Method of Automated Synthesis of the Fuzzy-Login Systems that Controls Sintering Process

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Abstract

This article proposes a method for the synthesis of fuzzy logic controllers for control of complex technological processes on the example of sinter production. The proposed method is based on the self-organizing knowledge bases of fuzzy controllers using the so-called fuzzy-supplementing optimizing algorithm. This method differs from the known ones by capability to synthesize control systems that meet the quality criteria and reduced amount of computation required to solve the problem of the synthesis.

Keywords: SINTERING PROCESS, SUPPLEMENTING FUZZY-OPTIMIZING ALGORITHM, SYNTHESIS OF CONTROL SYSTEMS

Introduction

The analysis of sintering technologies allowed to draw a conclusion [1] that this production is a typical non-linear multi-level process of the mining industry, for which the implementation of a comprehensive program of automation associated with the solution of problems of synthesis of adaptive systems of multi-level management, which will improve production efficiency and reduce power consumption.

As the dynamics of sintering process depends on a number of uncontrollable factors $c_i \in \Omega_{ci}, i = 1,2,3$ (i = 1 - vector of unknown quasi-stationary coefficients of the object; i = 2 – is a function of time which can't be measured; i = 3 - are unknown functions of state variables of the objects or the measured variable input-output) adaptation control system and signal to the parametric uncertainty can be implemented with the use of fuzzy logic controllers (FLC) [2-4] on the lower level of the automatic process control (APC) and functional uncertainties - on the basis of the calculation of the general strategy of vector control of the upper hierarchical level APC of sintering production.

In order to implement a comprehensive program of automation of production processes in the top-level adaptive APC should be included subsystem which allows to define: technological and techno-economic performance; the concept of the current management of local stabilization systems with implementation of the principle of robustness to disturbing influences; the main operating parameters of the process equipment; conditions and principles of load matching between the parallel stage of a multistage production complex; effective, in terms of technical and economic parameters, control channels in a subordinate regulation of multiply dynamic objects processes of adaptation of local loops on the lower hierarchical levels APC; graphics planned preventive maintenance of process equipment.

This article presents informative and formal statement of the problem of synthesis of fuzzy logic control systems of multi-level sintering process, organizational and technical measures to solve it are proposed.

The advantages of control systems with FLC generally include the following [4]:

1) the possibility of control systems synthesis in uncertainty conditions when there are only qualitative information in the object of management and control actions;

2) the special properties of control systems with FLC, in particular, low sensitivity to changes in the parameters of the control object;

3) synthesis of control systems of complex objects using fuzzy logic methods are often less labor intensive than traditional management systems;

4) linguistic form of the information is quite simple to interpret;

5) the fuzzy logic is a relatively new technology and its application allows you to easily reach the "non-infringement" designed products.

The main method of synthesis of FLC is expert method. In this case, controllers design is fulfilled in two stages.

On the first stage by means of interviewing of experts and specialists in the field of management of the object, for which the fuzzy logic controller is being developed, there buildt a knowledge base in the form of fuzzy production rules and then selected the type of algorithm, fuzzy logic and initial values of the controller parameters.

On the second stage the algorithm of fuzzy inference, knowledge base and the parameters FLC are customized using the conducting experiments on the real object or on a simulation model of the synthesized control system. This step is very time-consuming in terms of time spent for the experiments on the real object of management and needs a lot of computational costs when the experiments on the simulation model system will be made.

In this article there is a method that give opportunity to synthesize knowledge bases into fuzzy logic controllers which is differ by amount of calculations required for carrying out the synthesis.

Problem statement

Let us consider closed control system that includes FLC with control object (CO) in the figure 1.

Fuzzy logic controller consists of linear dynamic component (LDC) and module of fuzzy logic output (FLO). Such structure of controller makes us able to cover a wide class of fuzzy controllers of technological parameters of sintering production.

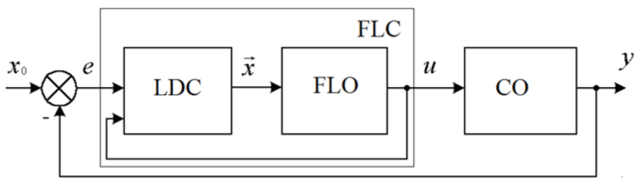

Figure 1. Control system structure with fuzzy logic controller

The aim of control is to get the best, as for chosen quality coefficient, correspondence of output coordinate of object y to the set value of x_0.

Initial data for synthesize of FLC are:

1) quality parameter of control, chosen according

to characteristics of control object (response time, time of the first coordination, overcontrol, integral square value etc);

2) manifold of typical input signals x_0; according to the reaction on them, it is possible to asses control system in the real worlk conditions;

3) model of the control object;

equation of LDC block (LDC should provide infeed rate of FLO signals of control error e and its derivative $\frac{de}{dt}$ [2-4]).

The task is to synthesize knowledge bases of FLO of FLC.

Synthesis of FLC knowledge base based on self-organizing algorithm

To solve the task we can use implementing optimizing algorithm of self-organizing of FLO system proposed in [5, 6]. This algorithm differs with smaller computational efforts as compared twith other known algorithms of fuzzy neural networks building-up [4-6].

Let us describe the algorithm in the context of the current task.

Let us assume that block of fuzzy interference (BFI) implements some nonlinear dependency between its input $\vec{x}$ and output u:

$$u = \eta(\vec{x}), \tag{1}$$

This dependence should give us a minimum of $I = G(\eta(\vec{x}))$, characterizing working quality of control system.

Let us consider that this composite function represents an integral square error of the system:

$$I = \int_0^{+\infty} [e(t)]^2 dt. \tag{2}$$

Let us assume, that we have some prior information about dependence (1) written in the form of battery m_0 fuzzy production rules in form:

Π_r: if x_1 is A_{r1} and x_2 is A_{r2} and…and x_n is A_{rn},then $u = u_r$,

Where r=1,2, … m_0 – is a rule number in the knowledge base, x_j (j=1,2,…, n) – are the components of the vector $\vec{x}$, A_{rj} – are some some fuzzy numbers, that have membership functions $\mu_{rj}(x_j)$.

Let us note that the given prior information may be absent (herein m_0=0). Let us assume that experiment can be performed to evaluate the value of composite function $I = I(\eta(\vec{x}))$ with current form of dependency $y = \eta(\vec{x})$. Such experiment is implemented by the imitational modeling of the given control system.

Algorithm consists in implementation of the next steps.

Step 0 (preliminary). There set a parameter ε characterizing error of the obtained minimum of the composite function. With the help of expert method there determined prior knowledge base of FLC in the form of m_0 of the fuzzy production rules. Current number of rules in the knowledge base is set m=m_0.

Step 1. If forming knowledge base (KB) is empty ($m_0 = 0$), then step 2 is performed, otherwise value $\eta_m(\vec{x})$ will be defined with help of Sugeno algorithm of 0 order of fuzzy output and with the help of certain production rules [4]:

$$\eta_m(\vec{x}) = \frac{\sum_{r=1}^{m} u_r \cdot \alpha_r(\vec{x})}{\sum_{r-1}^{m} \alpha_r(\vec{x})} \tag{3}$$

where $\alpha_r(\vec{x}) = \mu_{r1}(x_1) \times \mu_{r2}(x_2) \times \ldots \times \mu_n\ (x_n)$ – is the degree of validity of prerequisites of r^{th} rule.

Based on value of (3) the value of composite function I_m (2) with the help of imitational modeling is estimated.

Step 2. Rule with the next form is added to the KB.

Π_{m+1}: if x_1 is $A_{(m+1)1}$ and x_2 is $A_{(m+1)2}$ and … x_n is $A_{(m+1)n}$, then $u = u_{m+1}$,

where $A_{(m+1)j}$ – are fuzzy numbers with V-tent membership functions [4]:

$$\mu_{(m+1)j}(x_j) = \begin{cases} 1 - \dfrac{|x_j - c_{(m+1)j}|}{\lambda_{(m+1)j}}, \text{if } |x_j - c_{(m+1)j}| \le \lambda_{(m+1)j}, \\ 0, \qquad\qquad \text{if } |x_j - c_{(m+1)j}| > \lambda_{(m+1)j}, \end{cases} \tag{4}$$

where $c_{(m+1)j}$ – are the centers of fuzzy numbers $A_{(m+1)j}$.

Then we determine value

$\eta_{m+1}(\vec{x}, c_{(m+1)1}, \ldots, c_{(m+1)n}, u_{m+1}, \lambda_{(m+1)1}, \ldots, \lambda_{(m+1)n})$ with help of formula that is similar to (3). Parameters $c_{(m+1)1}, \ldots c_{(m+1)n}, u_{m+1}, \lambda_{(m+1)1}, \ldots \lambda_{(m+1)n}$ are set up by the optimization of function $I_{m+1} = I(\eta_{m+1}(\vec{x}, c_{(m+1)1}, \ldots, c_{(m+1)n}, u_{m+1}, \lambda_{(m+1)1}, \ldots, \lambda_{(m+1)n})$ in accordance with specified parameters.

Step 3. Checking inequality:

$$I_m - I_{m+1} \le \varepsilon. \tag{5}$$

where $I_m = I(\eta_m(\vec{x}))$, $I_{m+1} = I(\eta_{m+1}(\vec{x}))$.

Value m is changing: $m = m+1$.

In case of inequality (5) failes we'll go to 2, otherwise transition to step 4.

Step 4. KB of FLC is formed. Result is KB that consists of m production rules, herein the value of composite function is equal to I_m.

Simulation experiment. Let us illustrate the given method. Let us consider the control system of electric drive of sintering machine.

A feature of control of agglomerate sintering is the lack of methods of control for base value of the process - place of ending of the sintering process of the furnace charge. According to the previous statement, a comprehensive indicator of the process was considered as the main control parameter [1].

Neural-fuzzy system of determination of active automatic control system (ACS) [1] will carry out an analysis of the actual dynamic state of the process and according to the developed algorithm [1] will decide to activate the corresponding ACS in case of deviation of the given indicator.

We've got structural scheme with FLC and CO in form of fuzzy model for the control system of electric drive (fig. 2).

In the fig. 2 component M is the sampler with zero-order hold which is described by the equation:

$e^*(t) = e(t_k)$ with $t \in [t_k,\ t_{k+1}]$,

where $t_k = k \cdot T_0$ – is time of modulator firing, $k = 0, 1, 2, \ldots$ – are the numbers of discrete moments of time, $T_0 = 0{,}1$ – sampler work period.

Components of fuzzy logic output FLO 1 and FLO 2 of controller and CO respectively implement algorithm of fuzzy output Sugeno of 0 order [4].

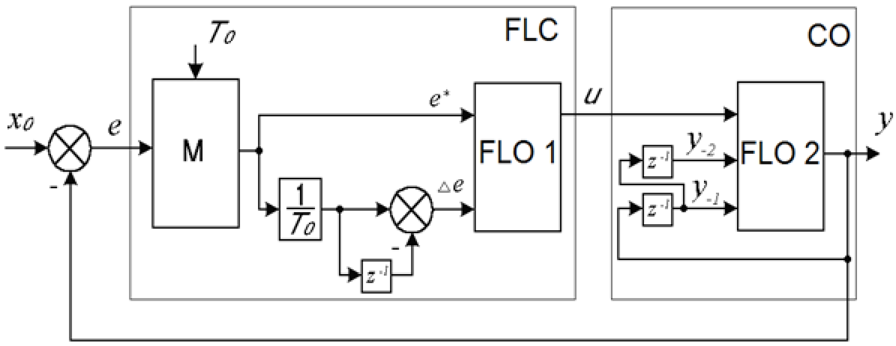

Figure 2. Structural scheme of electric drive control system of sintering machine.

KB of FLO 1 controller was obtained with help of expert method in the next form:

$$\Pi_1 : if\ e^*\ is\ P,\ then\ u = 1,$$
$$\Pi_2 : if\ e^*\ is\ N,\ then\ u = -1,$$
$$\Pi_3 : if\ \Delta e\ is\ P,\ then\ u = 1,$$
$$\Pi_4 : if\ \Delta e\ is\ N,\ then\ u = -1,$$
$$\Pi_5 : if\ e^*\ is\ Z\ and\ \Delta e\ is\ Z,\ then\ u = 0.$$

Membership functions of fuzzy variables N, Z and P have the form shown in fig. 3 (parameter $a = 0{,}5$).

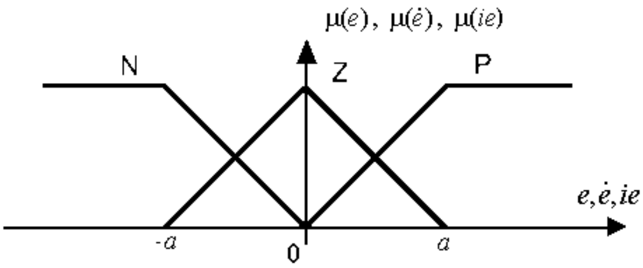

Figure 3. Membership functions of variables is "negative" (N), "approximately equal to zero" (Z), "positive" (P)

KB for FLO 2 of CO:

$\Pi_1 : if\ u\ "approximately -2",\ y_{-1}\ "approximately -2",$ $y_{-2}\ "approximately -2",\ then\ y = -2{,}02,$

$\Pi_2 : if\ u\ "approximately -2",\ y_{-1}\ "approximately\ 2",$ $y_{-2}\ "approximately -2",\ then\ y = 5{,}58,$

$\Pi_3 : if\ u\ "approximately -2",\ y_{-1}\ "approximately -2",$ $y_{-2}\ "approximately\ 2",\ then\ y = -5{,}62,$

$\Pi_4 : if\ u\ "approximately -2",\ y_{-1}\ "approximately\ 2",$ $y_{-2}\ "approximately\ 2",\ then\ y = -1{,}98,$

$\Pi_5 : if\ u\ "approximately\ 2",\ y_{-1}\ "approximately -2",$ $y_{-2}\ "approximately -2",\ then\ y = -1{,}98,$

$\Pi_6 : if\ u\ "approximately\ 2",\ y_{-1}\ "approximately\ 2",$ $y_{-2}\ "approximately -2",\ then\ y = 5{,}62,$

$\Pi_7 : if\ u\ "approximately\ 2",\ y_{-1}\ "approximately -2",$ $y_{-2}\ "approximately\ 2",\ then\ y = -5{,}58,$

$\Pi_8 : if\ u\ "approximately\ 2",\ y_{-1}\ "approximately\ 2",$ $y_{-2}\ "approximately\ 2",\ then\ y = 2{,}02,$

Composite functions of fuzzy variables "approx. -2" and "approx 2" are V shaped:

$$\mu(x) = \begin{cases} 1 - \dfrac{|x-c|}{\lambda}, & \text{if } |x-c| \le 4, \\ 0, & \text{if } |x-c| > 4, \end{cases} \quad (6)$$

with parameters $c = -2$ and $c = 2$ for "approx. -2" and "approx 2" accordingly.

As an indicator of control system quality, the integrated square mistake is considered (2) when supplying on the entrance of the system of single step influence $x_0 = 1_0(t)$

Imitational modelling of the system, where FLC is determined by above described 5 production rules, gave us the following result: I=3.829.

According to described algorithm there was performed synthesis. A priori KB was taken the same as for the first example. Accuracy parameter is ε =0,01

Rules in the next form:

$$if \quad e^* \; is \; A_{er} \; and \; if \quad \Delta e \; is \; A_{\Delta er}\,, then \; u = u_r\,.$$

The following parameters of added rules were optimized: centers of membership functions c_{er}, $c_{\Delta er}$; results of rules u_r; general variance λ_r for both membership functions. Result of self-organization algorithm: number of rules including prior m=8; parameters of added production rules:

$$c_{e6} = 0,9494\,,\; c_{\Delta e6} = -0,1892\,,\; \lambda_6 = 0,3561\,,\; u_6 = 0,9420\,;$$

$$c_{e7} = 0,7357\,,\; c_{\Delta e7} = -0,2119\,,\; \lambda_7 = 0,4184\,,\; u_7 = 0,6557\,;$$

$$c_{e8} = 0,4418\,,\; c_{\Delta e8} = 0,3533\,,\; \lambda_8 = 0,0768\,,\; u_8 = 0,6756\,;$$

Value of integral square error $I = 1,262$, which is three times less than in initial system.

Above mentioned example illustrates the effectiveness of suggested synthesis method of fuzzy logic controllers.

Conclusion

Proposed method for synthesis of fuzzy logic controllers based on self-regulztion of their knowledge base can be easy extended for case of multiple connected control systems and can be used to design automatic control systems with different technological processes.

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