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Cooperative-Corrector Multivariable Fuzzy Controller

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Abstract

This paper deals with the decomposition problem of a multivariable fuzzy controller. For this, is proposed the use of notions taken from the framework of the Game Theory. Using the notion of *couple* between variables, a partition of the rule space in subsystems is obtained. The subsystems are considered players that corrects the actions of the others. These ideas are applied to the control of a polymerization reactor (CSTR).

Keywords: multivariable fuzzy control, fuzzy control of polymerization processes.

1 Introduction

It is almost obligatory to mention to Zadeh [1], Mamdani and Assilian [2] as the pioneers in the setting of a new methodology of controllers design. As opposed to the algebraic methods (that we will call conventional) this new methodology (date at early 70's), is based on a logical reasoning on linguistic variables, into the mathematical framework started by Zadeh on 1965. It is intended, with this method, to solve control problems of complex or ill defined processes, using for this the human experience. Since then, the theory of fuzzy control has been developed profoundly, approaching all (or nearly all) the problems of the Theory of Control: stability, robustness, tuning the controller parameters, etc. [3]. As were expected appeared also new problems. We will approach one of them in this work: the great dimensionality of the rule set (or rule base) in multivariable control systems.

The biggest part of research about Fuzzy Controllers has been centered in single input-single output systems, with controllers of PID type (or similar); at this time, would be said that this class of systems is quite well "understood", in relationship to the design techniques of conventional controllers [4]. Does not occur the same with multivariable systems.

Takagi and Sugeno [5] propose a reasoning model (TSK model), that consists basically in the decomposition of the input space in fuzzy regions and to approximate the system in each region by a simple model. The fuzzy model of a system is a fuzzy combination of subsystems of simpler models. Yager [6] unifies the idea of parameters and structures identification. He solves the problem of the structure identification, that is to say, of the distribution of the input space among the different rule subsystems, using techniques of non-linear programming. But these studies are applied fundamentally in the fuzzy modeling of (non-fuzzy) systems, and not in control. Nevertheless, these ideas can be used in the design of controllers.

We do not intend to make a complete review of the topic, so alone to indicate that the decomposition problem can be approached from (at least) two distinguishable perspectives. The first one, we could name syntactic or structural, is followed in [7]. Paying attention to the form of the rules, it is possible to obtain a hierarchical structure that keeps the completeness of the rules system, with a linear number of rules instead of exponential. Controller variables are distributed between the different levels of the hierarchy.

The second approach, we could name semantic or conceptual, pay attention to the meaning of some concepts that signal the complexity of the system. This work takes up with this second approach, reasoning about the concept of couple. Controller variables moves from abstract symbols, as considered in the syntactic method, to meaningless symbols. The resulting structure of the decomposition could be hierarchical, as in [8], or could be made in any other way. The decomposition will be guided by the chosen interpretation of the controller variables. In this paper we propose to interpret the variables as cooperative or competitive players. The decomposition consists in a de-couple guided by this interpretation, but this cannot be done arbitrarily: the controller must take into account the disadjustment, that presumably could occur, between this interpretation and the true couple of the plant variables. It is advisable, therefore, to add an element of recouple, named in this work, a corrector. The more knowledge we have about the couple, the simpler will be the decomposition. The following paragraph deepen in this question.

Paragraph 3 is devoted to the study of a fuzzy controller applied to a polymerization process.

2 Cooperative-corrector controller

In the design of fuzzy controllers of multivariable systems is attempted that the set of rules satisfy certain properties: completeness, consistency, continuity and interaction [4]. We are interested especially in the completeness concept, that is to say, that for any input vector to the fuzzy controller at least one rule is fired with a nonzero degree of truth of the premise.

If a multivariable system is very coupled, that is to say, if any output $y_i \in Y = \{y_1, \dots, y_r\}$ depends on all the inputs $U = \{u_1, \dots, u_s\}$, the controller will have to take it into account in some way. It seems reasonable to think that it is sufficient that the control signal envisages this couple. That is to say, if we wish to design a feedback controller, each control signal will have to be a function of all the outputs of the system and, therefore, the first solution that we could adopt is to design a set of rules of the fuzzy controller under the general form:

$$\left.\begin{array}{l}\textbf{IF } v_1 \text{ is } A_{1j1}\textbf{AND .... AND } v_n \text{ is } A_{njn} \\ \textbf{THEN } (u_1 \textbf{ is } B_{1j1}, ..., u_s \textbf{ is } B_{sjs})\end{array}\right] \quad (1)$$

where :
$V = \{v_1, ..., v_n\}$: set of input variables (error, change of the error,...)
$L_{vi} = \{A_{i1}, ..., A_{ipi}\}$: set of linguistic terms of the input variable v_i (POSITIVE-LARGE, ZERO,...)
$U = \{u_1, ..., u_s\}$: set of output variables
$L_{ui} = \{B_{i1}, ..., B_{iqi}\}$: set of linguistic terms of the output variable u_i.

For this set of rules of the fuzzy controller to be complete they are needed $p = \prod_{j=1}^{n} p_i$ rules.

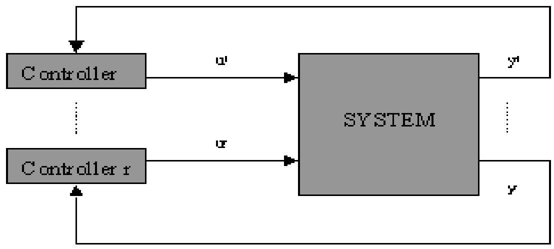


Figure 1

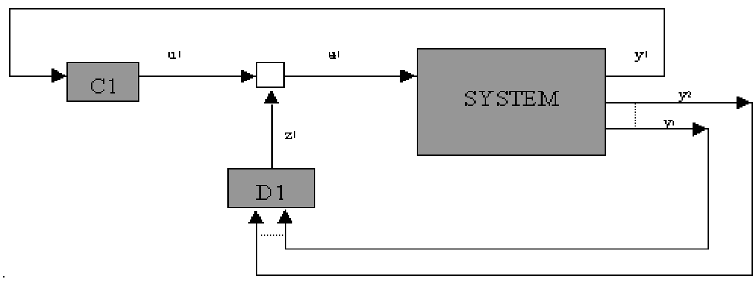


Figure 2

When the system has many inputs and many outputs, the total number of rules with the representation (1) can be excessively high, therefore, it is necessary to decompose the control system in subsystems (but this cannot be made arbitrarily) that must continue satisfying at least the property of completeness.

When the internal couples of the system are very weak, we can design a completely decoupled controller (see fig. 1). That is to say, a partition of the set of inputs $V = \{v_1, ..., v_n\}$ and outputs $Y = \{y_1, ..., y_r\}$ in s classes is accomplished, being s the number of system inputs (or control variables). Then, an independent controller for each class of the partition is designed.

When the strong and weak couples are known, this design method can be improved despising the weak and taking only into accounts the strong, accomplishing a partition of the input set of the system $U = \{u_1, ..., u_s\}$, designing, then, independent controllers for each new class.

In either case it is necessary to know the internal couples of the system, and this is not always possible.

This technique can still be improved compensating the weak couples with additive control signals (see fig 2). What is being making in this case is to define a set of intermediate control variables (that they do not need be the state variables), that we will call $Z = \{z_1, ..., z_m\}$.

What we have made until here has been to describe different control structures, reasoning about the concept of couple, in the sense of strong and weak. But this is not more than a rhetorical resource, since for example, the structure of the figure 2 can be interpreted in terms of linear couple (C1) and non-linear couple (D1), as for example in the computed torque method, in robotics [9]. To sum up, we could have chosen any concept of functional character to reason about it and to decompose the system of control in subsystems of smaller dimension (the classes of the previously mentioned partition), since, what interests us, in the first place, is to emphasize the structural character of the decomposition without forgetting the functional aspect.

In the fuzzy controllers is almost indispensable to define those intermediate variables (Z) with certain physical sense, since the design methodology of the rules demands a linguistic reasoning that relates outputs (U) to inputs (V). That is to say, the more abstract are these intermediate variables the more difficult will be to design each partial controller.

The corrections does not need be of additive character ($u1 = u1 + z1$), but they can be (as we have made in the application of the CSTR of the paragraph 3) of percentual character ($u_1 = u_1(1 + z_1)$) to facilitate the reasoning on the concept "correction". Thus, for example, if a controller (C1) decides "to increase much the temperature (u_1)" , other (D1) would amend this action with rules of the type "reduces in a 20% the action of the other controller (z_1)". On the other hand, as can be observed in the figure 2, it has not been still made a satisfactory decomposition in terms of the number of rules, since the corrector controller, that generated $z1$,continues receiving many inputs. The number of inputs can keep being excessive.

To solve this issue, that is to say, to reduce the number of rules and to preserve the completeness property of the set of rules, we propose in this paper the idea of a cooperative controller, that it will not be something else that a way of interpreting the interaction of the controllers to generate the final action. The cooperation can be blind or not informed, when none of the controllers have been informed of the action of generates z_1, continues receiving many inputs. The number of inputs can keep being excessive.

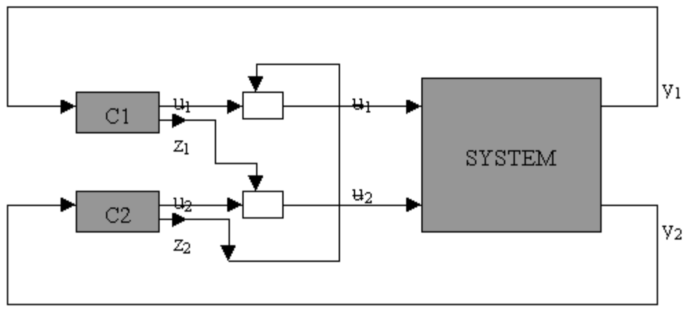


Figure 3

To solve this issue, that is to say, to reduce the number of rules and to preserve the completeness property of the rules , we propose in this paper the idea of a cooperative controller, that it will not be something else that a way of interpreting the interaction of the controllers to generate the final action. The cooperation can be blind or not informed, when none of the controllers have been informed of the action of the other (see fig 3) or informed (see fig 4) in otherwise.

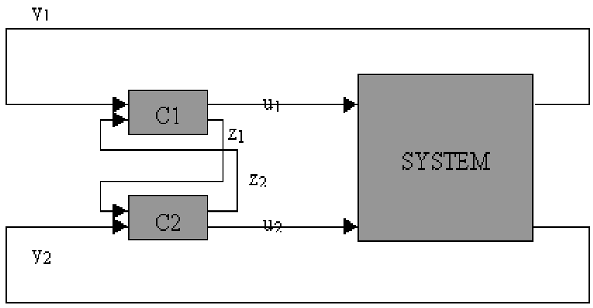


Figure 4

Under what conditions is possible to decompose the control system in a cooperative-corrector structure that takes into account the intrinsic couples of the system? The answer is not obvious.

What we want to say is that the notion of "couple" can be interpreted in the framework of the fuzzy logic in terms of a cooperative (or competitive) game between different controllers (or players) that deal the input variables. To the extent that they are or are not informed of the actions of the other, the corrections could be more intelligent.

In the following paragraph we analyze an application to the problem of polymerization reactors.

3 Application to a polymerization reactor

The idea of all this work originates from the application that we are go to describe below. It was attempted to design a controller for a polymerization reactor that corrects the action of other already designed controller; designed taking into account a simple mathematical model of the plant, and that has an admissible good performance.

The original idea was not to alter substantially the rules system of this "good" controller, when we can make use of a more complex and accurate mathematical model of the plant. This new model can have a greater dimension, what compel us to think about the decomposition of the control system.

We go to apply some of the general ideas previously exposed to the polymerization problem in a continuous stirred tank reactor (CSTR), through computer simulations, with real data obtained from an important Spanish company of the sector.

The design literature of this class of systems considers a CSTR with a coolant jacket for which circulate cold water, since the polymerization reaction is very exothermic. On the other hand, for the controllers design, a mathematical model [10] is used, that considers only one control variable (the water flow in the reactor) and only one output variable (the temperature within the reactor). It is designed, therefore, a Temperature Controller. This supersimplified model has been used for the design of all known types non-linear controllers (state feedback linearization [11], etc.). However the theoretical and practical studies of modeling of the polymerization process show a great variety of dynamical behaviors [12] not envisaged in the previous model. For this reason has been tended to the design of controllers not based on the exact model of the plant (adaptive control [13], fuzzy control [14,15]). Nevertheless, mathematical models are very useful to accomplish simulations and to analyze some qualitative relationships between inputs, outputs and states variables of the system.

For the development of the model is necessary to accomplish a macroscopic matter and energy balance. We have developed a mathematical model of the CSTR, that unlike the commented model (that we will call the simple model) does not despise factors as the contraction of volume in the monomer to polymer conversion due to phase changes (from liquid to solid). It is also introduced the possibility of controlling independently the monomer and solvent flow. And, in conformity with the kinetic studies of this type of processes, we consider a variable density within the reactor in addition to a variable control of the output flow (of the product).

With these small modifications the control system would have four control variables (monomer flow (FA), solvent flow (Fe), water flow of the jacket (Fj), and output flow of the reactor (Fo)) and three output variables (volume within the reactor (V), temperature within the reactor (T) and polymer concentration (B)).

We design thus a Temperature-Volume Controller. Figure 5 shows the block diagram of the control system studied in [16], following the lines exposed at the beginning of this paragraph. In the Figure 6 is indicated the set of linguistic terms for the input and output variables, and in Table 2 the set of used rules. The Secondary Controller is a corrector controller for the Volume Controller (not informed cooperation),. while the Volume Controller of the Primary cooperates informatively with the Temperature Controller of the Primary.

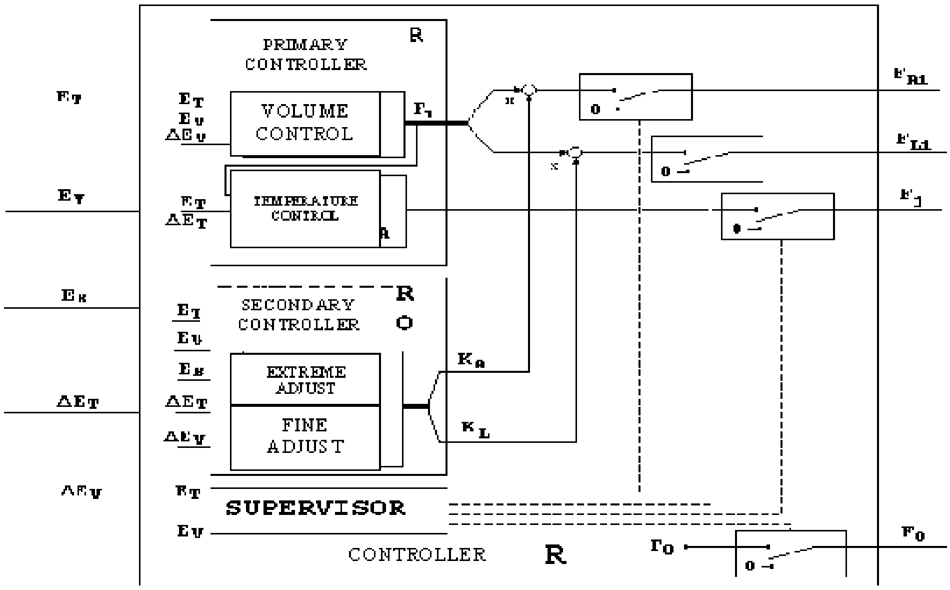


Figure 5

The Secondary fuzzy block has been split into two sets of rules to fulfil two different objectives: to reduce the transient and to increase the precision (to reduce the deviation to the set point defined for the steady state regime). In the Figure 5 these two parts are named "extreme adjustment" and "fine adjustment". (It has been included in the figure a third general block named "supervisory", that in reality comes to be a series of "alarms" that cut determined control flows of the reactor when the controller input variables are out of the normal range).

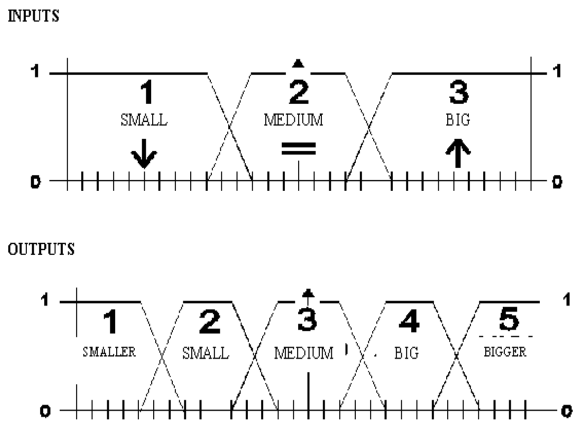
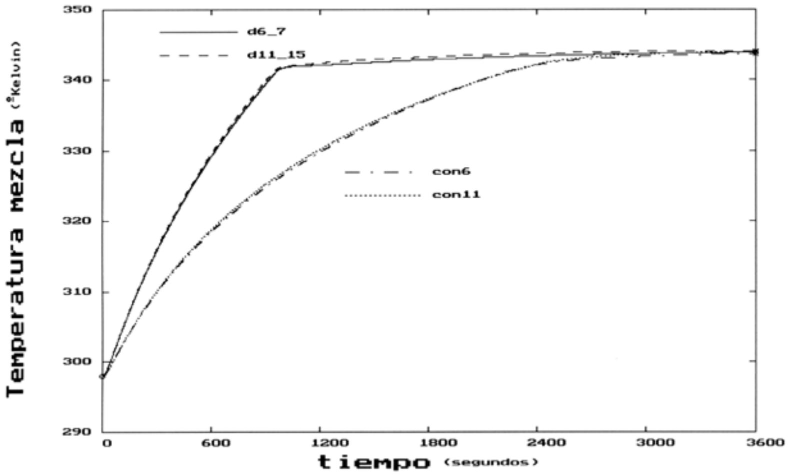
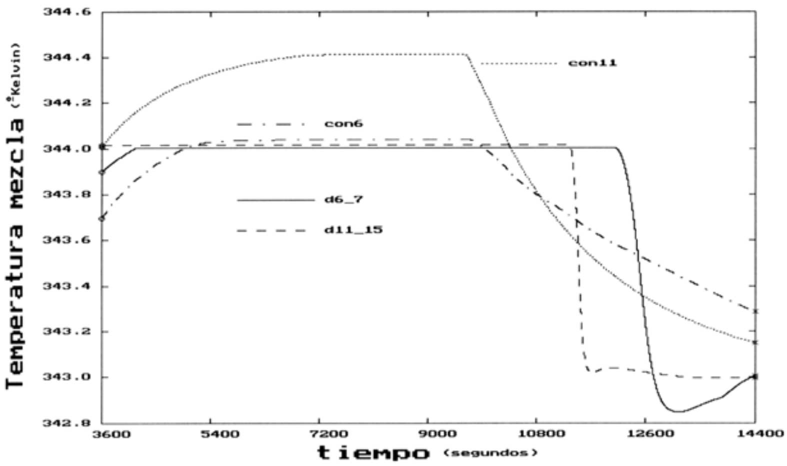


Figure 6

In graphics 1 and 1 bis are represented the mixing temperrature-time

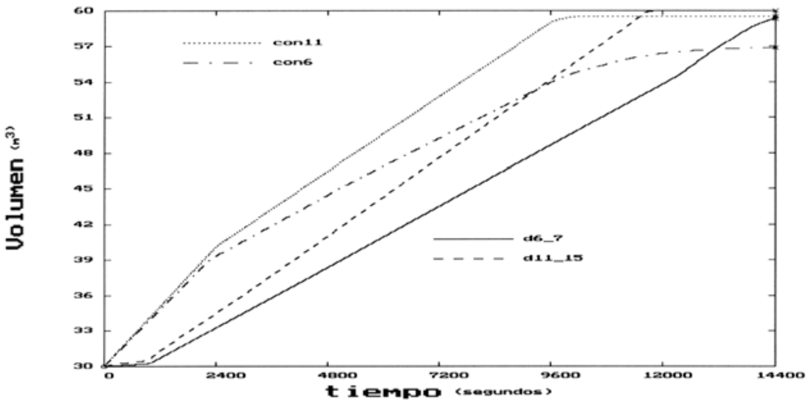


Graphics 1

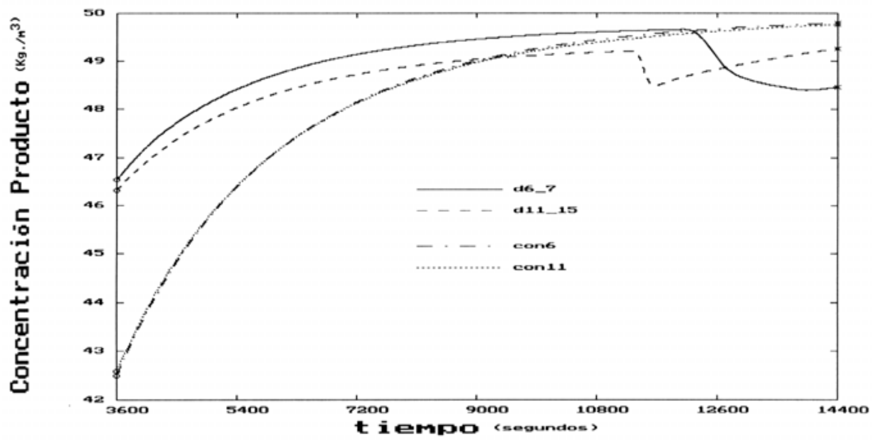


Graphics 1 bis

The graphics 2 represent volume –time



Graphics 2



Graphics 3

The graphics 3 represent concentration- time

Table 1: Conditions of simulations

STARTING	POINT	SET POINT
T	25°C (298°K)	70°C (343°K)
V	30 m^3	60m^3
C_B	0 Kg/m3	50 Kg/m^3

In Graphics 1 to 3 are presented comparative simulation results of the performance of the various control subsystems of the complete controller (Figure 5).

The authors in [17] are studying, with greater depth that in [16], the theoretical reaches of the ideas exposed in the previous paragraph, applying them to this class of reactors.

4 Conclusions

The Multivariable Fuzzy Controllers design has been little studied in the specialised literature. We have proposed a form of reasoning for the decomposition of the input space, that permits the design of the control rules being based on the experience and on the qualitative knowledge of the causal relations between input variables. The design pretends to be gradual, that is to say, controllers of lower dimension are first designed and tuned; the enlargement of the dimensionality is made designing new controllers that cooperate (as players of a game) with those which have been already proven, correcting percentively their actions. We have named this form of decomposition Cooperative-Corrector Control. These ideas has been applied to a polymerization reactor (CSTR). Nevertheless, many opened problems remains to be solved. At present, the systematisation of this approach is being studied in [17].

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