Adaptive Tuning of PID Controller for Multivariable System Using Bacterial Foraging Based Optimization

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Abstract. In this paper, design approach of PID controller with multivariable system is proposed using bacterial foraging based optimal algorithm. To tune PID controller for multivariable system, disturbance rejection conditions based on $H_{!}$ are illustrated and the performance of response based on the bacterial foraging is computed for the designed PID controller as ITSE (Integral of time weighted squared error). Hence, parameters of PID controller are selected by bacterial foraging based optimal algorithm to obtain the required response.

1 Introduction

A Proportional – Integral – Derivative (PID) controller has been widely used in the most industrial processes despite continual advances in control theory. This is not only due to the simple structure which is theoretically easy to understand but also to the fact that the tuning technique provides adequate performance in the vast majority of applications. However, it cannot effectively control such a complicated or fast running system such as multivariable system, since the response of a plant depends on only the three parameters (P, I, and D) and its gain has to be manually tuned by trial and error in the industrial world. Most of the PID tuning rules developed in the past years use the conventional method such as frequency-response methods [1]. This method needs a highly technical experience to apply since they provide simple tuning formulae to determine the PID controller parameters. In case of the Ziegler-Nichols rule tuning technique, it often leads to a rather oscillatory response to set-point changes. Despite the fact that many PID tuning methods are available for achieving the specified GPM, they can be divided into two categories. On the other hand, since natural selection of bacterial foraging tends to eliminate animals with poor foraging strategies for locating, handling, and ingesting food, optimization models can be provided for social foraging where groups of parameters communicate to cooperatively forage in engineering. That is, biological information processing systems such as human beings have many interesting functions and are expected to provide various feasible ideas to engineering fields. In this paper, an intelligent tuning method of PID controller for multivariable system by bacterial foraging based optimal algorithm is suggested for robust control with disturbance rejection function on control system of multivariable control loop.

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2 PID Controller Tuning with Disturbance Rejection Function

2.1 Condition for Disturbance Rejection

In Fig. 1, the disturbance rejection constraint can be given by [5, 6]

$$\max_{d(t)\in D} \frac{\|Y\|}{\|d\|} = \left\| \frac{w(s)}{1+K(s,c)G(s)} \right\|_\infty \langle \delta . \tag{1}$$

Here, $\delta\langle 1$ is constant defining by the desired rejection level and $\|\bullet\|_\infty$ denotes the H_∞-norm, which is defined as $\|G(s)\|_\infty = \max_{\omega\in[0,\infty)} |G(j\omega)|$.

The disturbance rejection constraint becomes

$$\left\| \frac{w(s)}{1+K(s,c)G(s)} \right\|_\infty =$$

$$\max_{\omega\in[0.\infty)} \left(\frac{w(j\omega)w(-j\omega)}{1+K(j\omega,c)G(j\omega,c)K(-j\omega,c)G(-j\omega,c)} \right)^{0.5}$$

$$= \max_{\omega\in[0.\infty)} \left(\sigma(\omega,c)\right)^{0.5} \tag{2}$$

The controller K (s, c) is written as $K(s,\, c) = c_1 + \frac{c_2}{s} + c_3 s$ and the vector c of the controller parameter is given by $c = [c_1,\, c_2,\, c_3]^T$. Hence, the condition for disturbance rejection is given as $\max_{\omega\in[0.\infty)} \left(\sigma(\omega,c)\right)^{0.5} \langle \delta$.

2.2 Performance Index for Disturbance Rejection Controller Design

The performance index defined as ITSE (Integral of the Time-Weighted Square of the Error) is written by $PI = \int_0^\infty t(E(t))^2 dt$, $E(s) = \frac{B(s)}{A(s)} = \frac{\sum_{j=0}^{m} b_j s^{m-1}}{\sum_{i=0}^{n} a_i s^{n-1}}$. (3)

Because *E(s)* contains the parameters of the controller *(c)* and plant, the value of performance index, *PI* for a system of n*th* order can be minimized by adjusting the vector c as $\min_c PI(c)$. The optimal tuning proposed in this paper is to find the vector c, such that the ITSE performance index, *PI (c)* is a minimum using bacterial algorithm and the constraint $\max_{\omega\in[0.\infty)} \left(\sigma(\omega,c)\right)^{0.5} \langle \delta$ is satisfied through real coded bacterial algorithms.

3 Behavior Characteristics and Modeling of Bacteria Foraging

3.1 Overview of Chemotactic Behavior of E. coli.

This paper considers the foraging behavior of E. coli, which is a common type of bacteria as in reference 4-5. Its behavior to move comes from a set of up to six rigid 100–200 rps spinning flagella, each driven as a biological motor. An E. coli bacterium alternates between running and tumbling. Running speed is 10–20 $\mu m/\sec$, but they cannot swim straight. Mutations in E. coli affect the reproductive efficiency at different temperatures, and occur at a rate of about 10^{-7} per gene and per generation. E. coli occasionally engages in a conjugation that affects the characteristics of a population of bacteria. Since there are many types of taxes that are used by bacteria such as, aerotaxis (it are attracted to oxygen), light (phototaxis), temperature (thermotaxis), magnetotaxis (it it can be affected by magnetic lines of flux. Some bacteria can change their shape and number of flagella which is based on the medium to reconfigure in order to ensure efficient foraging in a variety of media.

3.2 Optimization Function of Bacterial Swarm Foraging

The main goal based on bacterial foraging is to apply in order to find the minimum of $P(\phi)$, $\phi \in R^n$, not in the gradient $\nabla P(\phi)$. Here, when ϕ is the position of a bacterium, and $J(\phi)$ is an attractant-repellant profile. A neutral medium, and the presence of noxious substances, respectively can showed by

$$H(j,k,l) = \{\phi i(j,k,l) \big| i = 1,2,...,N\} . \tag{4}$$

Equation represents the positions of each member in the population of the N bacteria at the jth chemotactic step, kth reproduction step, and lth elimination-dispersal event. Let $P(i, j, k, l)$ denote the cost at the location of the ith bacterium $\phi^i(j,k,l) \in R^n$. Reference [20, 21] let

$$\phi^i = (j+1,k,l) = \phi^i(j,k,l) + C((i)\varphi(j) , \tag{5}$$

so that $C(i)$>0 is the size of the step taken in the random direction specified by the tumble. If at $\phi^i(j+1,k,l)$ the cost $J(i, j+1, k, l)$ is better (lower) than at $\phi^i(j,k,l)$, then another chemotactic step of size $C(i)$ in this same direction will be taken and repeated up to a maximum number of steps N_s . N_s is the length of the lifetime of the bacteria measured by the number of chemotactic steps. Functions $P_c^i(\phi)$, i=1, 2, . . . , S, to model the cell-to-cell signaling via an attractant and a repellant is represented by

$$\begin{aligned} P_c(\phi) = \sum_{i=1}^{N} P_{cc}^i = \sum_{i=1}^{N}\left[-L_{attract}\exp\left(-\delta_{attract}\sum_{j=1}^{n}(\phi_j - \phi_j^i)^2 \right)\right] \\ + \sum_{i=1}^{N}\left[-K_{repellant}\exp\left(-\delta_{attract}\sum_{j=1}^{n}(\phi_j - \phi_j^i)^2 \right)\right], \end{aligned} \tag{6}$$

When we where $\phi = [\phi_{1,...,}\phi_p]^T$ is a point on the optimization domain, $L_{attract}$ is the depth of the attractant released by the cell and $\delta_{attract}$ is a measure of the width of the attractant signal. $K_{repellant} = L_{attract}$ is the height of the repellant effect magnitude), and

$\delta_{attract}$ is a measure of the width of the repellant. The expression of $P_c(\phi)$ means that its value does not depend on the nutrient concentration at position ϕ. In tuning the parameter M, it is normally found that, when M is very large, $P_{ar}(\phi)$ is much larger than $J(\phi)$, and thus the profile of the search space is dominated by the chemical attractant secreted by E. coli. This paper describes the method in the form of an algorithm to search optimal value of PID parameter.

[step 1] Initialize parameters n, N, N_C, N_S, N_{re}, N_{ed}, P_{ed}, $C(i)(\ i=1,2,\ldots,N)$, ϕ^i, and random values of PID parameter. Where, n: Dimension of the search space (Each Parameter of PID controller), N: The number of bacteria in the population, N_C : chemotactic steps, N_{re} : The number of reproduction steps, N_{ed} : the number of elimination-dispersal events, P_{ed} : elimination-dispersal with probability, C(i): the size of the step taken in the random direction specified by the tumble. The controller parameter is searched in the range of Kp=[0 30], Ti=[0 30], and Td=[0 30].
[step 2] Elimination-dispersal loop: $l=l+1$
[step 3] Reproduction loop: $k=k+1$
[step 4]Chemotaxis loop: $j=j+1$
[step 5] If $j < N_C$, go to step 3. In this case, continue chemotaxis, since the life of the bacteria is not over.
[step 6] Reproduction:
[step 7] If $k < N_{re}$, go to [step 3]. In this case, we have not reached the number of specified reproduction steps, so we start the next generation in the chemotactic loop.
[step 8] Elimination-dispersal: For $i = 1,2...,N$, with probability P_{ed}, eliminate and disperse each bacterium. To do this, if you eliminate a bacterium, simply disperse one to a random location on the optimization domain. If $l < N_{ed}$, then go to [step 2]; otherwise end.

4 Simulation and Discussions

Fig. 1 shows the step response to variation of chemotactic step size. When step size is 0.15 response is best response. Fig. 2 illustrates search process of optimal parameters of PID controller by bacteria foraging (by Ns). Fig. 3 is representing search process of performance index (ITSE) by bacteria foraging and Fig. 4 is comparison of result by IA (Immune Algorithm), curve by FNN (Fuzzy Neural Network), and result by bacteria foraging suggested in this paper.

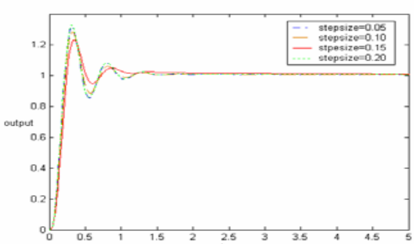

Fig. 1. Step response by Bacteria Foraging

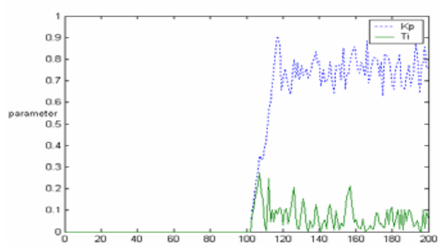

Fig. 2. Search process of optimal parameters by bacteria foraging (by Ns)

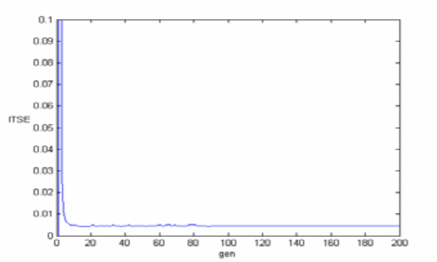

Fig. 3. Performance index for the optimal parameter by bacteria foraging

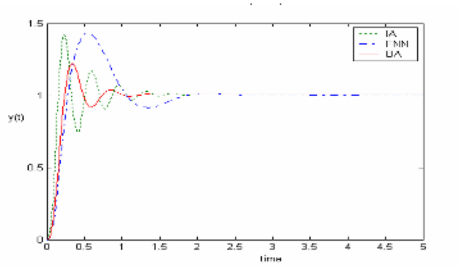

Fig. 4. Comparison of step response

Table 1. Comparison of PID parameter and ITSE of each optimal algorithm

	Kp	Ti	ITSE
FNN	0.29	1.11	0.026
IA	0.56	1.9	0.022
Ba	0.66	0.14	0.0046

5 Conclusions

Up to now, the PID controller has been used to operate the process loops including multivariable system. However, achieving an optimal PID gain is very difficult for the control loop with disturbances. Since the gain of the PID controller has to be tuned manually by trial and error. Since natural selection of animal tends to eliminate animals with poor foraging strategies for locating, handling, and ingesting food, they obtain enough food to enable them to reproduce after many generations, poor foraging strategies are either eliminated or shaped into good ones redesigned. Therefore, optimization approach can be provided for social foraging where groups of parameters communicate to cooperatively forage in engineering. In this paper, an intelligent tuning method of PID controller by bacterial foraging based optimal algorithm is suggested for robust control with disturbance rejection function on multivariable control system. Simulation results are showing satisfactory responses. The object function can be minimized by gain selection for control, and the variety gain is obtained as shown in Table 1. The suggested controller can also be used effectively in the control system as seen from Figs. 1-4.

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