FUZZY LOGIC: A MODERN APPROACH TO CONTROL SYSTEMS ARCHITECTURE

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Abstract

Control systems have been in existence for quite a long time now. The oldest and unarguably the best of these is the human brain. Some popular control methodologies are PID control, Bayesian control, neural networks, etc. The drawbacks of these are however lead by a striking point that all of them are either based on Boolean or multi-valued logic, which is no more than threshold or point to point logic. This work tends to introduce fuzzy logic control as a paradigm shift, this control method would to a large extent provide a physical model of the human brain. The distinction being that it is not only multi-valued logic, but also a 'degree' based logic. This paper would give a basic overview of a fuzzy control system and its physical implementation considerations.

Keywords: fuzzy logic, fuzzification, de-fuzzification, membership function

I INTRODUCTION

People do not require precise numerical input information and yet they are capable of highly adaptive control – Lotfi. A. Zadeh

Fuzzy logic is not such a new concept to thinking, it is actually the way the human brain work, albeit an advanced level though. however, it has not attained the level of publicity that primitive and rigid control methodologies like PID control have garnered. It is an improvement on previously known logic formats of Boolean logic where only two truth values (TRUE/FALSE or 1/0) are possible, and in multi-valued logic where a defined number of truth values are possible. Fuzzy logic tends to not only have a multi-valued truth values but also to associate to everything or every truth value a degree to which it is true to [1]. This is the method the brain uses to assign a level of importance to every situation it encounters. Take as an example the method the brain uses to analyze and to classify the degree of light intensity through the eyes. Another example to add to the above; is in the case of unemployment rates. In a country at a particular period. Unemployment rates greater than 10% are described as high and below 10% said to be low unemployment rates. so unemployment rates of 11% and 20% are both high, but one can say that an unemployment rate of 11% is 'just' high, and that of 20% is 'quite' high and that of 27.3% 'very' high. The terms quite, just, and very, as used above describes the extent of high unemployment rate, while terms as low and high describes the level of unemployment rates. The above gives a simple breakdown of how the human brain and fuzzy logic reasoning works. Fuzzy logic is a way of modelling the human brain to a reasonable extent. Control systems as we know, deals with systems whose functions are monitoring and manipulating the physical variables of a system to maintain a favorable or desired working condition for such a system. An example is a system to maintain the speed of a dc motor. thus with the advent of fuzzy logical techniques these controls can be made more human like since it has always been our aim to develop systems that will virtually replace us and spare us the hard work.

II FUZZY LOGIC CONCEPT

Fuzzy as a word in the English dictionary is defined as a state of being vague, imprecise, not clear, blurry or unfocussed. Fuzzy logic is thus a form of knowledge or logical representation suitable for notions and situations that can't be properly or precisely defined [2]. In our normal logic reasoning (Boolean or multi valued logic) the truth values can either be one or many values respectively for Boolean and multi valued logic respectively.

In fuzzy logic however, not only is the truth multi valued but also these truths have degrees or extents to which they are true to [2]. This degree analysis gives it the distinction and thus the name fuzzy. In fuzzy logic 'everything' is a matter of degree and not just truth [3]. In Boolean, there is some form of degree analysis, but only the two extremes of degrees are considered that is absolute truth or false.

As an example let's take a speed analysis of a speed range of 0 – 100 m/s. A normal person can comfortably infer that a speed of 0 – 25 m/s is slow or low speed, around 25 – 70 m/s is termed medium speed, while speeds of 70m/s and above are classified high speed. Thus the above person has successfully 'degreefied' the given speed range into low, medium and high speeds. Within these degrees however, say for the low speed region, we know that 0 m/s is way slower than 20 m/s, thus it is slow to a much greater extent or degree than that of 20 m/s but both are classified low speeds. from the below graph we represent the above argument, thus the slow speed region speed components have been assigned degrees, this was also done for the rest of the other regions. In Boolean or classical as stated earlier the only concern is whether an element is a member or not of a particular set. An example using the above speed methodology, gives that 50 m/s is the ideal medium speed from the given range hence a degree of full membership to the medium range thus every other speed value that are not up to that full membership status are taken as non-members and their relative nearness or farness from that ideal value is not considered.

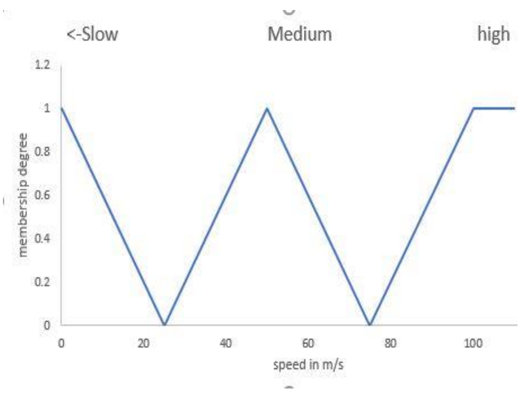


Fig 1: Speed degree analysis.

A. *Why fuzzy logic in systems?*

This is a necessary question by any reasonable control engineer. The glaring answer however is why not? A comparative example of the two can be taken from the control of air conditioning systems using temperature and humidity changes as control inputs. In the 'old' way the temperature and the humidity changes value only tells the controller to switch to a fixed or static pre-set value in the air conditioner.

Using the fuzzy way, a temperature and humidity change are evaluated to degrees first, example any given temperature value will be evaluated to know to what degree warm, hot, or cold it is. Then using appropriate means give out control value of the same degree to match and completely neutralize the temperature conditions of the room. This gives control systems a human face as against the rigid methodologies of the 'old/normal' ways. Conclusively we can come to a conclusion that while in the normal methods, pre-set output values are triggered once a corresponding threshold is crossed. In fuzzy method, there are no pre-set output values, outputs are unique to every different input.

To develop a fuzzy system only three basic stages are required namely;

1. Understanding of the physical system and control requirements.
2. Design of the control using fuzzy rules alone
3. Simulate, debug, and implementation. [4]

This as compared with the old paradigm were over 8 stages which included stages like the tedious mathematical modelling and analysis stage which has been totally bypassed.

B. Fuzzy logic vs Probability theorem

Arguments linking fuzzy logic with probability as being the same thing has always been in existence right from the time of the publication of the first paper on fuzzy sets by Dr. Lotfi Zadeh in 1965. Fuzzy logic and probability are both concerned with fuzziness or impreciseness or even uncertainties.

In fuzzy logic, the area of concern is 'to what extent or degree' is a situation or term or value true to in relation to the given universe of discuss, probability on the other hand is the measure of the likelihood of an event occurring from other possible events. Thus in Zadeh's own words "fuzzy set theory is boundary oriented while probability theorem is measure or volume oriented" [5]. Taking the case of the universe of height, a short man by standard is below 4.9 ft., thus in fuzzy logic view we will be trying to classify people who fall under this category to various degrees of shortness (that is to get the various boundaries of height to which a short man cannot pass), and also to put into boundaries or classes those classified as average, tall and short heights. Probability on the other hand aims to get the number or volume of elements in our case people who fall into the different classes of heights defined by each boundary.

C. Fuzzy sets in relation to classical set theory

Classical Sets: A set is a collection of related objects or elements in a given range within a sharp boundary and a form of common characteristics [6]. The above definition tends to only look at sets of distinctive objects, elements etc. thus only whole numbers can be dealt with this is of course the classical view and this is of course what makes it very limited. An example of this reasoning is in taking the set of people within 0-1 years. Classically looking at this we can only decipher two members of the set, people of 0year(s) and 1 year(s) written as {0,1}. But as humans we know we reason a bit more advanced than this, in that people might have ages as 0 years 5 months and so on. So how do we cover this level of reasoning? Enter fuzzy sets.

Fuzzy Sets: the breakthrough in use of fuzzy logic as a control methodology, hinged on the proposal of a fuzzy set theory by prof Lotfi Zadeh in 1965.fuzzy sets are just a generalization of the standard classical set [7][8]. Thus almost all the properties peculiar to classical sets also applies to fuzzy sets. To discuss fuzzy sets in particular, we look at them from two main perspectives that distinguishes them from the regular classic or crisp set;

1. Boundary specifications.
2. Membership specifications.

***Boundary Specifications*:** This is one of the main distinguishing factors of fuzzy sets from classical or crisp sets as enumerated above. In classical sets it is either an element is a member of a set or it is not. Example if high temperature is defined as 80°F and above then 70°F or 79°F are clearly not considered as high temperatures in classical sets, though they may somewhat be close to 80°F. This gives classical sets sharp boundaries [9], since members have membership degree of 1 and non-members have degrees of membership of 0 as rep in fig 2 below.

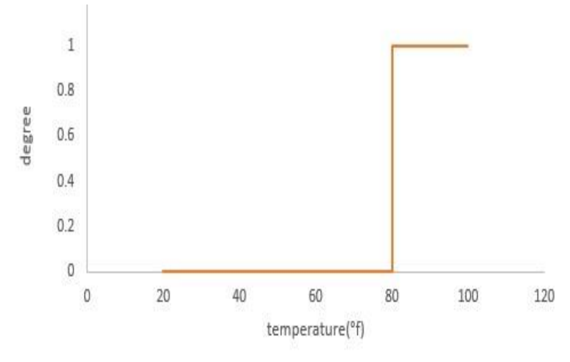


Fig 2: classical set degree specifications

In fuzzy sets however (as humans rightly do due to imprecision) one might see that 79°F is actually very close to 80°Fand might use terms as slightly high temperature translating this to degree might give a degree of 0.94 but still is not a full member but the closeness to the required set has been recognized this is rep in fig 3.

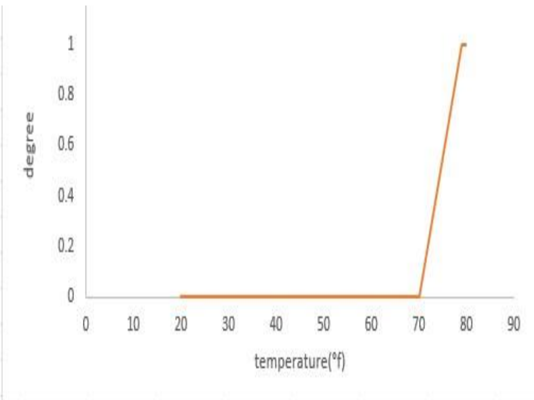


Fig 3: fuzzy set degree specifications

Membership Specifications: another dimension to the fuzzy set situation is in area of specified number of related sets an element is restricted to be a member of. An element in classical set theory can't be a member of more than one related sets in the same universe of discourse. Example; a particular height in classical sets can't belong to both tall and short height (this is due to the fact that the nature of the classical sets classification of using only 1/0). In reality, however we might have come across situations where we described as 'not too tall 'and not 'too short'. This is mainly due to imprecision on our parts as human, but still this vague explanation of the person can give a good description of the person's height. So in fuzzy logic an element can belong to 2 fuzzy sub sets but to varying degrees of membership to both set (the sum of the degree of membership to the two related should sum to 1 only when the membership degree to either of the set is not zero). Thus a person can be tall to x degree and y degrees short as shown below fig 3 and 4 hypothetically.

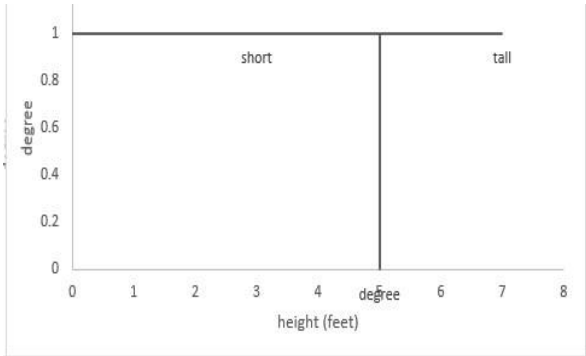


fig 4: classical membership

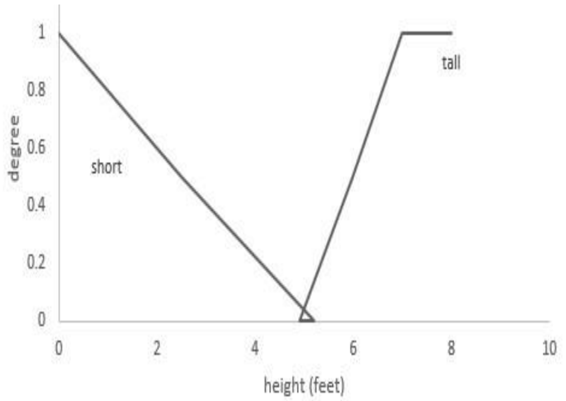


Fig 5: fuzzy membership assertion.

It should be noted that the above is just for explanation purposes, in real human situations one may get fuzzy sets of very short, moderately short, average, tall and very tall people. This assertion is also true for other assertions like speed, temperature etc.

D. Membership function and linguistic variable membership functions

In real life situations, the data available in nature is analogue in nature. In the classical or Boolean methods, we only have two different degrees of membership to a specified set 1/0 these corresponds to the logical states, where either the element is a member or not.in fuzzy methods, we group the available real world data to fuzzy sets, this can be done using membership functions. Membership function is considered a curve of the degree of truth of a given input value [10]. It is a mapping function that maps input values (available analogue values) to degrees in a particular fuzzy set [10]. That is to say that the extent to which a value or element belongs to a particular set is defined by the membership function. The fuzziness of a fuzzy set is characterized by its membership function [11].

In classical logic only two degrees of membership 1/0 are possible and corresponds to the number and identity the of logic states in the classical set domain, as stated earlier. In fuzzy logic, considering the membership function we have an infinite state of logical values between 0-1. Since there is an infinite degree of membership, the membership functions are in form of curves and it is a plot of degree of membership against values or elements. There are several types of membership functions available and possible, some are depicted below in fig 6.

Linguistic Variables

Linguistic variables are input or output variables of the system whose values are words or sentences from a natural language, instead of numerical values [12]. A linguistic variable is generally decomposed into a set of linguistic terms [12].

Example: consider an air conditioner system controlled by monitoring of an input of temperature (t). temperature is the linguistic variable representing the temperature of the room. To qualify the temperature terms like hot and cold are used in real life, these are the linguistic values of the temperature. Then T(t) = {too-cold, cold, warm, hot, too-hot} can be the set of decompositions for the linguistic variable temperature. Each member of the decomposition is called a linguistic term and can cover a portion of the overall values of temperature or in summary it can be a fuzzy set.

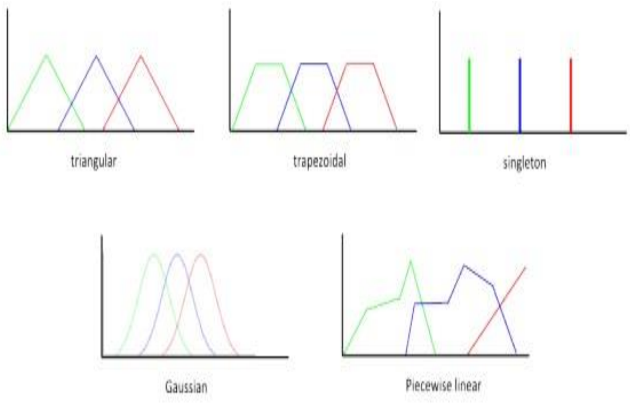


Fig6: different types of membership functions.

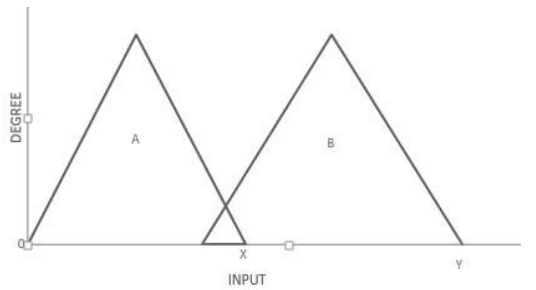
III THE FUZZY CONTROL SYSTEM ARCHITECTURE

A. Fuzzification

As stated in section 1.5, the only available form of data is the analogue signal (data). This is however inappropriate for use by a machine or a system and as such, as seen from the block diagram, a sensor converts this to discrete digital formats. This input is then fed to the Fuzzification unit (also known as the fuzzifier [13]) of the system to convert it to fuzzy form. Theoretically, the operation of the fuzzifier can be summarized as the operation of the membership function on the input, since the membership function is the mapping function that converts the crisp or normal values to fuzzy set. Thus the membership function resides here to assign degrees and belongingness to particular and appropriate fuzzy sets.

If then, the membership function residing here was a triangular membership function shown in fig 7a below, with the range of inputs given as shown. If an input value of x is gotten from the sensor, then the mapping is done as shown in fig 7b. To get the appropriate degree of membership for x and also its matching fuzzy set.

A



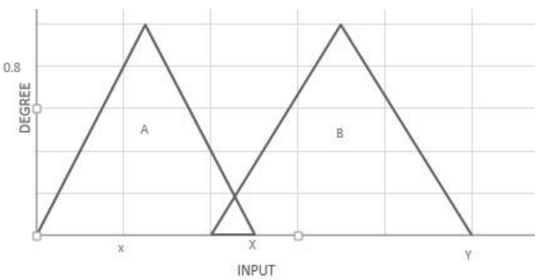


Fig 7 (a) the membership function of the defined input. (b) the mapping of 0.8 degree to the input.

Thus to fuzzy set an element x has a degree of membership of 0.8 and to fuzzy set by a degree of membership of ‘0’ (not a member).

B. Inference block/engine and rule base

This is the decision making block of a fuzzy based control system. Since fuzzy reasoning is similar to human reasoning the question becomes, how do we model a brain-like control system to take decisions as the brain does? The question has a very simple answer, take an example; a man, resting in his home on a hot afternoon with the air conditioner set to the coldest temperature.

Suddenly comes a weather change and the rain starts to pour down, a rational human being senses this and tunes the air conditioner to a hotter temperature for warmth. Taking the above we can deduce that for human it is already set in our sub-conscious that ‘IF’ THE TEMPERATURE is cold then we search for means to keep the body warm and vice-versa. We can decipher from the above that the human brain works based on a logical IF … THEN … pre-set rules of operation. Thus the fuzzy system is operated based on a set of fuzzy IF … THEN … rules defined for the conditions peculiar to the system. These rules are stored in the rule based of the inference system. Depending on the number of input to the system, a typical rule may look like;

IF A AND B THEN DO C

IF A OR B THEN DO C

IF A NOT B THEN DO C

Were all conditions before the ‘THEN’ are known as conditions, and those after the ‘THEN’ are the consequent [14]. The conditions are for the states of the input, while the consequent corresponds to the output. Thus for the above we have a one output two input system.

A practical example is a control system for an air conditioner. For these we wish to use the temperature and relative humidity (the amount of moisture content of the atmosphere at every particular point in time) to control the output of the air conditioner.so, for the described under temperature we might we might have linguistic values of hot and cold with linguistic terms of very-hot, hot, warm, cold and very cold. For the relative humidity input we only have 3 linguistic term or fuzzy sets, high relative humidity, medium relative humidity and low relative humidity. Thus from the above we can have the following set of rules.

IF TEMPERATURE IS A AND RELATIVE HUMIDITY IS B THEN OUTPUT IS C

A) i. very cold B) i. low C) i. hot

ii. very cold ii. medium ii. hot

iii. very cold iii. high iii. warm

. .

This can be viewed better in a look-up table as shown in fig 8

RELATIVE HUMIDITY/TEMPERATURRE	VERY COLD	COLD	NORMAL	HOT	VERY HOT
HIGH	warm	normal	cold	cold	very cold
MEDIUM	hot	warm	normal	cold	very cold
LOW	hot	hot	warm	normal	normal

Fig 8: the look-up table.

C. Defuzzification

This is the reversal of the process of Fuzzification. That is the conversion of the fuzzy set values gotten from the inference block back to useable formats of real world problems. To do this, the membership function of the output is called upon to help, this time instead of going from value to degree we go from degree to value. The gotten value is then supplied to an actuator for the proper control actions. In general, the fuzzy logic system is a nonlinear mapping an input data (feature) vector into a scalar output [15].

IV SYSTEM MODELLING OVERVIEW

Simulation Modelling

For this, many software can be used namely MATLAB, QT-FuzzyLite etc. However, MATLAB is generally accepted in engineering and having worked with the fuzzy tool box in MATLAB myself, I would recommend MATLAB, though fuzzy-lite has a simpler interface. MATLAB is thus more powerful for our scope.

B. Physical Implementation

A micro-controller can be used to implement the designs of a fuzzy inference engine. This is simpler if MATLAB's SIMULINK was used for the simulation aspect then all we need to do is convert the Simulink model to a c-code of the targeted microcontroller family. This is done in the simulation block of the SIMULINK menu bar.

V CONCLUSION

Fuzzy logic has seen some successful real life projects like remote monitoring of preterm in the intensive care unit [16], course time tabling application [17], evaluation of planet factors of a smart city model [18], to mention a few. These applications have proven that fuzzy logic control is not only feasible but also a success. These breakthrough applications of fuzzy logic have also shown that fuzzy control can be combined seamlessly with other control methods to increase efficiency. It has to be stated, that fuzzy logic is not here to replace any control method entirely but to combine with them to make their controlling functions more precise. Thus going into the future more collaborations of fuzzy logic and machine learning can be used to drive the next generation of Artificial Intelligence.

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