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Implementation of a Fuzzy Logic Controller for an Aerothermic Process

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Abstract**:*****The objective of any controller design is to maintain the set point value despite its variation, with a good rejection of various disturbances that can infect the system to be controlled and to minimize the energy consumption. To achieve these objectives, several control methods are proposed in the literature. Nevertheless, due to the non-linear behaviour of most industrial systems, fuzzy logic control remains the most appropriate method to control this type of system. This article compares two fuzzy logic control techniques having two inputs and one output. These methods are applied to an aerothermic process in our laboratory. The obtained experimental results allowed us to achieve the main control objectives, such asset-point trackingand regulation. These results encouraged us to exploit the advantage of each technique, in order to make the controller design simpler and to minimize the time required to calculate the command applied to the process.***

Keywords ***:aerothermic process, fuzzy logic controller, membership functions***

I. INTRODUCTION

The ventilation and heatingprocess is a system widely used in industry such as the pharmaceutical and food industry.The temperature control of these processes requires a controller with crucial capacities to ensure product quality, and the reduction of energy consumption.The latter is a very important factor in minimizing production costs. To achieve these objectives several approaches have been adopted for the control of the ventilation and heatingprocess such as the PI and MPC controller [1]-[3], the PI and GPC controller [4]. These approaches require a perfect knowledge of the systems model to be regulated, which does not give a high adjustment performance. In the case of the present system of non-linearity, these methods present the limitations in terms of stabilizations and performance. Furthermore, and their parameters are often poorly known and/or variable over time. In this context, the application of intelligent methods remains the optimal solution to solve these problems, because no Mathematical model is required for the configuration of this type of controller.

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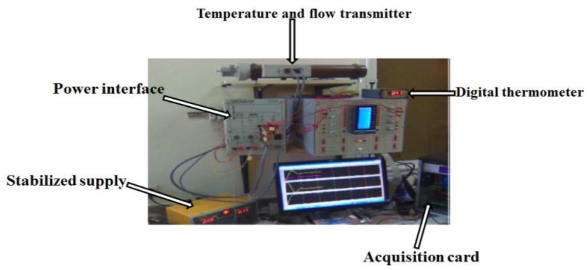
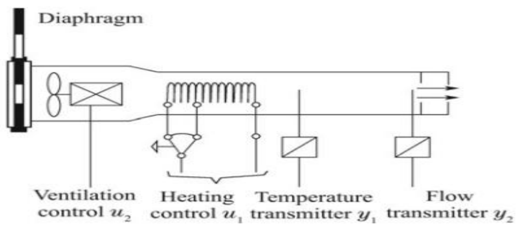
In order to formulate control rules, the development of control is based on prior knowledge of the process characteristics. Intelligent techniques are presented according to three main sub-categories: fuzzy logic, artificial neural networks and neuro-fuzzy. The last two methods are adaptive techniques, based on the iterative self-adjustment of the process during system operation. In this paper, it is focused on the functional aspect of Mamdani's algorithm for the fuzzy controller. The main advantage of this controller lies in its low sensitivity to variations in process parameters. It has been used to obtain promising results for many applications that are difficult to process by conventional techniques [xx]. In this research work, a fuzzy logic controller (FLC) was implemented to control a laboratory aerothermic process in real time. In this study, the objective is to control the air temperature at the process output [5]-[8]. For this purpose a comparison between two fuzzy control techniques of the Mamdani type are presented. The first are is based on three membership functions (FLC-3) and the second on five membership functions (FLC-5).The experimental results are analyzed and discussed in this work. In this paper, the second section presents the description of the aerothermic process from which the fuzzy controller will be implemented. The algorithm utilized to control the studied system is detailed in Section three. Finally, the obtained experimental results are presented in section four.

II. MATERIALS AND METHODS

A. Aeothermic Process description



(a) Experimental aerothermic process



(b) Schematic illustration of aerothermic process

Fig. 1 Aerothermic process

The real view and the principle diagram of the aerothermic system as represented in Fig. 1[2], [3]. This system is equipped with two measuring transmitters and two actuators. The transmitters measure respectively the temperature and the air flow rate whose ranges are from 25 to 75°C for the temperature and from 0 to 50 mmH2O for the flow rate. The actuators correspond respectively to a heating resistor with controlled power, and a motor equipped with a fan rotating at controlled rotation speed. Transmitters and actuators provide electrical quantities from 4 to 20mA. Two types of step disturbances are possible on this system. The objective of this study is to control the air temperature at the output of the process by the two techniques. Temperature control is obtained by varying the electrical power supplied to the heating network. The systems' is equipped with an electric resistance. Due to joule effect, the heat generated by the resistance and transmitted by convection to the circulating air, producing heated air. The air flow rate is fixed by varying the fan speed. In our case, the flow rate remains constant during the experiment.

B. Controllers based on fuzzy logic

The classical set theory (binary logic) provides a clear answer concerning the belonging or not an element to a given set. Binary logic has proven its effectiveness and success in solving well-defined problems. Nevertheless complex, or poorly structured problems remain difficult to resolve using this technique. As a result these problems cannot be resolved automatically. In this case, concepts are not clearly separable as true or false, but relatively vague (more or less true). Fuzzy set theory is one of the approaches to solving this kind of problem. This logic was developed in 1965 by LotfiZadeh. The main idea consists in replacing the set {0, 1} by the interval [0 1] corresponding to the belonging of an element to a considered fuzzy set.

Indeed, the fuzzy logic reasoning is more sensitive than the classical logic. It allows designers to understand imprecise and difficult model such as natural phenomena, which is difficult to model.This technique is based on the definition of rules and functions of membership to so-called "fuzzy sets". It makes it possible to obtain an effective control law, without complex theoretical developments. Furthermore, the experiences acquired by the users and operators of the process to be controlled, are take into account by the Fuzzy logic.

Fuzzy logic is an advanced control technique. Based on three main stages: fuzzification, the inference and deffuzification[7], [9].

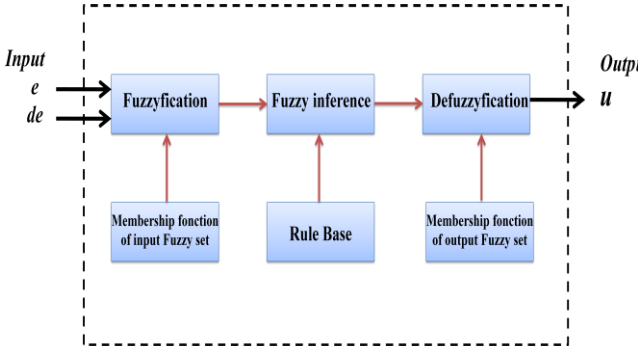


Fig. 2 Synoptic overview of a fuzzy system

- Fuzzification interface

The fuzzification interface consists in converting the input numerical values into linguistic values, based on the membership functions. The latter, makes it possible to define the degree to which a numerical data membership to a linguistic variable.

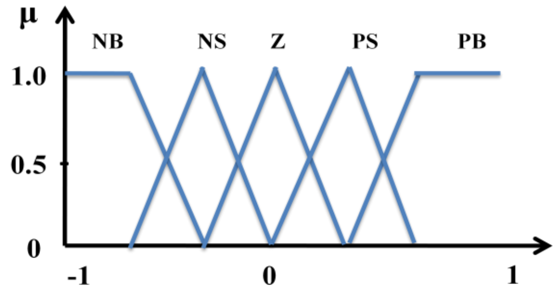


Fig. 3 Membership function of linguistic variables

- Fuzzy inference

Inferences link an output variable to measured quantities, i. e. the input variables transformed into linguistic variables. This step is applying each of the inference rules responsible in generating output signals. These rules represent also our knowledge about the system, due to human expertise. In the literature, two approaches are used to generate fuzzy inference systems: Mamdani (linguistics) and Takagi-Sugeno-kang (TSK). In this study, Mamdani's approach is utilized. The latter allows a description based on fuzzy rules having the following form:

$$\boldsymbol{IF}\ \ x_1 \text{ is } A_1 \text{and } x_2 \text{ is } A_2 \text{ and } \dots .\text{and } x\ _n\text{is } A_n$$

$$\boldsymbol{THEN}\ \ y_1 \text{ is } B_1 \text{and } y_2 \text{ is } B_2 \text{ and } \dots \text{and } y_m \text{ is } B_m \quad (1)$$

Where x_n and $y_m$are the input and output variables respectively and $A_n$and $B_m$correspond to fuzzy language sets.

- Defuzzification

The defuzzification interface allows merging the commands generated by the inference in a single output command. It transforms this linguistic output variable into real numerical data.

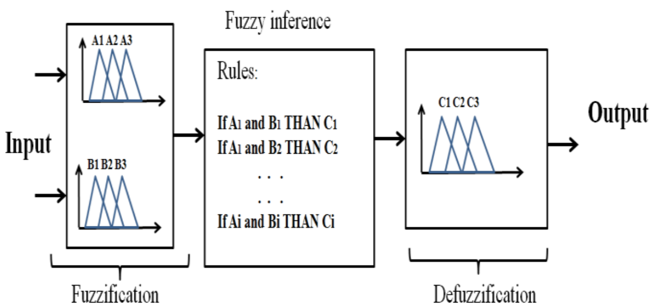


Fig. 4. Schematic of the fuzzy inference system

III. DESIGN OF THE FUZZY CONTROLLER

In our work, Mamdani's fuzzy inference method was chosen thanks to its simplicity of implemented this technique is used to control the aerothermic process, with two inputs and one output. The inputs are composed of the error (e), and its derivative (de/dt). Both inputs and output are all normalized in the range of [-1, 1]. The language labels used to describe the fuzzy sets were "Negative" (N), "Zero" (Z) and "Positive" (P) are given in table (1). In the same manner, "Large Negative" (NB), "Small Negative" (NS), "Zero" (Z), "Small Positive" (PS) and "Large Positive" (PB) are given in table (2).The output is determined according to the rules defined by (e) and (de) [10], [13]-[15].

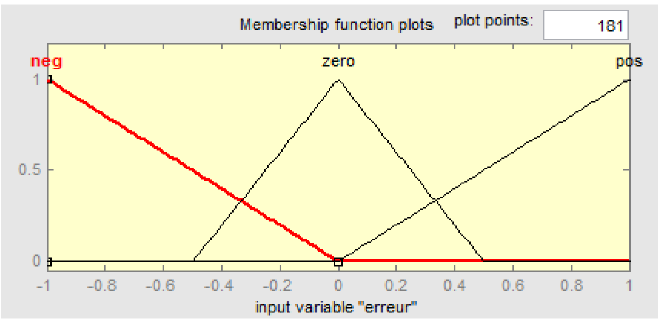
Table 1: Fuzzy Rules (FLC-3)

de/dt \ e	N	Z	P
N	N	N	Z
Z	N	Z	P
P	Z	P	P

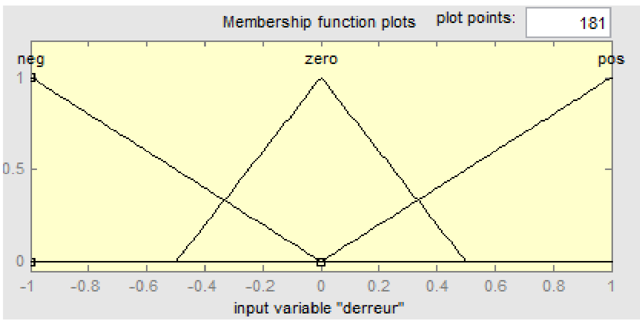
Tableau 2: Fuzzy Rules (FLC-5)

de/dt \ e	NB	NS	Z	PS	PB
NB	NB	NB	NS	NS	Z
NS	NB	NS	NS	Z	PS
Z	NS	NS	Z	PS	PS
PS	NS	Z	PS	PS	PB
PB	Z	PS	PS	PB	PB

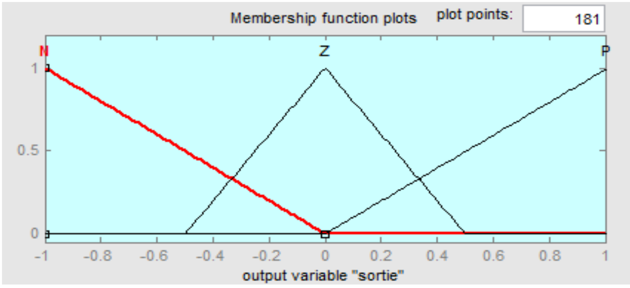
In this study, two Mamdani's controllers are utilized. The first one, is based on three membership functions (FLC-3): "Negative" (N), "Zero" (Z) and "Positive" (P) Fig. 5. The second, is based on five membership functions (FLC-5): "Big Negative" (NB), "Small Negative" (NS), "Zero" (Z), "Small Positive" (PS), "Big Positive" (PB) Fig. 6.



(a) Input variable e

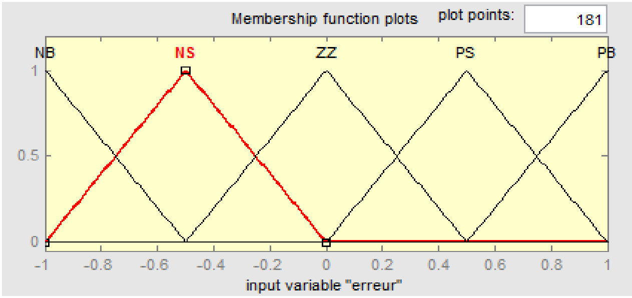


(b) Input variable de/dt

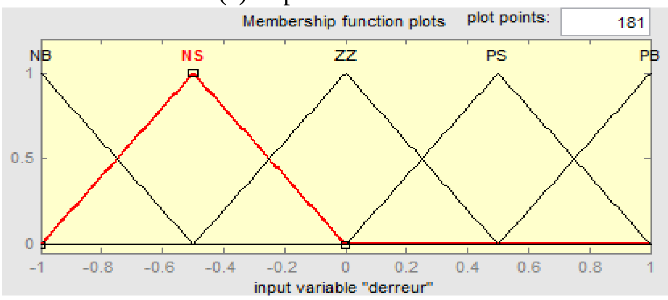


(c) Output variable u

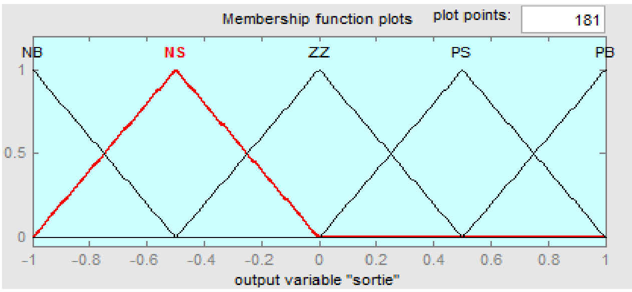
Fig. 5. Graphical representation of the input's and output's membership functions (FLC-3)



(a) Input variable e



(c) Input variable de/dt



(c) Output variable u

Fig. 6. Graphical representation of the input's and output's membership functions (FLC-5)

A. Controller Implementation in Aerothermic Process

The aerothermic process is a system with two variables should be controlled, the fan speed and the heating resistance. The objective is to control the temperature of the exhaust air by the two techniques proposed in the previous section. The flow of atmosphere air in the tube remains constant during the experimental phase. The proposed fuzzy controller was first simulated to select the setting parameters (input and output gains). To highlight the advantage of the proposed techniques (FLC-3; FLC-5), a real-time application was performed on the aerothermic process. Fig.7 shows the block diagram corresponding to this application [5], [9]-[12].

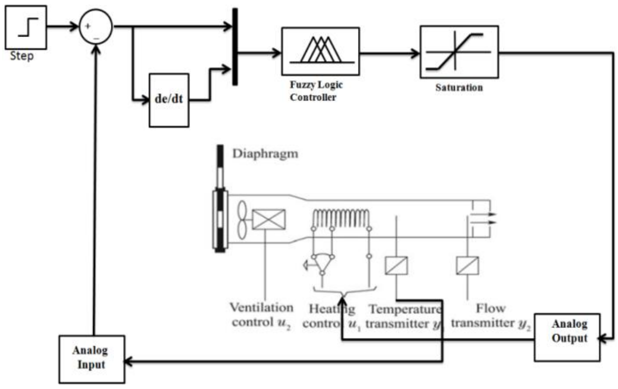
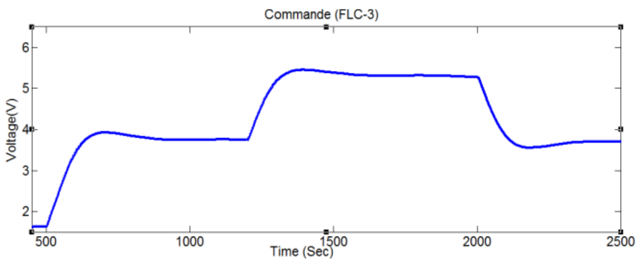


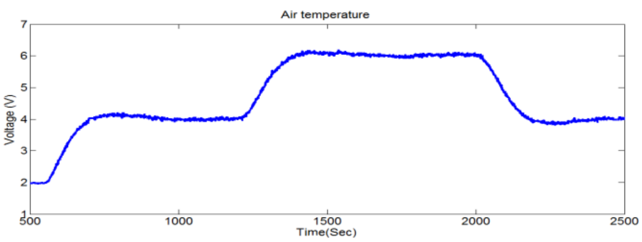
Fig. 7. Block diagram of the real-time application of the FLC

B. Experimental results and discussion

In order to test the performance of the proposed controller in real situation, the results obtained in real time are given in Fig. 8 and 9.These experimental results show a good tracking performance. It is clearly observed that the output signal follow the set point variation. In order to give an overall idea about the reaction of the aerothermic process to the number membership functions characterizing the fuzzy controller, the proposed two techniques are compared in Fig. 10. Based on these results, it can be easily seen that during the transient phase the output controlled by (FLC-3) presents a major advantage over the output controlled by (FLC-5) either in terms of energy consumption or exceeding the set point value. In the absence of the disturbance, the two outputs controlled by (FLC-3) and (FLC-5) present the same set point tracking behaviour in permanent regime. Otherwise, to test the robustness of both controllers against disturbances that may infect the process, a step signal was injected at the output of the system. The results obtained are shown in Fig. 10. It is clearly observed that the controller's (FLC-5) reaction to deny the effect of the perturbation is faster than the controller's (FLC-3). Consequently, it recovers the set point value quickly. This means that the controller (FLC-5) is better suited to control the process in regulation mode [16]-[17].

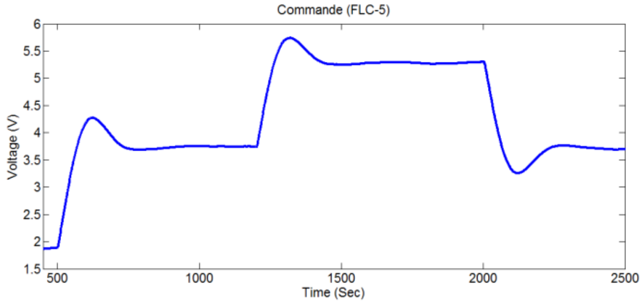


(a) Command's evolution

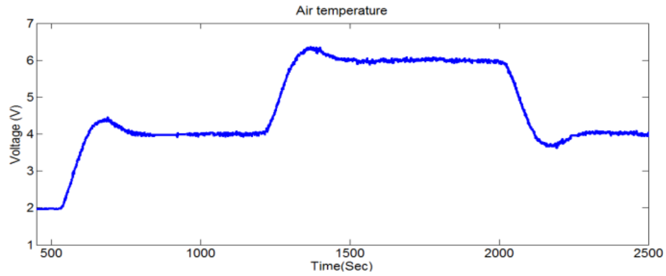


(b) System's response

Fig. 8. Control and response of the process controlled by FLC-3

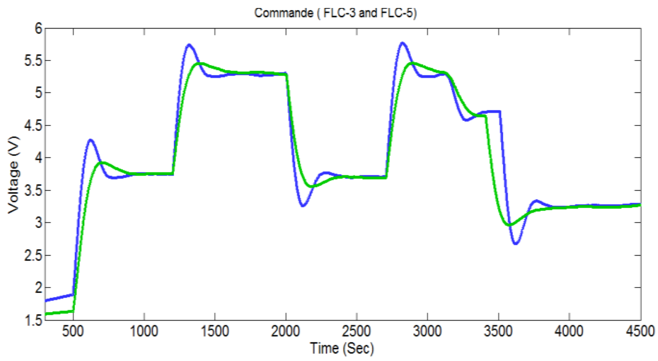


a) Command's evolution

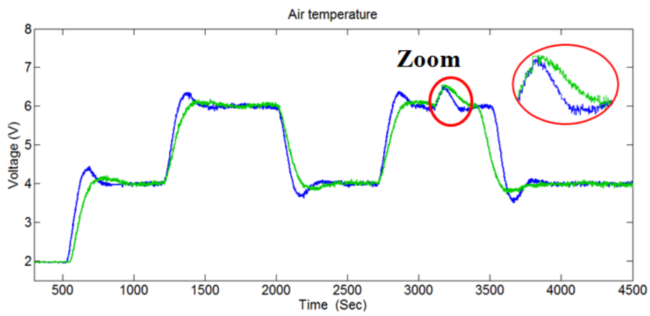


(b) System's response

Fig. 9. Control and response of the process controlled by FLC-5



(a) FLC-3 and FLC-5 commands



(d) FLC-3 and FLC-5system's responses

Fig. 10. Control and response of the process controlled by FLC-3(Green color) and FLC-5(Blue color)

IV. CONCLUSION

This article, focused on the intelligent control technology (FLC) of mono-variable systems and their practical implementation. This technique is utilized to control the temperature of the air leaving the aerothermic process.

Two methods (FLC-3) and (FLC-5)are applied to the process. The performance of each technique is tested in real time on a pilot laboratory process. The results obtained confirmed the efficiency of FLC-3 in term of pursuit and that of FLC-5 in term of regulation. In future works, a hybrid method, i.e. combination between FLC-3 and FLC-5, will be studied in order to make the controllerstrategysimpler, and to reduce the control calculation time. In conclusion, we can say that the proposed method presents a very powerful tool for the design of intelligent controllers.

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