# Reduction of the Control Rule Numbers in the Knowledge Base of an Expert System for Fuzzy Control

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*Abstract* – **In the paper is presented a method for reduction of the fuzzy control rule (FCR) numbers in knowledge base of an expert system for fuzzy control. In the reduction process valid is proceeded from complicated to complicated-composite FCR; as a result is obtained a minimization of the knowledge base and maximum quickness of the conclusion logics in real-time mode. The reduction is realized by: estimation of the nearness between the complicated FCR, fuzzy likeness relation, FCR grouping in equivalence classes and replacement of every class with one complicated-composite FCR.**

*Keywords* – **Fuzzy Control, Control rules**

## I. Introduction

The fuzzy control algorithms, received through application of the fuzzy sets theory for expert knowledge formalization are one form of an expert control systems. In the expert systems for fuzzy control (ESFC) in real time mode the correct structurization and minimization of the knowledge base are important for achieving quickness of the conclusion logic (control impact). Basically in the knowledge base (KB) of the ESFC there are data for membership functions (MF) to the terms of the linguistic variables (LV) used for the control and preliminarily defined numbers (list) of linguistic fuzzy control rules (FCR) with complicated structure. The numbers of these FCR can be great, depending radically from the numbers of terms for LV values. The great number of FCR makes worse ESFC quickness, which leads to the unsatisfactory dynamic precision of the control.

Because of this it is desirous to reduce and decrease the numbers of FCR with complicated structure in the KB. During reduction it well-funded proceeds from complicated to complicated-composite FCR.

## II. The core of the proposed method

The main difficulty in the creation process of an ESFC actually reduces to synthesis of FCR in the KB of the system. The set of FCR describes the relation between control error and control signal at the controlled plant input. For obtaining of more precise control, besides control error as input information in the precondition (left part) of every FCR it is included second condition for error variation rate. That way one elementary FCR has the following complicated structure:

$$R_i: \ \ If\ A\ is\ A_i\ \ and\ \ B\ is\ B_j\ ,\ \ then\ C\ is\ C_\kappa\ , \qquad (1)$$

where: A – control error; B – error variation rate; C – control signal; $A_i$ and $B_j$ are terms (values) of the LV – $L_A$ and $L_B$ with fuzzy subsets $Q_i^A$ and $Q_j^B$, defined on the corresponding universal sets (US) $U_A$ and $U_B$; $C_\kappa$ is term of the output LV - $L_C$ with fuzzy subset $Q_\kappa^C$ on the US - $U_C$. Every FCR reflects determinate dynamic particularity of the process flowing in the plant which is the subject of control.

There are different methods for the FCR synthesis [2], one of them is the method, using experimental information and described in details in the [3]. Its basic advantage is that at the synthesis process it is not used expert judgment and it is not necessary to find expensive experts well-knowing the object of the control. At the same time the subjective errors which are result of evidenced expert incompetence during FCR synthesis are avoided. Because of these causes this method is preferred to the other methods, using only expert knowledge.

Experimental information for FCR synthesis is collected in the conditions of passive experiment or by simulation analog modeling. It consists in two random realizations of the plant input (the control signal) and the plant output (the output signal) of the subject of control measurements. From them are received three discrete data realizations with equal length $T = N.\Delta t$ and time quantization step $\Delta t$, respectively for error signal, its variation rate and control signal. Universal sets $U_A$, $U_B$, $U_C$ and the term sets $\{A_i\}$, $\{B_j\}$ and $\{C_k\}$ are determined. After that from the control error values, its variation rate and control signal for every quantization moment is formed at the rate of one FCR with structure (1). That way is obtained the set $\{R\}$, including the preliminary list of n numbers FCR.

The input-output realizations are random processes wich have to be with big continuance, because of that the number of obtained FCR is very high. This embarrasses the work of ESFC conclusion mechanism. Moreover among the list of FCR there are identical and close by meaning and action rules, which allow reduction of their numbers with the purpose of KB minimization.

The reduction is realized by evaluation of the closeness between detached rules through fuzzy similarity relation. To this end complicated FCR complying with the condition of the fuzzy similarity relation are grouped in equivalent classes through constructing of simply similarity relations at the level $\alpha$ $(0 < \alpha \le 1)$ on the fuzzy relation. As an effect every equivalency class is substituted by one FCR with complicated-composite structure

$$R_i: \ \ If\ A\ is\ A_i\ \ and\ \ B\ is\ B_l\ or\ B_m\ ,\ \ then\ C\ is\ C_{\kappa 1}\ . \qquad (2)$$

It is possible for some of FCR to remain alone in a class as a result of grouping process if in the preliminary list there are not rules close enough to them. Such FCR save their initial complicated structure.

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The fuzzy binary relation of similarity $\rho^R$ is used for evaluation of the closeness between FCR and their grouping in different classes is defined as:

$$\rho^R:\ R_i\ \rho\ R_j \Leftrightarrow A_i = A_j\ \ u\ \ / B_i - B_j / \le \delta, \qquad (3)$$

where $R_i$ ($A_i$, $B_i$ ,$C_i$) is i rule and $R_j$ ($A_j$, $B_j$ ,$C_j$) is j rule from the list.

The relation conditions, described in (3), are: a) equal terms for control error; b) the absolute value of deviation between error rate terms to be smaller than preliminary given quantity - δ. The value of the deviation δ is determined accordingly the characteristics of the controlled plant and technology. In the particular case it is accepted this deviation referenced to the error rate to be one term. If this choice does not lead to good results at the reduction, it is necessary to reduce the value of δ. This is achieved by increasing the numbers of the terms $B_j$ in the set {$B_j$} keeping the range of the error rate in the universal set - $U_B$. At the determination of the relation $\rho^R$ , the conclusion terms for control signal –$C_i$ and $C_j$ do not take part, because they have to be determinate after the reduction for united complicated-composite FCR.

For every FCR with equal terms for A is constructed one similarity relation $\rho^R$. Similarity relation between FCR $R_i$ and $R_j$ has as a bearer the similarity coefficient– $K_{ij}$, which can be determined from the dependence:

$$K_{ij} = 1 - \frac{\left| Y_i - Y_j \right|}{\left| Y_i - Y_j \right|_{max}}\ ,\ 0 \le K_{ij} \le 1, \qquad (4)$$

where $Y_i$ ($Y_j$) recalculated on US $U_B$ evaluation of measured (calculated )error rate for i and j FCR. The denominator $|Y_i - Y_j|_{max}$ , for determinate plant is constant and can be accepted equal to the range of the error rate US $U_B$. The similarity coefficient has a sense only for FCR with equal terms for control error. It is not difficult to see that $K_{ij} = K_{ji}$, i.e. the similarity coefficients can to be consider as similarity rate between rules [1]. If {R} is set of N numbers of FCR, within it exists a fuzzy binary relation $\rho^R$ with membership function $\mu_\rho$ ($R_i$, $R_j$) = $K_{ij}$. This relation is reflective and symmetric, i.e. it really can be accepted as similarity relation alloying to evaluate the closeness between the rules. At the same time in [1] is proved that the transitive envelope $\hat{\rho}^R = \rho \cup \rho^2 \cup \rho^3 \dots$ of the relation $\rho^R$ is the smallest transitive equivalency relation compatible with $\rho^R$ and

$$K_{ij} = \mu_\rho( R_i , R_j) \le \mu_{\hat{\rho}}\ ( R_i , R_j), \qquad (5)$$

i.e. the preliminary defined similarities are kept and into the transitive envelope.

The numbers of relation $\rho^R$ is equal to the number of the terms in the term set {$A_i$}.

For every constructed relation $\rho^R$ is found the transitive envelop $\hat{\rho}^R$. Into the envelop $\hat{\rho}^R$ are kept the preliminary determined into $\rho^R$ correlations. The transitive envelop characters allow us in need a transpose of rows and columns, without a change of the correlations. This transposition can be necessary during grouping of the FCR in distinguish classes. The grouping process is realized by construction of simple relations $\hat{\rho}_\alpha$ at level α on the transitive envelop $\hat{\rho}^R$ of the fuzzy relation на $\rho^R$. The membership function - $\mu_\rho^R$ ($R_i$, $R_j$)$|_\alpha$ to the simple relation at level α is:

$$\mu_\rho^R (R_i, R_j)\big|_\alpha = \begin{cases} 1\ \ if\ \ \mu_{\hat{\rho}}^R\left(R_i, R_j\right) \ge \alpha \\ 0\ \ if\ \ \mu_{\hat{\rho}}^R\left(R_i, R_j\right) < \alpha \end{cases} \qquad (6)$$

At every separate case of the relations $\rho^R$ the choice of α is different. It depends of that to what summarization can we reach in the process of the rule coalescence in separate classes, complying with the laid in (3) restrictions. After achieving the admissible summarization and the replacement of every class with one FCR with structure (2), the reduction process finishes. Application of the described reduction leads to decrease of the numbers of FCR in the KB.

After the reduction it is necessary to determine corresponding terms $C_{k1}$ for conclusion in the right side of all substitute FCR with complicated-composite structure (2). The determination of these terms can be executed by different approaches but the best way is to use expert judgment.

## III. Demonstrative Example of Described Method Aplication

The described method for FCR numbers reduction is tested in the synthesis of the ESFC for energy object – mill-ventilator MB 3300. The controlled quantity is aero-mixture temperature – T at the mill output, the control error is the deviation of T from predefined value - ΔT, the control signal is the change of the rotation speed Δn of their mill-ventilator. The automatic control system is stabilizing at basic outside disturbance – the coal quality at constant load of the steam generator. The examined plant has a delay at dynamic channel “Δn - ΔT”. By this reason the information about error rate ΔT′ has a significant role for stabilization or the controlled quantity. This supposes decreasing of δ in (3) as permissible condition for the closeness of FCR evaluation. For the three quantities ΔT, ΔT′ and Δn was selected 7 similar by name terms (NB, NM, NS – negative big, middle, small; Z – zero; PS, PM, PB – positive small, middle, big). All terms have equal overlapped triangular membership functions. The universal sets are normalized in the interval 0 ÷ 100 %. For the obtaining of FCR is applied the method using experimental information from simulative analogical modeling with scales range for output quantities 0 ÷ 100 units. The quantization step at measuring of ΔT and Δn and ΔT′calculation was selected equal to Δt = 10 s. At synthesis of the FCR for every one term is accepted interval in which it is dominating over the two adjoining. These intervals are evaluated at % in relation to US and they are respectively equal: NB – 0 ÷ 9 %, NM - 9 ÷ 26 %, NS - 26 ÷ 42 %, Z - 42 ÷ 58 %, PS - 58 ÷ 74 %, PM - 74 ÷91 % и PB - 91÷100 %.

In the treatment of the realizations with length more then 1800 s a preliminary list of rules was received. After the sinking of the equal and removing of the inconsistent rules 78 FCR with complicated structure are obtained. In this FCR the values for ΔT fault into six terms (for term NB rules were not obtained). This allowed the construction 6 fuzzy binary similarity relations - $\rho^R$.

As an example for reduction of the numbers FCR trough the described method we will exercise the relation $\rho^{PB}$ for term of the control error of the PB. It includes 4 FCR with numbers from № 27 to № 30, for which ΔT falls in the term PB. For these rules the values of ΔT and ΔT′ in % of US and their relevant terms are given in table 1.

TABLE 1
VALUES OF ΔT AND ΔT′ IN % AND TERMS FOR 27, 28, 29 AND 30 FCR

| № of FCR | ΔT [%] | Term | ΔT ′ [%] | Term |
|---|---|---|---|---|
| $R_{27}$ | 94,62 | PB | 97,79 | PB |
| $R_{28}$ | 99,79 | PB | 75,37 | PM |
| $R_{29}$ | 100,0 | PB | 51,01 | Z |
| $R_{30}$ | 96,11 | PB | 30,95 | NM |

The similarity relation $\rho^{PB}$ with bearer the similarity coefficient - $K_{ij}$ , defined by (4) has the following form:

$$\rho^{PB} = \begin{array}{c|cccc} & R_{27} & R_{28} & R_{29} & R_{30} \\ \hline R_{27} & 1 & 0{,}7758 & 0{,}5322 & 0{,}3316 \\ R_{28} & 0{,}7758 & 1 & 0{,}7564 & 0{,}5557 \\ R_{29} & 0{,}5322 & 0{,}7564 & 1 & 0{,}7994 \\ R_{30} & 0{,}3316 & 0{,}5557 & 0{,}7994 & 1 \end{array} .$$

The transitive envelop - $\hat{\rho}^{PB}$ for the above relation is equal to:

$$\hat{\rho}^{PB} = \begin{array}{c|cccc} & R_{27} & R_{28} & R_{29} & R_{30} \\ \hline R_{27} & 1 & 0{,}7758 & 0{,}7564 & 0{,}7564 \\ R_{28} & 0{,}7758 & 1 & 0{,}7564 & 0{,}7564 \\ R_{29} & 0{,}7564 & 0{,}7564 & 1 & 0{,}7994 \\ R_{30} & 0{,}7564 & 0{,}7564 & 0{,}7994 & 1 \end{array}$$

We choose the alteration step for α, in decreasing direction, equal to Δα = 0,1. at this step for the levels α = 0,9 and α = 0,8 the simple relations $\hat{\rho}_\alpha$ have one and the same form:

$$\hat{\rho}^{PB}_{0,9} = \hat{\rho}^{PB}_{0,8} = \begin{vmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix} .$$

These relations concur with one of the border condition in case of α = 1,0 of the usual relation $\hat{\rho}_\alpha$. At this case every rule forms one class - $f_i$ , i = 1, 2, 3, 4. The rule in the class does not change and the number of rules doesn't decrease. Practically there is no reduction.

For level α = 0,7 the usual relation $\hat{\rho}_\alpha$ has the following mode:

$$\hat{\rho}^{PB}_{0,7} = \begin{vmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{vmatrix} .$$

In case of level α = 0,7 every FCR belong into one class - f, т.к. $\alpha \le \min \mu_{\hat{\rho}}(R_i , R_j)$ – second border condition. This isn't acceptable because of the failure in observing the second condition for the terms of ΔT′ in the relation of similarity, described in (3). In this unique class the diversion $|B_i - B_j|$ is equal to 5 terms, including the term ПМ for ΔT′ or $|B_i - B_j| > \delta$ (the given quantity δ is one term). Reason for passing from the one (α = 0,8) to the other border condition (α = 0,7) is the big step for change of α. It is necessary the step Δα for the change of α under 0,8 to be decreased. We choose step Δα = 0,01.

In the case of α = 0,79 the relation $\hat{\rho}_\alpha$ concur with this for α = 0,80 or $\hat{\rho}^{PB}_{0,79} = \hat{\rho}^{PB}_{0,8}$.

In the case of α = 0,78 the matrix of the usual relation has the following mode:

$$\hat{\rho}^{PB}_{0,78} = \begin{array}{c|cccc|} & R_{27} & R_{28} & R_{29} & R_{30} \\ R_{27} & 1 & 0 & 0 & 0 \\ R_{28} & 0 & 1 & 0 & 0 \\ R_{29} & 0 & 0 & 1 & 1 \\ R_{30} & 0 & 0 & 1 & 1 \end{array} .$$

At this level the four FCR fall in 3 classes and reduce themselves to 3 rules. The reduction isn't completely fulfilled because FCR $R_{27}$ and $R_{28}$ has valuations for ΔT′

distinguished with one term and they have to get into one class. It is obvious that α has to be decreased more. In the case of α = 0,77 we receive:

$$\hat{\rho}^{пг}_{0,77} = \begin{array}{c|cccc|} & R_{27} & R_{28} & R_{29} & R_{30} \\ R_{27} & 1 & 1 & 0 & 0 \\ R_{28} & 1 & 1 & 0 & 0 \\ R_{29} & 0 & 0 & 1 & 1 \\ R_{30} & 0 & 0 & 1 & 1 \end{array} .$$

$f_1$ (block $R_{27}$, $R_{28}$), $f_2$ (block $R_{29}$, $R_{30}$)

At that level the four FCR group themselves into two classes $f_1$ and $f_2$ and reduce themselves to two rules $R_k$ и $R_m$ with complicated-constituted structure (2). Every two FCR в in one class ($R_{27}$ and $R_{28}$ in class $f_1$ as well as $R_{29}$ and $R_{30}$ in class $f_2$) are with a degree of similarity not smaller than 0,77. After assignment of the terms for the regulating influence (conclusion) in the right part of the rules $R_k$ and $R_m$, they can be written in the following manner:

$R_k$: If ΔT is PB and ΔT′ is PM or PB, then Δn is $C_{k1}$

$R_m$: If ΔT is PB and ΔT′ is Z or NS, then Δn is $C_{m1}$

The following diminution of α doesn't lead to a better result.
The applying of the described procedure reduces FCR from the number of 78 to 29.

## IV. Conclusion

1. The passing from fuzzy relation of similarity to an usual relation at level α has the following border conditions:
   a) If α = 1 every element from the multitude {R} of the relation $\hat{\rho}_{\alpha}$ is equal to itself and forms its own class including only one rule;
   b) If $\alpha \leq \min \mu_{\hat{\rho}}(R_i, R_j)$, all elements from the relevant relation $\rho^R$ are equal between themselves and form one total class, which includes all the rules.

2. For every α ∈ [0, 1] there are exactly determinate number of classes – f in the interval $1 \leq f \leq N$, but if f is given previously, it can result that doesn't exist any α for which the relation $\hat{\rho}_{\alpha}$ consists of exactly of classes.

3. If after the assignment of the terms for the conclusions ($C_{k1}$ , $C_{m1}$) of the complicated-constituted FCR rules with same terms for the second condition in the precondition - B and for C and adjoining terms for the error of regulating – A are obtained, so they can, in need, to be combined into one new FCR. This union leads to a better result, if a bigger number of terms is used.

## References


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