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Genetic algorithms based on local variable weight synthesizing and its application to internal model control

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ABSTRACT

In this paper, a new objective function of genetic algorithms based on local variable weight synthesizing is proposed to improve the imperfect selection of performance indicator and unclear weight distribution in objective function of controller parameters optimization. Using both error integral indicators and eigenvalues of the system calculated by local variable weight synthesizing as a parameters optimization objective function to achieve the purpose that eigenvalues of the system are all in a reasonable range and error integral values are smaller as well. Compared with traditional objective function, the modified objective function is more comprehensive, flexible and open. At last, applying it to the parameters optimization of internal model control and the simulation results have shown its effectiveness and superiority.

KEYWORDS

Parameter optimization;
Local variable weight synthesizing;
Genetic algorithms;
Internal model control.

INTRODUCTION

Due to the controller parameters affect the validity and reliability of the control algorithm directly, thus parameter determination of the controller is one of the significant steps of different control algorithm design. The purpose of controller parameters optimization is to make the system performance optimal under certain guidelines.

At present, the error integral performance indicators are often used alone as the objective function of controller parameter optimization[1], such as ISE, IAE and ITAE. This kind of objective function can only make the system to achieve a certain effect with minimum error integral indicators, but cannot restrain the eigenvalues of the system. So there will be some vital eigenvalues of the system are in a unreasonable range. Therefore, some literatures introduced eigenvalues of the system[2,3], such as rise time and overshoot, into objective function by constant weight synthesizing to solve the multiple indicator optimizations. However, the error integral indicators cannot reach the minimum by this objective function.

In this paper, variable weight synthesizing is introduced into the objective function of genetic algorithm, and applied it to the parameters optimization of internal model control. The design of the objective function is no longer just using error integral indicator or only use the eigenvalues of the system, but combining two complementary error integral indicators and system eigenvalues which calculated by local variable weight synthesizing.

GENETIC ALGORITHMS

The optimization algorithm can be divided into exact algorithms and heuristic algorithms. Exact algorithm needs to conduct a thorough search of the solution space to obtain a global optimal solution, and it is not suitable for complex model. Heuristic algorithm is one of intelligent optimization algorithms. It is mainly developed by the various mechanisms of natural organisms.

The genetic algorithm which is simulating nature of biological evolution is a global search algorithm and it belongs to heuristic optimization algorithm. Besides, genetic algorithm is globally convergent and parallel computing, and it does not need auxiliary information. In addition, genetic algorithm uses the fitness function to evaluate the solution during the optimization process. Then, through evolution operations continue to search good fitness individuals and end up with find the optimal solution. Therefore, according to the desired system performance indicators to determine the fitness function of controller parameter optimization has significant meaning. The flow chart of basic genetic algorithm is illustrated in Figure 1.

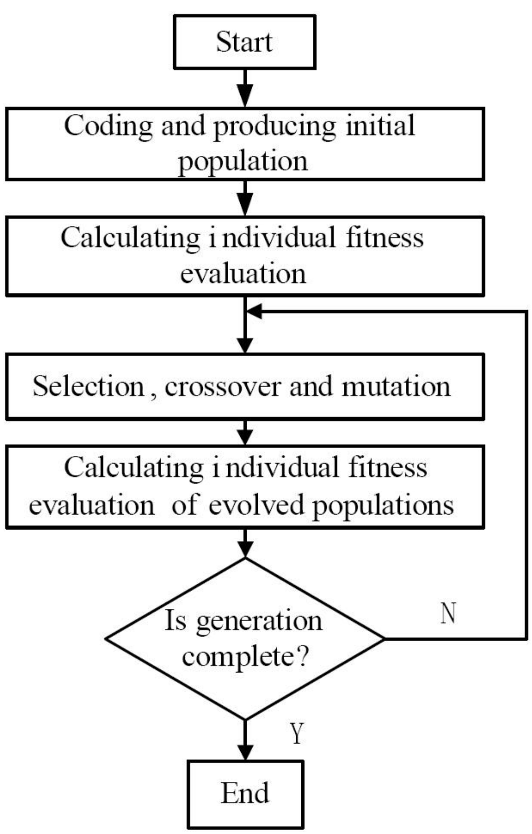

Figure 1 : The flow chart of basic genetic algorithm

The genetic algorithm start with population which is an initial set of random solutions. Each individual of population is called a chromosome. The generations is the results of the chromosomes evolve through successive iterations. In the period of each generation, the fitness function is used to evaluate the chromosomes. Some chromosomes are chosen to create the next generation according the values of fitness function after the operation of selection, crossover and mutation[4]. Selection reflect the principle of 'Survival of the fittest.' Some solutions are selected while others are eliminated. Crossover causes a structured with the possibility that 'good' solutions can generate 'better' ones. Mutation is to restore lost or unexplores genetic material into the population to prevent the premature convergence of the GA to suboptimal solutions.

These processes will lead to the new generation is more adaptive than the previous generation. After some generations, the best individual of the last populations after decoded is the approximate optimal solution of a problem.

TRADITIONAL OBJECTIVE FUNCTION

Error integral indicators

Because the error integral indicators are the time integral of the error in the transition process, they are composite indicators. Thus, they can reflect the general merits of the adjustment process comprehensively, and the resulting values are the smaller the better. Currently used error integral indicators are as following:

Integrated absolute error (IAE):

$$J_{IAE} = \int_0^\infty |e(t)| dt \quad (1)$$

When using IAE to evaluate systems, the transient response of the system is good, but the overshoot of the dynamic response is often too large and the adjustment process is long.

Integral of square error (ISE):

$$J_{ISE} = \int_0^\infty e^2(t) dt \quad (2)$$

Transient response of the system is fast by used ISE to evaluate systems. It focus on inhibiting large errors, but the system will have oscillation generally. Besides, overshoot is large and stability is not very good.

Integrated time absolute error (ITAE):

$$J_{ITAE} = \int_0^{\infty} t|e(t)|dt \quad (3)$$

Normally, ITAE has better control of the deviation in late period of transient response and has small overshoot. In addition, the system is relatively stable.

From the above analysis, it can be seen that different error integral indicator has different emphases to evaluate system. Thus, just choose a single indicator can not get reasonable regulation time, overshoot and stability.

Individual indicators

Individual indicators mean that using the output eigenvalues of the system as indicators of objective function, such as overshoot, rise time and settling time. These eigenvalues of the system can be selected according to the specific control system and control requirements[5]. But different eigenvalues can only make one kind of performance of the system tend to be optimal while without giving the best overall performance of the system. Moreover, we can select multiple eigenvalues through weight synthesizing to optimize various performances of a system at the same time.

MODIFIED OBJECTIVE FUNCTION BASED ON LOCAL VARIABLE WEIGHT SYNTHESIZING

From the above analysis, we can see that error integral indicators used alone as the objective function cannot make specific requirements for the eigenvalues of system, while the eigenvalues of system used alone as the objective function cannot get overall optimization. Therefore, this paper presents a method to combine these two kinds of indicators through variable weight synthesizing.

Variable weight synthesizing is an improvement on the basis of constant weight synthesizing. It no longer uses weighted-average method to evaluate results, but to reduce or increase the weights of some evaluation parameters under certain principles. Therefore, results are more reasonable. Literature[6] gives the fundamental of variable weight synthesizing. The difference from constant weight synthesizing and variable weight synthesizing is that variable weights comprehensive taking into account the relative importance of the basic elements and the target value changes with the basic elements. The axiomatic definitions of punishment variable weight, incentive variable weight and mixed variable weight are reported in literature[7]. The punishment variable weight means the overall evaluation value of system would rapidly reduce when the score one indicator is too low. In other words, the punishment variable weight has sensitive reaction for reduction of indicators. On the contrary, incentive variable weight has sensitive reaction for increase of indicators. Mixed variable weight has a punitive effect for a part of the factors while has an incentive effect for other factors. An axiomatic definition of local variable weight synthesizing is proposed in literature[8]. It reward or punish the factors when they are above or below a certain standard. The local variable weight synthesizing applied to the optimal design of the control system in literature[9]. Literature[10] introduces the variable weight theory into fuzzy comprehensive evaluation process. The reseach shows that variable weight makes evaluation method of imfprmation system more scitific and practice. Literature[11] introduces a variable weight factor to a decision-making model to achieve different preferences according to requirements. And this method can be used in a multicriteria decision-making process.

In this paper, the variable weight synthesizing introduced to the objective function of genetic algorithm, and applies it to the parameter optimization of internal model controller.

Subjective function J_1

By analyzing the different focus of integral of square error (ISE) and integrated time absolute error (ITAE) can be seen that they have complementary effects in the evaluation system. Therefore, the proposed method in this paper uses these two indicators simultaneously through constant weight synthesizing. The specific form is as follows:

$$J_1 = \alpha\int_0^{\infty} e^2(t)dt + \beta\int_0^{\infty} t|e(t)|dt \quad (4)$$

where α and β are two artificial constant weight that reflect the relative importance of two indicators in decision-making, at the same time meet the requirement that $\alpha + \beta = 1$.

These two error integral indicators can all reflect the overall performance of system, but have different

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emphasis. Thus, constant weight is used for these two error integral indicators because their weights do not need to change with the value of indicators.

Subjective function J_2

Error integral indicators are used as object function can evaluate the overall performance system, but cannot make specific requirements for the eigenvalues of system. In this paper, rise time t_r and overshoot σ% are used as a set of variables of performance indicator by variable weight synthesizing to evaluate system. Specifically, according to the values of rise time t_r and overshoot σ% in different time, the weights of them are changed. The score of system evaluation is the higher the better, but the value of objective function of controller parameters optimization is the smaller the better. So their determinations of both punishments and rewards are exactly the opposite. The weights would be rewarded when the values of rise time and overshoot are lower than a certain level, while when they are higher than a certain level the weights would be punished.

Due to different dimensions of rise time and overshoot, the first step is depending on specific control system to determine a reasonable variable range, then normalized rise time and overshoot to x_1 and x_2 which belong to [0,1]. The jth item of local variable weight model[8] is given by:

$$\mathbf{J}_j(\mathbf{x}_1,\mathbf{x}_2,\cdots,\mathbf{x}_m)=\frac{\boldsymbol{\omega}_j^0\mathbf{s}_j(\mathbf{x}_j)\mathbf{x}_j}{\sum_{k=1}^{m}\boldsymbol{\omega}_k^0\mathbf{s}_k(\mathbf{x}_k)} \quad (5)$$

where $s_j(x_j)$ is the local variable weight vector of x_j and $\boldsymbol{\omega}_j^0$ is the constant weight of x_j.

Function of local variable weight vector[5] is:

$$s_j(x_1,x_2,\cdots,x_m)=\begin{cases}\frac{A-1}{a_1}x_j+1, x_j\in[0,a_1]\\ A, x_j\in[a_1,a_2]\\ \frac{1-A}{1-a_2}x_j+\frac{A-a_2}{1-a_2}, x_j\in[a_2,1]\end{cases} \quad (6)$$

where a_1, a_2 and A are constants belong to [0,1]. A on behalf of the degree of rewards and punishments, and the smaller the value the greater the degree of reward and punishment. [0, a_1] is the range of reward. [a_1, a_2] is the range of constant weight. [a_2, 1] is the range of punishment.

After the above analysis, the subjective function J_2 by used rise time and overshoot as a set of variables is obtained as:

$$\mathbf{J}_2=\frac{\boldsymbol{\omega}_1^0\mathbf{s}_1(\mathbf{x}_1)\mathbf{x}_1+\boldsymbol{\omega}_2^0\mathbf{s}_2(\mathbf{x}_2)\mathbf{x}_2}{\boldsymbol{\omega}_1^0\mathbf{s}_1(\mathbf{x}_1)+\boldsymbol{\omega}_2^0\mathbf{s}_2(\mathbf{x}_2)} \quad (7)$$

The steps of determine fitness function

(1) Select performance indicators as variables of the objective function. This paper selects the error integral indicators ISE and ITAE as a set of variables, and then selects rise time t_r and overshoot σ% as another set of variables.

(2) Determining the allowable ranges for variables which have different dimensionless, and then normalized them.

(3) Determining the constant weight of each variable. In this paper, α, β, $\boldsymbol{\omega}_1^0$ and $\boldsymbol{\omega}_2^0$ are needed to determine.

(4) Determining the parameters of the local variable weight function, including a_1, a_2 and A.

(5) The objective functions are:

$$\mathbf{J}_1=\alpha\int_0^\infty \mathbf{e}^2(\mathbf{t})\mathbf{dt}+\beta\int_0^\infty \mathbf{t}|\mathbf{e}(\mathbf{t})|\mathbf{dt} \quad (8)$$

$$\mathbf{J}_2=\frac{\boldsymbol{\omega}_1^0\mathbf{s}_1(\mathbf{x}_1)\mathbf{x}_1+\boldsymbol{\omega}_2^0\mathbf{s}_2(\mathbf{x}_2)\mathbf{x}_2}{\boldsymbol{\omega}_1^0\mathbf{s}_1(\mathbf{x}_1)+\boldsymbol{\omega}_2^0\mathbf{s}_2(\mathbf{x}_2)} \quad (9)$$

(6) Fitness function is:

$$\mathbf{f}=\frac{1}{1+\mathbf{J}_1}+\frac{1}{1+\mathbf{J}_2} \quad (10)$$

According to the different control requirements of control systems, the objective functions are designed in this paper can select ranges of variables, constant weights and parameters of local variable weight function artificially. Therefore, the results of parameter optimization are closer to the ideal requirements.

SIMULATION ANALYSIS

Simulation for FOPDT process

Consider the following FOPDT process:

$$\mathbf{G}_P(\mathbf{s})=\frac{1}{5\mathbf{s}+1}\mathbf{e}^{-4\mathbf{s}}$$

Internal model controller is:

$$\mathbf{G}_{IMC}(\mathbf{s})=\frac{5\mathbf{s}+1}{\lambda\mathbf{s}+1}$$

where λ is the parameter of controller which needed optimization. The steps for determine fitness function are as following:

(1) Select performance indicators as variables of the objective function. This paper selects the error integral indicators ISE and ITAE as a set of variables, and then selects rise time t_r and overshoot $\sigma\%$ as another set of variables.

(2) Allowable ranges of the rise time t_r and the overshoot $\sigma\%$ are determined as $t_r \le 20s$; $\sigma\% \le 20\%$.

(3) Normalized processing:
$t_r:[0,20] \to x_1:[0,1]$; $\sigma\%:[0,20\%] \to x_2:[0,1]$.

(4) Constant weights are:
$\alpha = 0.5, \beta = 0.5; \omega_1 = 0.5, \omega_2 = 0.5.$

(5) Parameters of the local variable weight function are:
$a_1 = 0.3, a_2 = 0.7, A = 0.3.$

(6) Local variable weight function is:

$$s_j(x_1,x_2)=\begin{cases}-\dfrac{7}{3}x_j+1, x_j\in[0,0.3]\\ 0.3, x_j\in[0.3,0.7]\\ \dfrac{7}{3}x_j-\dfrac{4}{3}, x_j\in[0.7,1]\end{cases}$$

(7) Objective functions are:

$$\mathbf{J_1 = 0.5\int_0^\infty e^2(t)dt + 0.5\int_0^\infty t|e(t)|dt}$$

$$\mathbf{J_2 = \frac{0.5s_1(x_1)x_1 + 0.5s_2(x_2)x_2}{0.5s_1(x_1) + 0.5s_2(x_2)}}$$

(8) Fitness function is:

$$\mathbf{f = \frac{1}{1+J_1} + \frac{1}{1+J_2}}$$

Compare the proposed method to different fitness functions of genetic algorithm to verify its effectiveness and superiority. The others fitness functions are:

$$\mathbf{f_1 = \frac{1}{1+ISE}},\quad \mathbf{f_2 = \frac{1}{1+ITAE}},\quad \mathbf{f_3 = \frac{1}{1+J_1}},$$

$$\mathbf{f_4 = \frac{1}{1+0.5x_1+0.5x_2}},\quad \mathbf{f_5 = \frac{1}{1+J_2}}$$

At a perfect matching of a process plant and model, the responses of FOPDT process after controller parameter optimization by genetic algorithm for a unit step are shown in Figure 2. When process plant mismatches with process model, the responses of FOPDT process after controller parameter optimization by genetic algorithm for a unit step are shown in Figure 3.

Simulation for SOPDT process

Consider the following SOPDT process:

$$\mathbf{G_P(s) = \frac{1}{(3s+1)(7s+1)}e^{-4s}}$$

The responses of SOPDT process after controller parameter optimization by genetic algorithm for a unit step when model matched are shown in Figure 4.

The Figure 5 shown the responses of SOPDT process after controller parameter optimization by genetic algorithm for a unit step, when process plant mismatches with process model.

According to the simulation results of both FOPDT process and SOPDT process in the case of model matching and model mismatching, we can give the conclusions as follows:

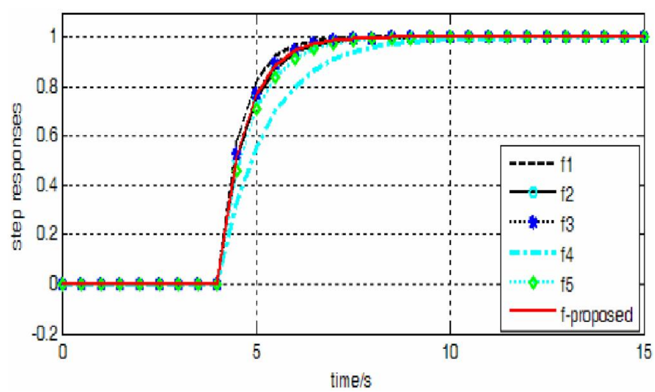

Figure 2 : Step responses of FOPDT process after controller parameter optimization by different fitness functions of genetic algorithm (matched model)

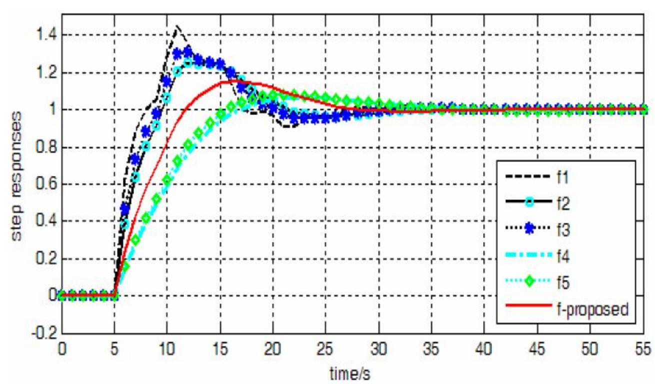

Figure 3 : Step responses of FOPDT process after controller parameter optimization by different fitness functions of genetic algorithm (mismatched model)

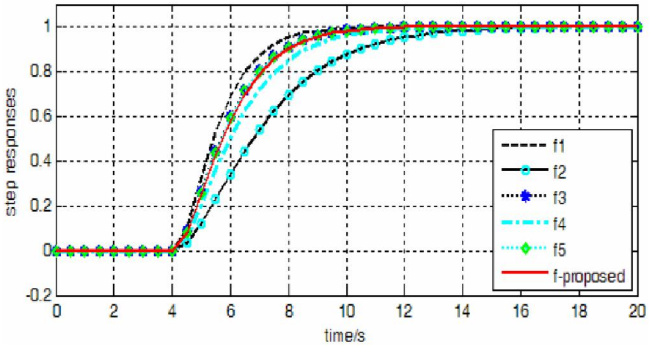

Figure 4 : Step responses of SOPDT process after controller parameter optimization by different fitness functions of genetic algorithm (matched model)

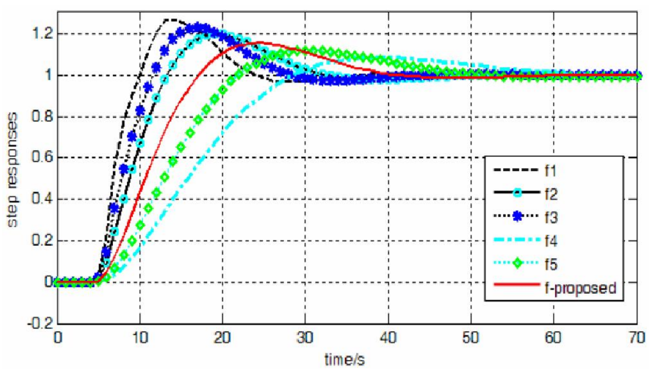

Figure 5 : Step responses of SOPDT process after controller parameter optimization by different fitness functions of genetic algorithm (mismatched model)

(1) The system has speed response, large overshoot and instability when using ISE alone as the objective function. When using ITAE alone as the objective function, the speed of response is slower than using ISE, and the values of ISE and ITAE are larger, but it has smaller overshoot. Using these two indicators at the same time as the objective function through constant weight synthesizing has better effect than using one of them alone. However, using the error integral indicators alone as objective function would lead to the value of overshoot is beyond the control requirements.

(2) When rise time t_r and overshoot σ% are used as a set of variables of objective function by constant weight synthesizing, the system has smaller overshoot and smooth reaction in both matched model and mismatched model. But the values of ISE and ITAE are larger. The system achieves a better balance between rise time and overshoot after using local variable weight. Besides, the values of ISE and ITAE all decrease.

(3) The objective function proposed by this paper has a better result of parameter optimization. It keeps the rise time and overshoot in the range of control requirement while has smaller values of ISE and ITAE.

CONCLUSIONS

Aiming at solving the imperfect performance indicator selection and unclear weight distribution in objective function of controller parameters optimization, this paper proposes a modified objective function of genetic algorithms based on local variable weight synthesizing and applying it to parameters optimization of internal model control. Eigenvalues of system and error integral indicators are both used in the proposed objective function. In addition, introduced local variable weight to calculate rise time and overshoot as a set of indicators. The simulation results demonstrate that compared with traditional objective function the new one achieves a good balance between different eigenvalues of system and the error integral indicators. Meanwhile, the designed objective functions can choose ranges of variables, constant weights and parameters of local variable weight function according to different control requirements of control systems. Thus, the results of parameter optimization are closer to the ideal requirements and enhance the openness of optimization algorithm.

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