ISSN 2347 - 3983
Volume 7, No. 9 September 2019
International Journal of Emerging Trends in Engineering Research
Available Online at http://www.warse.org/IJETER/static/pdf/file/ijeter16792019.pdf
https://doi.org/10.30534/ijeter/2019/16792019

Fuzzy Logic Control System with Gaussian Membership Functions

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ABSTRACT

One of the most widely known advanced control techniques is Fuzzy Logic Control. This paper aims to define the concept and function of Fuzzy Logic Control. Furthermore, this paper consists of brief discussion on how this type of control works, and how it is applied to several types of control systems. The procedure followed by this approach is explained and presented in this paper as well. This includes a discussion on the three steps namely fuzzification, Fuzzy Logic has become a popular approach in researches in the fields of science, technology, engineering, and medicine. This paper also shows the versatility of this approach in terms of numerous functions and applications.

Key words : Fuzzy Logic, Gaussian Membership, Controller, Fuzzy Sets.

1. INTRODUCTION

In most situations and conditions, there are no discrete answers. Between one or zero, on and off, true or false, and high or low, there is a “gray area” or uncertainty. Some information or data are inaccurate, incomplete, vague, or generally unreliable. These types of information are handled by Fuzzy Logic [1].

Fuzzy set theory was first presented in 1965 by L.A. Zadeh, introducing an alternative to the concept of set membership in relation to Boolean logic. Its purpose is to address incorrectness or vagueness. Fuzzy logic summarizes the Boolean logic wherein a single object can be included to more than one set provided that there is a degree and the truth contains values in the gaps or intervals. Moreover, Fuzzy Logic enables the translation of a given numerical value into a linguistic expression, and vice-versa. Numerical variables and linguistic expressions can copy the incorrect human method of information presentation because of the generalization of the Fuzzy Logic [2].

Fuzzy Logic Control is one of the classifications of advanced control techniques. It is a rule-based controller method that utilizes variable-developed rules like IF-THEN which indicates condition-conclusion relationship. Instead of indicating whether or not an object belongs to a set, Fuzzy Logic may state that an object belongs to a set partially [3]. The Fuzzy Logic Controller offers a systematic and organized method for the conversion of expert knowledge into a heuristic control algorithm. This controller serves a huge benefit for food processing systems that includes human experts but there is no availability of mathematical models. Numerous research studies focus on the applications of Fuzzy Logic Control. The wide range of applications it suggests shows that this method plays a significant role in complex systems and processes [4]. One of the most significant functions of Fuzzy Logic is in the field of medicine. Several studies on medicine utilized the fuzzy logic approach. This method has explored different applications for diagnosis and disease predictions. Instances of studies that applied Fuzzy Logic systems are fields of breast cancer, diabetes, dental, brain tumor, heart, kidney, eyes, chest, lung and liver conditions [5].

2. LITERATURE REVIEW

Nowadays, composites based on carbon fiber are prevalent and significant in the market and several fields of research. These composites consist of excellent mechanical properties. Carbon fiber composites also have several applications such as industries, automotive, and construction. This paper shows that Fuzzy Logic is utilized in identifying the characteristics and behavior including delamination factor, thrust force, and torque in the drilling of such composite. Fuzzy Logic, unlike other control techniques, calculates the “degree of truth” instead of determining “true or false.” The degree of truth is employed to obtain the various modes of logic and reasoning such as ambiguity and imprecision. These two conditions or environment play an important role in the decision-making of human beings. For this study, a drilling test was performed to assess the impact of cutting parameters on the delamination factor, thrust force, and torque of the laminate. Through performing the ANOVA analysis, the percentage contribution of different process parameters on specific performance characteristics can be determined by estimation. Analysis of the obtained variance results shows that the most relevant factors for thrust force and torque are the drill diameter and feed, while the spindle speed and drill diameter appears to be the most relevant for the delamination factor. In conclusion, there was a good relationship demonstrated between the experimental results and the fuzzy results [6].

In one study, a Smart Watering System (SWS) aided with an Android application is proposed. This watering system aims to provide a smart water consumption system in small to medium scales of fields or gardens. The system consists of sensors that can seize real-time data of plants. Moreover, the system is also designed to capture environmental conditions like air temperature, humidity, light intensity, and soil moisture level. The presented SWS will process the information to decide on the watering schedule once the sensors have transmitted the data on a server. The processing methods to be used by the SWS are block-chain and fuzzy logic methods. In this study, the approach of Fuzzy Logic assists in the decision-making considering the watering requirements, while the block-chain offers the necessary security for the IoT enabled system by only permitting trusted and reliable devices to have access and control over the SWS. Since the system is developed in Android, multiple devices and users can utilize the application for the monitoring and management of plants using the SW. The actuators are activated by the SWS for the watering process the moment the Fuzzy Logic based system approves the action depending on the values of input variables. Results of the study and tests indicate that the proposed system performs efficiently in the management of watering plants [7].

Another study focuses on the utilization of an approach based on fuzzy logic to be used for a ship-bridge collision alert by consideration of factors such as bridge parameters, environment condition, ship specifications. For save navigation, this alert may be implemented in the support system of the decision. The analysis of the conditions of the ship-bridge collision is dependent on the ship's trajectory direction, distance to the bridge, speed, and location. In this paper, the said factors are considered as the input variables. After the fuzzification process of the input variables, the if-then rules are implemented. These rules will then be used for the fuzzy inference for the ship-bridge collision risk derivation. According to the analysis and obtained results of the study, the presented approach shows great potential for the development of ship management in the area of bridge waterways [8].

With the fuzzy logic handling the representations of logical reasoning containing imprecision and ambiguity, it can also be expanded to manage hedges as well, according to one study. Hedges are used to describing emphasis at various levels. Examples of common hedges are slightly, very, rather, and highly. This paper presents a proposal wherein the function of fuzzy logic is extended for multiple hedges. This is because every hedge might indicate a "dual." An instance given in the paper is that slightly can appear as a dual hedge of very. The proposed axiomatizations are expanded to first-order level. Generally, this paper proposes an approach in the construction of linguistic or descriptive fuzzy logic expressions depending on the axiomatization and algebra for hedges, wherein the truth values of ambiguous phrases are displayed in linguistic expressions [9].

3. THEORETICAL CONSIDERATIONS

The development of Fuzzy Logic introduced a novel mechanism in data processing with the utilization of partial sets instead of crisp sets. Before the late 1970s, the theory of fuzzy set was not implemented in control systems due to the limitation in the processing capacity of the computers. Fuzzy logic is an approach for problem-solving and decision-making which considers partial truths, vagueness, imprecisions, and uncertainties in calculations. Since it considers everything in between true and false, it can offer a number of practical solutions for addressing conflicts. The methodology of Fuzzy Logic has a wide variety of applications – from simple embedded systems to more complex and larger control systems including, image processing, robotics, consumer electronics, power engineering. Examples of applications from different a different disciplines are medical diagnosis, weather forecasting, bioinformatics, and stock trading. Another remarkable quality of this approach is that it can have both a hardware and software implementation.

In a study by M.A. Cardenas-Viedma, et.al., a first-order logic called FTCLogic (Fuzzy Temporal Constraint Logic) was proposed. This logic can handle "fuzzy temporal constraints" effectively in between variables. The bases of the model presented in this study are First-Order Logic, Fuzzy Temporal Constraints Network, and Possibilistic Logic [10]. According to the paper, the following are the demonstrated advantages of the FTCLogic:

- It provides a combination of the first-order logic which serves as the domain and the FTCN model which represents the time.

- It generalizes the system which makes it flexible in terms of the fields of application.

- It observes a reliable inference rule which allows it to be the basis for a fuzzy temporal PROLOG.

The principle of fuzzy logic focuses on the membership of a certain object to a set. There are only two results possible in Boolean Logic. Either the object is a member of the set or not. However, partial membership is possible in the concept of Fuzzy Logic. A popular example of an application is the temperature of a certain environment. There can be three fuzzy sets for this condition. Having a crisp input, which is not a fuzzy value like 28 degrees Celsius, its membership to every fuzzy set can be computed. This situation is illustrated in Figure 1.

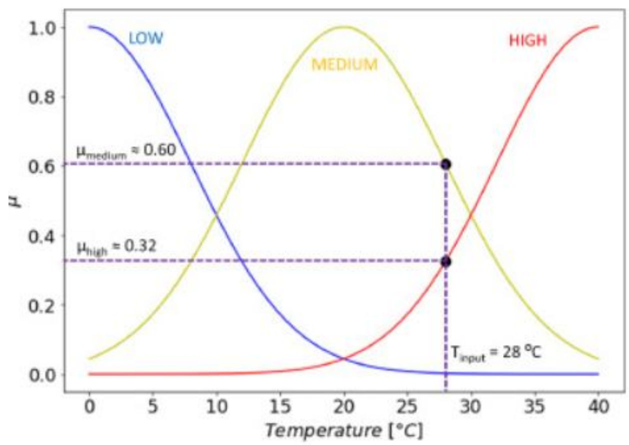

Figure 1: Environmental Temperature as Fuzzy Sets [11]

4. DESIGN CONSIDERATIONS

In problem-solving, Fuzzy Logic utilizes the "if x and y then z" rule. With this, the features of the Fuzzy Logic approach make it an appropriate component for a lot of control and modeling applications. Robustness to inaccurate inputs, ability to have a safe failure, the capacity to process a number inputs producing corresponding outputs and the capability of nonlinear system modeling are some of the notable features of Fuzzy Logic. The procedure of modeling and control based on Fuzzy Logic is composed of three important steps:

1. Fuzzification
2. Inference Rule
3. Defuzzification

The process of fuzzification provides an unbiased, systematic transformation method for quantitative or numerical values to be converted into qualitative or descriptive information. First, the complete set of input information is measured. Then, it is "fuzzified" into discrete parts with the use of "membership functions" or MF. The MF describes the participation magnitude and provides a "weight" to each input. The MF is employed to locate the inputs which are non-fuzzy to fuzzy linguistic expressions, and vice-versa. For the step of inference, the objective is to provide conclusions depending on the rule base. The last step, defuzzification, generate the results as fuzzy values that are required to be fuzzified to obtain a crisp final output [12].

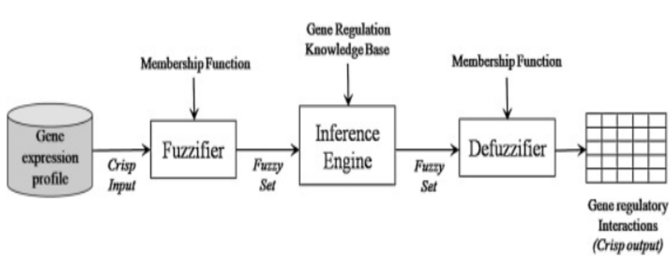

Figure 2: Fuzzy Logic Methodology

Aside from defining systems by combining linguistic and numerical expressions, Fuzzy Logic is able to express explicit concepts which are used in the representation of fuzzy rules. This provides Fuzzy Logic with more edge over Machine Learning algorithms. Fuzzy Logic is considered to have two types: Type-1 and Type-2 Fuzzy Logic Systems.

A type-1 fuzzy set A on a universe X is a set has a membership function displayed as μA(x) places every element of X to a certain degree of membership with the use of the values on the interval [0, 1].

$$A = \{ (x,\ \mu_A(x)) \,|\, x \in X \}$$

Eq. 1

Below is an instance of the Gaussian membership function having three parameters l, m, and r, where l represents the lower boundary of the function, m is the mean of the type-1 Gaussian membership function, and r represents the upper boundary of the function. The membership degree is equal to zero for the two points.

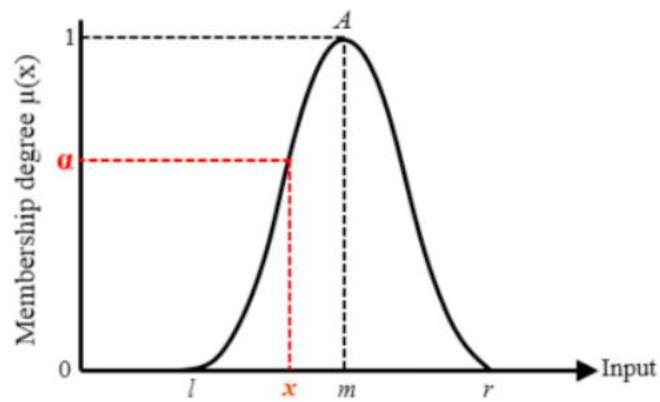

Figure 3: Gaussian Membership Function of T1FL

The degree of membership can be computed using the given equation below:

$$\mu_A(x) = \exp\left(-\frac{1}{2}\ \frac{(x-m)^2}{\sigma^2}\right)$$

For most cases, the type-1 fuzzy system is composed of four primary parts:

1. Fuzzifier
2. Fuzzy Rules
3. Inference Engine
4. Defuzzifier

The composition and structure of a basic type-1 fuzzy logic system is illustrated below:

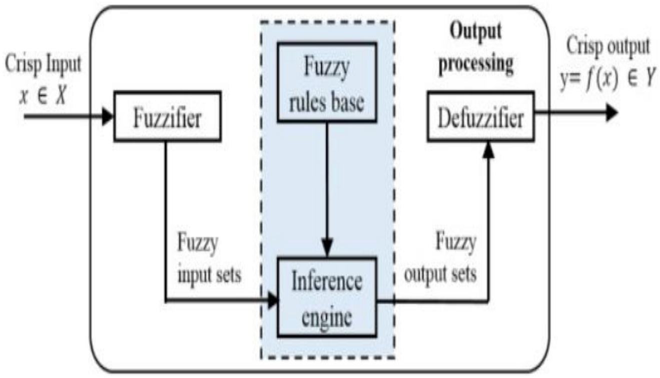

Figure 4: Structure of a Type-1 Fuzzy Logic System

The difference between the type-1 and type-2 fuzzy logic systems is that the type-2 associates the uncertainty of the membership functions into the fuzzy set theory. Thus, the type-2 fuzzy logic system can manage more complex uncertainty levels in prediction models. With this, an example of a Type-2 Gaussian membership function is shown below.

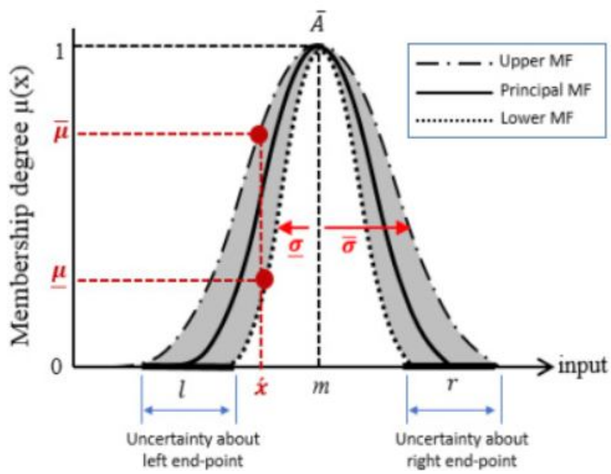

Figure 5: Gaussian Membership Function of T2FL including uncertainty levels

The formation and structure of a Type-2 Fuzzy Logic System is almost the same as that of the Type-1 shown in Figure 2. The only difference is that in the Type-1 system, the output processor consists only of a defuzzifier, while in the Type-2 fuzzy logic system, the output also has a defuzzifier but contains an additional type producer which is responsible for the conversion of type-2 fuzzy logic sets into type-1 fuzzy logic sets [13].

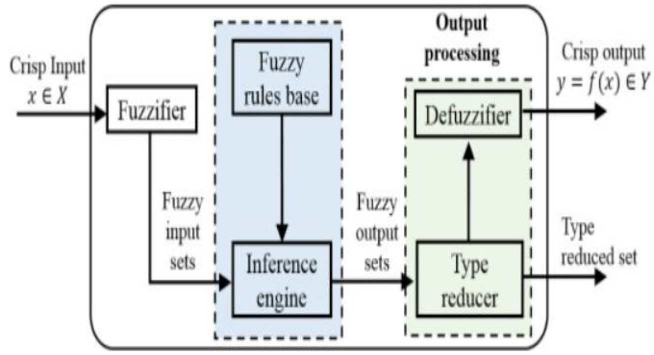

Figure 6: Structure of Type-2 Fuzzy Logic System

5. CONCLUSION

As human beings, our daily lives include a lot of ambiguous and incorrect information. It is not always a "yes" or "no". Sometimes, we have answers like "maybe" or "perhaps." This is the same with control systems. In the world of control systems with practical applications, the Fuzzy Logic handles the imprecisions and ambiguities in the systems [14].

Fuzzy Logic is a well-known approach to problem-solving used in modeling and control systems. Recent studies show that this approach suggests several applications in various fields of research and other disciplines. Fuzzy Logic allows the consideration of partial truth, imprecision, and vagueness in coming up with a concrete decision or action. Fuzzy Logic systems have two types: Type-1 Fuzzy Logic (T1FL) system and the Type-2 Fuzzy Logic (T2FL). The two types are similar in terms of composition and architecture, however, the type-2 is somehow an improvement of the type-1 fuzzy logic system. The type-2 fuzzy logic system contains a component that allows the conversion of type-2 fuzzy logic sets into type-1 fuzzy logic sets. The use of Fuzzy Logic Systems as an advanced control technique has become a prevalent method in controlling nonlinear systems when these systems have challenging mathematical models. Aside from its robust and flexible procedure, this approach is proven to work and function properly with the presence of uncertain and noisy inputs, even disturbances [15]. It is evaluated and verified by numerous studies that Fuzzy Logic is an efficient approach that also generates effective outputs. In the event this system is going to be programmed, it can follow the program structure of [16,17,18]. Its database configuration can duplicate the systems of [19, 20]. The concept of this research can be used in the following Control Systems model in the studies of [21,22,23,24,25,26].

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