

Fundamentals of Fuzzy Logic with an Easy-to-use, Interactive Fuzzy Control Application

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ABSTRACT

The Fuzzy Logic and the Fuzzy Control approach is an important Artificial Intelligence technique, which allows designing and developing “human-thinking” based, intelligent systems or applications that employ effective mathematical calculations to solve real-world based problems. At this point, the related technique is widely used by scientists, researchers and engineers in different disciplines and fields. In this context, this work introduces an easy-to-use, interactive Fuzzy Logic application that enables users to develop a simple “two inputs – one output” Fuzzy Control system. With its interactive using features and functions, the application also introduces fundamentals of the fuzzy logic technique.

Keywords: Artificial Intelligence, computer application, Fuzzy Control, Fuzzy Logic, Fuzzy Set Theory, visual programming

I. INTRODUCTION

In Computer Science, Artificial Intelligence field has an extremely important place with its effective approaches, methods, techniques and wide working domain. Currently, there are many different Artificial Intelligence techniques introduced to be used for providing accurate, effective and efficient solving approaches for real-world based problems. Some of these techniques are developed to be used for solving specific problems whereas other remaining ones have wide application scopes. Because of their effective and flexible mathematical foundations, some of these techniques are still used by scientists, researchers or engineers to solve real-world based problems. The Fuzzy Logic is one of these techniques, which is widely used in today’s intelligent problem solving systems or applications.

This work introduces an easy-to-use, interactive Fuzzy Logic application that enables users to develop a simple “two input – one output” Fuzzy Control system. The application is based on Adobe Flash technology and so, it uses visual, vector features of the related technology to form general using structure of the application. With its interactive using features and functions, the application also introduces fundamentals of the fuzzy logic technique. By using the application interfaces, users can easily design and test their Fuzzy Control systems. The programming infrastructure of the application has been designed and coded carefully in order to provide accurate mathematically and logically correct results for any type of “two inputs – one output” system.

The rest of the paper is structured as follows: The next section explains the fundamentals of the Fuzzy Logic; Fuzzy Set Theory, basics of the Fuzzy Logic technique and also Fuzzy Control. Next, Section 3 explains general structure and using features and functions of the developed Fuzzy Control application. Section 4 is devoted to the testing process, which were performed to evaluate effectiveness of the application. Finally, Section 5 outlines the conclusions that have been reached with the work and expresses some future works.

II. FUZZY SET THEORY, FUZZY LOGIC AND FUZZY CONTROL

Before introducing the developed application, it is better to explain its theoretical and mathematical foundations to understand the performed work better. In this sense, the related Artificial Intelligence technique: Fuzzy Logic and the Fuzzy Control concepts must be explained.

The Fuzz Logic technique is based on the Fuzzy Set Theory, which was first introduced by Lotfi A. Zadeh in a seminar organized at University of California at Berkeley, USA [1]. Following the seminar and the related ideas introduced by Zadeh, more about theoretical infrastructure of the Fuzzy Logic technique was expressed in many different sources [2, 3]. In this context, Fuzzy Logic was developed from the Fuzzy Set Theory in order to reason with uncertain and vague information and represent knowledge with an operationally powerful approach [2]. On the other hand, the Fuzzy Control term is used to define intelligent control systems designed and developed via Fuzzy Logic principles.

In addition to the related explanations, differences between the Crisp Logic and the Fuzzy Logic must also be introduced to provide more information about theoretical foundations of the Fuzzy Logic.

In the Crisp Logic, variables are provided with the value: “true” or “false”. At this point, certain classifications are made by using the Crisp Logic. So, a member can be included in only one set. For example, for the relationship with the set “S”, the characteristic function gives us “true – 1” if an element named “a” is the member of the set “S” or “false – 0” if an element named “a” is not the member of the set “S” [4]. This situation is shown in the graphic provided in Fig. 1.

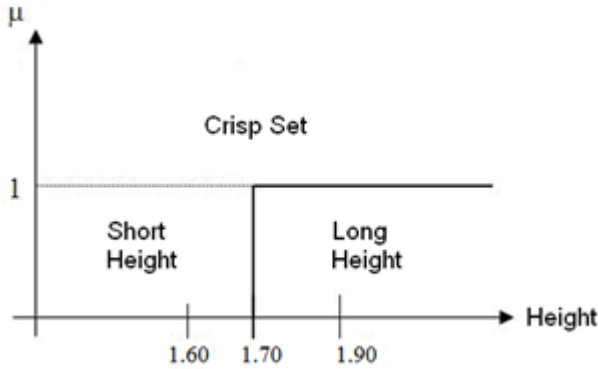


Fig. 1. A crisp set.

As different from the Crisp Logic, the related member may be in one or more sets within the Fuzzy Logic approach. In this context, it has a value defining its membership degree. The related situation is presented in the graphic within Fig. 2.

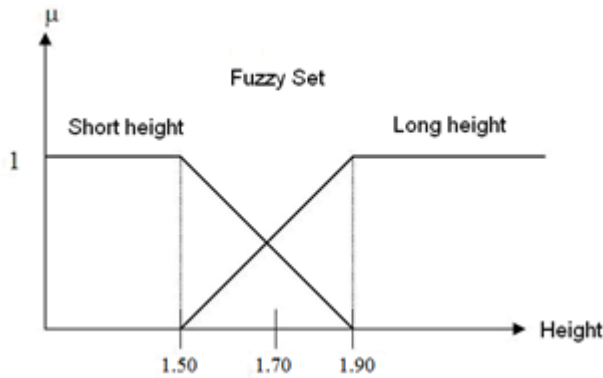


Fig. 2. A fuzzy set.

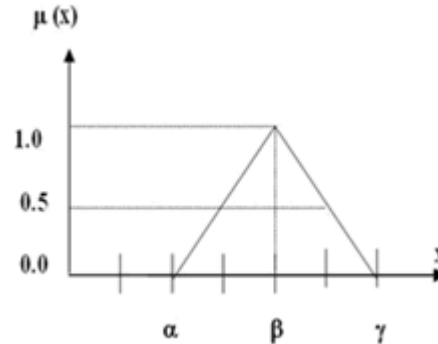
In the Fuzzy Logic, the expressed membership degree of the element is defined by using different types of functions (membership functions). In mathematical approach, the relationship between the set “S” and the element “a” can be defined as in “equation 1”.

$$\mu_S(a): F \rightarrow [0, 1]; \quad \mu_S(a): \in [0, 1] \quad (1)$$

In the “equation 1”, the set F is the fuzzy set of S(a) [4].

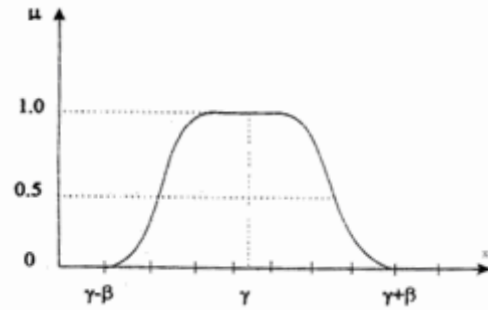
Within the Fuzzy Logic, after determining fuzzy sets that will be used, membership functions for the sets should be chosen. At this point, a membership function is some kind of curve converting the numerical value of input within a range from 0 to 1. In this sense the belongingness of the input to a fuzzy set is indicated [5]. In addition to assignment of membership functions, it also extremely important that the type of membership functions for inputs and outputs must be defined by the expert experience [2, 3, 6]. In this way, thinking structure of the person who has an expert experience about the subject the Fuzzy Logic used in is associated with the designed Fuzzy Logic based system or application.

As it was explained before, there are many different types of membership functions used within the Fuzzy Logic. Widely used ones are triangle, gaussian and trapezoid membership functions. These functions and their mathematical explanations are shown in Fig. 3.



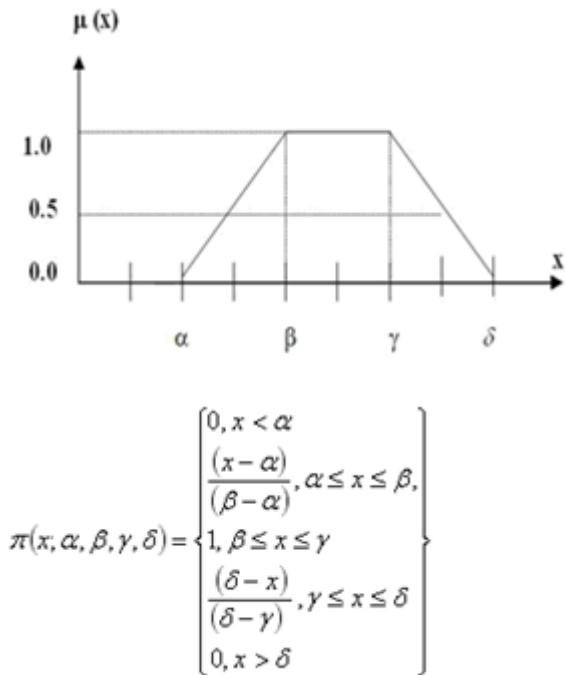
$$\Delta(x, \alpha, \beta, \gamma) = \begin{cases} 0, & x < \alpha \\ \frac{(x - \alpha)}{(\beta - \alpha)}, & \alpha \leq x \leq \beta \\ \frac{(\gamma - x)}{(\gamma - \beta)}, & \beta \leq x \leq \gamma \\ 0, & x > \gamma \end{cases}$$

a) Triangle membership function



$$\pi_s(x, \beta, \gamma) = \begin{cases} \left(x, \gamma - \beta, \gamma - \frac{\beta}{2} \right), & x \leq \gamma \\ 1 - \left(x, \gamma, \gamma + \frac{\beta}{2}, \gamma + \beta \right), & x \geq \lambda \end{cases}$$

b) Gaussian membership function



c) Trapezoid membership function

Fig. 3. Different types of membership functions.

After determining the related input, output fuzzy sets and so membership functions, some kind of “linguistic rules” must be determined in order to enable system to transform the input variables to the output variables during the operation. In this context, a linguistic rule is formed by writing a “if – then” rule. For example in a Fuzzy Logic system or application that uses two inputs for one output, some simple rules can be written as follows:

IF (*weight IS LOW*) AND (*height IS NORMAL*) THEN (*result IS HEALTHY*)

IF (*weight IS NORMAL*) AND (*height IS HIGH*) THEN (*result IS HEALTHY*)

IF (*weight IS VERY LOW*) AND (*height IS SHORT*) THEN (*result IS ILL*)

IF (*weight IS VERY LOW*) OR (*height IS VERY HIGH*) THEN (*result IS CRITICAL*)

In a typical Fuzzy Logic system or application, the related linguistic – “if-then” rules are combined in a table named as the “rule table”. Each output for different input variables can be observed by using this table. As it can be understood, this table is formed with the “expert knowledge”.

After the last step, the Fuzzy Logic system or application is ready to be operated. At this point, it gets the output from given input variables. However, the obtained output is also a “fuzzy set”. So, in order to use the output value in the real-world, its fuzzy value must be translated into real values.

This translation approach is named as “defuzzification” [7]. There are many methods of defuzzification such as centroid, centre of sums, mean of maxima and left-right maxima.

By combining theoretical infrastructure of the Fuzzy Logic and real-world based control problems, Fuzzy Control systems or applications are designed and developed easily. This type of intelligent control systems allows solving control problems via more accurate, effective and efficient logical and mathematical approaches. Fig. 4 shows a typical Fuzzy Control system schema [8].

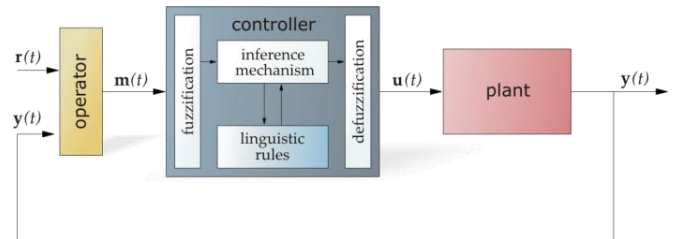


Fig. 4. A typical Fuzzy Control system schema [8].

III. AN EASY-TO-USE, INTERACTIVE FUZZY CONTROL APPLICATION

The interactive Fuzzy Control application has been designed and developed to provide a fast and easy-to-use using experience for anyone who wants to design a “two inputs – one output” system by using simple interfaces and controls provided within. The strength of the application is based on a popular, widely used animation and Web technology: Adobe Flash. With its object oriented “Action Script” coding approach and visually improved designing tools, the related technology has allowed forming such an interactive application environment. In order to improve easy using experience, colored, simple application controls and interfaces has been provided. Additionally, all working processes of a typical Fuzzy Logic and so Fuzzy Control system have been tried to be provided with visually powered tools and interfaces. In this way, users are enabled to understand performed processes better while working on a system.

In order understand the whole application, it is better to explain using features and functions of the application. For this aim, a typical working session can be explained as below:

III.I. Designing – Adjusting Inputs

As it was expressed before, the application allows user to design “two inputs – one output” systems. So, the main interface of the application was designed to fit for two different inputs and their visual presentations with membership functions. Fig. 5 presents a screenshot from the main interface of the application.

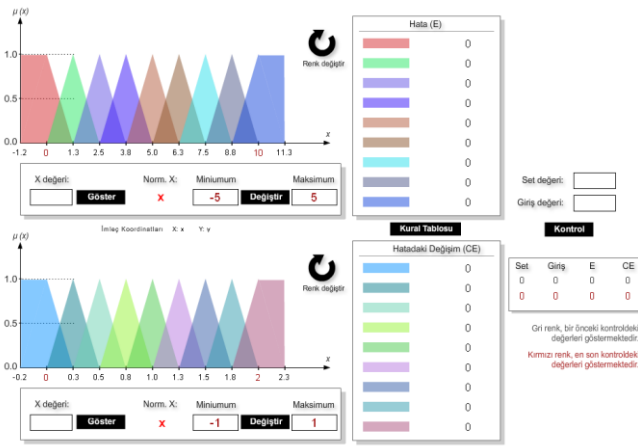


Fig. 5. A screenshot from the main interface of the application.

As shown in Fig. 5, both two inputs were formed by 9 triangular membership functions. At this point, number of membership functions, type of each membership functions and their values can be adjusted by clicking on each input graphic and so visual membership function set. After adjusting general structures of inputs, contents of each table provided on right side of inputs are also changed. These tables are used to give information about membership values for any given input.

In addition to the explained adjustments, it is also possible to change minimum and maximum values of each input. This can be done by using the provided text box objects under each input graphic. It is also important that, the application also allows users to change visual presentation of each input graphic according to determined “normalization” values. Fig 6 shows a screenshot from an input graphic (including 9 triangle membership functions) with normalization to a minimum value of 0 (according to min: 25 max: 120).

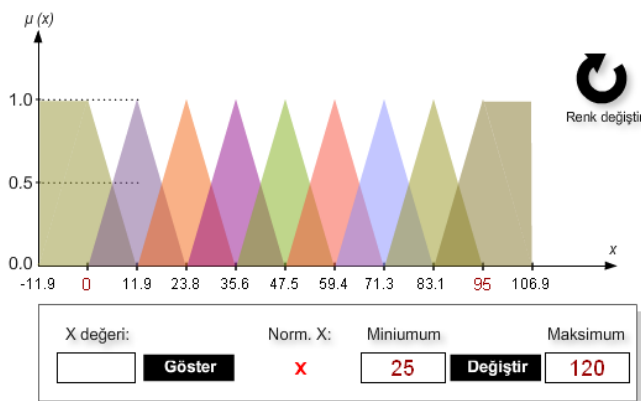


Fig. 6. A screenshot from an input with norm. min: 0.

III.II. Getting an Input Result

By using the text box located under-left side of each input graphic, it is possible to feed the related input set with a value and see the obtained results. On each input graphic, the input value is shown with a “red line indicator” over the related membership functions of the current graphic. After

feeding the input, obtained membership value results are also shown on the associated table located on right side of the graphic. Fig 7 presents a input value and obtained results on the table (In this input, min: -150 max: 150 and the normalization to min: 0)

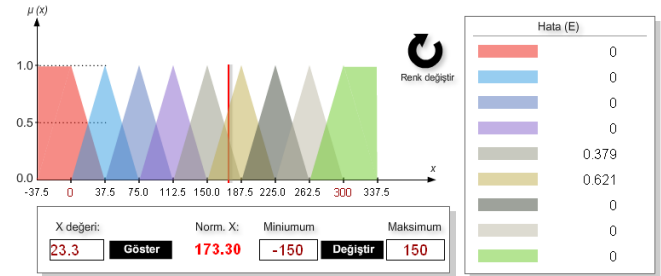


Fig. 7. An input value and its results.

As it can be understood from the Fig. 7, the value of 23.3 has 0.379 membership value for the 5th membership function whereas it is 0.621 for the 6th membership function.

III.III. Rule Table

By clicking on the button located between two result table, users can open the rule table interface for the designed system. After opening the related interface, values each cell can be changed by clicking on them or the related button located on top side of the interface. Fig. 8 shows a screenshot from the rule table interface.

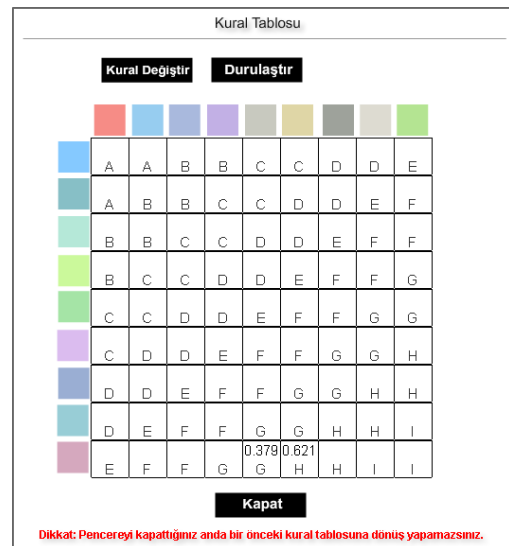


Fig. 8. A screenshot from the rule table interface.

It is also noticeable that any obtained result for input values are also shown over the rule table.

III.IV. Defuzzification

For the given input values and obtained fuzzy output, the defuzzification process can be performed by clicking on the related button located on top side of the rule table interface. After clicking on the button, the visually powered defuzzification interface is opened. Over this interface, users can see both visual presentation of the related input and output results and also “defuzzified” output value. At this

point, it is possible to change defuzzification method by clicking on the defuzzification method name on top side of the interface. Fig. 9 shows a screenshot from the defuzzification interface.

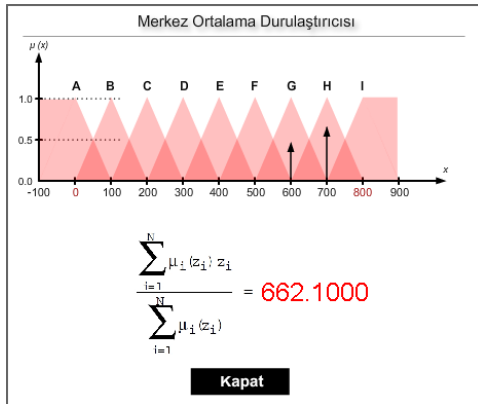


Fig. 9. A screenshot from the defuzzification interface.

III.V. Obtaining Fuzzy Control

In order to perform a Fuzzy Control, controls provided on right side of the main interface are used. In this sense, after designing the related input, output structures and any other elements, users can determine u, reference and error limit values by using the provided controls (because of the limited visual space, the related text boxes are changed during determination of the values). A screenshot from the related controls is shown in Fig. 10.



Fig. 10. A screenshot from the Fuzzy Control adjustment controls.

After determining the related values, users can start control process by clicking on the "control button". The control process is shown simultaneously by the application in order to provide better information about the process. Brief values for changes in error value, u value and the output (du) are automatically shown on the table provided within Fuzzy Control adjustment controls.

IV. EVALUATION

In order to test accurateness and effectiveness of the application, some sample inputs values and obtained output values are compared with the obtained results for same inputs provided in more advanced and popular Fuzzy Logic software systems like MATLAB Fuzzy Logic Toolbox and

Fuzzy TECH. Obtained results showed that the application provides an accurate and effective performance. At this point, one disadvantage of the application can be expressed as limitations on number of digits after the comma.

After getting accurate results against advanced software systems, same procedures are also performed to be compared with other similar academic software works. At this point, the developed system was compared with Dot Fuzzy (a C# based software) and also jFuzzy Logic (a Java based software). The developed application showed similar accurate and effective performances against these works.

The last test was performed against another academic software work, which was designed and developed by the author [3]. As similar to the developed application, this work is also based on designing and developing "two inputs – one output" Fuzzy Control systems. But its working mechanism is based on using matrix forms in the context of state-space analysis methods and controlling different systems that can be defined with A.x + B.u equation form. Additionally it also provides more advanced design, developing and testing approaches. Both environments are used to design same systems and fed with same values. Eventually, results obtained with the developed application were same with the ones via other work.

V. CONCLUSIONS AND FUTURE WORK

The application developed in this work provides an easy-to-use, interactive Fuzzy Logic environment enabling users to design and develop their own Fuzzy Control works with the support of Adobe Flash based objects. At this point, users are enabled to work on simple, fast interfaces that also allow them to understand fundamentals of the Fuzzy Logic technique. According to results obtained within evaluation process, the whole application provides accurate mathematical and logical results for any type of "two inputs – one output" Fuzzy Control system.

The application has been designed and developed with the support of Adobe Flash technology that employs effective, object oriented coding approaches and visually improved elements to provide better using experience in application projects. In this sense, the application provides an alternative, interactive way to design simple Fuzzy Control systems fast and work on them via visually improved interface tools. With its using features and functions, the developed application is also an effective, fast and simple approach for understanding fundamentals of the Fuzzy Logic technique better.

Regarding the future works for the developed system, there are some works to increase number of inputs and outputs that can be used within a Fuzzy Control system. Additionally, future versions of the application will also include templates for working on different Fuzzy Logic models like "Sugeno". The application functions will also be modified for any potential integration with other widely used Artificial Intelligence techniques like Artificial Neural Networks. In parallel with all of the future works, interfaces of the application will also be re-designed and re-adjusted in order to provide better using experiences for users.

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