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A Simple, Convenient and Practical Method for Self-adaptive Dynamic Optimizing Control with Simulated Results

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Abstract: In this paper, a simple, convenient and practical self-adaptive dynamic optimizing method for an extremum control system is presented to solve a never evading problem in practical industrial processes by using the previous method. The problem is that accurate identification of the parameters of linear part in the extremum value control system is too difficult, even its order is difficult to obtain accurately. The new method in this paper only needs much less apriori information concerning the controlled plant, only knowing it enough that the linear part of the controlled plant could be approximated by a cascade of 1st order or 2nd order dynamic element and a pure time delay element. The result of simulation study indicates that. it is practical to substitute a real accurate dynamic elements of higher order by a cascade of a lower dynamic element and a pure time delay element. The optimum point of continuous drift could be well sought and trackable in time by using this simple and practical self-adaptive dynamic optimizing method. In those real industrial processes, their parameters, even their orders of the controlled plants, are difficult to obtain accurately, this simple and practical method can automatically not only identify the parameters of the controlled plant, but also adapt to the drift of the parameters. It is more important that by using this method the apriori information of the controlled plant needs getting much less, adjustment of controller parameters becomes much simpler and much more convenient. Its special effect of control is easier to be realized in the real industrial processes.

Keywords: self-adaptive dynamic search; simplification model; drift; practicability

1. Introduction

As to the extremum value controlled plant, a self-adaptive dynamic optimizing method is presented in reference [1], which is successful in solving a never evading difficulty in practical industrial process by using the conventional method, and in keeping the continuity and stability of the control system in operation. After the parameters of the control plant drift, the control system can not work well so it has to stop to identify the parameters of the control plant and to adjust the parameters of the control system again by using the previous method. The outstanding advantage of the self-adaptive dynamic optimizing method is that it can automatically not only identify the parameters of the control plant, but also adapt to the drift of the parameters during the search process for the optimum point. Therefore, the continuity and stability of the control system in operation is effectively guaranteed. Its basic idea is briefly introduced in the next section.

2. Brief review of the previous method

Let a step-by-step controller be used in the extremum value control system. Assuming the step-by-step period T_0 is changeless, the extremum value controlled plant may be expressed as a cascade

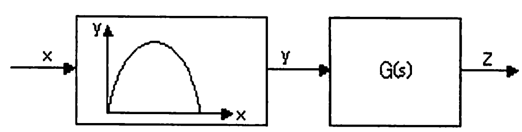


Fig.1 Block diagram of extremum value control system

form of a non-linear element and a linear element as shown in Fig.1.

Assuming that the transfer function of linear part in the extremum value control system is given as

$$G(s) = \frac{1}{(T_1S+1)(T_2S+1)\cdots(T_NS+1)} \quad , \tag{1}$$

$$T_1 > T_2 > T_3 \cdots\cdots > T_N > 0 \quad .$$

the corresponding unit step response function becomes as follows :

$$\hbar(t) = A_0 + \sum_{i=1}^{N} A_i e^{-\frac{t}{T_i}}, \quad A_0 = G(s)\,|_{s=0} = 1, \text{ and}$$

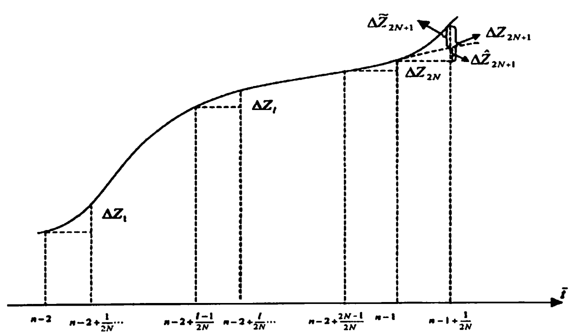
$$A_i = (s + \frac{1}{T_i})\frac{1}{s}G(s)\,|_{s=-\frac{1}{T_i}}, \quad i = 1,2,\cdots,N. \tag{2}$$

If time t is quantized with step-by-step period T_0, it then becomes

$$\hbar(\bar{t}) = 1 + \sum_{i=1}^{N} A_i e^{-\alpha_i \bar{t}}, \quad \alpha_i = T_0/T_i, \quad i = 1,2,\cdots,N \text{ and}$$

$$\bar{t} = t/T_0 . \tag{3}$$

Assuming each step-by-step period is divided into $2N$ equal intervals as shown in Fig.2, the sample values are taken at every dividing point. $2N+1$ sample values would then be obtained, and the pre-estimating comparative point is the first sampling point after a probing step.



$\Delta\hat{Z}_{2N+1}$: pre-estimating difference value of the system output if the probing step is not exerted at $\bar{t} = n-1$

ΔZ_{2N+1} : the real difference value of the system output as the probing step is exerted at $\bar{t} = n-1$

$\Delta\tilde{Z}_{2N+1}$: the deviation in value between the real difference value and the pre-estimating difference value of the system output at the comparing point .

Fig.2 Diagram showing self-adaptive dynamic optimizing algorithm

As given in reference [1], the comparing value becomes:

Since the direction of the step-by-step increment can be determined by using Eq.(4) with the output sample values, the expression of judging the step-by-step direction is as follows :

$$\mathrm{sgn}[\Delta x_n] = \mathrm{sgn}[\Delta\tilde{Z}_{2N+1}\Delta x(n-1)], \tag{4}$$

where $\mathrm{sgn}[x]$ implies the sign of x, and

$$\Delta\tilde{Z}_{2N+1} = \frac{\begin{vmatrix} \Delta Z_1 & \Delta Z_2 & \cdots & \Delta Z_{N+1} \\ \Delta Z_2 & \Delta Z_3 & \cdots & \Delta Z_{N+2} \\ \cdots & \cdots & \cdots & \cdots \\ \Delta Z_{N+1} & \Delta Z_{N+2} & \cdots & \Delta Z_{2N+1} \end{vmatrix}}{\begin{vmatrix} \Delta Z_1 & \Delta Z_2 & \cdots & \Delta Z_N \\ \Delta Z_2 & \Delta Z_3 & \cdots & \Delta Z_{N+1} \\ \cdots & \cdots & \cdots & \cdots \\ \Delta Z_N & \Delta Z_{N+1} & \cdots & \Delta Z_{2N-1} \end{vmatrix}} . \tag{5}$$

It can be found from Eqs. (4) and (5) that the expression of judging the step-by-step direction is independent of the time constants , T_1, $T_2 \cdots T_N$, of the dynamic elements. So slow variation of these parameters with time can not affect the correctness of the judging expression at all. In other words, Eq. (4) can adapt automatically to the variation of the parameters in the controlled plant. Therefore, this method can be known as a self-adaptive dynamic optimizing method [5],[6]. The extremum value control system designed with this method could automatically not only identify the parameters of the controlled plant, but also adapt to their variations. However, It is also very difficult only to obtain the accurate order of the linear part of the extremum value controlled plant in real industrial processes, let alone obtaining the parameters of that. It is known from Eqs.(4) and (5) that Judgement of the direction of the step-by-step increment is on the basis of $\Delta\tilde{Z}_{2N+1}$ and is independent of its absolute value. However, the absolute value of $\Delta\tilde{Z}_{2N+1}$ is bigger or smaller means that the capability of resistance against disturbance is stronger or weaker [3], [4]. If sample points are strictly divided on the basis of the order of linear part in the controlled plant, the bigger the number $2N$ of sample points in a step-by-step period are as the bigger the order N of the controlled plant becomes. Assuming a sample period is Δt, then the time interval of both adjoining sample points is Δt, $\Delta t = T_0 / 2N$. Too big $2N$ must make Δt become very small and make ΔZ_l also become very small, so let the absolute value of $\Delta\tilde{Z}_{2N+1}$ become very small. Accordingly, the control system is very poor against disturbance. A rather small disturbance may then result in a wrong judgement of step-by-step direction. Furthermore it is very difficult to obtain accurately the order N of linear part in the controlled plant. So it is very necessary to simplify the model of the controlled plant and to look for a simple, convenient and practical self-adaptive dynamic optimizing method.

3. A simple, convenient and practical self-adaptive dynamic optimizing method

It is known that the linear part of the controlled plant consists of dynamic elements, its transfer function may be described as follows :

$$G(s) = \frac{1}{(T_1S+1)(T_2S+1)\cdots(T_NS+1)} ,$$

$$T_1 > T_2 > T_3 \cdots\cdots > T_N > 0 .$$

If $T_1 >> T_2 > T_3 > \ldots > T_N > 0$, it then becomes

$$G(s) \approx \frac{e^{-\tau s}}{1+T_1 s}, \tau = T_2 + T_3 + \cdots + T_N . \qquad (6)$$

Therefore, a real, accurate and higher order linear part of the controlled plant could be approximated by a cascade of a lower order dynamic element and a pure time-delay element. As for the effect of a pure time-delay element, as we pointed out in reference [4] that: the moment when the step-by-step step is exerted is in advance of time τ compared with that when there is no pure time-delay element in the controlled plant. We could delete the effect of pure time-delay τ in using Eq.(5). It does not make any effect to the self-adaptive dynamic optimizing method [1] by this supplementing method, the method of judging the direction of the step-by-step increment described in [1] can be used all the same. Furthermore, after simplifying a complex and accurate model of the real controlled plant, N=1. The Eq.(5) of calculating the comparative value can simply be expressed as follows:

$$\Delta\widetilde{Z}_{2N+1} = \Delta\widetilde{Z}_3 = \begin{vmatrix} \Delta Z_1 & \Delta Z_2 \\ \Delta Z_2 & \Delta Z_3 \end{vmatrix} \Big/ \Delta Z_1 \quad \text{for } N=1. \qquad (7)$$

We will show the simplicity, convenience and actual effectiveness of this method through the following simulation study.

4. Simulation study

Fig. 3 shows the block diagram of simulation

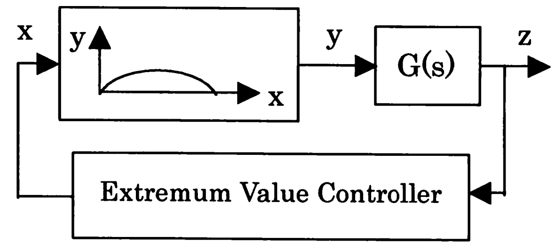


Fig. 3 Block diagram showing extremum value control system

system, where a non-linear extremum value property at the beginning is assumed to be expressed by

$$y = 0.4x(10 - x) . \qquad (8)$$

The coordinate of an extremum value point is given as (5,10), the expression of judging the step-by-step direction of extremum control system are calculated by Eqs.(4) and (5) or by Eqs.(4) and (7). The flow chart of simulation procedure is briefly given in Fig.4. The supplemental explanation of the flow chart is as follows:

① The main task of initialization is to set their initial values of each variable and to input the parameters.

② Non-linear extremum value property is realized by function subprogram, Nth order dynamic elements are realized by Runge-Kutta method of 4th order.

③ According to the requirement for calculating Eq.(5), each step-by-step period is divided into $2N$ equal intervals of sample period $\Delta t = T_0 / 2N$. When $L = 2N+1$, $\Delta\widetilde{Z}_{2N+1}$ is calculated and the step-by-step direction is judged in order to be ready for the next step-by-step step.

If $\bar{\tau}$=0, when $L = 2N$ the nth step-by-step step is exerted based on the last $\Delta\widetilde{Z}_{2N+1}$ and the sign of $\Delta x(n-1)$. If $\bar{\tau} \neq 0$, the nth step-by-step step is exerted in advance of time τ – τ denotes a quantized pure time delay with T_0, $\tau = \tau / T_0$.

5. Simulated results

In real industrial processes, the effect of disturbance will make the extremum value property drift slowly in most conditions [4], [5]. So its optimum point will change with the drift of extremum value property, the task of the control system is to search the optimum point and to track continuously the drift of optimum point in the transient process. Therefore, the main purpose of simulation is devoted to the

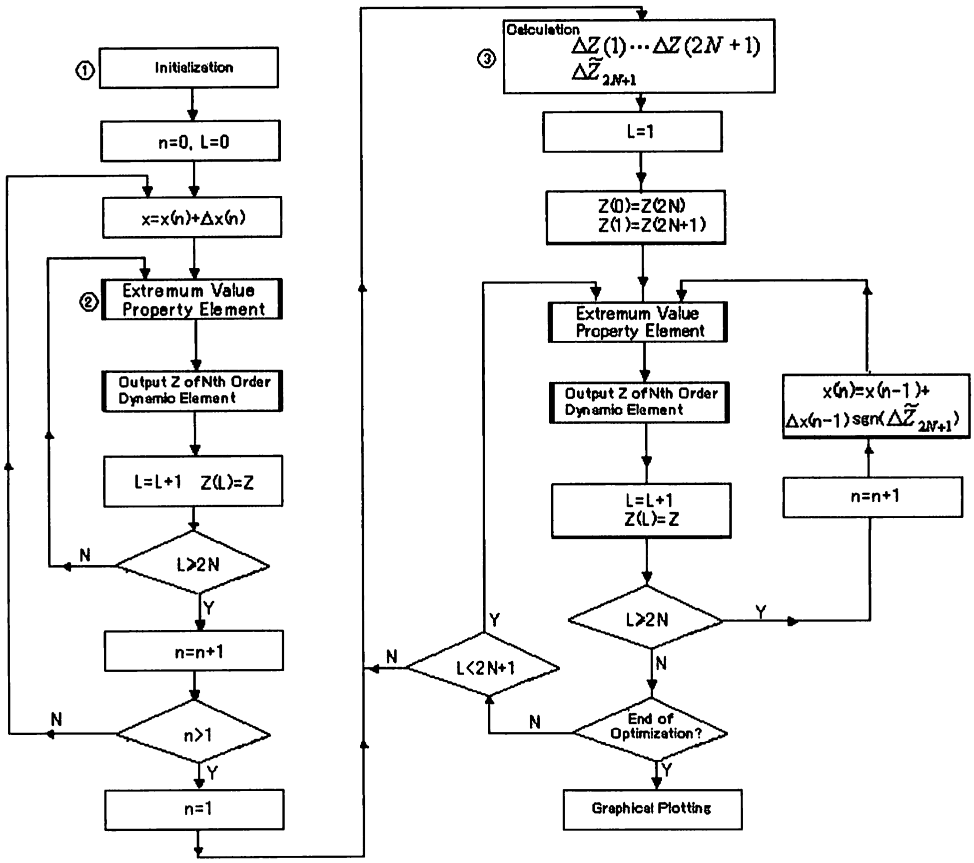


Fig.4 Flow chart of simulation program

examination whether the control system could work well or not.

Case 1: According to the real accurate order of the linear part in the controlled plant, the simulation is done by using the method of self-adaptive dynamic optimizing presented in reference [1].

For a controlled plant of 2nd order dynamic element, its transfer function of linear part is as follows:

$$G(s) = \frac{1}{(1+T_1 s)(1+T_2 s)}, \tag{9}$$

where $T_1 = 100$ s and $T_2 = 40$ s.

The parameters of extremum value controller used in simulation are given as follows :

Δx=0.2, T_0=40s, N=2, and $\Delta t = T_0/2N$=10s.

The result of dynamic optimizing is plotted in Fig.5. In the plotted diagram, Z, X denotes respectively the output and input of the extremum value control system. In Fig.5(a), $t_3 > t_2 > t_1$, the extremum value property curve drifts with time t owing to the disturbance, and the optimum point also drifts with time t. Fig. 5 (a) shows the process of searching and tracking the optimum point which continuously drifts. Fig.5(b) shows the time behaviors of Z and X in search process. Although the optimum point of extremum value property drifts continuously owing to the disturbance, it can be found that: the extremum value control by using the self-adaptive dynamic optimizing method is good at searching and tracking it quickly and effectively. It is unnecessary for the method to identify the parameters of the linear part in the controlled plant. However, it is necessary to know the order of the controlled plant. The simpler method to know less apriori information will be simulated in case 2.

Case 2: The simulation is done by using a simple, convenient and practical method for self-adaptive

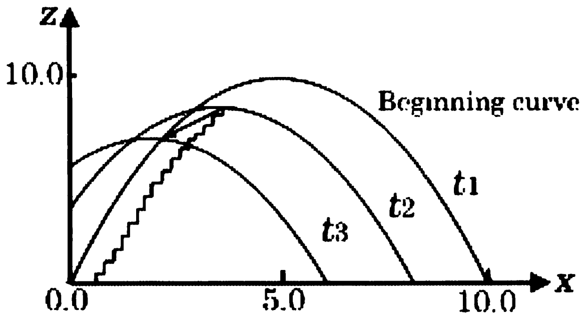


Fig.5(a)

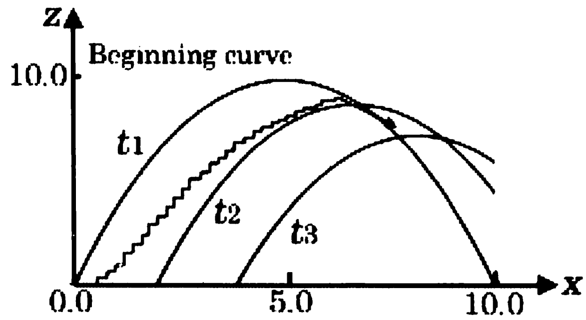


Fig.6(a)

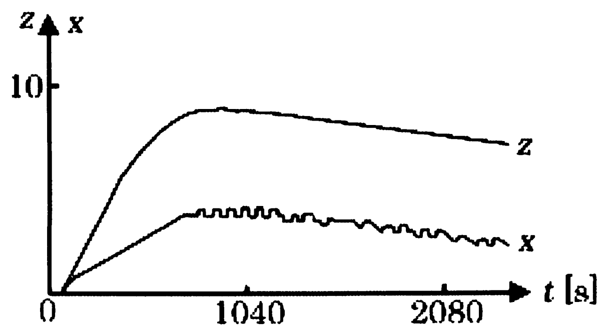


Fig.5(b)

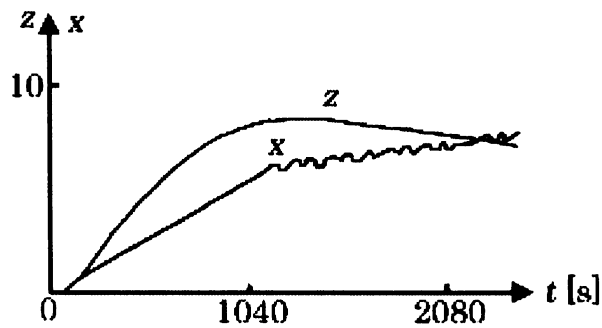


Fig.6(b)

dynamic optimization.

For a controlled plant of 3rd order dynamic element, its transfer function of linear part is as follows:

$$G(s) = \frac{1}{(1+T_1 s)(1+T_2 s)(1+T_3 s)}, \tag{10}$$

where $T_1 = 100\,\text{s}$, $T_2 = 30\,\text{s}$ and $T_3 = 10\,\text{s}$.

According to Eq. (6), the approximate transfer function becomes $G(s) \approx e^{-\tau s}/1 + T_1 s, \tau = 40$ s, the simulation result shows: as τ =30s ~ 55s, the extremum value controller can work well. It can automatically search and track the optimum point of extremum value property which continuously drifts. τ can be selected in rather wide-range value. Obviously, judgement is very simple and convenient in the real industrial processes. The simulated result of $\tau = 45$ s is shown in Fig. 6.

In Fig.6(a), $t_3 > t_2 > t_1$, the extremum value property curve drifts with time t, and the optimum point also drifts with time t, Fig.6 shows the result of dynamic searching the optimum point when the extremum value property drifts along the vertical and horizontal direction at the same time. In diagram, Z, X denotes respectively the output and input of the extremum value control system. Fig. 6 (a) shows the process of searching and tracking the optimum point which continuously drifts. Fig.6 (b) shows the time behaviors of Z and X in search process. The real order of linear part in extremum value controlled plant is 3, in other words, N =3. We approximate the real higher order and accurate model by a cascade of lower order dynamic element and a pure time delay element. Select N =1, the parameters of controller are as follows: Δx =0.2, T_0=100s, $\Delta t = T_0/2N$=50s, τ =45s. It can be found from Fig.6 that although we only use much less apriori information, this simple, convenient and practical self-adaptive dynamic optimizing method is very good at searching and tracking quickly and effectively the optimum point of extremum value property which drifts continuously. This is the outstanding advantage of this new method over other methods. Apriori information which we only need is whether the linear part of the controlled plant may be approximated by a cascade of 1st order or 2nd order dynamic element and a pure time delay element.

6. Conclusion

From the result of simulation study, it could conclude that the method of self-adaptive dynamic optimizing is good at searching and tracking quickly and effectively the optimum point of extremum value property which drifts continuously. In the real industrial process, however, it is very difficult to obtain accurately the parameters of the linear part in the extremum vale controlled plant, and it is also difficult to obtain accurately its order. However, we may use a cascade of a lower order model of dynamic elements and a pure time delay element instead of the real higher order model to be optimized dynamically. This is not only to get very good effect, but also to do more easily, more conveniently and to do more simply. The outstanding advantage of the present method over others is that the a priori information of the controlled plant needs getting much less. So adjustment becomes much simpler and more convenient. Furthermore its special effect of control is easier to be realized in the real industrial processes.

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