Comparison of Defuzzification Methods: Automatic Control of Temperature and Flow inHeat Exchanger

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1. Introduction

The purpose of this work is to analyze the behavior of traditional and fuzzy control, applying in flow and temperature control to load current of a heat exchanger, and the analysis of different methods of defuzzification, utilized just as itself this carrying out the fuzzy control. Acting on the fuzzy controller structure, some changes of form are carried out such that this tune in to be able to obtain optimal response. Proceeds on the traditional controller and comparisons techniques on these two types of controls are established. Inside the changes that are carried out on the fuzzy controller this form of information defuzzification, that is to say the methods are exchanged defuzzification in order then to realize comparisons on the behavior of each one of methods.
In many sectors of the industry where include thermal processes, is important the presence of heat exchangers (Shah & Sekulic, 2003, Kuppan, 2000). Said processes are components of everyday life of an engineer that has as action field the control systems, therefore is considered interesting to realize a control to this type of systems. This work studies two significant aspects: A comparison between traditional and fuzzy control, and an analysis between several defuzzification methods utilized in the fuzzy logic (Kovacic & Bogdan, 2006, Harris, 2006), development an analysis on each one of methods taking into consideration, contribute that other authors have done and leaving always in allow, that the alone results obtained will be applicable at the time of execute control on an heat exchanger (Xia et al., 1991, Fischer et al., 1998, Alotaibi et al., 2004,). The test system this composed for two heat exchangers, one of concentric pipes and other of hull and pipes, to which implemented them a temperature and flow automatic control to the load current of heating (Fig. 1).

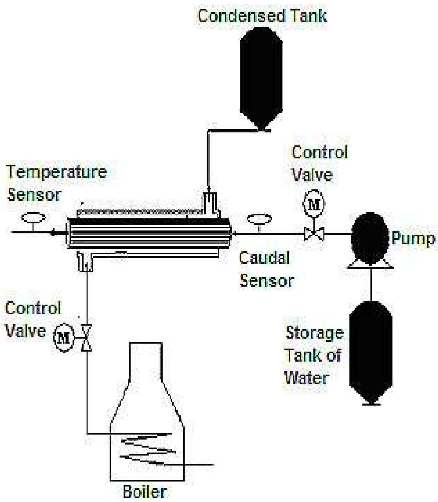


Fig. 1. Thermal pilot plant scheme

The control is realized through two proportional valves, one on input of the water, responsible for keep the value of order of the water and other installed in the line of input of the vapor (source of heat), responsible of keep the quantity necessary of vapor to obtain the target temperature. Physical experimentation typically attaches the notions of uncertainty to measurements of any physical property state (Youden, 1998). The measurement of the flow is realized by a sensor of rotary palette and the measurement of the temperature by thermocouples (Eckert & Goldstein, 1970, McMillan & Considine, 1999, Morris, 2001). The signals supplied by sensors are acquired by National Instruments® FieldPoint module (Kehtarnavaz & Kim, 2005, Archila et al., 2006, Blume, 2007) that takes charge and send signal to the control valves, after to be processed the data by controller.

2. Fuzzy and Classic Control Software

The control software designed uses two sections, the fuzzy and PID (Proportional/Integral/Derivative) control program. These controllers are created on environment Labwindows/CVI by National Instruments Company®, which permits to realize the pertinent operations with the data captured through FieldPoint modules, utilized in systems control. The fuzzy control interface, is the responsible for receiving data of sensors, so much of temperature for the temperature control case, as of the flow sensor for control of the same one, to process, and according to an order established, to determine an response sent to the actuators. Basically, this program is responsible of to schematize the fuzzy sets, according to established by the user, defuzzification of the inputs, to realize the inference of these inputs in rules, to realize aggregation in the outputs sets, and to execute the defuzzification process, to determine the response that assist to the system to obtain the established state. The PID control classic interface is similar of fuzzy control interface, but the difference is in entrusted of to execute the three control actions, proportional, derivative and integral to determine the responses that assist to the system to obtain its target state.

The PID control system general is represented in figure 2, where R(s), is the signal target or set point, U(s), is the output of the PID controller that goes in the direction of the plant G(s), and Y(s), is the value in use of the variable to control, which reduces to the reference and the error is determined (controller input).

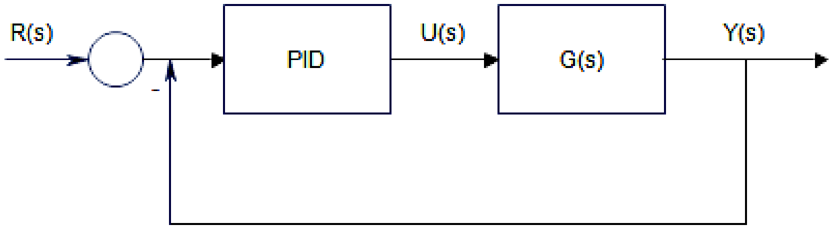


Fig. 2. General PID Control System

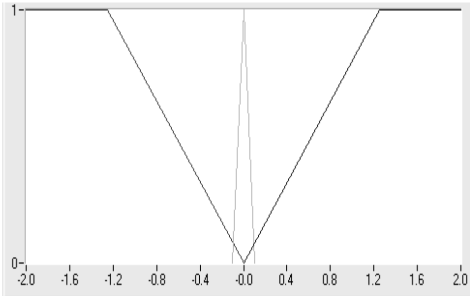
The purpose of temperature control is to achieve that water that the heat exchanger overtakes the value of target temperature and to keep it in the value even with external disruptions. On operate control valve is supplies the quantity of vapor that heats water. The input to system control is the temperature error, obtained since the thermocouple placed on the exit of the exchanger, and the exit control the quantity of necessary current to open or to close the proportional valve (Plant). This control is realized through a PID controller.
The flow control has as purpose to obtain that water mass flow that enters to heat exchanger, achieve the target value, and can to keep it during its operation, and even with disruptions. This means that should operate on the valve of control, who is the one that restrain the water quantity that enters to the system. The system input will be the error obtained through the flow sensor installed in the input of the system, and the PID controller will control the quantity of necessary current to manipulate the proportional valve. Both processes begin, calculating the difference between the measured temperature and the temperature desired or flow measured and flow desired. In this form, identify the error. The values of control parameters are taken, and the output is calculated that goes in the direction of the plant. This output obtains values since 0 to 20 mA, they will represent aperture angles of proportional valve.

3. Fuzzy Control System

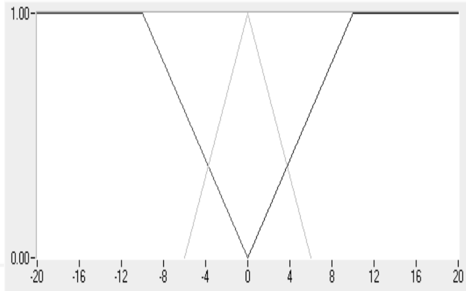
The inputs to control system are temperature error and gradient, obtained since the sensor placed on the way out of exchanger, and the exit control the quantity current necessary to open the proportional valve. The rules and membership function system are obtained in table 1 and figure 3, respectively.

Error / **Δ Error**	**Negative**	**Zero**	**Positive**
Negative	Open	Open	Not operation
Zero	Open	Not operation	Close
Positive	Not operation	Close	Close

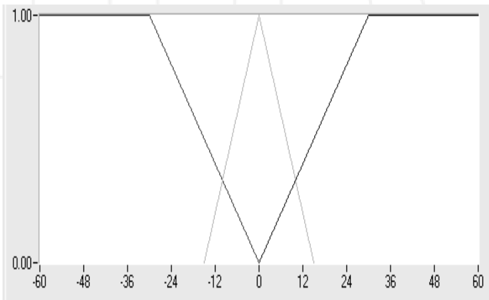
Table 1. Temperature control rules assembly



Membership functions - current at the outset



Membership functions – derived variable from Error



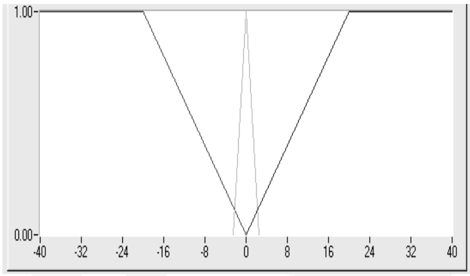
Membership functions - variable Error

Fig. 3. Membership Functions - temperature control

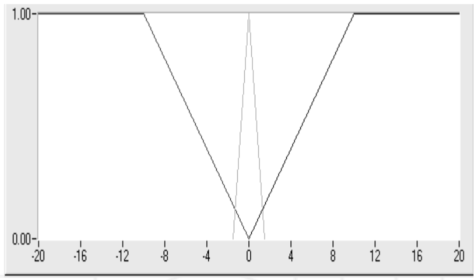
The flow control has as purpose to obtain that water mass flow that enters to heat exchanger, achieve the order value and can to maintain it during its operation, and even before disruptions. This means that should act on the control valve is the one that restrain the water quantity that enters to system. The system input, they will be the error obtained through the flow sensor installed to system entrance, and change of error in the time, and the output will quantity control necessary of current to manipulate the proportional valve. Both processes begin, calculating the difference between measured temperature and desired temperature, or measured flow and desired flow. In this form identify the Error. Calculate the gradient, reducing the error new of previous one. Once known these variables, that constitute the inputs of fuzzy logic controller, proceeds to realize the fuzzification, inference and defuzzification, to obtain the controller output. This output obtains values since 0 to 20 mA; represent aperture angles of proportional valve. The system rules and membership function are obtained in table 2 and figure 4, respectively.

Error / **Δ Error**	**Negative**	**Zero**	**Positive**
Negative	Close	Close	Not operation
Zero	Close	Not operation	Open
Positive	Not operation	Open	Open

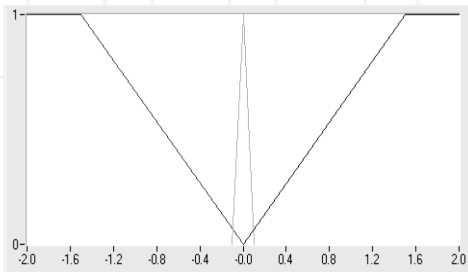
Table 2. Flow control rules assembly



Functions of membership - variable error



Functions of membership – derived variable from error



Functions of membership - current at the outset

Fig. 4. Functions of membership - flow control

3.1 Comparative Results Relating Defuzzification Methods Implemented

The defuzzification methods selects were five; identify in the control area by center of gravity weighted by height, center gravity weighted by area, average of centers, points of maximum criterion weighted by height and points of maximum criterion weighted by area (Zhang & Edmunds, 1991, Guo et al., 1996, Saade & Diab, 2000). In systems control, the main term is the stability that can offer the system, for this is necessary the delayed time that the system in being stabilized, error margin between value desired (V_c), and system stabilization values (V_e) and inertial influence of system. For temperature and flow control tests, is defined a set point 25 [Lts/min] and 40 [ºC]. The parameters and equations used for different responses in each one of the methods are shows in table 3, table 4 and table 5, according the parameters established in table 3.

METHODS	EQUATIONS	
1. Center of gravity weighted by height	$\bar{x} = \dfrac{\sum_{i=1}^{n} h_i * w_i}{\sum_{i=1}^{n} h_i}$	Where, w is gravity center of resultant assembly after fuzzy operation select, and h is the height of the same assembly.
2. Center of gravity weighted by area.	$\bar{x} = \dfrac{\sum_{i=1}^{n} s_i * w_i}{\sum_{i=1}^{n} s_i}$	Where, w is gravity center of resultant assembly after fuzzy operation select, and s is the area of the same assembly.
3. Points of maximum criterion weighted by area.	$\bar{x} = \dfrac{\sum_{i=1}^{n} s_i * G_i}{\sum_{i=1}^{n} s_i}$	Where, G is the point of maximum criterion of resultant set after to realize fuzzy operation select and s is the area of the same set.
4. Points of maximum criterion weighted by height.	$\bar{x} = \dfrac{\sum_{i=1}^{n} h_i * G_i}{\sum_{i=1}^{n} h_i}$	Where, G is the point of maximum criterion of resultant set after to realize fuzzy operation select and h is height of the same set.
5. Average of centers	$y = \dfrac{\sum_{l=1}^{M} y^{-l}(\mu_{B'}(y^{-l}))}{\sum_{l=1}^{M}\left(\mu_{B'}(y^{-l})\right)}$	Where y^{-l} represents the center of fuzzy set G^l (defined as the point V in which $\mu_{G^l}(y)$ reaches its value maximum), and $\mu_B(y)$ defined for the degrees of membership resultant by fuzzy inference.

Table 3. Methods and models defuzzification

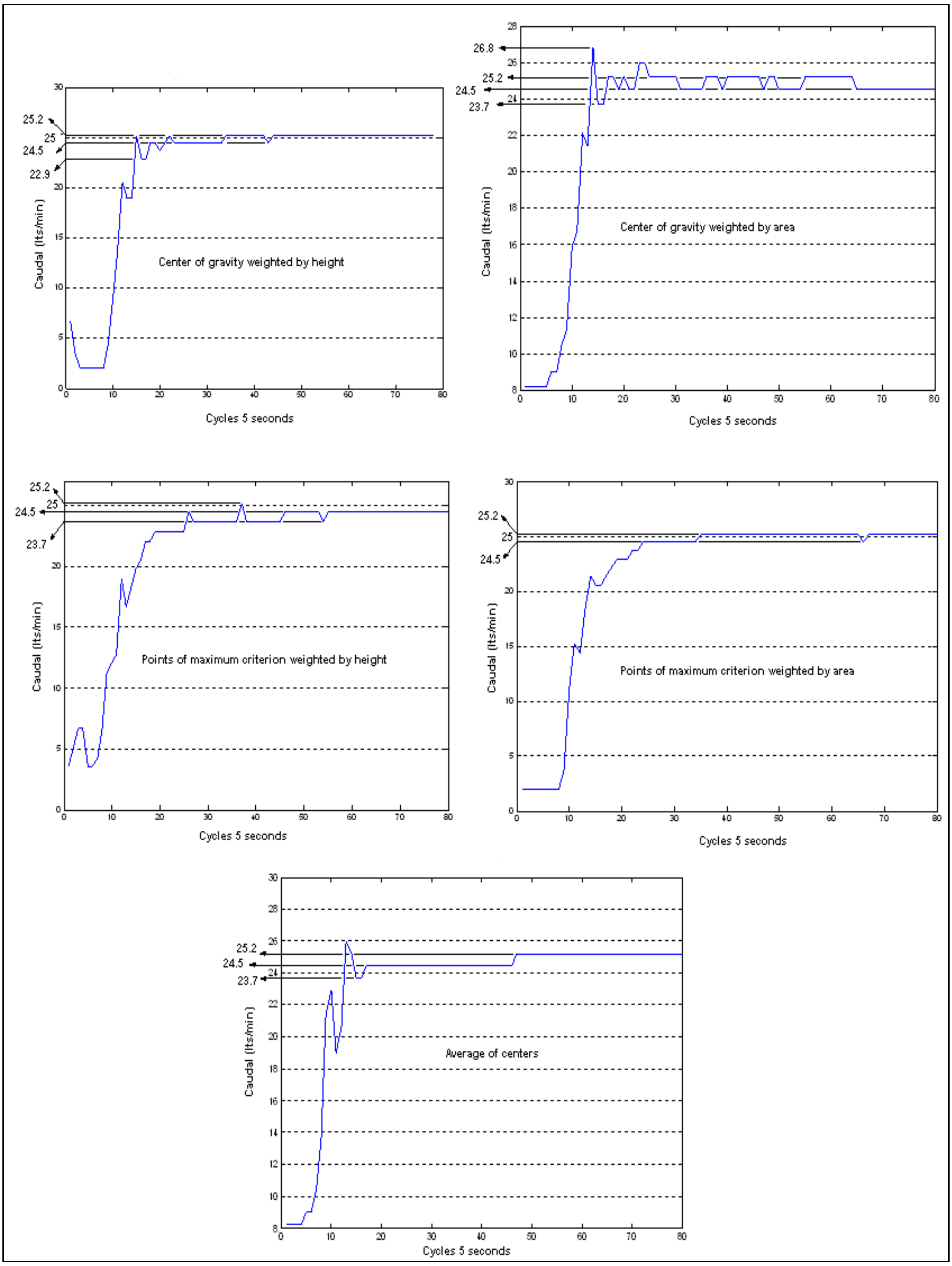


Table 4. Flow control response

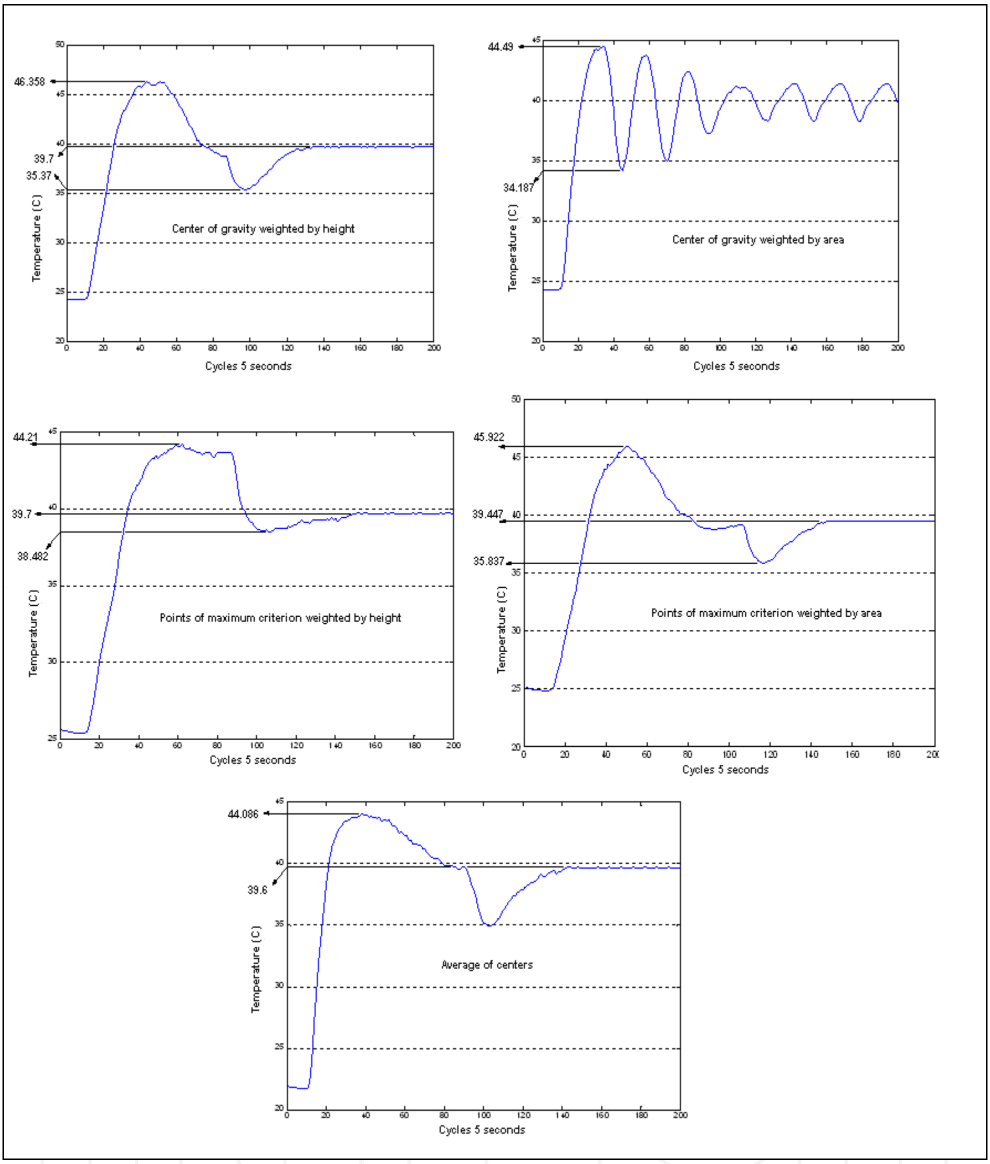


Table 5. Temperature control response

A summary of results obtained on different methods is shown in table 6 for flow control and table 7 for temperature control.

Defuzzification method	Stability time [sec]	Error margin (V_c - V_e)	Inertial influence of system
Center gravity weighted by height	105	0.8% above of the set point 2% below of the set point	0.8% above of the set point 8.4% below of the set point
Center gravity weighted by area	125	0.8% above of the set point 2% below of the set point	7.2% above of the set point 5.2% below of the set point
Average of centers	85	0.8% above of the set point 2% below of the set point	4% above of the set point 5.2% below of the set point
Points of maximum criterion weighted by height	230	2% below of the set point	0.8% above of the set point 5.2% below of the set point
Points of maximum criterion weighted by area	120	0.8% above of the set point 2% below of the set point	0.8% above of the set point 2% below of the set point

Table 6. Response of defuzzification methods - flow control

Defuzzification method	Stability time [sec]	Error margin (V_c - V_e)	Inertial influence of system
Center gravity weighted by height	670	0.75% below of the set point	40.89% above of the set point 11.57% below of the set point
Center gravity weighted by area	Not stabilized	Not stabilized	11.25% above of the set point 14.53% below of the set point
Average of centers	710	1% below of the set point	10.21% above of the set point 12.5% below of the set point
Points of maximum criterion weighted by height	745	0.75% below of the set point	10.52% above of the set point 3.79% below of the set point
Points of maximum criterion weighted by area	735	1.38% below of the set point	14.80% above of the set point 10.40% below of the set point

Table 7. Response of defuzzification methods - temperature control

3.2 Comparative Analysis between Classic and Fuzzy Controller

To be able to realize this analysis should make use of fundamentals concepts at the moment of to evaluate the controller efficiency. The concepts in this case are: systems delayed time in being stabilized, error margin between order value (V_c) and stabilization values (V_e) and inertial Influence of system. For the comparative analysis between fuzzy controller and PID controller, in the flow control use of tests realized to each one of these controllers with set point 25 [Lts/min] and 40 [ºC]. The results obtained are shown in the table 8.

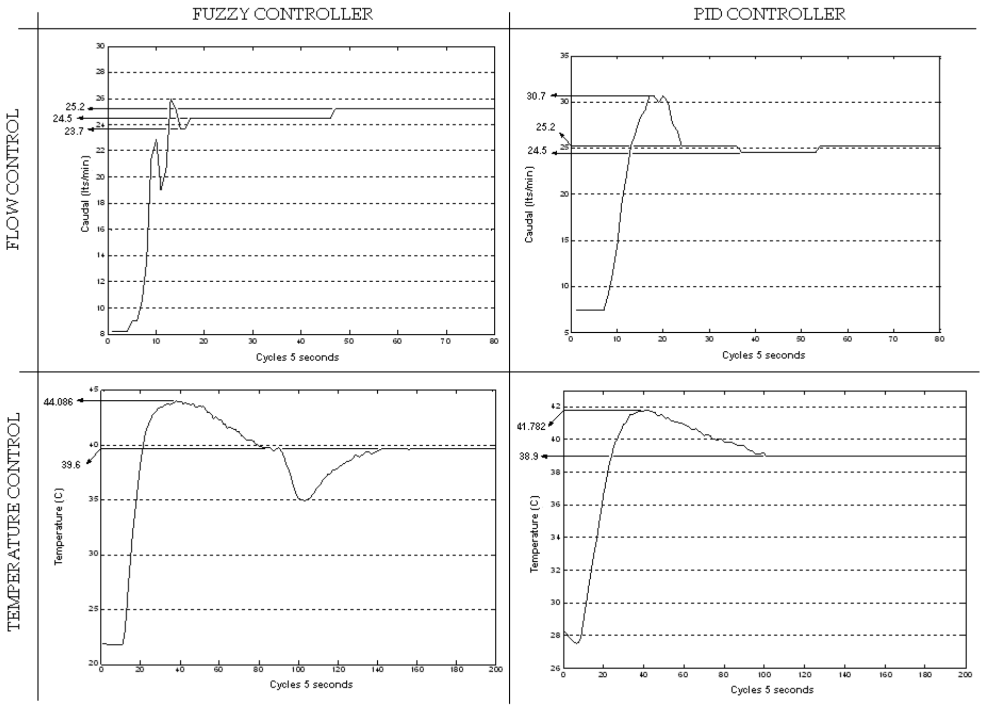


Table 8. Controllers response

A summary of results obtained on different methods is shown for flow control (table 9) and temperature control (table 10).

Controller	**Stability time [sec]**	**Error margin (V_c - V_e)**	**Inertial influence of system**
FUZZY CONTROL	85	0.8% below of the set point 2% above of the set point	4% below of the set point 5.2% above of the set point
PID CONTROL	115	0.8% below of the set point 2% above of the set point	22.8% below of the set point 2% above of the set point

Table 9. Response of controllers - flow control

Controller	Stability time [sec]	Error margin (V_c - V_e)	Inertial influence of system
FUZZY CONTROL	710	1% below of the set point	10.21% above of the set point 12.5% below of the set point
PID CONTROL	505	2.75% below of set point	4.45% above of set point 2.75% below of set point

Table 10. Response of controllers - temperature control

7. Conclusion

The results obtained in this work show the technical viability of the utilization fuzzy logic in the flow and temperature control to the warming-up current input of heat exchanger. The implementation the flow and temperature control with fuzzy logic possesses the advantages of not requires a precision mathematical model for control system. Some disadvantage is the design should be realized generally with test and error method. Is possible to control through fuzzy techniques industrial process with greater facility and errors minimum and sufficient with to identify its general behavior to structure a series of fuzzy sets and its respective rules. The fuzzy controller tune, depending on the rules matrix, also, depends on the size of variable sets, already itself of input or output. This depends on the same behavior system. For the implementation of fuzzy control, is necessary, the establishment of methods and alternatives utilized in each one of the blocks that conform it. In this form, can be obtained optimal results, at the moment of tuning the system. The respond of the fuzzy controller does not depend on the defuzzification method utilized, if not of the adequate utilization of the membership functions, and of numbers of linguistic variables utilized for each one of the variables of input and output of the system. Also, depends on type and size of the sets utilized.

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Automation Control - Theory and Practice
Edited by A D Rodi

ISBN 978-953-307-039-1
Hard cover, 350 pages
Publisher InTech
Published online 01, December, 2009
Published in print edition December, 2009

The present edited book is a collection of 18 chapters written by internationally recognized experts and well-known professionals of the field. Chapters contribute to diverse facets of automation and control. The volume is organized in four parts according to the main subjects, regarding the recent advances in this field of engineering. The first thematic part of the book is devoted to automation. This includes solving of assembly line balancing problem and design of software architecture for cognitive assembling in production systems. The second part of the book concerns different aspects of modelling and control. This includes a study on modelling pollutant emission of diesel engine, development of a PLC program obtained from DEVS model, control networks for digital home, automatic control of temperature and flow in heat exchanger, and non-linear analysis and design of phase locked loops. The third part addresses issues of parameter estimation and filter design, including methods for parameters estimation, control and design of the wave digital filters. The fourth part presents new results in the intelligent control. This includes building a neural PDF strategy for hydroelectric satation simulator, intelligent network system for process control, neural generalized predictive control for industrial processes, intelligent system for forecasting, diagnosis and decision making based on neural networks and self-organizing maps, development of a smart semantic middleware for the Internet , development of appropriate AI methods in fault-tollerant control, building expert system in rotary railcar dumpers, expert system for plant asset management, and building of a image retrieval system in heterogeneous database. The content of this thematic book admirably reflects the complementary aspects of theory and practice which have taken place in the last years. Certainly, the content of this book will serve as a valuable overview of theoretical and practical methods in control and automation to those who deal with engineering and research in this field of activities.

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