Algorithmic Approaches to Synthesis Fuzzy Control Systems for Objects with Continuous Technology

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Abstract: This article considers three approaches to discretization continuous technological processes: "from processes", "from operations" and "from modes" and two algorithmic which coming to replace the classical methods for synthesis of control automata and creation of fuzzy control systems for complex objects by example of cement clinker kilns. When developing of fuzzy control systems considered traditional method and approach based on fuzzy nodes behavior charts proposed by authors. Here is shown their mutual complement by each other and some benefits of the proposed method. Algorithmic approaches based on fuzzy control systems already make it possible to create advising control systems for cement kilns operating on "wet" production method and further, as authors believe, their complete automation system as it takes place for "dry" method kilns.

Key words: Algorithm · Algorithmic approaches · Discrete description · Fuzzy nodes behavior charts · Fuzzy control system · The object · Parameters · The mode · Control system · "dry" and "wet" method of cement production · Technological value · Technological condition · The control action · Cement clinker kiln

INTRODUCTION

Realizing the difficulty of using classical methods based on the application of differential equations to describe such complex technological objects as chemical reactors, rotary cement kilns, steel blast furnaces and many others, researchers began to shift using algorithmic approaches. Quoting [1, p.16], "awareness" of the fact that every phenomenon could be decomposed into a number of well-defined discrete steps was led to this. As a result to describe the phenomenon uses so called "algorithm". The concept of the algorithm, respectively, also comprises any structure based on differential equations.

In particular, possible variants of transitions from continuous description of technological process to its discrete form considered in [2]. There are three possible variants: "from processes", "from operations" and "from modes". Transitions allow consideration of continuous process as a discrete, respectively, basing discretization on such concepts as process, operation or mode, which, in its turn, allows passing to control of continuous processes based on control automata, that is, to algorithmic methods of control describing the algorithm with marked Petri-nets-operation graphs [3].

Another example of transition to algorithmic control is the creation of fuzzy control systems. Classical fuzzy approach is based on the fact that by analyzing the state of technological values represented in the form of terms of their membership functions (MF) [4, 5] are synthesized production rules like "IF-THEN" for control action that should be applied to control object in order to bring it to normal state (technological regulations). One of the first papers on fuzzy control for cement clinker kilns can be called work [6].

At the same time fuzzy control systems could be created in a different way taking as a basis research of behavior the particular technological value as the function of its determining control actions, technological conditions, perturb technological variables and object parameters as it is made, for example, in [7]. Otherwise in the approach proposed by authors considered what
should be done with the control actions and (or) technological conditions to bring technological value to normal state of process regulations, that is, to create production rules to bring the rate of technological value to normal.

The focus of this article is about reviewing last two methods of creation fuzzy control systems and the latter is based on sampling continuous technological process based on the concept of "mode". Rotary cement clinker kiln was taken as the object for consideration which works on "wet" method of production where both of approaches are applied.

**Main Part:** Regarding of cement clinker kiln the first is classic approach which is outlined quite clear, for example, in [8-10]. The essence of this method is convenient to represent by depicting control system of the object as follows at Figure 1 where highlighting technological values in system "defining" one or another control action for the object. Hereby the control action hereinafter means the technological stream (flow) of substance (water, gas, steam, etc.) regulated by actuator (A) placed on the pipe with the flow controlled, in its turn, by the control device (C). The word "define" put in quotation marks because the control actions determine the behavior of technological variables and not vice versa.

Figure 1 shows that control action $U_j$ of the control device is "defined" by technological values of the object:

$$x_2 = f(U_1,U_{12},U_j); x_i = f(U_2,U_j); x_{i+1} = f(U_{k-1})$$

(1)

At the same time these values themselves can also depend upon other control actions for example:

$$x_2 = f(U_1,U_{12},U_j); x_i = f(U_2,U_j); x_{i+1} = f(U_{k-1})$$

(2)

Including from values which are independent from $U_j$ that is shown in relation to $x_{i+1}$.

From the point of view of the entire control system the control action $U_j$ is a following functional

$$U_j = F \left[ x_2(U_1,U_{12},U_j); x_i(U_2,U_j); x_{i+1}(U_{k-1}) \right]$$

(3)

In this case production rules are written to control action $U_j$ such as:

If $x_j$-"higher than normal" and $x_i$-"normal" and $x_{i+1}$-"medium" and $x_{i+2}$-"very high", THEN $U_j$ -"slightly increase".

Construction of production rules as "IF-THEN" should be done for all control actions of the object which you plan to operate.

Now we can consider the second proposed variant of algorithmic approach. To clarify its meaning the structure of the same control system with slight changes should be represented as shown in Figure 2. Changes affected control actions which are now applied to technological control object (TCO) through the virtual discrete actuators shown in the form of keys which state enable (disable) is determined by certain technological conditions (TC). Moreover, it was taken into account effect on the technological value such as $x_i$, the effect of other

Fig. 1: Structure of control system in consideration of the classical approach to synthesis of fuzzy control system.
technological variables- $x_2$ and $x_n$, perturb technological variables $y_i$, for example, $y_1$ and parameters $p_i$ of the object (not shown in the diagram).

Contrary to the first approach where the basis for research was taken according to the $j^{th}$ control action $U_j$ on the object depending on the change of those or other technological variables. In that approach research of behavior the particular $x_i$ technological value as function of all defining its control actions, keys with determine of their TC, perturbing technological variables and object parameters was taken as the basis, that is, in given structure we investigate

$$x_i = f(U_2, U_j, TC_2, TC_j, x_2, x_n, y_1, p^T)$$

where $p^T = \langle p_1, p_2, ..., p_m \rangle$-parameter vector.

Research reduces to build nodes behavior charts (NBC) [3, 11] represented in form of the finite state automaton graph whose vertices are mapped with modes of technological value behavior and arcs are written by logical conditions in form of Boolean functions define the transition from mode to mode.

In this case node is a part of the object schema technological structure which corresponds to its specific technological output value $\sigma_i$ [sigma] and includes all affecting this value input values and the directed bonds between them, taking into account all intermediate values and parameters. In addition it includes control actions (including regulating actuators) and control technology coordinates that determine state ON (OFF) of keys in case of certain TC.

The meaning of technological coordinate could be simply explained with example. Let suppose that control action is the water flow to the object. Thus regulation of water flow in the pipeline regulates by actuator. But beyond that actuator of water flow could be controlled by temperature. At temperatures below zero water freezes and it will stop the flow. In this case, the temperature (in the general case it is one or another technological value like pressure, level, density, etc.) is the technological coordinate which exerting discrete technological effect on water consumption. Technological condition is its value less than 0°C, at which we will assume that the water supply to the object will abruptly stopped.

Generally the TC can be defined as a condition that changes technological stream of substance without changing position of actuator or vice versa-it does not change stream when the position of actuator is changed. In fact technological coordinate in cooperation with defining it TC can be seen as a virtual discrete technological actuator (key) which stands in sequence with real regulating actuator and have a joint impact on technology flows of substances.

In this context node of technological value $y_i$ of the object highlighted in Figure 2 but somewhat simplified by the fact that the technological coordinates which influence on the flow of substances are determined and taken into account through the keys with TC does not show here.

In its turn mode determines the behavior of the node technological value in a particular range of its behavior or at the "point" of rest as the special case of interval.
At the formalized language mode of $K$-rank of the output technological value of the object $\sigma_i$ is a pair $(\sigma_i, \delta_i)$ which determines the law of motion $\sigma_i$ in the area $\sigma_i$ from the field of changes $\sigma_i$ by setting the $K$-rank vector $\delta_i = (\delta_i^1, ..., \delta_i^K)$. 

of derivatives changes in this area where $\delta_i^k$ is characteristics of $K$-rank order value derivative $\sigma_i$ as a function of time takes one of three values: $\delta_i^k = 0, \delta_i^k > 0, \delta_i^k < 0$.

Thus, the mode $R_i = \langle \sigma_i, \delta_i \rangle$ is a pair that determines the qualitative behavior of technological value $\sigma_i$ within the area. Mode description with more details and examples is given in [3, 11, 12]. Logical conditions for transition from mode to mode are determined by arguments of technological value in accordance with (4). The word "point" is put in quotation marks because in the construction of fuzzy behavior charts [7] point which is characteristic for clear behavior charts converted into the field. In addition, the concept of fuzzy mode as the mode defined by various MF introduces for fuzzy node behavior charts (FNBC).

Construction of nodes behavior charts makes for the most important technological variables of the object. Further, as in the first approach production rules are recorded for determining control actions and technological conditions by FNBC to maintain the desired (investigated) technological value of the object within the required regulatory and mode, taking into account the available information in FNBC about other technological values disturbing influences and parameters of the object. Of course, the construction of terms MF of entire technological units, disturbing and control actions is preceded to writing of production rules. Largely, the kind of conditions for writing rules can be discovered only while considered the joint work of nodes [3, 12] as collaborative sweep nodes.

Otherwise, in the proposed approach, we have production rules for finding the technological value $x_i$ in regulatory limits by changing the appropriate control actions and technological conditions taking into account information about other technological values, disturbing influences and parameters of the object, that is, with a deeper study of them.

As an example of production rules record as proposed can be written, for example, as follows:

\[ \text{IF } TC_i \text{ "provided" AND } x_i \text{ "medium" and } x_i \text{ "high" and } y_j \text{ "low" and } p_j \text{ "normal" and } TC_j \text{ "bring to required" and } U_j \text{ "slightly increase", and } U_j \text{ "slightly reduce", THEN } x_i \text{ "will be within regulatory limits".} \]

Otherwise, the same rule can be expressed perhaps on a more understandable language to user in the form of:

"TO-WITH-SHOULD":

TO $x_i$ "will be within regulatory limits " WITH $x_i$ "medium" AND $x_i$ "high" and $y_j$ "low" and $p_j$ "normal" and $TC_j$ "bring to required" AND $U_j$ "slightly increase" and $U_j$ "slightly reduce". In simpler cases, this rule takes the form: "TO-SHOULD".

This method also allows identifying and taking into account abnormal situations and emergencies. In this example of production rules this condition is: $TC_j$ "bring to required". However their identification will also require consideration the joint operation of nodes in the form of their sweeps [3, 12]. It should also be noted that the FNBC is built by researcher himself without help of experts. At the same time the production rules in the first approach are based on the knowledge of experts. In the second-this knowledge possible to use for checking the rules derived from nodes behavior charts.

**Summary:** The above approaches projected as independent from each other are at least complementary to synthesis fuzzy control of objects. Furthermore the second method may produce certain advantages in depth of study the question, for example, by taking into account technological conditions, lack of experts for creation fuzzy control system but in the presence of scientists able to build fuzzy nodes behavior charts and to make a joint analysis to identify and writing control production rules.

**CONCLUSIONS**

The complexity of modern engineering systems including objects with high unit power leads to the abandonment from the classical methods of control based on describing their work in the form of differential equations and to transition to algorithmic descriptions. Fuzzy control systems which find more and more applications in various areas including the creation of control systems for household appliances (refrigerators, washing machines, air conditioners, etc.) are built according to this principle. Approaches to the construction of fuzzy control systems respectively
extend and that is considered in the article with an example of their construction based on fuzzy nodes behavior charts for technological objects. New methods provide some advantages in building of fuzzy control systems in terms of their deeper study, to identify abnormal and emergency situations, taking into account technological conditions in control algorithms, the effects of disturbing variables and parameters of the object. In the new variant there is a possibility to refuse from the knowledge of experts, if there was made an adequate model of the object at the level of fuzzy nodes behavior charts and consideration of their joint work as a set of nodes sweeps. In general, two methods considered here for construction fuzzy control systems for incompletely defined objects complement each other allowing synthesizing fuzzy control systems for complex objects. Variant suggested by authors was used to create advising control system for cement kiln at CJSC "Oskolcement" (Stary Oskol). In general algorithmic approaches based on fuzzy control systems already allow creating advising control systems for cement kilns working on "wet" production method and later, in the opinion of authors, the system of its full automation as it takes place for "dry" method kilns.

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