

## **Fuzzy relations – fuzzy rules – Defuzzification**

### **General aspects**

Treating information using fuzzy logic has developed over the past 50 years, this mathematical theory being an interesting tool for researchers to solve complex scientific and technical problems. In these years, research has always yielded new results in the field of advanced fuzzy logic applications. Fuzzy logic has found applications in various sectors of human activity, such as, industry, business, finance, medicine, and in many scientific fields such as, machine learning, big data technologies, fuzzy control, expert systems, dynamic fuzzy neural networks, and others. Fuzzy logic provides a different way of dealing with mathematical calculus problems. In the case of fuzzy logic, conventional algorithms are replaced by a series of linguistic rules of the If (then) condition (conclusion). Thus, a heuristic algorithm is obtained, and human experience can be taken into account in the subject matter of the calculation.

As advantages of fuzzy logic are useful in the calculations, we can list the following:

- Development of fuzzy controllers without a complex mathematical modelling of the problem addressed
- The possibility of implementing “human linguistic knowledge” on the application solved.
- The possibility of using fuzzy logic for complex, nonlinear, and variable relations
- The possibility of performing exceptional treatments, that is, changing the calculation strategies as a result of a change in the course of application
- Possibility of using it when making decisions specific to artificial intelligence
- Interpolation among rules, usable in exceptional treatments to change the scope of application

### **Fuzzy logic algorithm**

#### **Fuzzification of Input**

In the fuzzification process, a real scalar value changes into a fuzzy value. Arrangements of fuzzy variables ensure that real values get translated into fuzzy values. After translating those real values into fuzzy values, the possible outcome is called “linguistic terms”. The input linguistic variables for Fuzzy Logic Temperature Controller

(FLTC) suggest two things. First it shows linguistically the difference between the set point and second it also express the measured and calculated signals from a temperature sensor. Input to FLTC is  $\text{Error} = (\text{Set point} - \text{Temperature sensed})$ . For fuzzified input, two functions including trapezoidal and triangular are used. To

determine the range of fuzzy variables according to the crisp inputs is the primary requirement for proper running of the fuzzier program. Temperature difference which was sensed previously, is restricted to positive value. The following fuzzy sets are used: NEG =negative, SNEG=small negative, ZERO= zero, SPOZ=small positive, POZ= positive. Table suggests the Membership function for input linguistic variable. Membership functions for input linguistic variable.

Sl.No	Crisp Input Range ( Error = Set Point – Current Temperature )	Fuzzy Variable Name
1	-15 to -50	NEG
2	0 to +30	SNEG
3	-15 to +15	ZERO
4	0 to +30	SPOZ
5	+15 to +50	POZ

The output linguistic variables express linguistically the applied values to the FLTC actuators for temperature control. Present study considered typically one output variable, which is a PWM Wave for fan and Heater. In this case it is essential to attribute fuzzy memberships to yield variable, which has to be identical to the input variable. The fuzzy sets used for PWM Wave are as follows: Z = zero, L = large, M = medium, H = high, VH = very high.

The outcome of defuzzification has to be in a numeric form so that it defines the PWM Wave of the MOSFET which is used to force the fan and heater. Out of the number of ways to execute defuzzification; in the given scenario, weighted average

defuzzification is the best technique to obtain the crisp output.

The temperature System has a Heater coil and a Fan. The heater assembly consists of an iron plate placed at a distance from a nichrome coil. When current passes through the coil it gets heated and in turn raises the temperature of the iron plate. We are interested to alter the heat generated by the coil and also the speed at which the fan is operated. The amount of power which is to be delivered to fan and heater can be assured by several methods. We are using the PWM technique.

Modulation of the square wave which is in duty cycle is done by Pulse Width Modulation action.

$$\text{Duty cycle} = T_{\text{ON}} / T$$

Where;  $T_{\text{ON}}$  : ON time of the wave

$T$  : Total time period of wave Power delivered to the load is proportional to  $T_{\text{ON}}$  time of the signal.

This is used to control the current flowing through the heating element and also speed of the fan.

An 80% duty cycle indicates that the fan is ON 80% of the time and OFF 20% of the time. The relation between the speed of the fan and the value of the applied pulse width modulation duty cycle is in direct proportion. In other words, a high duty cycle will produce high speeds and a low duty cycle will produce low speeds.

### Water Level Controller using Fuzzy Logic

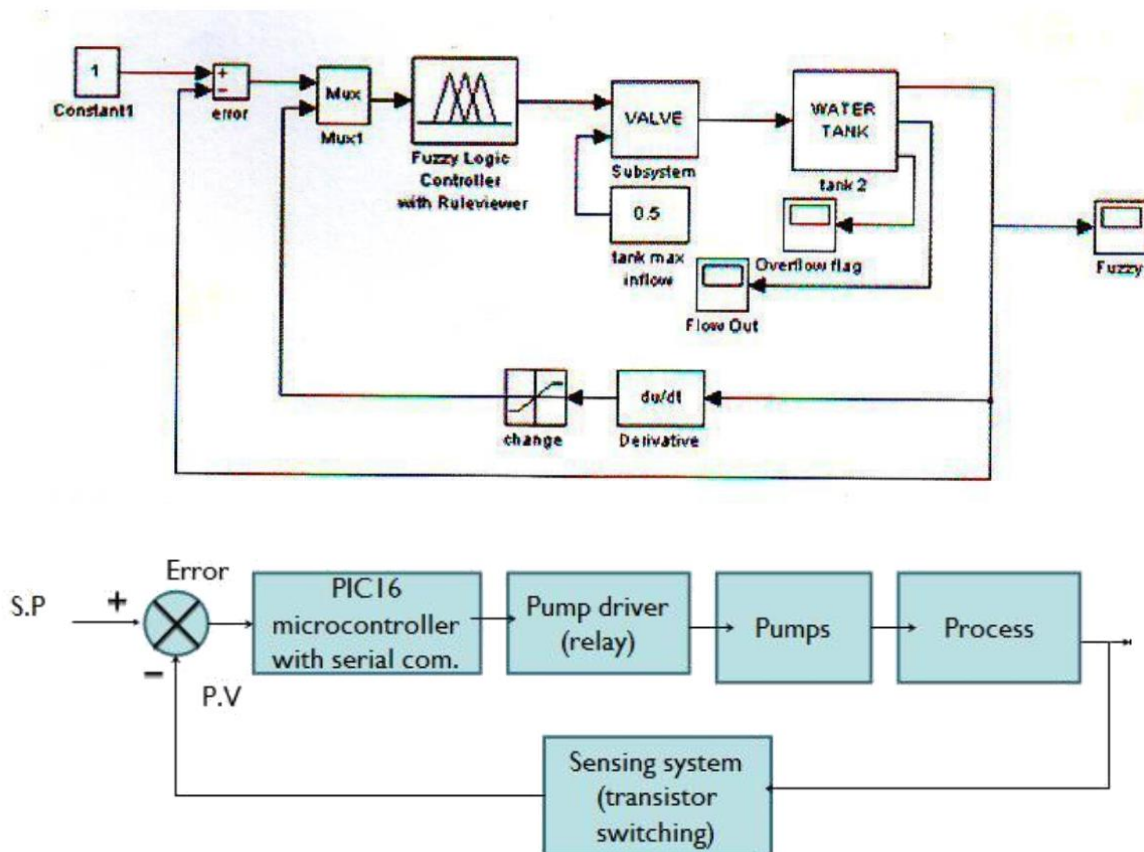


Fig.1: Block diagram of water level controller by using fuzzy logic

The objective is to control the water level in the tank according to the set point given by the user through the user interface by measuring the present level, computing the error, applying fuzzy logic and thereby draining or feeding water into the tank accordingly.

The sensing system used is based on transistor switching principle. The base of a transistor, connected to a resistor, is given at a certain level inside the tank. A 5V power supply is connected to the collector of the transistor and this line is given to the base of the tank. The emitter of the transistor is grounded. When the water level has not reached the level at which the transistor base line is attached, the circuit is open and hence, there is no current to the base. The transistor is now in cut off condition with no collector current and the entire voltage is across the transistor. When the water comes in contact with the base line of the transistor, the switch is closed and collector to emitter voltage becomes negligible and there is a collector current. This change in voltage is considered by the microcontroller and the current level is sensed. In order to detect the various levels across the tank, 8 such circuits are present to detect 8 different levels. It should be noted that the number of levels can be increased or decreased as and if required. Fig. 2 shows the circuit diagram for sensing one level. The same circuit has been developed eight times for eight levels.

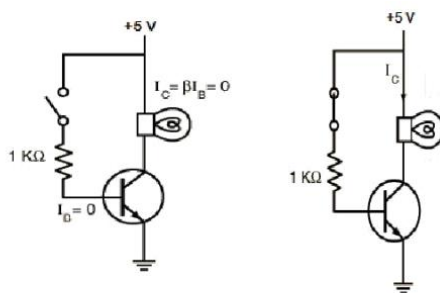


Figure. Transistor Switching (a) When switch is open (b) When switch is open

There are 3 steps in fuzzy logic implementation: Fuzzification, Development of Rule Base, Defuzzication.

## **Fuzzification**

The following Table I, Table II and Table III provide the ranges for the input and output membership functions respectively. The error (set point - process variable) ranges are the input membership functions. The percentage closing of the control valves (drain and feed) are given as the two output membership functions.

TABLE I: Input membership functions

Error	Tag name
-80 to -50	VLN (very large negative)
-60 to -30	LN (large negative)
-40 to -10	N (negative)
-20 to 10	SN (small negative)
0 to 30	VSP (very small positive)
20 to 50	SP (small positive)
40 to 70	P (positive)
60 to 80	LP (large positive)

TABLE II: Output membership functions of the feed valve

Percentage closing of valve	Tag name
0 to 30	OVF1 (open very fast)
20 to 50	OF1 (open fast)
40 to 70	O1 (open)
60 to 90	OS1 (open slowly)
80 to 100	OVS1 (open very slowly)

TABLE III: Output membership functions of the drain valve

Percentage closing of valve	Tag name
0 to 30	OVF2 (open very fast)
20 to 50	OF2 (open fast)
40 to 70	O2 (open)
60 to 90	OS2 (open slowly)
80 to 100	OVS2 (open very slowly)

**Rule base:** There are 8 fuzzy rules which relate the input and output membership functions. These do not conflict such that one output is picked for each possible input combination. The rules are as follows:

1. If (error is VLN) then ((drainvalve is OVF2) and (feedvalve is OVS1))
2. If (error is LN) then ((drainvalve is OF2) and (feedvalve is OVS1))
3. If (error is N) then ((drainvalve is O2) and (feedvalve is OVS1))
4. If (error is SN) then ((drainvalve is OS2) and (feedvalve is OVS1))
5. If (error is VSP) then ((feedvalve is OS1) and (drainvalve is OVS2))

6. If (error is SP) then ((feedvalve is O1) and (drainvalve is OVS2))
7. If (error is P) then ((feedvalve is OF1) and (drainvalve is OVS2))
8. If (error is LP) then ((feedvalve is OVF1) and (drainvalve is OVS2))

*Defuzzification:* The defuzzification method used is mean of maximum (MOM) method. This method computes the average of those fuzzy outputs that the highest degree.

The entire fuzzy implementation along with the conversion of the defuzzified valve outputs to pump on-off controls is coded in PIC16 microcontroller in Embedded C programming language

The microcontroller majorly has 5 ports, namely A, B, C, D, E. The ports A and E are generally used for analog to digital data conversion. The port D is generally used for data and control functions of LCD. The port B has internal pull up resistors and hence there is no need to connect any more resistors with it. This port is used as the input port for the eight level transistor switching sensing system. This port is by default high, and hence is activated by ground signals. The port C has eight pins, of which pin 5, 6 are used for serial communication for transmission and reception respectively. The port D is used as the pump driver (relay) inputs.

The four feed and four drain pumps are controlled by a 8-channel relay board. The input of the relay board comes from the port D of the microcontroller. The output of each relay has 3 pins, namely NO (normally open), C (common), NC (normally closed). One of the wires of the power supply of each pump is connected to NO of each relay. The other wires of the power supply of all the pumps are connected together and this provides a connection for one of the pins of a two pin plug which is connected to AC mains. The other pin of the two pin plug provides connection for all the C pins of all the relays. When a relay receives an input from the microcontroller, the coil inside it gets energized, which then closes the contact pin NO and the circuit is complete.

## **Summary on Defuzzification**

**Defuzzification** is the process of producing a quantifiable result in Crisp logic, given fuzzy sets and corresponding membership degrees. It is the process that maps a fuzzy set to a crisp set. It is typically needed in fuzzy control systems. These will have a number of rules that transform a number of variables into a

fuzzy result, that is, the result is described in terms of membership in fuzzy sets. For example, rules designed to decide how much pressure to apply might result in "Decrease Pressure (15%), Maintain Pressure (34%), Increase Pressure (72%)". Defuzzification is interpreting the membership degrees of the fuzzy sets into a specific decision or real value. The simplest but least useful defuzzification method is to choose the set with the highest membership, in this case, "Increase Pressure" since it has a 72% membership, and ignore the others, and convert this 72% to some number. The problem with this approach is that it loses information. The rules that called for decreasing or maintaining pressure might as well have not been there in this case. A common and useful defuzzification technique is center of gravity. First, the results of the rules must be added together in some way. The most typical fuzzy set membership function has the graph of a triangle. Now, if this triangle were to be cut in a straight horizontal line somewhere between the top and the bottom, and the top portion were to be removed, the remaining portion forms a trapezoid. The first step of defuzzification typically "chops off" parts of the graphs to form trapezoids (or other shapes if the initial shapes were not triangles). For example, if the output has "Decrease Pressure (15%)", then this triangle will be cut 15% the way up from the bottom. In the most common technique, all of these trapezoids are then superimposed one upon another, forming a single geometric shape. Then, the centroid of this shape, called the fuzzy centroid, is calculated. The x coordinate of the centroid is the defuzzified value.

## References

"Fuzzy Logic". Stanford Encyclopedia of Philosophy. Bryant University. 2006-07-23. Retrieved 2008-09-30. Zadeh, L.A. (1965). "Fuzzy sets". *Information and Control*. 8 (3): 338–353

Deng H, Deng W, Sun X, Ye C, Zhou X. Adaptive Intuitionistic Fuzzy Enhancement of Brain Tumor MR Images. *Sci Rep*. 2016 Oct 27

Neural Networks, Fuzzy Logic and Genetic Algorithms Aug 30, 2004 by S. Rajashekar and G.A. Vijayalaxmi