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FUZZY APPROACH TO THE PROCESS CONTROL IN A CEMENT PLANT

The use of the fuzzy set theory in design of controllers for complex industrial processes has appeared in several studies in recent years. The experiences of these studies were used in this paper to come to the simple control algorithm which is close to the decision-making process of a human operator.

The controlled process in this case is the raw material mill in a cement plant where the waste heat from the rotary kiln is used for drying the raw material in the mill. The output raw powder temperature is controlled via material feed regulation. In each next sample a feed change $\Delta D(t+1)$ is made to respond to the current temperature error $\Delta\vartheta(t)$ and to the last feed change $\Delta D(t-\tau)$ that correlates with this temperature error. This can be symbolically written

$$[\Delta\vartheta(t),\ \Delta D(t-\tau)] \longrightarrow \Delta D(t+1) \qquad (1)$$

In terms of fuzzy sets the control algorithm is given by set of rules

$$\text{if } P1 \text{ then (if } P2 \text{ then } P3) \qquad (2)$$

where P1, P2 and P3 are statements:

$$\begin{aligned} P1 &: \Delta\vartheta(t) \text{ is } U \text{, where } U \subset \mathcal{U} \\ P2 &: \Delta D(t-\tau) \text{ is } V \text{, where } V \subset \mathcal{V} \\ P3 &: \Delta D(t+1) \text{ is } W \text{, where } W \subset \mathcal{W} \end{aligned} \qquad (3)$$

U, V and W are fuzzy sets of the universes of discourse $\mathcal{U}$, $\mathcal{V}$ and $\mathcal{W}$ respectively. $\mathcal{U}$, $\mathcal{V}$ and $\mathcal{W}$ are finite sets of elements u, v and w respectively.

Let $\Delta\mathcal{U}(t)$, $\Delta D(t-\tau)$ and $\Delta D(t+1)$ be fuzzy variables of a fuzzy controller, for which finite sets of values, i.e. fuzzy sets U_i, $i=1,\dots,I$; V_j, $j=1,\dots,J$; W_k, $k=1,\dots,K$ are defined. Each individual control rule (2) of a fuzzy controller will express relation R_n, $n=1,\dots,N$ over space $\mathcal{U}\times\mathcal{V}\times\mathcal{W}$.

$$R_n = U_{i(n)} \times V_{j(n)} \times W_{k(n)} \tag{4}$$

The overall relation R is then formed as an union of the individual R_n's

$$R = R_1 \cup R_2 \cup \dots \cup R_N = \bigcup_n R_n \tag{5}$$

Now having given this fuzzy relation and some fuzzy sets U' and V' representing input values (the antecedents), the output fuzzy set can be infered, which has a membership function

$$\mu_{W'}(w) = \max_u \max_v \min \left[\mu_{U'}(u), \mu_{V'}(v), \mu_R(u,v,w)\right] \tag{6}$$

Because the input variables $\Delta\mathcal{U}(t)$ and $\Delta D(t-\tau)$ at each sample are represented by numbers rather than fuzzy sets, they have to be discretized to quantified levels u_o and v_o respectively. These are nonfuzzy values which infer output fuzzy set W' with a membership function

$$\mu_{W'}(w) = \min \left[\mu_U(u_o), \mu_V(v_o), \mu_W(w)\right] = \mu_R(u_o, v_o, w) \tag{7}$$

and for all control rules $(U_{i(n)} \rightarrow V_{j(n)}) \rightarrow W_{k(n)}$

$$\mu_{W'}(w) = \max_n \min \left[\mu_{U_{i(n)}}(u_o), \mu_{V_{j(n)}}(v_o), \mu_{W_{k(n)}}(w)\right] \tag{8}$$

A fuzzy set W' as such cannot be used for control purpose. One nonfuzzy value w_o must be chosen as the control action fed to the process. Decision procedure used here is to take that value w_o, at which the membership function is a maximum, that is w_o of which

$$\mu_{W'}(w_o) = \max_w \left\{ \max_n \min \left[\mu_{U_{i(n)}}(u_o), \mu_{V_{j(n)}}(v_o), \mu_{W_{k(n)}}(w)\right]\right\} \tag{9}$$

Now assume that all input and output fuzzy sets are normal. Especially $\max \mu_{W_{k(n)}}(w)=1$. Further, commutativity of the operators $\max_{w}$ and $\max_{n}$ in (9) leads to result

$$\mu_{W}'(w_{o}) = \max_{n} \min \left[\mu_{U_{i(n)}}(u_{o}), \mu_{V_{j(n)}}(v_{o}) \right] \qquad (10)$$

In the case that N=I.J it can be seen that this expression is equal to the expression

$$\mu_{W}'(w_{o}) = \min \left[\max_{i} \mu_{U_{i}}(u_{o}), \max_{j} \mu_{V_{j}}(v_{o}) \right] \qquad (11)$$

Let's mark the fuzzy sets U_i and V_j to which inputs u_o and v_o respectively belong with the greatest grade of membership as U_{i_o} and V_{j_o} respectively. Then

$$\mu_{W}'(w_{o}) = \min \left[\mu_{U_{i_o}}(u_{o}), \mu_{V_{j_o}}(v_{o}) \right] \qquad (12)$$

There is certain n_o corresponding to a pair (i_o, j_o).

Then the equation (12) can be written also as

$$\mu_{W}'(w_{o}) = \min \left[\mu_{U_{i(n_o)}}(u_{o}), \mu_{V_{j(n_o)}}(v_{o}), \mu_{W_{k(n_o)}}(w_{o}) \right] \qquad (13)$$

The value $\mu_{W}'(w_o)$ in (13) will be reached for such w_o, for which $\mu_{W_{k(n_o)}}(w_o)=1$.

From above results the following procedure to specify nonfuzzy control action:

(1) For given u_o, v_o the i_o, j_o are specified, which maximize $\mu_{U_i}(u_o)$ and $\mu_{V_j}(v_o)$.

(2) According to a pair (i_o, j_o) the n_o and $W_{k(n_o)}(w)$ will be found.

(3) Values w_o are searched for, for which $W_{k(n_o)}(w_o)=1$. However if there is more than one such w_o, the mean of maxima is calculated.

It can be seen that this procedure is more convenient from point of view of memory and algorithm than the procedure according the equation (9). If can be also seen that procedure above can be easily generalized even for more than two inputs.