent - Three membership functions are used to determine the quantity of detergent required - less[10 10 55], average[25 55 85] and much[55 100 100]. The range is 10 to 100grams of detergent.
4. Color of Water - this parameter relates to fast color fabrics with non-greasy dirt. The water saturation is not as due to greasy dirt but fabric color removal and it is a factor of the amount or type of detergent.

#### **Designing the Fuzzy Logic Controller**

The fuzzy logic controller will take a set of inputs from the user, and subsequently, produce the best possible subset of outputs. For this, we will use a Mamdani-style fuzzy inference system. The fuzzy logic controller for the smart washing machine would have four important components. The fuzzifier, which would check the incoming signals

coming from sensors to the respective truth value of the parameter, and assign a fuzzy value. All the signals would be converted into fuzzy inputs and aggregated. The resulting fuzzy input set would be cross checked against a knowledge base. The knowledge base contains all possible scenarios of fuzzy input subsets and a corresponding fuzzy output subset, and each output subset represents a certain degree of matching with the output parameters. The matching rule would be used to evaluate the given input case. These steps would be performed by the inference engine. At last, the defuzzifier would convert the fuzzy output subset into a crisp output subset. These crisp values correspond to a particular value at which the output parameters, like water level will be set.

#### **Fuzzy Logic Controller and Its Applications:**

Fuzzy Controllers, compared to classical controllers are capable of utilizing knowledge elicited from human decisions or human operators (Fazlollahtabar & Saidi-Mehrabad, 2015). Fuzzy Logic Controller for Gas Heater was designed using behavioral modeling and then these modules are connected via structural VHDL to control "Valve Angle." (Ahmed & Toki 2016). The fuzzy logic controller for Liquid Level Control was designed using MATLAB for controlling "Valve" and compared with the PID controller. The comparison results show that fuzzy logic controller significantly reduced overshoots and steady state error (Zahir, *et al.*, 2020). In the work of Zhe-Xue & Zhi-Qiang (2007), fuzzy inference was used for determining Wash time. In the design, Membership Function (MF) used was triangular; the inputs of the Fuzzy Controller were Change of Turbidity,

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and the output was Washing Time. In 2009, “An improved Controller Microchip for Washing Machine” that comprises of three linguistic inputs (LIs) - Types of Dirt, Dirtiness of Clothes and Mass of Clothes and the linguistic output (LO) - Wash Time, with 25 rules was designed. (Lohani & Hasan 2009). (Aggarwal, 2011) proposed the Fuzzy Logic Control for Washing Machine having two inputs - Type of Dirt and Different Degree of Dirt and the output was Wash Time with the inference engine which provides 9 rules for the FLC. The input-output relation is determined by using Fuzzy Interface Unit.

### Fuzzy Control of Washing Machines

In the past, a user had to select the type of wash in a washing machine manually; the amount of water and the duration of the wash cycle had to be keyed in before the washing process began. Today, automatic washing machines employ what is known as fuzzy logic to automate this process. Fuzzy logic is a mathematical system that is capable of analysing analog input values and converting them into logical variables.

Fuzzy logic is an important development in washing machines as it helps save water. Machines that employ fuzzy control are able to calculate the effect of a number of variables and decide the right settings for the wash. The variables that fuzzy control evaluates in a washing machine include the weight of the clothes in the machine, the type of dirt, water and electricity required for an optimal wash.

### Fuzzy Logic Structure

The basic elements of fuzzy logic; Fuzzy inputs, outputs, rules and defuzzification; are shown in Figure 1. Fuzzy take the information from a

system; which is in normal language; and converts it to values. The values of input quantities, which are associated with of membership functions, are given in form of words such as small, smallest (Ahmed & Toki, 2016). Input and output variables of fuzzy system are determined and their values i.e. less, much, hot and cold etc. are being selected.

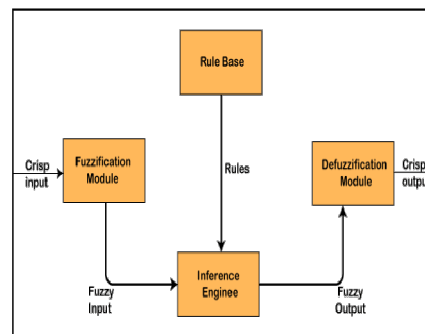


Figure 1: Structure of a fuzzy logic system (Ahmed & Toki, 2016).

Afterwards, rules are being developed and by using those rules input and output relationship is developed. Outputs are being produced by using fuzzified inputs and rules which are being determined. Those fuzzified outputs must be converted to real values so that they can be used in real systems. This whole process is known as defuzzification (Tuncer & Cirpan 2022).

### Development of Fuzzy Controllers for Washing Machine

When one uses a washing machine, the person generally selects the length of wash time based on the amount of clothes he/she wish to wash and the type and degree of dirt cloths have. Mohammed & Alhaddad (2013) proposed a paper to optimize wash time of washing machine using fuzzy logic. They described the procedure that can be used to get a suitable



washing time for different cloths by using only two variables.

The two inputs are:

1. Degree of dirt
2. Type of dirt

The fuzzy controller takes two inputs (as stated for simplification), processes the information and outputs a wash time. How to get these two inputs can be left to the sensors (optical, electrical or any type). We assume that we have these inputs at our hand. The degree of dirt is determined by the transparency of the wash water. The dirtier the clothes, less transparent the water being analysed by the sensors is. On the other hand, type of dirt is determined by the time of saturation, the time it takes to reach saturation. Saturation is a point, at which there is no more appreciable change in the color of the water. Degree of dirt determines how much dirty a cloth is. Whereas type of dirt determines the quality of dirt. Greasy cloths, for example, take longer for water transparency to reach transparency because grease is less soluble in water than other forms of dirt. Thus a fairly straight forward sensor system can provide us the necessary input for our fuzzy controller.

### ARTIFICIAL NEURAL NETWORK REVIEW

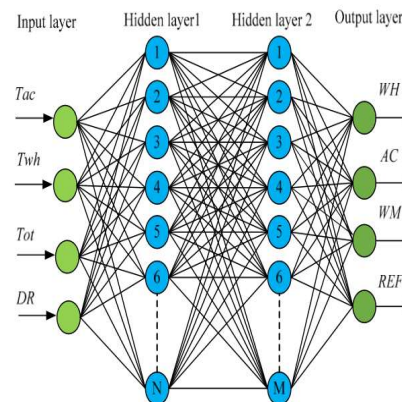
Artificial Neural Network System (ANNS) is a class of networks that are functionally equal to fuzzy inference systems. This section present ANN networks and explained as well as the architecture of ANNS and how this system works.

### Application of Artificial Neural Network

Towards enabling smart technologies at the household level, a home energy management system

(HEMS) plays an important role for efficient operation of home appliances coordinated by load management under residential demand response (DR) strategies (Safdarian, *et al*, 2014). DR is one of the most cost effective and reliable techniques used by utilities for load shifting and scheduling. Through DR program, power utilities and homeowners can get information about dynamic price signals and home load profiles by using smart meters (Palensky & Dietrich 2011). The home energy management controller is proposed using artificial neural network (ANN) to predict the optimal ON/OFF status of the home appliances.

An ANN is information processing algorithm which models non-linear systems and tries to simulate the human brain. It has a unique capability especially with the complex nonlinear relationships between system input and output which tackle any complex nonlinear functions through training. In this paper, a feed-forward neural network type and Levenberg–Marquardt (LM) training algorithm are chosen for training the ANN in the MATLAB toolbox as shown in Figure 2.



**Figure 2.2** Architecture of the ANN (Palensky & Dietrich 2011).



The ANN structure consists of two hidden layers, four input ( $T_{ac}$ ,  $T_{wh}$ ,  $T_{ot}$ ,  $DR$ ) and four outputs ( $AC$ ,  $EWH$ ,  $WM$ ,  $REF$ ). The actual training data for the ANN are generated from the simulation models. From figure 2, the inputs are the room temperature, ( $T_{ac}$ ), is in  $^{\circ}C$ , temperature of electrical water heater, ( $T_{wh}$ ), demand response signal ( $T_{ot}$ ) and total power consumption, ( $DR$ ). On the other hand, the outputs of the ANN are the signals to turn ON or OFF the four home appliances that include  $AC$ ,  $EWH$ ,  $WM$  and  $REF$  according to the customer lifestyle and priority of appliances.

### HYBRID SYSTEM

The hybrid systems of interest contain two distinct types of components, subsystems with continuous dynamics and subsystems with discrete dynamics that interact with each other. Such hybrid systems arise in varied contexts in manufacturing, communication networks, auto-pilot design, automotive engine (Hussain, *et al.*, 2022). A hybrid system is a dynamical system that exhibits both continuous and discrete dynamic behavior - a system that can both flow (described by a differential equation) and jump (described by a state machine or automaton). Often, the term "hybrid dynamical system" is used, to distinguish over hybrid systems such as those that combine neural nets and fuzzy logic, or electrical and mechanical drivelines. A hybrid system has the benefit of encompassing a larger class of systems within its structure, allowing for more flexibility in modeling dynamic phenomena. In general, the state of a hybrid system is defined by the values of the continuous variables and a discrete mode. The state changes either continuously, according to a flow condition, or

discretely according to a control graph. Continuous flow is permitted as long as so-called invariants hold, while discrete transitions can occur as soon as given jump conditions are satisfied. Discrete transitions may be associated with events.

### Neuro-Fuzzy Systems

According to (De Campos Souza, 2020), the term neuro-fuzzy system refers to combinations of neural networks and fuzzy systems which, in the literatures are given several different taxonomies such as neuro-fuzzy, neural-fuzzy or fuzzy-neuro systems. In this study, we shall adopt and give a meaning to the term neuro-fuzzy, which is currently the most popular of the three aforementioned terms.

This work describes the notion of a neuro-fuzzy system, examines how to represent a fuzzy system in a neural network-like architecture and discusses an implementation of a neuro-fuzzy system in the area of control theory with particular application to the washing machine.

### WASHING MACHINE

Laundry is an essential activity in every household. Traditional washing involves soaking, beating, scrubbing, rinsing dirty textiles and of course, drying them. The whole process often took an entire day of hard work, particularly when ironing of the washed clothes is included. Technological advancement ushered in the washing machine to take the drudgery off the typical washing process thus saving time and energy. Automatic washing machine frees the user's hands, so that the user can better allocate the time to do other work, and so, improve overall work efficiency (Agarwal, *et al.*, 2016).

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Good washing machine apart from saving energy should also carry out the washing process efficiently enough to maintain clothes' service life but, the latter is not usually the case. In a wash cycle, the simplest washing machines may simply agitate clothes in water, and automatic machines may fill, heat, empty water, and spin the washed clothes for faster drying. Most washing machines remove substantial amounts of water from the laundry at the end of a wash cycle, but do not completely dry it.

Around late 19th century, a couple of thousand patents were granted in Great Britain and America for a variety of washing appliances. These early washers used either rotating drums, gyrators or dollies to agitate the clothes and had to be filled with heated water for any given wash cycle (Tuncer, 2022). Tandale, et al., (2015), designed washing machine for cleaning of small components. Eyere, et al., (2017) also modeled and designed a portable washing machine with the use of advanced parts like microcontroller and sensors that are not cost effective. After the World War II, numerous appliance manufacturers were given permission to undertake the research and development of washers during the war years. Many took the opportunity to develop automatic machines, realizing that these represented the future for the industry. A large number of manufacturers introduced automatic machines (mainly of the top-loading type) in the late 1940s and early 1950s. An improved front-loading automatic model, the Bendix Deluxe was introduced in 1947. General Electric also introduced its first top loading automatic model in 1947; a machine, which had many of the features that are incorporated into modern machines. Several manufacturers produced semi-

automatic machines, requiring the user to intervene at one or two points in the wash cycle. A common semi-automatic type included two tubs: one with an agitator or impeller for washing, plus another smaller tub for water extraction or centrifugal rinsing (Hatagar and Halase, 2015).

## CONCLUSION

The proposed scheme solves the problem related to consumer needs by satisfactorily supplying the demand side while saving cost, time and stress. However, this kind of systems requires an intelligent controller to manage the power flow and sustain the system. We discussed the various types of fuzzy logic controllers (FLC) having different types of input and output lead to get precise wash time and reduce energy cost and lot of time along with artificial neural network (ANN). The conventional method required the human interruption to decide upon what should be the wash time for different cloths which makes the machine much more automatic and represents the decision taking power of the machine. A more fully automatic washing machine is straightforward to design using fuzzy logic and hybridized technology in future. FLC attempts to capture intuition in the form of IF-THEN rules, and conclusions are drawn from these rules. Based on both intuitive and expert knowledge, system parameters can be modelled as linguistic variables and their corresponding membership functions can be designed. Fuzzy logic can make development and implementation much easier. It does not require intricate mathematical models, only a practical understanding of the overall system behavior. For washing machines, FLC is almost becoming a standard feature.

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