A New Approach to Fuzzy Control

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Abstract: The authors made a new appraoch to the artificial intelligent (AI) control, combining fuzzy control with the conventional PID regulation and utilizing a self-optimizing technique. The regulation strategy of this new regulator developed by the authors, the method of fuzzication of the variables involved—the expressions of their membership functions, and the way of on-line self-optimization of operating parameters were described in detail. Also, some results of the emulation, such as the data and response curves were given as examples, showing the excellence of our regulator.

It is well known that fuzzy language is an effective means for expressing human's thought, thus came out many kinds of fuzzy controller, provided with its related artificial intelligence (AI).

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The fuzzy controllers so far belonged to either one of the following types: non-linear proportional or non-linear PD controller . Some of them, which been more or less effectively used in practice, are of the latter type(2,3). S.Z. Long and P.Z. Wang succeeded in realizing some kind of relation between them—a simple and effective relation(4). It's easily seen that, this kind of relation implies just a PD control function, of course, again with the characterizing non-linearity of fuzzy control—a valuable properity which has been used to conveniently simulate the human's thought as well as his operation skill.

Nevertheless, none of the up to date fuzzy controller, even that one developed by S.Z. Long and P.Z. Wang, has been provided with the I-function of the conventional PID controller so as to minimize it's static error.

We, now, develop a strategy of fuzzy control as follows:

$$\underset{\sim}{Y} = K\underset{\sim}{E} + K_i \int \underset{\sim}{E}\, dt + K_d D \qquad (1)$$

where

$$E = U0 - U, \quad D = \frac{dE}{dt} \qquad (2)$$

U......the real value of the quantity to be controlled;

U0.....it's set-point value;

E......the deviation of U from U0, or the input to the fuzzy controller;

Y......output from the controller, or the magnitude of the controlling function.

A new kind of controller, the fuzzy PID controller thus been developed. It holds simultaneously the conventinal PID as well as the fuzzy control function as it's excellent features.

Furthermore, it has been provided with self-optimization function—self-optimization of K, K_i and K_d. During the first period of our research, we merely, however, optimize K, for the purpose of simplization of our design. Also for this purpose, the coocresponding quantities in eq. (1) are fuzzified merely to seven grades: NB (negative big), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), PB (positive big), as so did in paper[4].

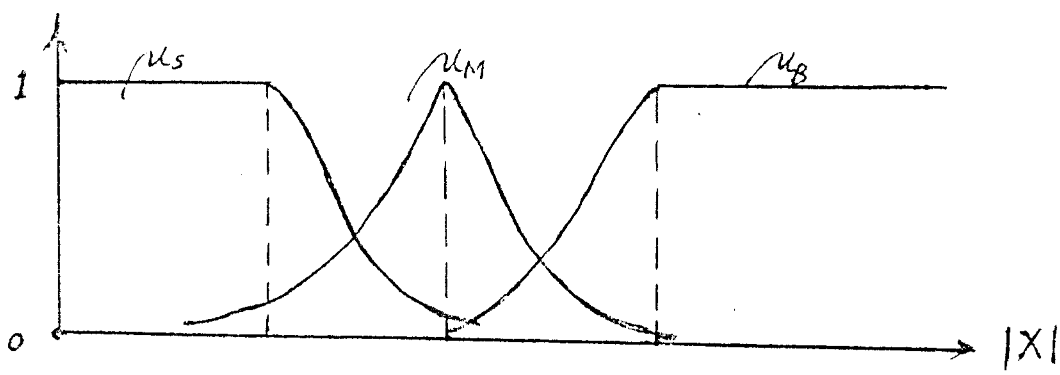
The membership functions used in our regulator are as follows:

$$\mu_S(|x|) = \mu_M(|x|) = \mu_B(|x|) = 0 \qquad |x| = 0$$

$$\mu_S(|x|) = \begin{cases} 1 & 0 < |x| \leq x_1 \\ \exp[-(\frac{|x| - x_1}{\sigma_x})^4] & |x| > x_1 \end{cases}$$

$$\mu_M(|x|) = \exp[-(\frac{|x| - x_2}{\sigma_x})^4] \qquad |x| > 0 \tag{3}$$

$$\mu_B(|x|) = \begin{cases} \exp[-(\frac{|x| - x_3}{\sigma_x})^4] & 0 < |x| \leq x_3 \\ 1 & |x| > x_3 \end{cases}$$



Here, X may denote any of the variables E, D and Y (we let $D = \frac{dE}{dt}$ for the purpose of convenience to deal with BASIC II programming). Moreover, all these expressions do deal with the absolute value of X, thus subscripts used are simplified into S (Small), M (Medium) and B (Big), and the letter P (Positive) or N (Negative) before them as generally used may be omitted.

Substituting the real parameter E, D or Y for X into (3), we have:

$$\mu_S(|E|) = \mu_M(|E|) = \mu_B(|E|) = 0 \qquad |E| = 0$$

$$\mu_S(|E|) = \begin{cases} 1 & 0 < |E| \leq E_1 \\ \exp[-(\frac{|E|-E_1}{\sigma_E})^4] & |E| > E_1 \end{cases}$$

(4)

$$\mu_M(|E|) = \exp[-(\frac{|E|-E_2}{\sigma_E})^4] \qquad |E| > 0$$

$$\mu_B(|E|) = \begin{cases} \exp[-(\frac{|E|-E_3}{\sigma_E})^4] & 0 < |E| \leq E_3 \\ 1 & |E| > E_3 \end{cases}$$

$$\mu_S(|D|) = \mu_M(|D| = \mu_B(|D|) = 0 \qquad |D| = 0$$

$$\mu_S(|D|) = \begin{cases} 1 & 0 < |D| \leq D_1 \\ \exp[-(\frac{|D|-D_1}{\sigma_D})^4] & |D| > D_1 \end{cases} \qquad (5)$$

$$\mu_M(|D|) = \exp[-(\frac{|D|-D_2}{\sigma_D})^4] \qquad |D| > 0$$

$$\mu_B(|D|)=\begin{cases}\exp[-(\frac{|D|-D_3}{\sigma_D})^4] & 0<|D|\leq D_3\\ 1 & |D|>D_3\end{cases}$$

$$\mu_S(|Y|)=\mu_M(|Y|)=\mu_B(|Y|)=0 \qquad |Y|=0$$

$$\mu_S(|Y|)=\begin{cases}1 & 0<|Y|\leq Y_1\\ \exp[-(\frac{|Y|-Y_1}{\sigma_Y})^4] & |Y|>Y_1\end{cases} \tag{6}$$

$$\mu_M(|Y|)=\exp[-(\frac{|Y|-Y_2}{\sigma_Y})^4] \qquad |Y|>0$$

$$\mu_B(|Y|)=\begin{cases}\exp[-(\frac{|Y|-Y_3}{\sigma_Y})^4] & 0<|Y|\leq Y_3\\ 1 & |Y|>Y_3\end{cases}$$

In our emulation experiments, the following values have been used: $E_1 = 1$, $E_2 = 3$, $E_3 = 5$, $\sigma_E = 1.6$; $D_1 = 0.05$, $D_2 = .1$, $D_3 = .2$, $\sigma_D = 2.8$; $Y_1 = 101$, $Y_2 = 110$, $Y_3 = 120$, $\sigma_Y = 18$.

The on-line self-optimization of K was implemented with a target function somewhat like $Q = \int |E|\, t\, dt$, an useful criterion for the optimization of the control systems. And the method of on-line optimization used is similar to the limited Depth-first Search in AI. We practise this kind of optimization in an one-dimension space of the parameter K. As for our design idea, it is evident from the following fig.

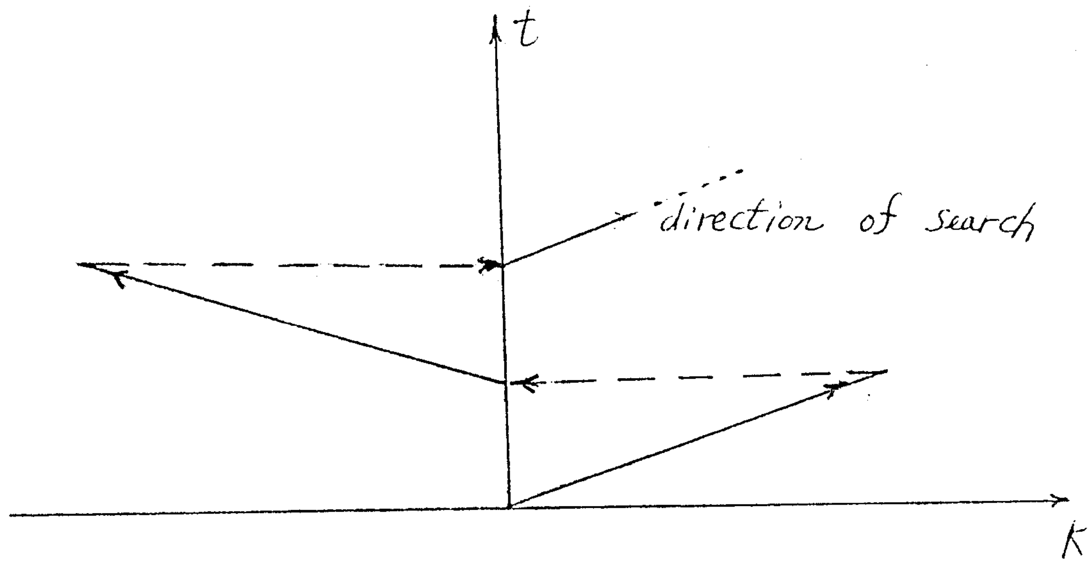


Fig. 1. The method of limited Depth-first search for K

The generalized plant to be controlled is either a 1'st order inertial element 1/(TS+1) only, or together with a time-lag element $e^{-\tau S}$ serially connected between them, which been usually recommended as the typical simplized model for most technical thermodynamic processes (Fig. 2).

Our simulation experiments were carried out on microcomputer TP80, an equivalent to TRS-80, being programmed in BASIC II. The sampling rate choosed was 1 time per ΔT = 0.01, as compared with T = 10, or again together with τ = 0.05 in our simulation system.

Transient responses of this system were obtained for 50% set-point disturbance (i.e. starting from U = 50% when U0 = 100%), as well as for a δ-disturbance in the interval t = 9 - 9.5. Fig. 3 and 5 show the results, with the curve-plotting rate choosed as 40 ΔT, i.e., 40 times the sampling rate. For recognition's sake the ordinates in these two fig. have been replaced by another quantity-the deviation, and been twice doubled to 4E, as shown in Fig. 4 and 6, where the listing rate was 50 ΔT, and the plotting rate 2 ΔT. The influence of δ-disturbance is easily seen.

Evidently, the results obtained, even if from our preliminary and rough experiments, are quite satisfactory: the overshoot $< 0.1\%$ for the system $1/(10s+1)$, and $< 0.8\%$ for a system $1/(10s+1)$ in series with $e^{-0.05s}$.

However we are sure that, the foregoing results can be much more improved by means of increasing the number of grades of $\underset{\sim}{E}$, $\underset{\sim}{\frac{dE}{dt}}$ and $\underset{\sim}{Y}$ to some tens, as well as by means of carefully adjustment of the parameters of the fuzzy controller. This will be just the furthermore work of the author's research.

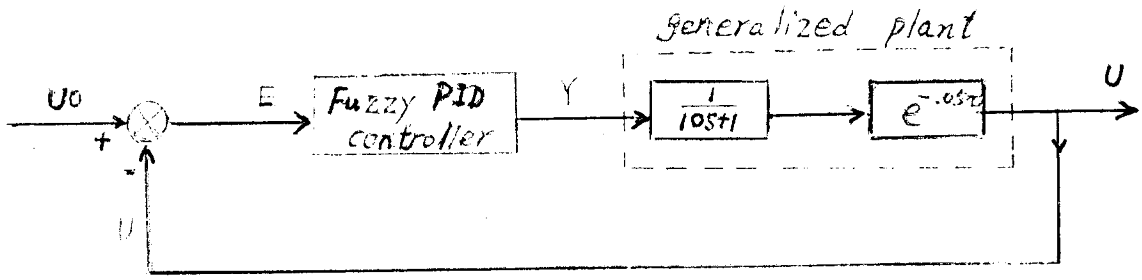


Fig. 2 Block diagram of the simulation system

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