A Simple and Effective Set-point Regulator of Artificial Intelligence Type

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Abstract The author had developed a simple and effective set-point regulator with distinguished features, which possesses the skilled artificial intelligence, i.e. it can automatically realize some specialist's functions. This kind of regulator incorporates the advantages of the conventional controller with that of the fuzzy controller, and hence it's a mixed type regulator. The preference of this configuration lies on its ability to implement an on-line dynamic auto-setting of the operation parameters of the controller, simulating the specialist's trains of thought and his operation skills. As for in the feed-forward regulations, the fuzzy controllers possess an additional advantage: It's possible to correct the influences of many disturbances, i.e. to replace many conventional feed-forward correctors by one, by only one fuzzy corrector. In this paper, the results of a simple simulation experiment were listed as an example, which show the preference of this new regulator to the conventional one. Besides, the author's furthermore work is shown briefly: an advanced fuzzy language had been written, so as to compose a new fuzzy regulator which should be much preferable to the conventional PID controller, and be used in the industrial process control,

and finally, a fuzzy self-adaptive controller resulted from the related practical experience.

1. Introduction

Set-point control has widely used in scientific reseach , as well as in industrial processes. We especially often organize set-point controls in the processes of electrical power industry, metallurgic industry, chemical industry, machining industry, oil-refining industry etc., and name them as set-point regulations. In fact, any kind of physical quantity, such as electrical quantities (current, voltage, frequency ...), mechanic quantities (linear and anglar displacements, velocity ...), thermo-engineering quantities (temperature, flow, pressure, level ...) etc., all have their own set-point regulations.

Fuzzy controllers which simulate human language of fuzzy type had been developed, and more or less effectively used in industrial process control[1], [2] . However, after analyzing the related data, we easily see that this kind of fuzzy regulator is somewhat inferior to the conventional PID regulator, as the main indexex of quality of control (such as the static error, response time, regulation time etc.) are concerned. Aiming at incorporation the advantages of conventional regulator with that of fuzzy regulator, so as to remarkably improve the quality of control, the author developed a simple and effective set-point regulator of artificial intelligence type. Its main point is merely a model of fuzzy control, or the simulation of specialist's trains of thoughts and his operation skills, basing upon the plentiful practical experiences of skilled operators, so as to implement an on-line dynamic auto-setting of the operation parameters of regulator.

2. General principles about the fuzzy regulator

Any kind of controller may be regarded as a dynamic system. According to C.J. Kickert [3], a controller C may be written down as the following quinary set:

$$C=\{X,\ E,\ Y,\ \delta,\ \beta\} \tag{2.1}$$

here X (the sate), E (input) and Y (output) are all non-empty finite sets, whereas δ (reflection mapping) and β (output mapping) are all relations:

$$X=\{x_1\ ,\ x_2\ ,\ \ldots,\ \ x_n\} \tag{2.2.1}$$

$$E=\{e_1\ ,\ e_2\ ,\ \ldots\ ,\ e_m\} \tag{2.2.2}$$

$$Y=\{y_1\ ,\ y_2\ ,\ \ldots.,\ y_e\} \tag{2.2.3}$$

$$\delta:\ X\times E \rightsquigarrow X\ (\text{or}\ \delta:\ X\times E\times X) \tag{2.2.4}$$

$$\beta:\quad X \rightsquigarrow Y\ (\text{or}\ \beta:\ X\times Y) \tag{2.2.5}$$

Analogously, the dynamic expression for a fuzzy regulator e.g. for a feedback type fuzzy regulator, is as follows:

$$\underset{\sim}{C}=\{\underset{\sim}{X},\ E,\ Y,\ \underset{\sim}{\delta},\ \underset{\sim}{\beta}\} \tag{2.3}$$

here $\underset{\sim}{X}$ (the state) is a fuzzy subset, where as $\underset{\sim}{\delta}$ (reflection mapping) and $\underset{\sim}{\beta}$ (output mapping) are all fuzzy relations:

$$\underset{\sim}{\delta}:\ \underset{\sim}{X}\times E \rightsquigarrow \underset{\sim}{X}\ (\text{or}\ \underset{\sim}{\delta}:\ \underset{\sim}{X}\times E\times \underset{\sim}{X}) \tag{2.4.1}$$

$$\underset{\sim}{\beta}:\quad \underset{\sim}{X} \rightsquigarrow Y\ (\text{or}\ \underset{\sim}{\beta}:\ \underset{\sim}{X}\times Y) \tag{2.4.2}$$

The author's scheme to improve the quality of control lies upon expanding the expression (2.3), composing,for instance, a fuzzy regulator as follows:

$$\underset{\sim}{C} = \left\{ \underset{\sim}{X}, U_0, E, G_i, K_\nu, T_\nu, Y, \underset{\sim}{\alpha_\nu}, \underset{\sim}{\delta}, \underset{\sim}{\xi_\nu}, \underset{\sim}{\zeta_\nu}, \psi_{i\nu}, \sigma_\nu, \underset{\sim}{\beta} \right\} \qquad (2.5)$$

here $\underset{\sim}{X}$, E, Y, $\underset{\sim}{\delta}$, $\underset{\sim}{\beta}$ are all just the same as defined above, whereas U_0 (set point), G_i (disturbances), K_ν (configuration parameters$_\nu$), T_ν (time parameters$_\nu$), $\underset{\sim}{\zeta_\nu}$(feed-interior mapping), $\underset{\sim}{\xi_\nu}$(time-feed mapping$_\nu$), $\psi_{i\nu}$(disturbances-time mapping), σ_ν(set point-time mapping), $\underset{\sim}{\alpha_\nu}$(configuration mapping$_\nu$) are respectively defined as

$$U_0 = \{ u_{01}, u_{02}, \ldots, u_{0w} \} \qquad (2.6.1)$$

$$G_i = \{ g_{i1}, g_{i2}, \ldots, g_{iS_i} \} \quad i=1,2,\ldots,p \qquad (2.6.2)$$

$$K_\nu = \{ k_{\nu 1}, k_{\nu 2}, \ldots, k_{\nu h_\nu} \} \quad \nu=1,2,\ldots,q \qquad (2.6.3)$$

$$T_\nu = \{ t_{\nu 1}, t_{\nu 2}, \ldots, t_{\nu f_\nu} \} \quad \nu=1,2,\ldots,q \qquad (2.6.4)$$

$$\underset{\sim}{\zeta_\nu} : K_\nu \times E \rightsquigarrow K_\nu \quad (\text{or } \underset{\sim}{\zeta_\nu}: K_\nu \times E \times K_\nu) \qquad (2.6.5)$$

$$\underset{\sim}{\xi_\nu} : K_\nu \times T_\nu \rightsquigarrow K_\nu \quad (\text{or } \underset{\sim}{\xi_\nu}: K_\nu \times T_\nu \times K_\nu) \qquad (2.6.6)$$

$$\underset{\sim}{\alpha_\nu} : \underset{\sim}{X} \times K_\nu \rightsquigarrow \underset{\sim}{X} \quad (\text{or } \underset{\sim}{\alpha_\nu}: \underset{\sim}{X} \times K_\nu \times \underset{\sim}{X}) \qquad (2.6.7)$$

$$\psi_{i\nu} : T_\nu \times G_i \rightsquigarrow T_\nu \quad (\text{or } \psi_{i\nu}: T_\nu \times G_i \times T_\nu) \qquad (2.6.8)$$

$$\sigma_\nu : T_\nu \times U_0 \rightsquigarrow T_\nu \quad (\text{or } \sigma_\nu: T_\nu \times U_0 \times T_\nu) \qquad (2.6.9)$$

It should be emphasized that $\psi_{i\nu}$ and σ_ν are all belonged to zero-time reset operations, i.e. we will certainly have $t=0$ whenever a disturbance comes or the set point is changed, which means that a new regulating process begins (see the fuzzy linguistic algorithm (3.1) of the 3rd paragraph of this paper).

Analogously, the expression for a fuzzy corrector in the feed-forward system is

$$\underset{\sim}{C} = \left\{ \underset{\sim}{X}, G_i, K_j, T_j, Y, \underset{\sim}{\alpha}_j, \underset{\sim}{\delta}_i, \underset{\sim}{\xi}_j, \underset{\sim}{\eta}_{ij}, \psi_{ij}, \underset{\sim}{\beta} \right\} \qquad (2.7)$$

here $\underset{\sim}{X}$, G_i, Y, $\underset{\sim}{\beta}$ are all just the same as defined above, whereas K_j (configuration parameters $_j$), T_j (time-parameters $_j$) $\underset{\sim}{\alpha}_j$ (configuration mapping $_j$), $\underset{\sim}{\eta}_{ij}$ (feed-experior mapping), $\underset{\sim}{\xi}_j$ (time-feed mapping $_j$), $\underset{\sim}{\delta}_i$ (reflection mapping $_i$), ψ_{ij} (disturbance-time mapping $_{ij}$) are defined respectively as

$$K_j = \{k_{j1}, k_{j2}, \ldots, k_{j\nu_j}\} \quad j=1,2, \ldots, r \qquad (2.8.1)$$

$$T_j = \{t_{j1}, t_{j2}, \ldots, t_{ju_j}\} \quad j=1,2, \ldots, r \qquad (2.8.2)$$

$$\underset{\sim}{\eta}_{ij}: K_j \times G_i \rightsquigarrow K_j \quad (\text{or } \underset{\sim}{\eta}_{ij}: K_j \times G_i \times K_j) \qquad (2.8.3)$$

$$\underset{\sim}{\xi}_j: K_j \times T_j \rightsquigarrow K_j \quad (\text{or } \underset{\sim}{\xi}_j: K_j \times T_j \times K_j) \qquad (2.8.4)$$

$$\underset{\sim}{\alpha}_j: \underset{\sim}{X} \times K_j \rightsquigarrow \underset{\sim}{X} \quad (\text{or } \underset{\sim}{\alpha}_j: \underset{\sim}{X} \times K_j \times \underset{\sim}{X}) \qquad (2.8.5)$$

$$\underset{\sim}{\delta}_i: \underset{\sim}{X} \times G_i \rightsquigarrow \underset{\sim}{X} \quad (\text{or } \underset{\sim}{\delta}_i: \underset{\sim}{X} \times G_i \times \underset{\sim}{X}) \qquad (2.8.6)$$

$$\psi_{ij}: T_j \times G_i \rightsquigarrow T_j \quad (\text{or } \psi_{ij}: T_j \times G_i \times T_j) \qquad (2.8.7)$$

Hence we can easily write down the expression for a feedforward-feedback type fuzzy regulator as follows:

$$\underset{\sim}{C} = \{\underset{\sim}{X}, U_o, E, G_i, K_\nu, K_j, T_\nu, T_j, Y, \underset{\sim}{\alpha}_\nu, \underset{\sim}{\alpha}_j, \underset{\sim}{\delta}, \underset{\sim}{\delta}_i, \underset{\sim}{\zeta}_\nu, \underset{\sim}{\xi}_\nu, \underset{\sim}{\xi}_j, \underset{\sim}{\eta}_{ij}, \psi_{i\nu}, \psi_{ij}, \sigma_\nu, \underset{\sim}{\beta}\} \qquad (2.9)$$

3. A new way to use the fuzzy controller

Any regulating system, e.g. a feedback control system, may be formally divided into two main parts: the regulator and the generalized regulated plant. The optimization of an auto-regulating system must then deal with these two factors synthetically. As for the ideal design, installation and running of a generalized regulated plant (composed of the regulated plant, measuring transducer and actuating equipment), it's out of the scope of this paper, and we might as well assume the optimization in all these respects, and the only thing that we shall deal with is to realize the corresponding optimization of the regulator itself. From the purely-technical point of view , the principle indexes of quality of a set-point regulator are: static error, overshoot, regulating time, responding time etc. Hence we always, in accordance with our demand, deal with these indexes synthetically: make a selection with regards to the degree of their importance, or take a compromise among them with a slight preference to some of them. And furthermore, we always, in our engineering practice, demand a high-level realization of all of these indexes of quality, at least, of some important ones among them, keeping in mind the strategy of "simple and effective implementation".

Upon this point of view, our discussion begins with an improvement on the proportional regulation by means of a fuzzy controller. We know that, in technical practice the optimization of a regulator depends upon a selection among the regulating schemes, as well as upon the setting of its operation parameters. Now, having selected the proportional regulation as our scheme, the only thing at our disposal is the setting of K. As for in the conventional proportional regulator, its K is fixed during the whole regulating period, unless been changed to a new and more favourable value otherwise set merely by a skillful specialist, that's to say, the setting of its K is non-automatic and stepped. We go, therefore, to study how to use the fuzzy controller to implement an on-line dynamic auto-setting of K.

It's well known that, the chief shortcoming of a proportional regulator is its bigger static error. Increasing K, we will get a less static error and faster response, both as benefits resulted. Nevertheless, excessively large K leads to intense oscillation of the system, even to occurence of ill divergence. The way out of this difficulty is as follows: K of the regulator must not be fixed during its operation period, but, instead, be increased or decreased in time to satisfy our demand. At the very beginning of the regulation process, K must be large, so as to overcome the time-lag of various elements of the regulating system, to quicken the response, whereas in the middle stage of this process, it's preferable to properly decrease K, in order to avoid a too large overshoot and serious oscillation; and finally in the last stage we must again increase K, in order that we may get rid of the substantial shortcoming of a proportional regulation — a bigger static error.

This kind of on-line dynamic auto-setting of K may easily be fulfilled by means of fuzzy controller, e.g. by using the following algorithm on fuzzy operation (where the various values of t compose the set (2.6.4), values of e compose the set (2.2.2), and values of K compose the set (2.6.3):

01 $t = 0$

02 $t \leftarrow t - 1$

03 If $t = S$, then if$\Big\{ |e| = L$, then $K = VL$, else

$\Big[$if $|e| = M$, then $K = L$, else $K = M \Big] \Big\}$,

else $\Big\{$if $t = M$, then if$\Big(|e| = L$, then $K = L$,

else (if $|e| = M$, then $K = M$, else $K = S$)$\Big)$,

else $\Big[$if $t = L$, then $K = M$, else $K = L \Big] \Big\}$

04 If $t \leqslant t_L$, then go to 02, else to 05

05 If Gi, then go to 01, else $K = L$ $(i=1,2, \ldots, p)$

06 If U_o, then go to 01, else $K = L$ (3-1)

where S = small, M = medium,

L = large, VL = very large

the statements in the above algorithm are realized in the prescribed order, where 01 corresponds to the beginning of a regulating process, and 02, to time-sampling (with 1 ms, or 10 ms, ... as its sampling-time interval according to the user's demand). 03 is a multiple conditional statement, and 06 a conditional statement: for each element of the set-point set $U_o = \{ u_{o1} , u_{o2}, \ldots \}$, i.e. whenever the set point changed, once again the 06 statement is implemented. Analogously, 05 is a cyclic statement which embedding the conditional statement: for each element of the disturbance set $G_i = \{ g_{i1} , g_{i2}, \ldots \}_{i=1,2,\ldots, p}$, or the same, for each action of every one disturbance, once again 05 is implemented. t_L in the statement 04 represents the shortest value provided for a regulation period. In this algorithm, the time parameter t is fuzzilized to four grades:

S, M, L, VL; the deviation parameter e to three grades: L, M, S; and the amplification K to four grades: VL, L, M, S. Evidently, a fuzzy language like (3.1) is easily transformed into the program of an electronic computer.

Even if the fuzzy language (3.1) is rather simple, it may, however, roughly realize all the functions related to (2.6.5) ~ (2.6.9), so as to realize an on-line dynamic auto-setting of K, and hence a mixed type regulator which includes this fuzzy controller may be preferable to the conventional regulator in all respects as the quality of control, e.g. the static error, responding time, overshoot, regulating time etc. are concerned. Furthermore, taking a view of the particularity of the technological process, and summarizing the rich and advantageous experiences of the skilful specialists, we can write down a more precise and effective fuzzy linguistic algorithm, so as to further improve the quality of control of our system.

Analogously, by means of the fuzzy controller we may also realize an on-line dynamic auto-setting of the operation parameters of PI, PD and PID regulators, achieving an ideal quality of control.

As for in the feed-forward regulation, fuzzy controllers may take its place not only upon an on-line dynamic auto-setting of the operation parameters, but also upon that they can be used to substantially simplify the composition of the feed-forward correcting system — an advantage which is also much valuable.

It's well known that the just function of a feed-forward corrector is to correct the influence of somewhat disturbance as early than expected. In a conventional feed-forward correcting system, we always need one feed-forward corrector just for every one disturbance. In order to simplify the system, we can but select the chief one, or at most, select some primary ones among the disturbances, and equip ourselves with one or some appropriate feed-forward correctors, and this is often done at somewhat sacrifice of the quality of control. Nevertheless, one, only one fuzzy feed-forward corrector is enough to do the correction of many disturbances, i.e. to replace the function of many conventional correctors. For instance, a fuzzy feed-forward corrector may be gotten from the following multi-conditional statement.

$$\begin{aligned}&\text{If } G_1 = FL_{11}\text{, then }\Big\{\text{ if } G_2 = FL_{21}\text{, then}\Big[\text{if } \ldots,\\ &\text{then (if } G_p = FL_{pd}\text{, then } Y = FL_b\text{, else } Y = FL_{b+1}),\\ &\text{else}\Big[\text{if } G_2 = FL_{22}\text{, then } \ldots\Big]\Big\}\text{, else if }\Big\{\\ &G_1 = FL_{12}\text{, then}\Big[\text{if } G_2 = FL_{21}\text{, then } \ldots\Big]\text{, else}\Big[\ldots\Big]\Big\}\end{aligned} \tag{3.2}$$

In this algorithm, various disturbances G_1, G_2, ... is usually arranged from left to right according to the degree of their influences, and where FL_{11}, FL_{12}, ... are the fuzzy linguistic values of G_1, ..., FL_{p1}, FL_{p2}, ..., $FL_{p(d+1)}$ —— that of G_p, whereas FL_1, FL_2, ..., FL_{b+1}, ... —— that of Y, the conclusion of this statement.

4. The preliminary simulation experiment

We've carried out a lot of experiments on microcomputer

TRS-80. The generalized plant to be regulated in our simulation system consists of a 1st order inertial elements (with T = 10) and a time-lag element (with time-lag $\tau = 0.2$), being serially connected each other. After rough adjustment of the parameters of this fuzzy regulator, the preliminary results obtained were as follows:

the static error $\Delta < 0.01\%$

the overshoot $\sigma < 0.02\%$

the regulation time $t_s < 0.45$

Evidently, these results show that, a mixed regulator including the fuzzy controller is indeed much preferable to a conventional one.

5. <u>The furthermore research</u>

The author's work is of course, far from being confined to the preliminary simulation research. Advanced fuzzy language had been written down to provide a mixed regulator with the quality of control which is much better that of the conventional PID controller. Finishing its laboratory experiment, this new regulator will come into a real industrial process, and begin its on-line application. Basing upon the related knowledges, especially, upon that from the on-line operations, we may realize the fuzzy self-adaptive control, achieving the advanced artificial intelligence as the aim we shall attain. All of these, however, will be discussed in the author's next papers.

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Bibliography

(1) M. Gupta et al., Fuzzy Automata and Decission processes, Elsevier North-Holland Inc., 1977, § 14, 19 and 20.

(2) D. Dubois et al., Fuzzy Sets and Systems, Academic press, Inc. (London), 1980, pp. 297-305.

(3) W.J.M. Kickert, Fuzzy Theories on Decission-making, Martinus Nijhoff Social Sciences Devision, Netherlands, pp. 106-107, 130-133. .