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SELF-TUNING PI FUZZY CONTROL: APPLICATION TO A MULTIVARIABLE HEAT EXCHANGER SYSTEM

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Abstract: At present, very complex systems have been generated that require highly sophisticated controllers to comply with the correct performance under adverse conditions. Sometimes, the lack of precise knowledge about some processes is a problem, due to the fact that the parameters and the structure of the systems change significantly and unpredictably, that is, they have changing dynamics over time. This paper shows the development of a PI control of self-tuning parameters using fuzzy logic for a multivariable heat exchanger system. The development was carried out in Matlab with the Fuzzy Logic Designer tool and later simulated in Simulink. Linguistic variables such as: Error, Error sum, Kp (proportional gain), Ki (integral gain) were used. Linguistic values were defined: High Negative, Medium Negative, Zero, Medium Positive, High Positive, Low, Medium, High. Gaussian and triangular membership functions were adopted. Subsequently, the simulation was carried out in Simulink. Through the simulation carried out, it is observed that the system uses the fuzzy rules that have been generated to bring the values of the controlled variables to their new reference values. In this sense, the PI control that has been implemented behaved adequately under other simulation conditions, such as the
Keywords: PI Control, Fuzzy Control, Multivariable System, Fuzzy Logic, Simulation.

INTRODUCTION

At present, very complex systems have been generated that require highly sophisticated controllers to comply with the correct performance under adverse conditions. Sometimes, the lack of precise knowledge about some processes is a problem, due to the fact that the parameters and the structure of the systems change in a significant and unpredictable way, that is, they have a changing dynamics through time [7].

In the literature there are different approaches in the design of controllers with the aim of stabilizing a heat exchanger system. In [1], they used computed parameter PI controllers, to which they added different decouplers – including simplified steady-state decoupling, simplified decoupling, and generalized decoupling – and compared system responses using transient and state measurements. stationary, against disturbances in the outputs of the system. In a more direct way and based on the author mentioned above, in [3] they focus on the use of the PI controller with simplified decoupling.

In this contribution, a self-tuning PI controller is implemented using fuzzy logic. The difference with the previously mentioned strategies is that it does not eliminate the interaction between variables and that the fuzzy system is in charge of tuning the profits of the controller based on two parameters: the error and the sum of the error. The application was implemented in a multivariable heat exchanger system, which is described in the next section.

THEORETICAL FRAMEWORK

MULTIVARIABLE SYSTEM

For the development of the application, a multivariable thermal system of heat exchanger was selected, which is developed in [1] and [3] but here the most notable issues are shown. The system is shown in Figure 1.

This system has a concrete application in a refrigeration plant mentioned in [1] and [3], however the criteria and analysis also allows its application in other processes where it is required, for example, the heating of a fluid to be used in another process.

The controlled variable temperature of the water at the outlet of the tubes is paired with the manipulated variable valve opening percentage at the tube inlet. The controlled variable The temperature of the water at the outlet of the casing is paired with the manipulated variable opening percentage of the valve at the inlet of the casing.

The transfer function matrix for this 2x2 system is given by the following equation:

$$\begin{bmatrix} \frac{0.4241}{148.6s+1} & -\frac{0.214}{(142.2s+1)(28.4s+1)} \\ \frac{0.0695}{(126s+1)(26.4s+1)} & -\frac{0.5}{150s+1} \end{bmatrix} \quad (1)$$

Figure 2 shows the system in Simulink and has been modified to display the location of the controllers.

FUZZY CONTROL

Fuzzy Logic is a multi-valued logic that allows uncertainty and vagueness to be represented mathematically, providing formal tools for its treatment that allows establishing a mapping of input-output values in an appropriate way, according to meaning criteria and not precision [2].

Fuzzy logic is mainly applied in fuzzy control systems that use ambiguous expressions to formulate rules that control the system. A fuzzy control system works very differently from conventional control systems. These use the knowledge of an expert to generate a knowledge base that will give the system the ability to make decisions about certain actions that occur in its operation [2].

Figure 3 presents the structure of a fuzzy model.

Fuzzification is the process by which a specific numerical value in an input variable is transformed into a fuzzy set that imprecisely represents said value [5].

The fuzzy rule base is the part of the fuzzy control system architecture where knowledge is stored in the form of rules [5].

At each discrete instant, the inference mechanism can activate one, several, or none of the rules. Activation of a rule means that a fuzzy set of inputs is mapped to a fuzzy set of outputs. Each rule will fire to a different degree, depending on the degree to which the antecedents of the rule are satisfied [5].

Once the input has been processed by the fuzzy inference mechanism, a global output is obtained, given by a fuzzy set. Defuzzification is used to choose a precise (representative) output value, from this output fuzzy set [5].

DEVELOPMENT

For the development of this application, “Fuzzy Logic Designer” from Matlab was used. First, the linguistic variables are defined, which in this case are:

- Error
- Error sum
- Kp (proportional gain)
- Ki (integral gain)

The aforementioned linguistic variables are shown in Figure 4 and Figure 5.

Once the linguistic variables are defined, the linguistic values are defined: High Negative, Medium Negative, Zero, Medium Positive, High Positive, Low, Medium, High

In Figure 6, Figure 7, Figure 8 and Figure 9, the mentioned linguistic values are represented by membership functions.

Once these parameters are defined, the fuzzy rules of the form IF A and/or B THEN C are made. Figure 10 and Figure 11 show the fuzzy rules used.

RESULTS

Once the aforementioned configurations have been made, the changes of the Kp gain of the P controller with respect to the error can be represented, in Figure 12, and the changes of the Ki gain of the I controller with respect to the sum of the error, in Figure 13.

Finally, Simulink from Matlab is used to represent the multivariable system with the fuzzy control developed. Figure 14 depicts the

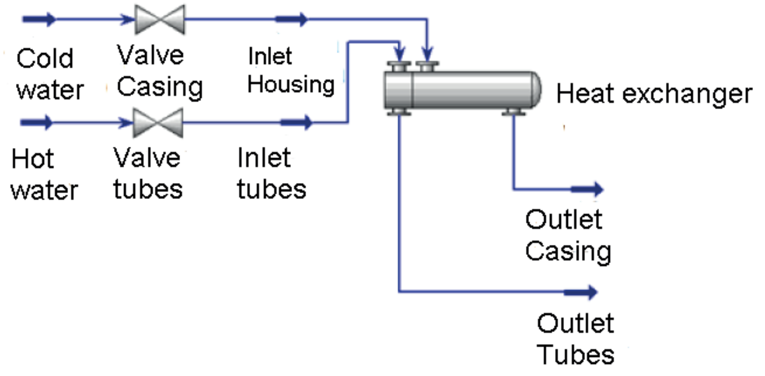

Figure 1: Multivariable 2x2 heat exchanger system.

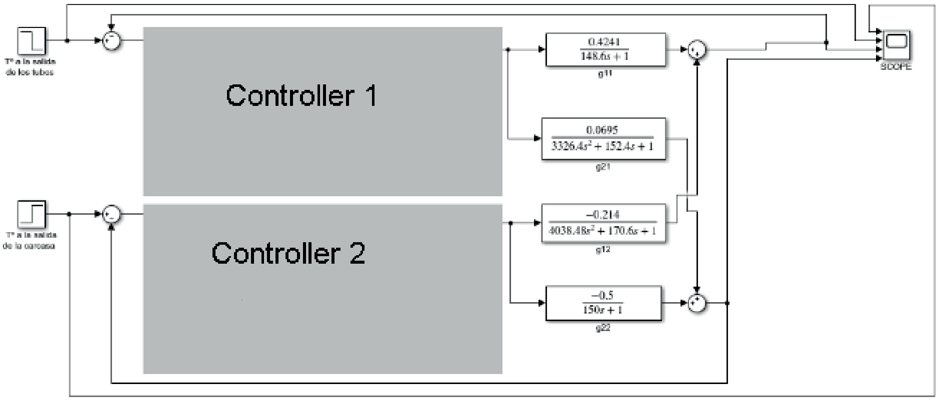

Figure 2: Graphical representation of the multivariable system.

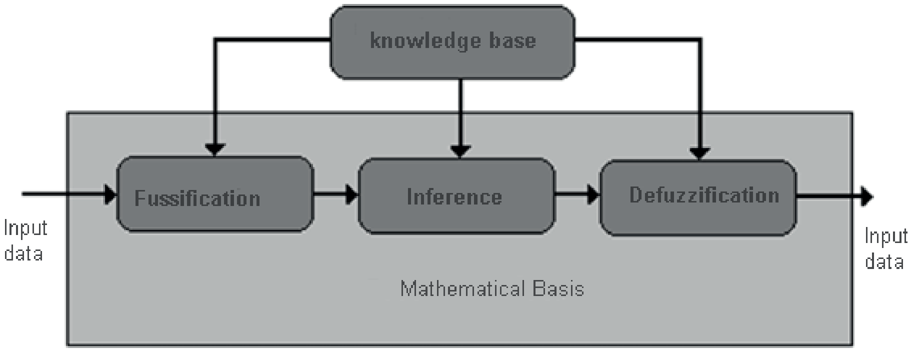

Figure 3: Structure of a fuzzy model.

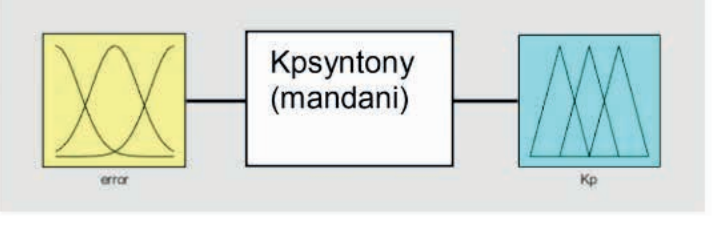

Figure 4: Linguistic variables for the proportional control part.

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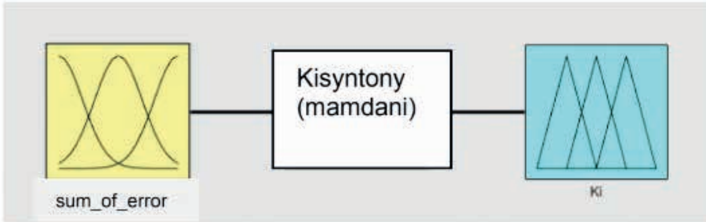

Figure 5: Linguistic variables for the integral control part.

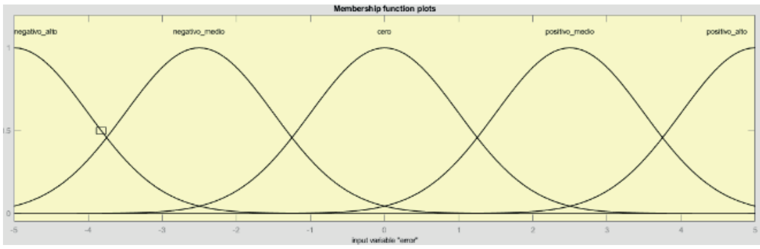

Figure 6: Membership function for the error.

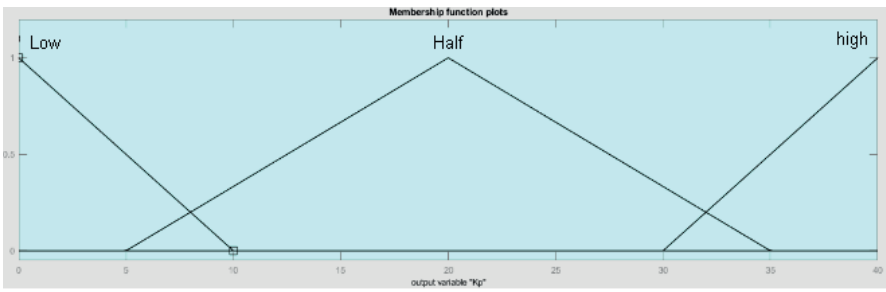

Figure 7: Membership function for Kp.

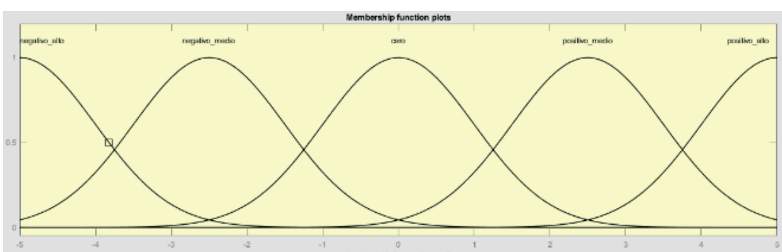

Figure 8: Membership function for the sum of the error.

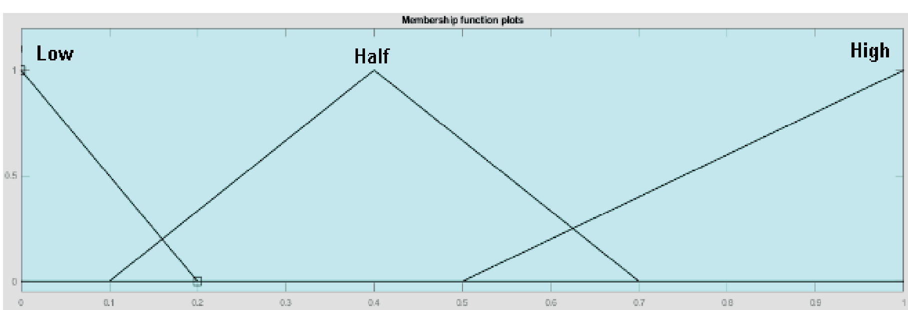

Figure 9: Membership function for Ki.

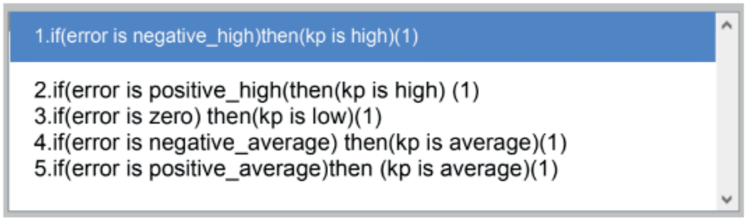

Figure 10: Fuzzy rules for tuning Kp.

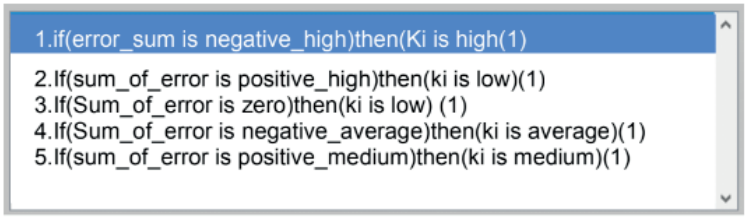

Figure 11: Fuzzy rules for Ki tuning.

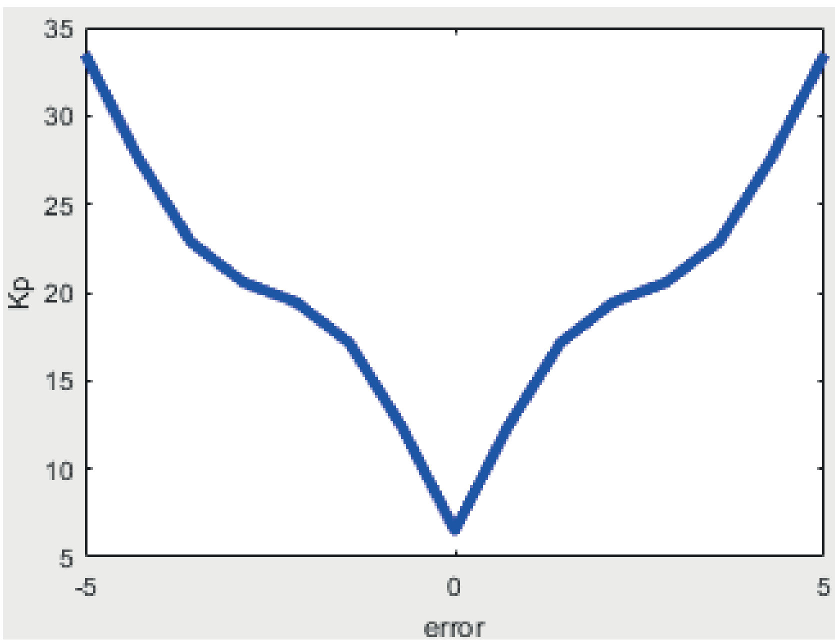

Figure 12: Response of the controller P.

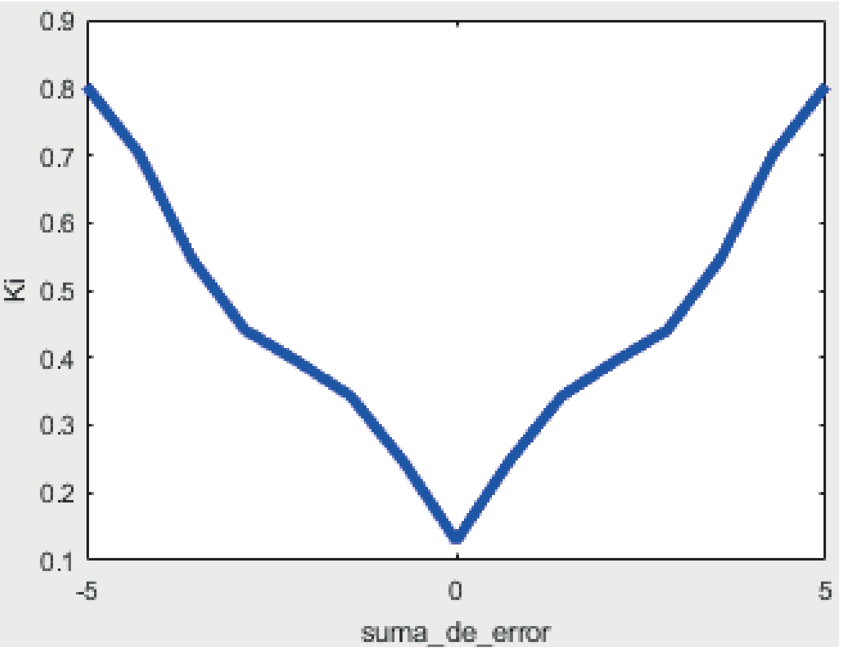

Figure 13: Controller response I.

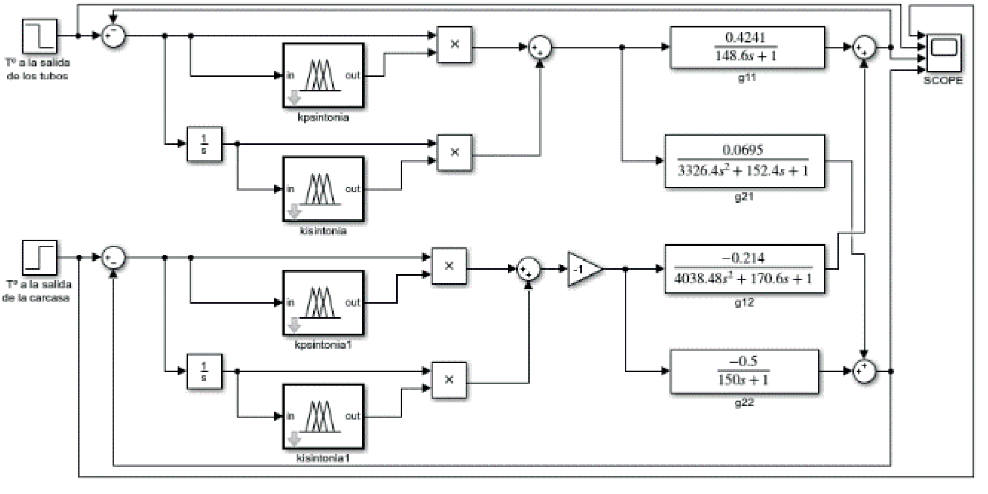

Figure 14: Diagram in Simulink.

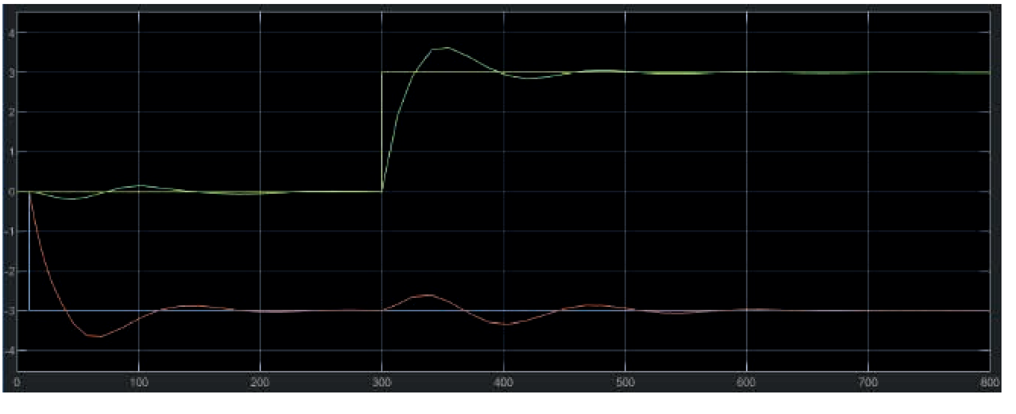

Figure15: System response in Simulink.

diagram in Simulink.

The simulation result can be seen in Figure 15. In this case, the system was subjected to a change in the reference temperature of the tubes of -3ºC 10 seconds after starting the simulation (blue curve). While a change of +3ºC in the reference of the case temperature at 300 sec (yellow curve).

CONCLUSION

Through the simulation carried out, it is observed that the system uses the fuzzy rules that have been generated to bring the values of the controlled variables to their new reference values.

In this sense, the PI control that has been implemented behaved adequately under other simulation conditions, such as the change of sign in the references.

If the objective is to adjust the response of the system to design criteria, it is necessary to advance in controller tuning methods based on fuzzy logic, however, the approach to the tuning problem is carried out starting from a predetermined initial structure [4].

On the other hand, if the objective is to eliminate the interactions between the variables, a solution may be to use an interaction compensator whose parameters are generated by genetic algorithms [6].

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