HYBRID ALGORITHM FOR THE CONTROL OF TECHNICAL OBJECTS

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ABSTRACT

The paper is dedicated to the actual problem of modeling and development the hybrid control systems. The peculiarity of such systems consists in the combined application of methods of the classical control theory and fuzzy inference systems. The block diagrams of the hybrid control system and its operating algorithm have been described herewith. Application of the model for speed regulation of DC engine has been considered. Fuzzy control is done with the help of a PI-FUZZY controller. The basic stages of hybrid modelling have been described.

Keywords: modelling, hybrid control systems, uncertainty, PID controller, fuzzy inference system, DC engine, engine speed regulation.

1. INTRODUCTION

During the design of automatic control systems of technical objects and physical processes there is a task to develop models. The aim of models development is to provide the high-quality control action for objects when their parameters and requirements with regard to the regulation process undergo changes [1, 2].

Solving the control tasks only by means of the classical control theory brings several difficulties. For example, the delays in the control of technologic objects with highly dynamic changes of output parameters are not acceptable. The Application of PID control does not guarantee the fulfillment of this requirement. Significant difficulties also can arise while solving the tasks only by means of fuzzy logic with only quantitative indicators available.

The topic for the modern control theory is to design the hybrid control systems with combined usage of tools of the classical control theory and the theory of fuzzy sets. The hybrid method uses the classical control theory and the fuzzy logic. It allows significant improvement of major quality indicators of the system transition process [3].

2. FUZZY CONTROL MODEL WITH APPLICATION OF THE FUZZY INFERENCE SYSTEM

Measured input values (variables) are used as the information which enters the input of the fuzzy control system (general logic inference) [4, 5, 13]. At the output of the system the output control variables are constructed. The general logic inference is produced in four stages: fuzzification; fuzzy inference; composition, and de-fuzzification.

Fuzzy inference is realized on the basis of fuzzy production rules. The central component of fuzzy production is the core $A \Rightarrow B$, which is defined as «IF *A*, THEN *B*»; *A*, *B* are fuzzy expressions.

The set of rules of fuzzy productions composes the production fuzzy system. This system is recorded in the form of the structured text:

Rule-1: (IF «Precondition 1», THEN «Conclusion1»)
Rule-2: (IF «Precondition 2», THEN «Conclusion 2»)
……………………………………..
Rule-*N*: (IF «Precondition *N*», THEN «Conclusion *N*»)

So, to build up the base of rules of fuzzy productions, it is required to define the set of rules of fuzzy productions and also the set of input and output linguistic variables (LV). Special acronyms are used to define the terms of input and output LV [6]. Values of LV terms can be represented by such acronyms as: ZN - a negative close to zero; Z - close to zero; ZP - a positive close to zero; PS - a small positive; PMS - a positive larger than small; PM - a medium positive; PMM – a positive larger than medium; PB - a big positive; PMB - a positive larger than big.

The control action will be achieved at the forth stage in the defuzzification block in the form of an explicit value. The following defuzzification methods are used to convert the resulting membership function into the numerical value [7]: centre-weight method, method of area bisectrix and method of left (right) modal value.

The following algorithms of fuzzy inference are applied [7 – 12, 14]: Mamdani algorithm; Sugeno algorithm proposed by Sugeno and Takagi; Tsukamoto algorithm. During modelling of the PID controller the following variables are used: system error θ, speed of error change $\dot{\theta}$, error integral $\int\theta dt$, error acceleration $\ddot{\theta}$ and control action *U*. The block diagram of the hybrid system is shown on Figure-1.

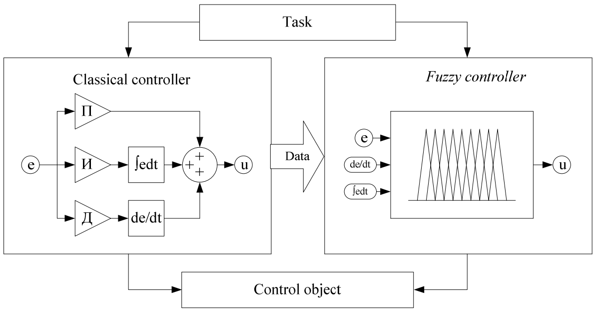

Figure-1. Block diagram of the hybrid control system.

Operating algorithm of the hybrid system is composed of the following stages:

Step-1. Mathematical calculating of the control object parameters.

Step-2. Mathematical calculating of the classical controller parameters.

Step-3. Development of the classical control model and analyzing of the quality major indicators of the transition process.

Step-4. Selection of the variables θ, $\dot{\theta}$, $\ddot{\theta}$, $\int\theta dt$, U required for the development of the fuzzy model of variables. The variables of the classical system simulation are determined in the discrete moments t_i from the moment t_0 of changing till the moment t_k of the steady state. The variables are transformed into the table values t_r. Thus, the investigated range of each variable (θ, $\dot{\theta}$, $\ddot{\theta}$, $\int\theta dt$, U) change is determined.

Step-5. Development of the fuzzy control model where the input variables are θ, $\dot{\theta}$, $\ddot{\theta}$, $\int\theta dt$, and the output variable is U.

Step-6. Specification of the input LV with the term-sets

$\theta=\{\theta_1,\theta_2,\theta_3,\ldots\ \theta_n\}$, $\dot{\theta}=\left\{\dot{\theta}_1,\dot{\theta}_2,\dot{\theta}_3,\ldots,\dot{\theta}_n\right\}$,

$\ddot{\theta}=\left\{\ddot{\theta}_1,\ddot{\theta}_2,\ddot{\theta}_3,\ldots,\ddot{\theta}_n\right\}$,

$\int\theta dt=\{(\int\theta dt)_1,(\int\theta dt)_2,(\int\theta dt)_3,\ldots,(\int\theta dt)_n\}$, and the output LV with the term-set $U=\{U_1,U_2,U_3,\ldots,U_n\}$. Specification of the membership functions. The numbers of the output LV terms have to be more than the number of the input LV terms for the model to be adequate. After the membership functions are constructed, their parameters will be obtained within the range determined during implementation in the classical model.

Step-7. Figure-2 shows how the value t_r grade of membership to a term of LV is determined. Every table value t_r of every variable from the set $\{\theta, \dot{\theta}, \ddot{\theta}, \int\theta dt, U\}$ corresponds with a value of the membership function $\mu(x)$ within the range [0 - 1] according to the *min* or *max* method, depending on the requirements to the control process (*max* method allows obtaining the transition process of higher quality).

Step-8. Constructing the base of fuzzy rules.

Step-9. Simulation of the system. Construction of the fuzzy inference surface in order to specify the correlation between values of the output variable and values of the input variables of the fuzzy model. This correlation represents the solution of the task which is known in the classical control theory as the task of synthesis of control actions.

Step-10. Analysis of the basic quality indicators of the transition process of the obtained fuzzy model.

Step-11. Correction of the rule base of the fuzzy controller in order to achieve the desired transition process.

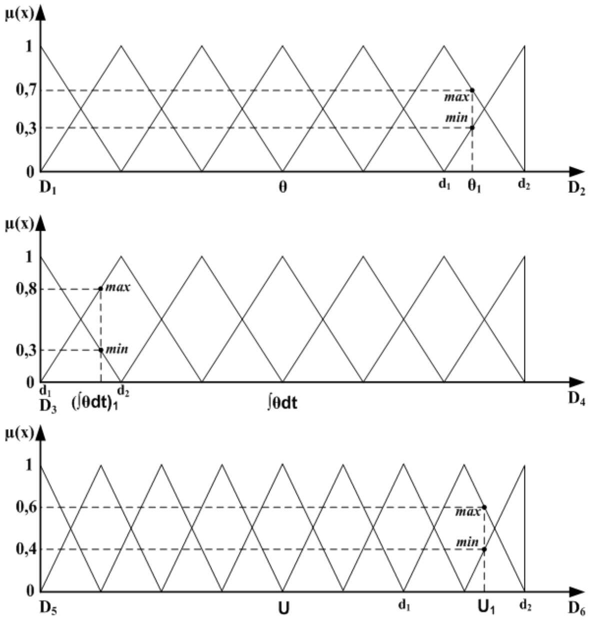

Figure-2. Determination of the membership grade of the value t_r to the LV term.

Analysis of results determines the ways how to improve the adequacy of the fuzzy inference system for the solution of automatic control tasks. Analysis of correlations between the output variable and the values of the fuzzy model input variables serves as a basis for changing the fuzzy rules or changing the range of the output LV. The rule base can be corrected by changing the rules during the further tuning of the obtained fuzzy model.

The model has been applied to the development of the automated control system for the technological process of the steam-generating unit USG-50/6M for the oil industry.

There was a loss of synchronization during opening and closing the valves in the channels of air- and gas-supply. The concentration of output flow was constantly changing in the channel of chemical purification and this led to the activation of the blocking system. Approbation of the PI-controller model is fulfilled on the example of regulation of the DC engine speed (valve drive).

The fuzzy control is carried out by the fuzzy PI-controller. The following two LV were selected as the input parameters of the fuzzy inference system: the signal of system error and the error integral. The control signal (control action) was selected as the output LV. The triangular shape was selected for the membership function.

The structure of fuzzy inference was constructed on the basis of Mamdani algorithm. *Min* method is used as the activation method; the operation of *min*-conjunction is used as the aggregation method. The method of *max*-disjunction is used to accumulate the conclusions of rules. The centre-weight method is used as the defuzzification method. The block diagram of the developed fuzzy system is shown on Figure-3.

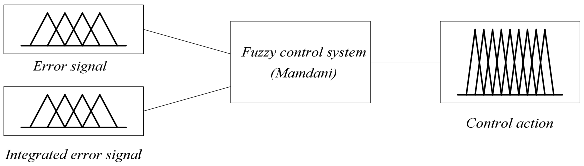

Figure-3. Block diagram of the developed fuzzy system.

The first LV θ has the term-set $T_1 = \{t^1{}_1, t^1{}_2, t^1{}_3, t^1{}_4, t^1{}_5\}$ ={«negative close to zero», «close to zero», «positive close to zero», «small positive», «medium positive»}. The second LV $\int\theta dt$ has the term-set $T_2 = \{t^2{}_1, t^2{}_2, t^2{}_3, t^2{}_4, t^2{}_5\}$={«close to zero», «positive close to zero», «small positive», «medium positive», «big positive»}. The output LV U has the term-set $T_3 = \{t^3{}_1, t^3{}_2, t^3{}_3, t^3{}_4, t^3{}_5, t^3{}_6, t^3{}_7, t^3{}_8\}$ = {«close to zero», «positive close to zero», «small positive», «positive larger than small», «medium positive», «positive larger than medium», «big positive», «positive larger than big»}.

In Figure-4 the block diagram of regulation of the output flow concentration in the mixer (mixing of two original components) is shown.

At the entrance to the mixer the flow F has the concentration C which is changeable in the course of time. In is required to determine the concentration C_0 of the output flow.

The model of control object is represented by the following transfer function:

$$W_{CO}(p) = \frac{k_{CO}e^{-p\tau_{CO}}}{T_{CO}p+1}. \tag{1}$$

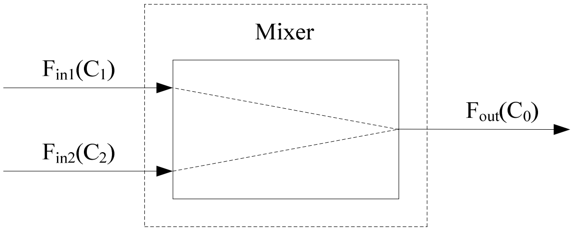

Figure-4. Scheme of regulation of concentration of output flow in the mixer.

The PID-controller with the following transfer function was chosen:

$$W_{PID}(p) = K_p\left(1 + \frac{1}{T_i p} + T_d p\right) \tag{2}$$

The block diagram of the control object and the regulation channel are shown on Figure-5.

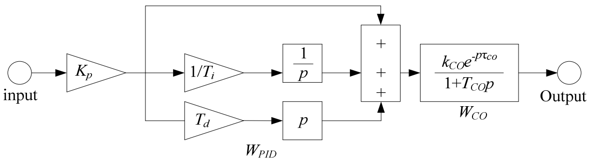

Figure-5. Block diagram of the control object and the regulation channel.

Let's calculate the value K_p as follows:

$$K_p = \frac{0,95T_{CO}}{k_{CO}\tau_{CO}}, T_i = 2,4\tau_{CO}, T_d = 0,4\tau_{CO}, \tag{3}$$

Then let's calculate the parameters of the PID-controller according to the desired phase margin γ_c defined the Nyquist criterion. The larger this margin is the more monotonous transition process is. The following operations were done in the calculation process:

- determination of the transfer function of the open-loop system $W(p) = W_{PID}(p)W_{CO}(p)$;
- determining the form of the phase response $\varphi(\omega)$ of the open-loop system;
- the obtained expression is equaled to the desired phase margin on the cutoff frequency $\varphi(\omega_c) = \gamma_c$ and the value ω_c is determined at $T_i = T_{CO}$, $T_d = \tau_{CO}$;
- the calculated value ω_c is substituted into the formula for the module of the complex transfer coefficient of the open-loop system $A(\omega_c) = \left|W(p)_{p=j\omega_c}\right|$ and the tuned parameter K_p is determined by equalling $A(\omega_c)$ to 1;
- the value of K_p is changed and thus the value of the phase stability margin γ_c is regulated. And γ_c affects the transition process quality.

The formula for the calculation of K_p is:

$$K_p = \frac{T_{CO}\omega_c}{K_{CO}}\sqrt{\frac{(T_{CO}^2\omega_c^2+1)(T_\mu^2\omega_c^2+1)}{T_{CO}^2\omega_c^2+(1-T_{CO}\tau_{CO}\omega_c^2)^2}}, \tag{4}$$

where T_μ is the time constant of the equivalent inertial unit.

We used the software package MATLAB for the calculation of ω_c by the graphical solution of the equation

$$\arctan\frac{-\omega_c T_\mu + \omega_c^3(T_{CO}^2\tau_{CO} + \tau_{CO}T_{CO}T_\mu - T_\mu T_{CO}^2)}{1+(T_{CO}^2 - T_{CO}\tau_{CO})\omega_c^2 + T_{CO}^2\tau_{CO}T_\mu\omega_c^4} = \\ = -\frac{\pi}{2} + \gamma_c + \omega_c\tau_{CO}, \tag{5}$$

where the phase margin $\gamma_c = 75° = \pi / 2,4$.

The input parameters of the fuzzy inference system are represented by two linguistic variables (LV): the signal of system error and the error differential. The output variable is the control signal (control action). The triangular shape was chosen for membership functions.

Mamdani algorithm is applied for the fuzzy inference. The *min* operation is used as the activation method; the operation of *min*-conjunction is used as the aggregation method. The method of *max*-disjunction is used to accumulate the conclusions of rules. The centre-weight method is applied as the defuzzification method. The block diagram of the developed fuzzy system is shown on Figure-6.

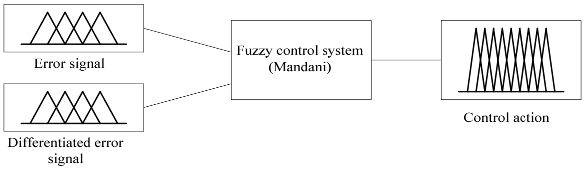

Figure-6. Block diagram of the developed fuzzy system

The first LV «error signal» θ has the term-set $T_1 = \{t^1_1, t^1_2, t^1_3, t^1_4, t^1_5\}$ = ={«negative close to zero», «close to zero», «positive close to zero», «small positive», «medium positive»}.

The second LV «error differential» θ has the term-set $T_2 = \{t^2_1, t^2_2, t^2_3, t^2_4, t^2_5\}$={«close to zero», «positive close to zero», «small positive», «medium positive», «big positive»}.

The term-set $T_3 = \{t^3_1, t^3_2, t^3_3, t^3_4, t^3_5, t^3_6, t^3_7, t^3_8\}$ of the output LV «control action» consists of eight fuzzy variables which determine the linguistic variable.

The sequence of actions for the solution of the control task is shown on Figure-7.

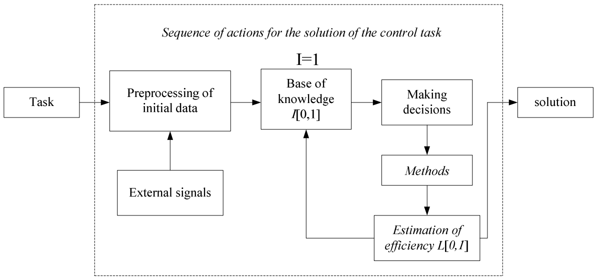

Figure-7. Sequence of actions for the solution of the control task.

The developed algorithm for the control task solution allows solving the task by means of several autonomous methods [2]. The structure of the algorithm is composed of several steps.

First of all, let us define the variables:

- implementation of the method from the conventional control theory corresponds to the condition $I = 1$;
- unimplementation of the method from the conventional control theory corresponds to the condition $I = 0$;
- positive estimation corresponds to the condition $L = 1$;
- negative estimation corresponds to the condition $L = 0$.

The content of basic steps of hybrid modelling has the following structure.

Step-1. The task is stated, that means the exact formulation of conditions with a description of input and output data for the task solution.

Step-2. The information is collected. The signals received from the outer environment are used as input signals for the block of the initial data preprocessing.

Step-3. The initial data is pre-processed, that means the creation of a classified system for all methods used in the hybrid system according to the purpose of information preparation for the decisions making about the selection of an appropriate method.

Step-4. The base of knowledge is created in the form of mathematical description of the investigated system objects.

Step-5. The decision about the chosen method for the control task solution is made. With regards to the considered task it is required to be sufficiently competent, whether the knowledge obtained after implementation of the conventional control method is enough to continue the process of the control task solution. If the condition $I = 1$ is fulfilled, then the algorithms goes to the

Step-7, otherwise ($I = 0$) the algorithm goes to the Step-6.

Step-6. The conventional method of the hybrid system is realized.

Step-7. The fuzzy method of the hybrid system is realized.

Step-8. The efficiency of the made solution is estimated. If the condition $L = 1$ is fulfilled, then the algorithm proceeds to the

Step-10, otherwise ($L = 0$) the algorithm proceeds to the Step 9.

Step-9. The results are corrected in order to continue the solution.

Step-10. The operation of the algorithm is finished, the solution is displayed.

The above-mentioned algorithm of the control task solution can be considered as a hybrid method. This makes it reasonable to speak about the application of the hybrid algorithm for the control task solution. Integration of analytical and statistical knowledge in fuzzy systems allows speaking of the intelligent hybrid control system, thus providing the multi-aspect character of the research.

3. CONCLUSIONS

We considered the application of fuzzy control methods for the development of the hybrid system. The block diagram and the operating algorithm of the hybrid control system were demonstrated. Application of the proposed solution on the example of DC engine speed regulation for the steam-generating unit USG-50/6M for oil industry was considered. The expressions for the calculation of classical control model parameters in the form of differential equations and transfer functions have been suggested. We developed the block diagrams of the control object and the controller as well as the model of fuzzy control with a description of basic stages of fuzzy inference. The algorithm of the control task solution in the conditions of incomplete data was developed.

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