Fuzzy Control Implementation for the Chemical Reactor

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1. Abstract

Fuzzy control is a dynamic developing area in the field of system science. This paper gives a short explanation of how fuzzy controllers work and an example of generating of fuzzy control rules based on the method of cell-to-cell mapping, which applies the possibility theory and the theory of graphs. Method of cell-to-cell mapping is used to propose a fuzzy logic controller for the chemical reactor.

Keywords: Fuzzy control, fuzzy model, cell-to-cell mapping, system graph

2. Introduction

In these days application of fuzzy sets theory can be observed in a whole class of human activities. It started in general theory of systems and in control science and now fuzzy systems are widely used in such areas as economics, medical diagnostics, prediction of stability of constructins, earthquake prediction, modeling of chemial reactors, but also in libraries or on financial market. Let's look closer, why fuzzy systems are becoming so popular.

In the real world, objects are often classified into different categories. For such categories as tall man, high inflation rate, pretty woman etc., all of them convey linguistic vague information. The concept of membership of an object in such categories is not obvious and not precise. Thus, the application of classical two-valued logic to the real world is limited in some cases. The idea of fuzzy sets proposed by Zadeh aims to deal with such information.

Application of fuzzy inference systems to automatic control was first reported in Mamdani's paper in 1975, where, based on Zadeh's proposition, a fuzzy logic controller (FLC) was used to emulate a human operator's control of a steam engine and boiler combination. Since then, fuzzy logic control became the most significant application for fuzzy logic and fuzzy set theory.

3. Fuzzy Logic Controllers

FLCs accept numeric inputs from the outside world and convert these into linguistic values that can be manipulated by using fuzzy logic operations with linguistic if-then rules given by human operators. The linguistic outputs, the result of the fuzzy logic operations, are converted into numeric outputs which are delivered to the outside world then. Thus, fuzzy systems provide a framework of representing human expert rules with fuzzy logic to infer human decision. Based on this ability, FLCs can approximate human reasoning and achieve some intelligence.

The FLC (Fig. 1) is composed of four function blocks: fuzzification, rule base, inference engine and defuzzification. All settings of the FLC are stored in data base. The mechanism of the fuzzy system is as follows: the measurements of the outside world in the form of numeric, crisp data are transformed by fuzzification into linguistic values. Then the linguistic values are processed by the fuzzy rules in the rule base in the form of „if-then“ fuzzy implications. The output expressed in fuzzy sets after fuzzy implication is finally transformed into a nonfuzzy (crisp) output of the system to the outside world.

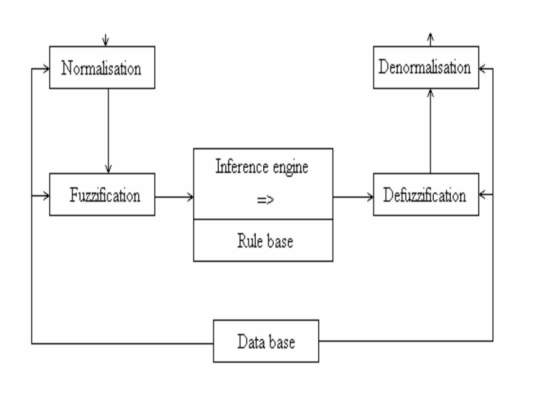

Fig. 1 – Fuzzy logic controller

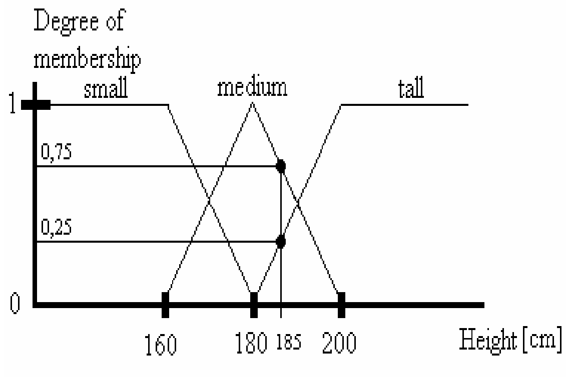

Fig. 2 – Fuzzification

Fuzzification transforns the input, cisp data into a fuzzy data. I means, that for each input variable is its degree of membership to all of the defined fuzzy sets assigned. An example of fuzzification of the crisp value „height“ is shown in fig.2. As we can see, man 185cm tall belongs to the „medium“ fuzzy set with the degree of membership 0,75 and to the „tall“ fuzzy set with degree of membership 0,25.

Rule base consists of the if-then conditions, which describe the behaviour of the FLC. An example of such rule is: „If temperature is *low* and pressure is *low* then valve is *almost opened*. Words printed in italics represent the fuzzy sets, temperature and presure are input variables and valve is an output one.

Inference engine is, in other words, implementation of implications given in the rule base. Fig. 3 graphically describes the process of fuzzy inerence using Mamdani’s inference engine for two input variables and two rules fired.

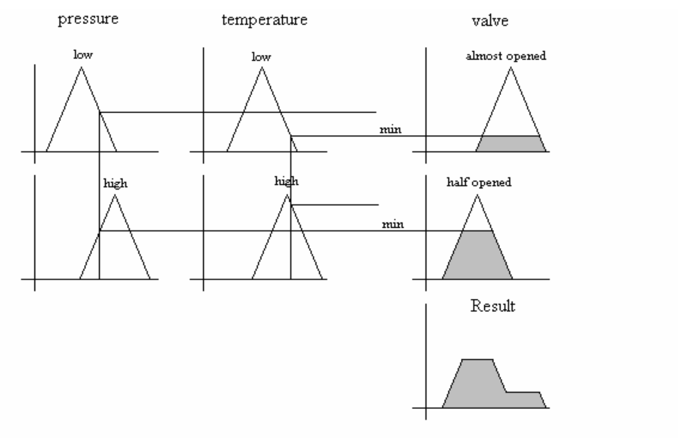

Fig. 3 – Inference engine, Mamdani’s implication

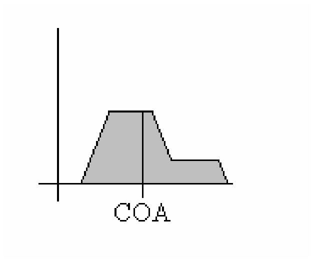

Fig. 4 – Deffuzification, COA

Defuzzification means to find appropriate functional, which assigns number to the membership function of the resultating fuzzy set. The center of area (COA) method is frequently used here. The defuzzificated, crisp, value is a coordinate of the centroid of a polygon assigned by the resulting fuzzy set, as shown in fig. 4.

4. Generating of Fuzzy Control Rules based on the Method of Cell-to-Cell Mapping

The main idea is based on the assumption that the precise model of the process dynamics in the form of differential equations is not known. Known are only some formulas resembling the control rules of the FLC, which are equivalent to differential equations in the finite number of points. Some discretization of state space might be be made then, similarly as in the method of cell-to-cell maping introduced by Hsu.

Let us consider a multivariable control system as shown in fig. 5. Let x_i and u_j denote components of the state and control vectors. The universes of discourse (intervals, which input variables are from) for each variable are finite intervals of real numbers on which at least three fuzzy sets are defined.

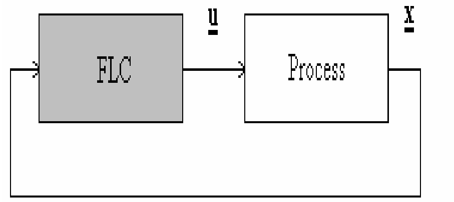

Fig. 5 – Feedback control system

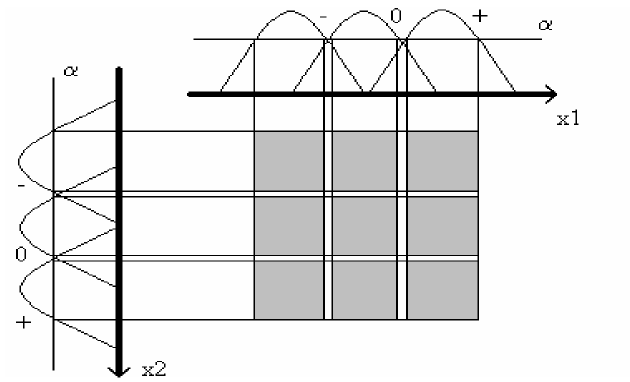

Fig. 6 – Cell state space

Now the cell phase space (at the α level) can be defined as can be seen on fig. 6. Fuzzy set with superscript „0“ denotes fuzzy „zero“, whereas „+“ and „-“ express fuzzy „negative“ and fuzzy „positive“ values. In the cell space the nominal state *s* such that $0 \in s$ can be distinguished. The cell controll space can be defined in the same manner now.

The process dynamics may be roughly described by a graph, where nodes represent cells in the cell state space and arcs are described by pairs „control action/possibility of transition“. An oriented arc from node „a“ to node „b“ exists, when the possibility of transition is greater than some treshold. In other words, the system trends from an arbitrary cell „a“ to neighborhood cell „b“, when appropriate control action is applied.

The analysis of the possibility of transition plays a key role in construction of the system graph. An alternative, how to compute the possibility of transition is to take the index α=1, so the cell state space degenerates to a „dot“ state space. Now the angle ϕ between the line connecting two neighborhood dots and an approximate phase vector of the system, described in the form of „if-then“ rules can be computed. We are able to assign the possibility of transition according to the angle ϕ and possibility distribution function Π(ϕ). Π(ϕ) may be defined as follows:

1. $\Pi(\phi) = 1$ for $\phi=0$ or $\phi=2\pi$
2. $\Pi(\phi)\in(0,1)$ for $\phi\in(0,\pi/2)$ or $\phi\in(3\pi/2,2\pi)$
3. $\Pi(\phi) = 0$ for $\phi\in<\pi/2, 3\pi/2>$

From the control objective point of view, each cell should trend to some nominal state cell. It means, that determining the control rules can be understud as finding critical paths in the system graph starting from the initial states resulting to the nominal state. The critical path is the path with the highest possibility of transition computed as a product of all possibilities of transition across the path. Thus, we achieve a graph for the closed loop system, which can be easily transformed to the rulebase of the desired FLC.

5. Implementation for the chemical reactor

The original model of the chemical reactor is given by two nonlinear differential equations:

$$\dot{x}_1 = -x_1 + Da\,(1 - x_1)\exp\left(\frac{x_2}{1 + x_2/\gamma}\right)$$

$$\dot{x}_2 = -x_2 + BDa(1 - x_1)\exp\left(\frac{x_2}{1 + x_2/\gamma}\right) - u(x_2 - x_c)$$

where x_1 denotes the conversion, x_2 is the dimensionless temperature, u is the dimensionless heat transfer coefficient (control), x_c is the dimensionless cooling jacket temperature, Da = Damkohler number and B = dimensionless heat of reaction. We have taken $x_c = 0$, Da = 0,05, B = 8, $\gamma = 2100$. $x_{10} = 0,5$ and $x_{20} = 3$ was chosen as the operating point. Chosen membership functions for the state variables are shown in fig. 7 and fig. 8. Membership functions for the output variable were taken fuzzy singletons (degree of membership 1 in one point, elsewhere 0) in points –0,5; 0; 50.

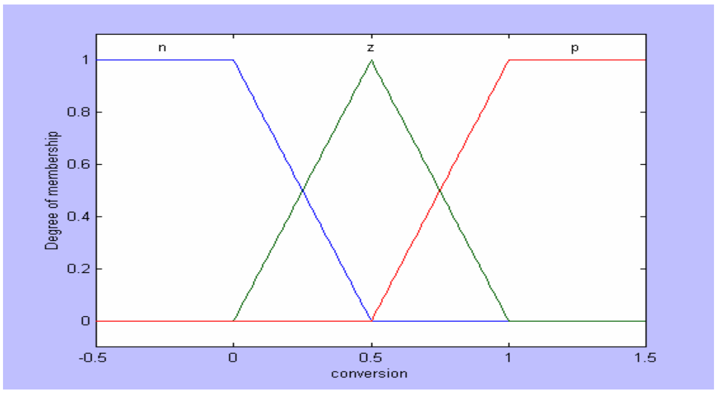

Fig. 7 – Membership functions for x_1

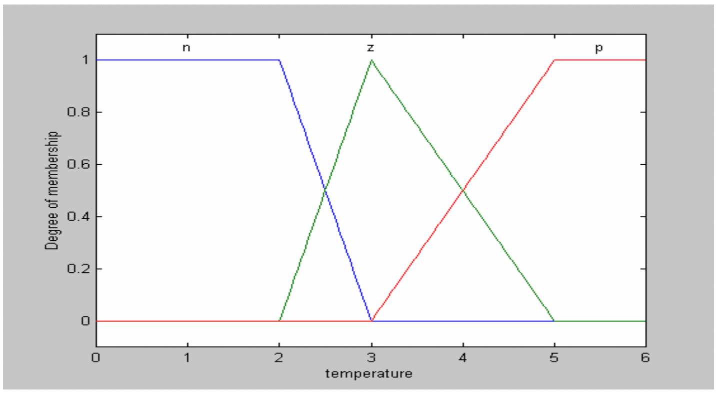

Fig. 8 – Membership functions for x_2

Graphs of the single system and of the closed-loop system are in fig. 9 and fig. 10. Rulebase of the controller is in fig. 11 and simulations for various initial conditions are in fig. 12. As we can see, the closed-loop system is stable for chosen initial conditions and reaches the desired state x_1=0,5 and x_2=3.

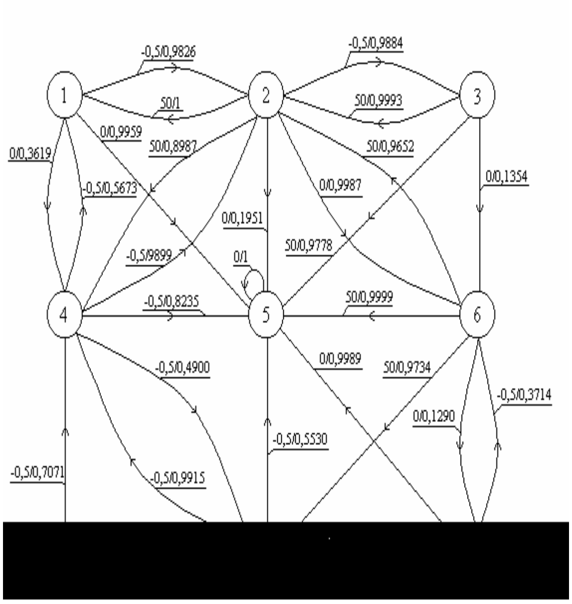

Fig. 9 – Graph of the single system

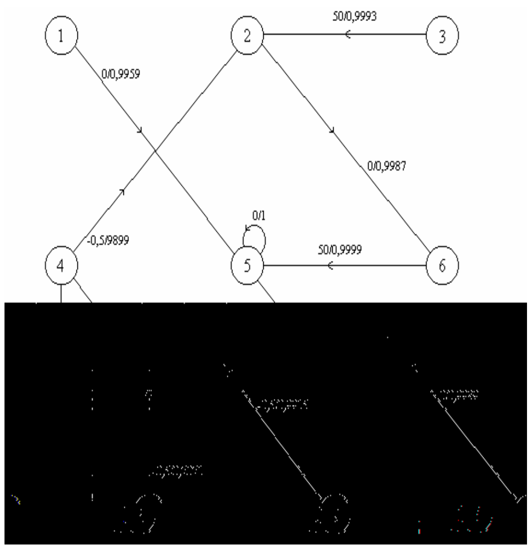

Fig. 10 – Graph of the closed-loop system

Rulebase of the controller is in fig. 11 and simulations for various initial conditions (x_1=1 and x_2=5; x_1=0,1 and x_2=4; x_1=0,4 and x_2=2) are in fig. 12.

x_1/x_2	n	z	p
n	0	0	50
z	-0,5	0	50
p	-0,5	-0,5	0

Fig. 11 – Rulebase

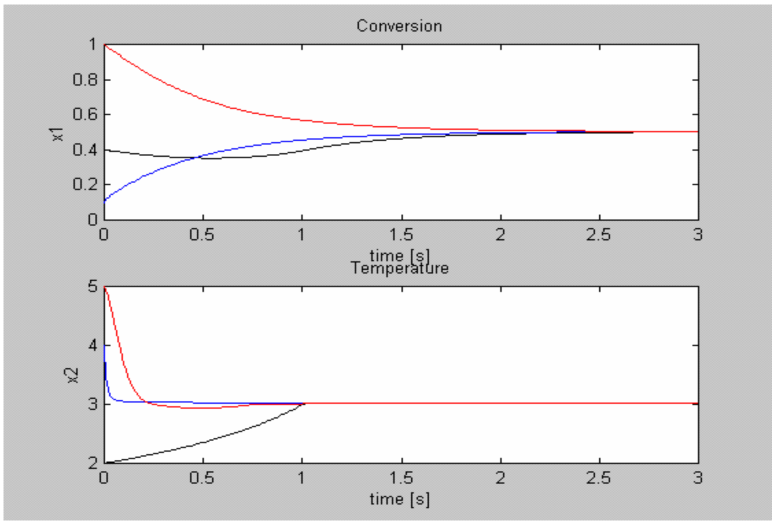

Fig. 12 – Simulations for various initial conditions

6. Conclusions

Methods for generating of parameters of fuzzy controllers are still an open area for reasearch. In this article, very brief description of construction of FLC was given. Such controller is easy to design, even if the mathematical description of the controlled plant is not known. Only some imprecise description of the process in the form of linguistic „if-then“ rules is needed. The main disadvantage of controller designed using the cell-to-cell mapping method is, that it ensures convergence only under assumption of smoothness of the function describing the controlled process and uniqueness of its equilibrium point **x**=0 and **u**=0. Anyway, it can be used as the method for seting of the initial parameters of FLCs.

7. References

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