Educational approach for fault detection in Internal Combustion Engines with Matlab Toolbox Fuzzy Logic

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Abstract

Fuzzy logic is the logic defined from the theory of fuzzy sets. It differs from the crisp logic (traditional) in their characteristics and their details. In textbooks on fuzzy inference systems, exemplified superficially implementation creating doubts among computer science students. Traditionally, teachers teach IC with the use of conceptual models. This model was to serve specified parameters computing courses, allowing students to study and development of computational models using Matlab Fuzzy Logic Toolbox (MFLT) for fault detection in engines. This paper proposes an academic learning model based on fuzzy inference and modeling to detect incipient faults in components of internal combustion engines.

Keywords: Fuzzy logic, Matlab Toolbox, Computer Science.

Introduction

Fuzzy logic was initially set by Zadeh [1] and shared in the scientific community through his article "Fuzzy Sets" published in the journal Information and Control[2]. Zadeh introduced the concept of fuzzy sets defining them in terms of mapping a set in the unit interval on the real line[3]. The problem of making decisions to classify the objects of the universe into two or more classes was considered appropriate in the context of the theory of fuzzy sets[4]. Fuzzy logic is a logic based on the theory of fuzzy sets [5]. It differs from traditional logic systems in their characteristics and their details. In this logic, the exact reasoning corresponds to a limit case of approximate reasoning, being interpreted as a writing process of fuzzy relations[6]. Being a key topic in the discipline of Computational Intelligence (CI), in several Computer courses, considered a method of excellence in the world of computer systems to support decision making. Traditionally, teachers teach IC with the use of conceptual models. This model was to serve specified parameters computing courses, allowing students to study and development of computational models using Matlab Fuzzy Logic Toolbox (MFLT) for fault detection in engines. Matlab is a renowned software environment and widely used for research and teaching applications in control and automation, powerful linear algebra tool, with a good collection of toolboxes that extend the basic functionality of Matlab, with an interactive open environment[7]. This paper proposes an academic learning model based on fuzzy inference and modeling to detect incipient faults in components of internal combustion engines. The proposed method allows detection of incipient faults in the main motor, whereas the values of the following quantities: the combustion pressure in the cylinder, and cooling water temperature and pressure. The proposed failure patterns are based on values set in the characteristic structure of the machine so that they can be reproduced in a wide range of sets of motorcycle generators. The advantages of the proposed system are its low intrusiveness, simplified installation and cost efficiency. A laboratory test was designed to simulate failures in a small diesel generator and apply the methodology for detecting the values of these quantities.

Problem statement

Matlab Fuzzy Logic Toolbox is a collection of functions built in numerical computing environment MATLAB, which provides students tools to create and edit fuzzy inference systems under the Matlab [8]. The student can build independent programs in C language calling diffuse systems built with Matlab. This toolbox depends heavily on Graphical User Interface (GUI) tools to help you do your job. The objective and exemplify the use of MFLT to create these fuzzy inference systems.

Methodology

The fuzzy logic is the point of an input spatial map to an output space, and the main mechanism to define this space is a list of if-then rules called instructions. Unlike conventional logic, Fuzzy logic uses the idea that all things admit membership degrees[9] [10].

Fuzzy logic-based adaptive controller design depends upon proper formulation of control rule base [11]. All rules are validated in parallel, and the end of the rules depends on the expertise of the specialist[12]. The rules are useful because they refer to variables and adjectives that describe these variables.

Rules If ... Then: The basic rules logically lists the information that forms the knowledge base of the fuzzy system[13].

The fuzzy inference model adopted for the failure prediction system of the engine is based on computer simulations of the combustion pressure in the cylinder values and cooling water temperature and pressure, selected as relevant variables for analysis.

So it can be built the system that interprets the rules, you must first define all terms adjectives that describe them.

Formally, a fuzzy set A is defined by a membership function uA: [0-1]. This function assigns to each element x of the fuzzy set A is a degree uA (x) of relevance, that is the degree of compatibility between x and concept expressed by A[14] [15].

As an example, the description of the membership functions with numeric range and the linguistic value of each selected variable, are presented in Table 1:

Table 1: System Suitability Functions.

Type	Linguistic variables	set Cloudy	Numeric range	description
Input	Water temperature (TAGUA)	Low	[0 - 100]	The expected value for the water temperature is between 40 and 80 degrees Celsius.
		Normal		
		High		
	Water pressure (Pagua)	Low	[0 - 6]	The expected value of the water pressure is between 2 and 5 bar.
		Normal		
		High		
	Combustion pressure (PComb)	Low	[0 - 220]	The expected value for the combustion pressure is between 40 and 180 bar.
		Normal		
		High		
Output	Instability	Normal	[0 - 100]	The expected value for stability is up to 50 points.
		Not normal		

Source: Authors, (2019).

In the Command window of *Matlab*, type the word fuzzy (fuzzy >>), and then press the enter key which will display the initial window of this toolbox as shows what appears in Figure 1.

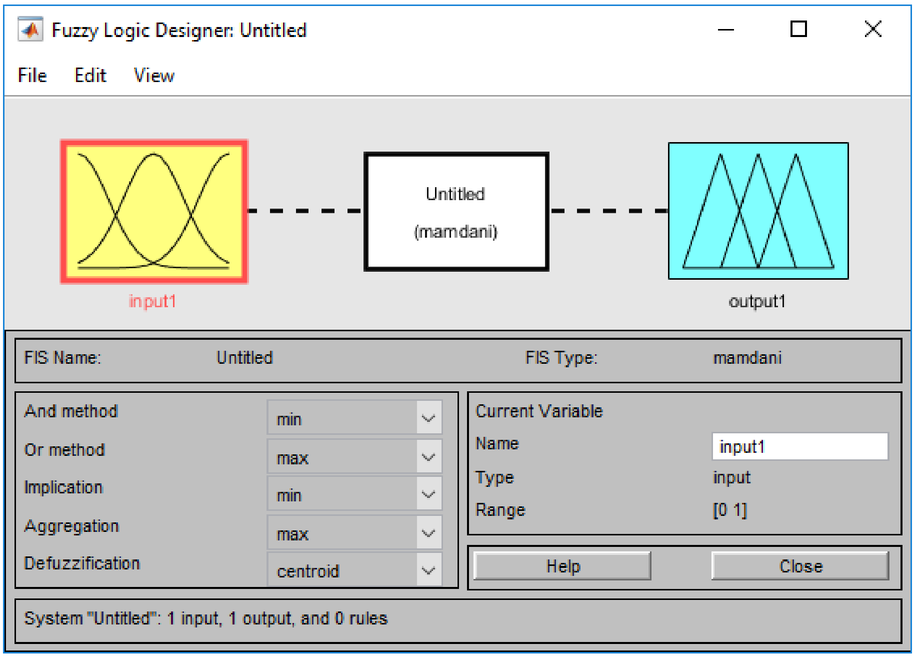

Figure 1: Initial Window Toolbox Matlab.
Source: Authors, (2019).

In Figure 1, it is highlighted the option for the type of analysis described as fuzzy Mamdani name.

The Fuzzy Logic Toolbox MATLAB provides two options methods, Mamdani and Sugeno. Because of the simplicity and efficiency, the use of linguistic variables and is very consistent, brings us closer to human intuition[16]The contents of this work has been specified using the following methods: Mamdani method, the inference step and the method of center of gravity (centroid), the defuzzification step.

A fuzzy output to a defuzzification system, it is a procedure or a method to find a common (non-fuzzy) output means for each linguistic variable [17].

It is not the aim of this study detailing these methods of inference and fuzzification, it is suggested to get a better understanding, reading Pedrycz & GOMIDE [18].

Adding Input / Output variables

To add the input variables or output by selecting the options exemplified in Figure 2:

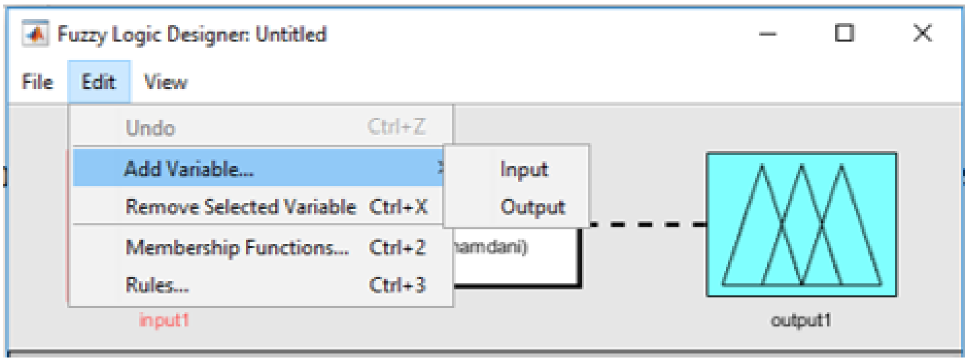

Figure 2: Adding input / output variables.
Source: Authors, (2019).

It is emphasized that there can be no input variables and output. In this work, it will be considered the three input variables and a system output, which is described as Multiple Input and Simple Output (MISO)[19].

In Figure 3, an example is implemented the failure prediction system in the interface area Graphic user.

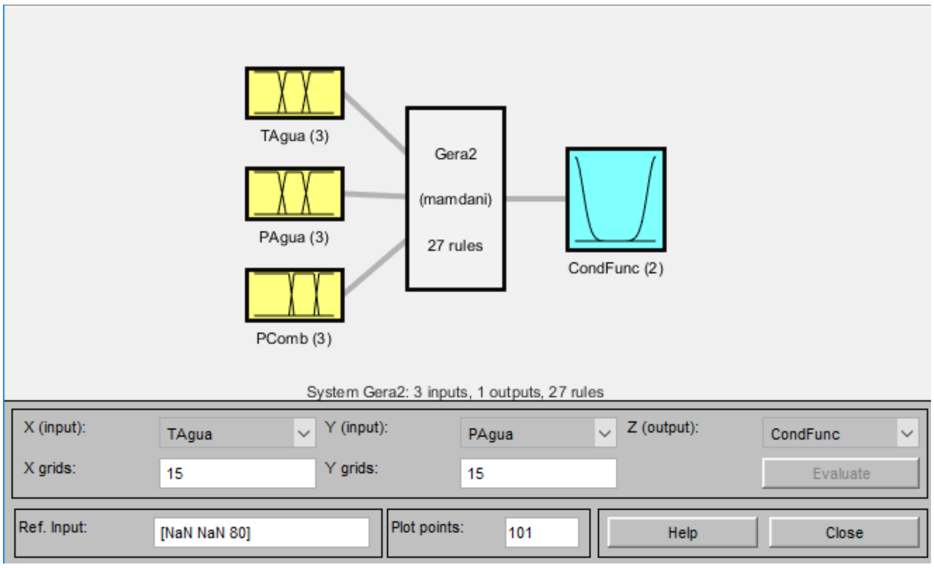

Figure 3: Variables input and system output.
Source: Authors, (2019).

Changing the domain of input variables and / or output

To determine the domain of each variable, you must double-click on the "box" of the variable, changing the value of the option of the text box RANGE seen in Figure 4, and press Enter.

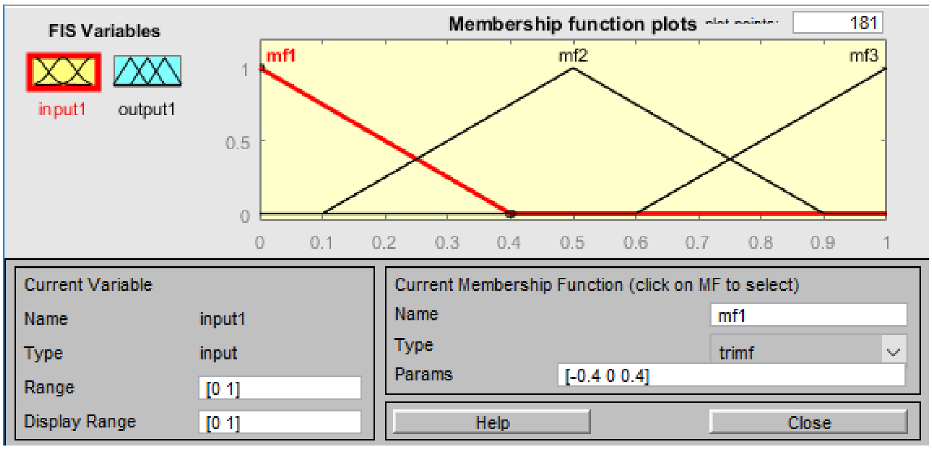

Figure 4: Variable Properties dialogue box.
Source: Authors, (2019).

Defining the membership functions

To change the number and shape of the relevance of the input variables of functions should be, from what is indicated in Figure 5, press the left mouse button on the Edit menu:

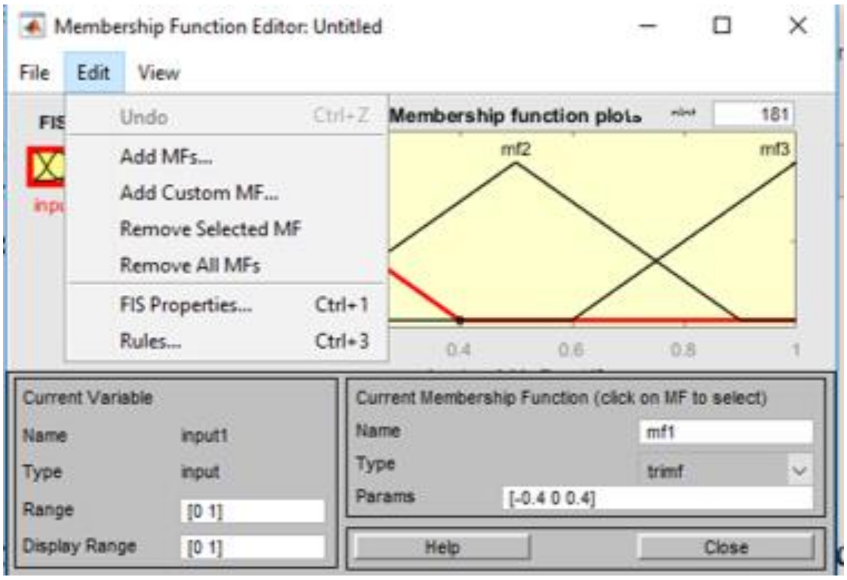

Figure 5: Editing Relevance functions of each variable.
Source: Authors, (2019).

Once the number and format of the membership functions are selected, for each of the membership functions, the values associated with the maximum and minimum membership should be determined, with the maximum values being equal to 1 (one) and the associated values the least pertinence is equal to 0 (zero) [20]. This procedure is different for the different shapes of the membership functions available on MFLT. The most commonly used formats for membership functions are triangular (trimf), trapezoidal (trapmf) and Gaussian (gaussmf).

Regarding the description of the variables they represent the knowledge of the expert in the fuzzy inference being termed as input variables and system output, matched linguistically representing inaccuracy mode[21] [22]. Thus, the variables of the proposed system are:

Tagua- The water temperature may not be less than 40 degrees Celsius or exceed 80 degrees Celsius. The fuzzification of this variable is trapezoidal, as shown in Figure 2.

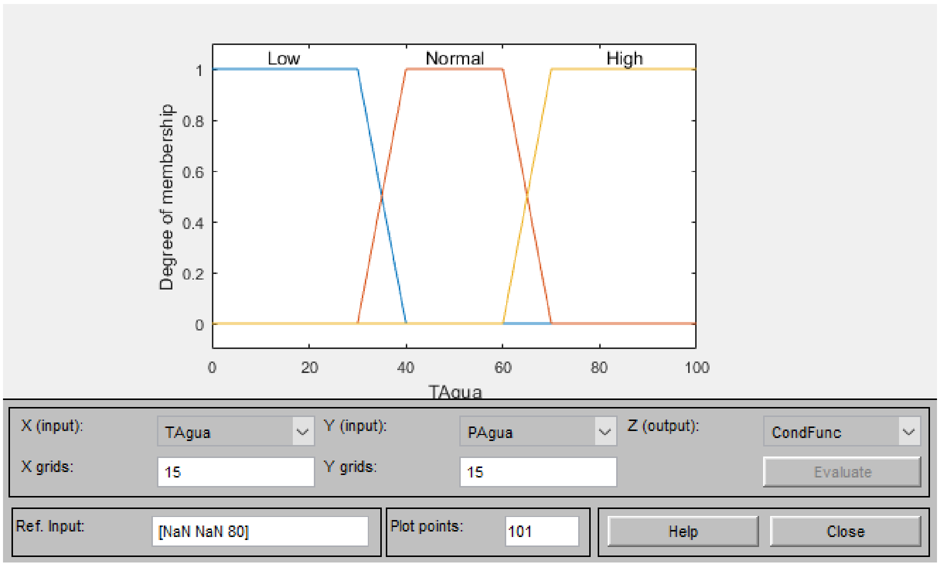

Figure 2: Variable Tagua.

Source: Authors, (2019).

Pagua- The water pressure must not exceed 5 bar. The fuzzification of this variable is trapezoidal and triangular ends in the central part of the graph, as, according to Figure 3.

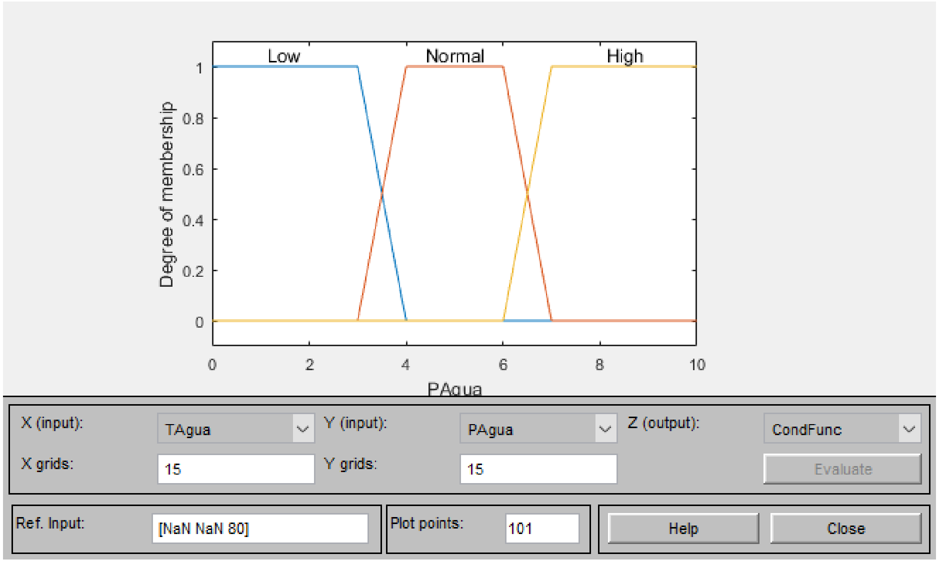

Figure 3: Variable Pagua.

Source: Authors, (2019).

pComb- The combustion pressure can not exceed 180 bar. The fuzzification of this variable is trapezoidal and triangular ends in the central part of the graph, as, according to Figure 4.

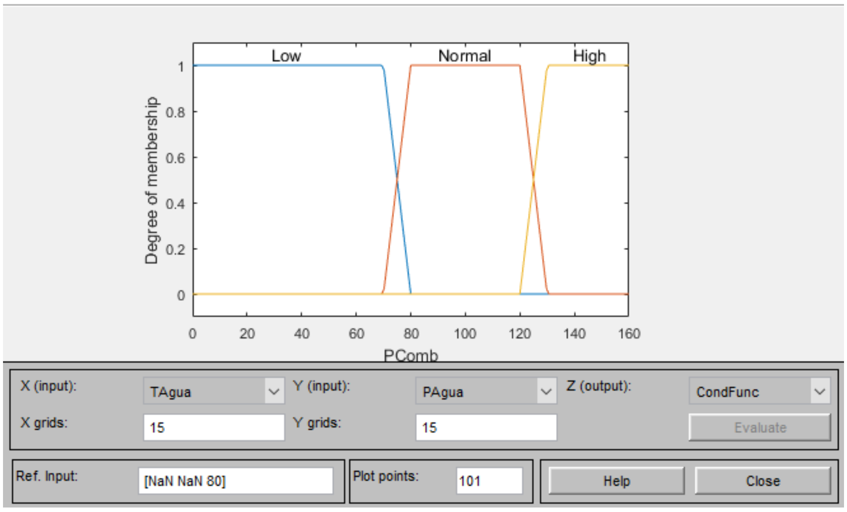

Figure 4: Variable pComb.

Source: Authors, (2019).

CondFunc - associations of input variables are related to the output variable operating conditions (CondFunc), which has a fuzzification shown in Figure 5.

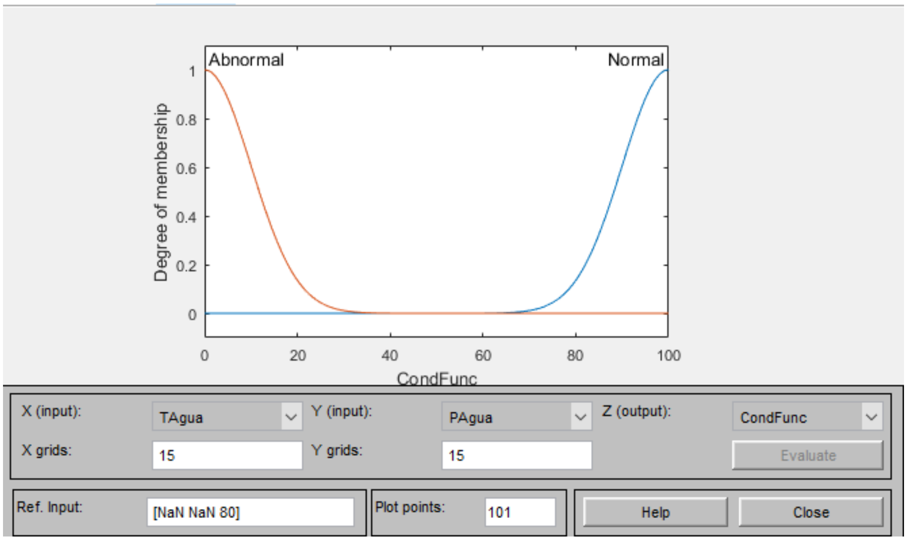

Figure 5: Instability output variable.

Source: Authors, (2019).

Demonstration of main Inference Rules base of linguistic variables resulted in 27 combinations, applied in this fuzzy solution, where part of power seen in Figure 6.

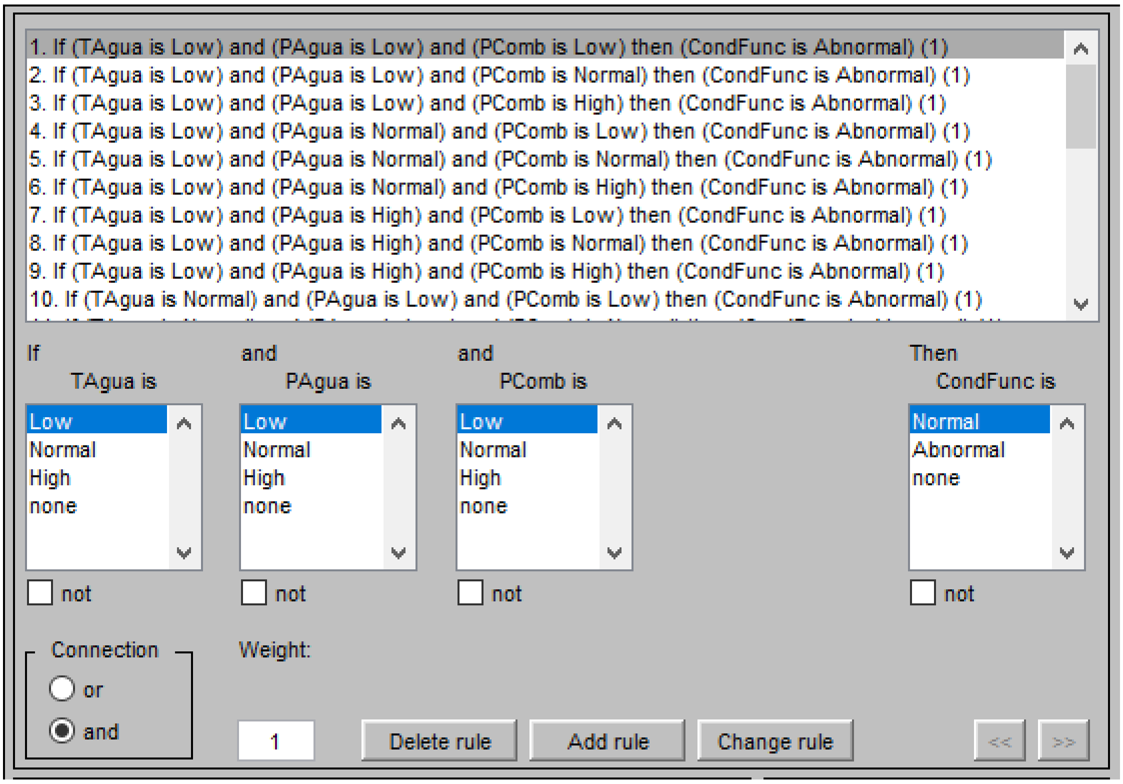

Figure 6: Inference rules of linguistic variables.

Source: Authors, (2019).

Results and discussions

In the viewer rules Matlab Toolbox, the data is arranged in a way that facilitates the simulation and interpretation of various scenarios by combining values for inferences variables of the fuzzy inference process, showing the functions that reflect the overall result of the system.

By varying the input values it is possible to evaluate the outputs of the proposed system, obtaining a value that allows a correct analysis of the efficiency of the method adopted for fault detection in motor operation, seen in Figure 7.

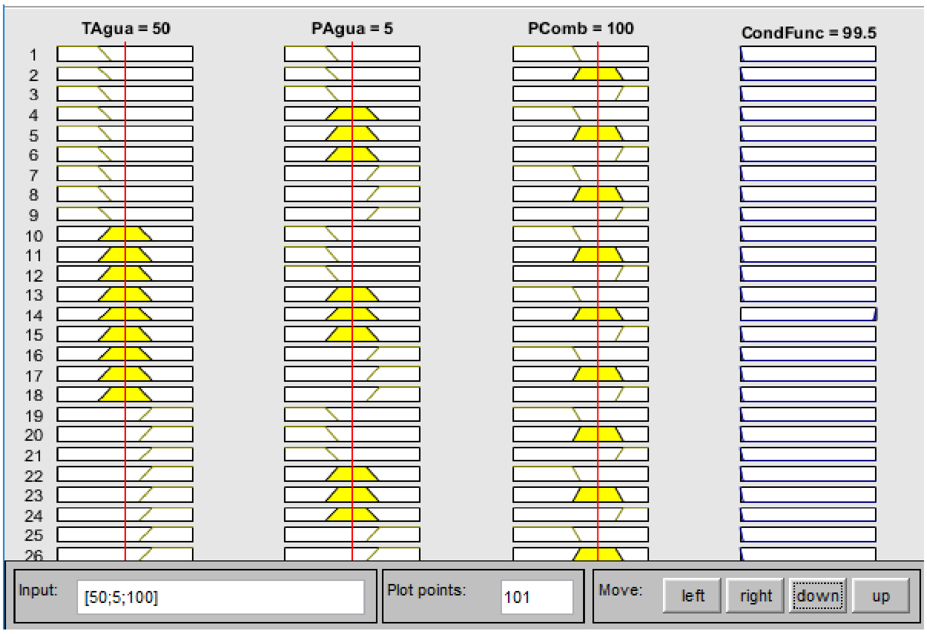

Figure 7: Results shown from inferences.
Source: Authors, (2019).

Adopting hypothetical input values, considering them wherein for the water temperature input variables is 50 Celsius, the water pressure of 5 bar and the combustion pressure 80 bar, resulting is an operating condition 99.5 %, i.e. a favorable environment for the operation of the motor generator.

In any other operating condition exceeds the upper or lower limits of normal for the variables defined, has a worst case scenario for operation of the motor generator, indicated with the same shut down for maintenance.

Figure 8 shows the resultant surface plot of the proposed system.

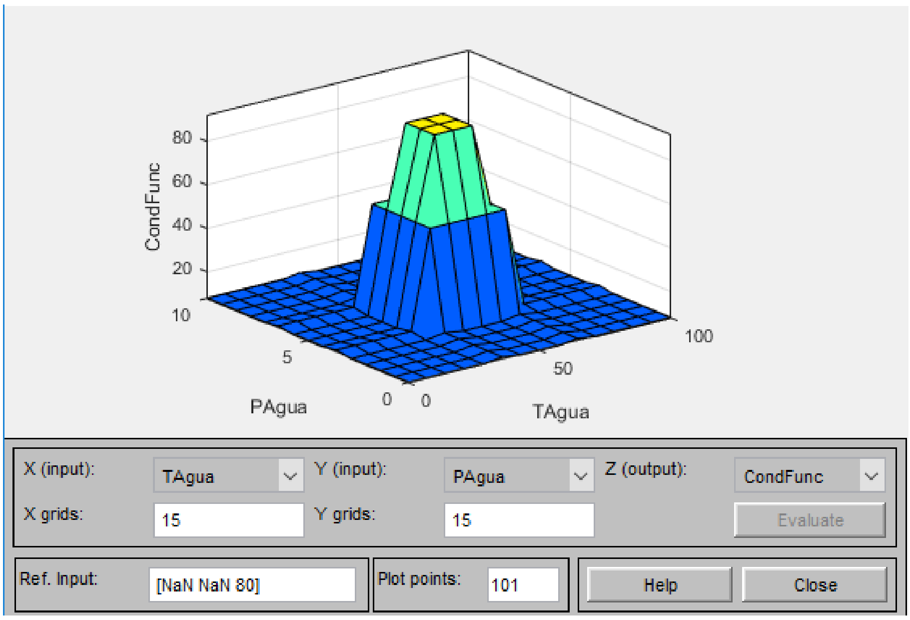

Figure 8: Graph surface.
Source: Authors, (2019).

Summary

In this work, an approach to implement a simplified fuzzy inference model using Matlab Fuzzy Logic Toolbox is presented to students in general who have difficulties with complex books about is tool. This approach uses a system for monitoring the operating conditions of the motorcycle generators, based on three quantities. Students and teachers can use this approach as parameters to implementations and studies of other fuzzy systems.

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References

[1] L. A. Zadeh, "Fuzzy sets," *Information and Control*, vol. 8, pp. 338-353, 1965/06/01/ 1965.

[2] G. P. Chenci, D. G. Rignel, and C. A. Lucas, "Uma introdução á lógica Fuzzy," *Revista Eletrônica de Sistemas de Informação e de Gestão Tecnológica*, vol. 1, 2011.

[3] J. G. Brown, "A note on fuzzy sets," *Information and Control*, vol. 18, pp. 32-39, 1971/02/01/ 1971.

[4] R. M. Capocelli and A. De Luca, "Fuzzy sets and decision theory," *Information and Control*, vol. 23, pp. 446-473, 1973/12/01/ 1973.

[5] B. P. Gonçalves, J. A. B. Junior, J. C. Leite, C. T. da Costa Junior, and M. E. de Lima Tostes, "Avaliação de impactos harmônicos na rede elétrica através dos indicadores THD e fator de potência utilizando lógica Fuzzy," *Revista brasileira de energia,* vol. 19, pp. 9-27, 2013.

[6] F. A. C. Gomide and R. R. Gudwin, "Modelagem, controle, sistemas e lógica fuzzy," *SBA controle & Automação,* vol. 4, pp. 97-115, 1994.

[7] C. S. Besta, A. K. Kastala, P. R. Ginuga, and R. K. Vadeghar, "MATLAB Interfacing: Real-time Implementation of a Fuzzy Logic Controller," *IFAC Proceedings Volumes,* vol. 46, pp. 349-354, 2013/12/01/ 2013.

[8] M. D. Žarković and Z. Stojković, "Fuzzy logic and artificial neural network-based thermography approach for monitoring of high-voltage equipment," *International Journal of Electrical Engineering Education,* vol. 52, pp. 81-96, 2015.

[9] A. A. Marro, A. d. C. Souza, E. d. S. Cavalcante, G. S. Bezerra, and R. O. Nunes, "Lógica fuzzy: conceitos e aplicações," *Natal: Universidade Federal do Rio Grande do Norte (UFRN),* 2010.

[10] D. F. Pereira, C. A. Bighi, L. R. A. Gabriel, and C. P. Gabriel, "Sistema fuzzy para estimativa do bem-estar de matrizes pesadas," *Engenharia Agrícola,* pp. 624-633, 2008.

[11] B. Subudhi and S. K. Pradhan, "A flexible robotic control experiment for teaching nonlinear adaptive control," *International Journal of Electrical Engineering Education,* vol. 53, pp. 341-356, 2016.

[12] J. M. Vargens, R. Tanscheit, and M. M. Vellasco, "Previsão de produção agrícola baseada em regras linguísticas e lógica fuzzy," *Sba: Controle & Automação Sociedade Brasileira de Automatica,* vol. 14, pp. 114-120, 2003.

[13] G. M. D. Ganga, L. C. R. Carpinetti, and P. R. Politano, "Gestão do desempenho em cadeias de suprimentos usando lógica fuzzy," *Gestão & Produção, São Carlos,* vol. 18, pp. 755-774, 2011.

[14] M. Bilobrovec, R. F. M. Marçal, and J. L. Kovaleski, "Implementação de um sistema de controle inteligente utilizando a lógica fuzzy," *XI SIMPEP, Bauru/Brasil,* p. 42, 2004.

[15] A. D. Santos, L. S. Machado, R. M. Moraes, and R. G. Gomes, "Avaliação baseada em lógica fuzzy para um framework voltado à construção de simuladores baseados em RV," in *Anais do XII Symposium on Virtual and Augmented Reality. Natal: Sociedade Brasileira de Computação,* 2010, pp. 194-202.

[16] F. L. Camargos, "Lógica Nebulosa: uma abordagem filosófica e aplicada," *Florianópolis: UFSC,* 2002.

[17] N. A. Kopylova, A. I. Taganov, O. A. Bodrov, and A. N. Kolesenkov, "The analysis of ecological risks in geoinformational systems in fuzzy conditions," in *2018 7th Mediterranean Conference on Embedded Computing (MECO),* 2018, pp. 1-4.

[18] W. Pedrycz and F. Gomide, *An introduction to fuzzy sets: analysis and design*: Mit Press, 1998.

[19] L.-X. Wang and J. M. Mendel, "Generating fuzzy rules by learning from examples," *IEEE Transactions on systems, man, and cybernetics,* vol. 22, pp. 1414-1427, 1992.

[20] S. Medeiros, R. de Mello, and P. Campos Filho, "Análise de projetos para unidades de conservação, usando lógica fuzzy," *Production,* vol. 17, pp. 317-329, 2007.

[21] E. L. Nogueira and M. H. R. Nascimento, "Inventory control applying sales demand prevision based on fuzzy inference system," *Journal of Engineering and Technology for Industrial Applications - JETIA*, vol. 03, p. 6, 2017.

[22] E. Poletti and J. Meyer, "Dispersão de poluentes em sistema de reservatório: modelagem matemática via lógica fuzzy e aproximação numérica," *Biomatemática,* vol. 19, pp. 57-68, 2009.