Tuning of a PID controller using improved chaotic Krill Herd algorithm

Saber Yaghoobi, Hamed Mojallali*

Electrical Engineering Department, Faculty of Engineering, University of Guilan, Rasht, Iran

ARTICLE INFO

ABSTRACT

This paper presents an improved version of the Krill Herd optimization algorithm. The proposed algorithm has been applied to determine coefficients of PID controller to achieve desired system response. For this purpose, a cost function based on weighted sum of step response characteristics is considered to be minimized. Simulation results compare performance of the ICKH algorithm with many other optimization algorithms.

© 2016 Elsevier GmbH. All rights reserved.

1. Introduction

Mankind has always been looking for best possible solution of problems in environment around himself. According to the situation, these solutions could be whether smallest or biggest possible solutions. Nowadays in engineering problems, achieving the solution with the lowest possible cost, is one of the designers' problems. Former methods to solve optimization problems require enormous computational efforts, which tend to fail as the problem size increases. This is the motivation for employing bio-inspired stochastic optimization algorithms as computationally efficient alternatives to deterministic approach [1]. Observation in nature for inspiration had been the old interests of scientists to achieve optimization methods. Therefore, many optimization algorithms such as ACO [2], PSO [3], GA [4] etc. have been designed with nature-inspired and animals' behavior.

Recently, a new evolutionary algorithm had been proposed by Alavi and Gandomi, inspired by herding behavior of Antarctic krill [5]. Antarctic krill is one of the best-studied species of marine animal. The Krill Herds are aggregations with no parallel orientation existing on time scales of hours to days and space scales of 10 s to 100 s of meters. One of the main characteristics of this specie is its ability to form large swarms [6,7]. Conceptual models have been proposed to explain the observed formation of the Krill Herds [8].

Krill Herd algorithm, nevertheless its powerful skill in solving optimization enigmas, has the problem of trapping in local optima. Confronting this problem using Chaos theory and its mappings would be suggested in Krill Herd algorithm. Chaos can be described as a bounded nonlinear system with deterministic dynamic behavior that has stochastic properties [9,10]. In what is called the "butterfly effect", small variations of an initial variable will result in huge differences in the solutions after some iterations. Mathematically, chaos is random and unpredictable, yet it also possesses an element of regularity [11]. The aim of this paper is to suggest chaotic Krill Herd algorithm with logistic mapping to solve the problem of trapping in local optima. Later, the proposed algorithm is used to determine coefficients of a PID controller and then simulation results are compared with other optimization algorithms.

Proportional–Integral–Derivative controller or in extenuating words; PID is the most widely used and popular controllers in industrial means because of ease of design and low cost implementation [12,13]. But, the problem is the precise and optimal tuning of PID coefficients. In various books and papers, evolutionary algorithms such as PSO [14], DE [15], GA [16] etc. have been used to tune PID coefficients.

Surveying the operation of a closed-loop system parameters which generally are considered are maximum overshoot, settling time, steady state error, and rise time. In this paper maximum overshoot, distance of nearest pole from imaginary axis, and settling time are examined as indicators of system performance. Desirable performances are short settling time, long distance of nearest pole to the imaginary axis and low maximum overshoot. Thus, the goal is to minimize the weighted sum of maximum overshoot, settling time and distance of nearest pole from imaginary axis.

The rest of this paper is organized as follows. In section 2, the standard Krill Herd algorithm is introduced. The ICKH algorithm

* Corresponding author. Postal address: Electrical Engineering Department, Faculty of Engineering, University of Guilan, PO Box: 3756-41635, Rasht, Iran. Tel.: +98 13 33690270; fax: +98 13 33690271.
E-mail addresses: saber.yaghoobi@gmail.com (S. Yaghoobi), mojallali@guilan.ac.ir (H. Mojallali).

are presented in section 3. Section 4 reviews PID controller and step response characteristics. Also, cost function is introduced. In section 5, the ICKH algorithm has been applied for tuning of PID controller and results are shown. Finally, the paper is concluded in Section 6.

2. Krill Herd algorithm

Krill Herd (KH) algorithm is a new bio-inspired swarm intelligence, that is based on herding conduct of krill and formulating their swarm movement. The herding of the krill individuals is a multi-objective process including two main goals: (I) increasing krill density, and (II) reaching food. In the present study, this process is taken into account to propose a new metaheuristic algorithm for solving global optimization problems. Density-dependent attraction of krill (increasing density) and finding food (areas of high food concentration) are used as objectives which can finally lead the krill to herd around the global minima. In this process, an individual krill moves toward the best solution when it searches for the highest density and food [5].

The position of a krill in a 2D surface is determined by the following three actions [9,10]:

(i) Movement induced by other krill individuals;
(ii) Foraging activity; and
(iii) Random diffusion

Therefore, the following Lagrangian model is generalized to an n dimensional decision space:

$$\frac{dX_i}{dt} = N_i + F_i + D_i \tag{1}$$

where N_i is the movement induced by other krill, F_i the is foraging movement and D_i is the physical diffusion of ith krill.

Direction of N_i which is called α_i, is affected by local density and position of the best krill. N_i is calculated with following formula:

$$N_i^{new} = N^{max}\alpha_i + \omega_n N_i^{old} \tag{2}$$

where

$$\alpha_i = \alpha_i^{local} + \alpha_i^{target} \tag{3}$$

and N^{max} is the maximum induced speed, ω_n is the inertia weight of the motion induced in the range [0,1], N_i^{old} is the last motion induced, α_i^{local} is the local effect provided by the neighbors and α_i^{target} is the target direction effect provided by the best krill individual. According to the measurements of the maximum induced speed [9], it is taken 0.01 (ms^{-1}).

In KH algorithm, the effect of neighbors (α_i^{local}) is formulated as follows:

$$\alpha_i^{local} = \sum_{j=1}^{NN} \hat{K}_{i,j}\hat{X}_{i,j} \tag{4}$$

$$\hat{X}_{i,j} = \frac{X_i - X_j}{||X_i - X_j|| + \varepsilon} \tag{5}$$

$$\hat{K}_{i,j} = \frac{K_j - K_j}{K_{worst} - K_{best}} \tag{6}$$

where K_{best} and K_{worst} are the best and the worst fitness values of the krill individuals so far; K_i represents the fitness or the objective function value of the ith krill individual; K_j is th fitness of jth ($j = 1,2,...,NN$) neighbor; X represents the related positions; and NN is the number of the neighbors.

For choosing neighbors at the first hand, the sensing distance of each krill are calculated with following equation:

$$d_{s,i} = \frac{1}{5N}\sum_{j=1}^{N}||X_i - X_j|| \tag{7}$$

If the distance of two krill individuals is less than the defined sensing distance, then they are neighbors [5].

The best krill affects on others by α_i^{target} which is given by:

$$\alpha_i^{target} = C^{best}\hat{K}_{i,best}\hat{X}_{i,best} \tag{8}$$

and

$$C^{best} = 2\left(rand + \frac{I}{I_{max}}\right) \tag{9}$$

The foraging motion (F_i) is estimated by the two main components. One is the food location and the other is the prior knowledge about the food location. For the ith krill individual, this motion can be approximately formulated as follows: [17]

$$F_i = V_f\beta_i + \omega_f F_i^{old} \tag{10}$$

where

$$\beta_i = \beta_i^{food} + \beta_i^{best} \tag{11}$$

V_f is the foraging speed, ω_f is the inertia weight of the foraging motion and it is a number in the range [0,1], F_i^{old} is the last foraging motion. In this paper, we set V_f to 0.02 [18].

The physical diffusion of the krill individuals is considered to be a random process. It can be formulated as follows:

$$D_i = D^{max}\delta \tag{12}$$

where D^{max} is the maximum diffusion speed, and δ is the random directional vector, and its arrays are random values in range of [−1,1]. The better position of krill leads to the less random motion. Furthermore, another term is added to the physical diffusion formula to consider this effect. This term linearly decreases the random speed with the time (iterations):

$$D_i = D^{max}\left(1 - \frac{I}{I_{max}}\right)\delta \tag{13}$$

According to three main actions mentioned above, velocity of each krill can be calculated. The new position of each krill from t to $t + \Delta t$ is formulated as below:

$$X_i(t + \Delta t) = X_i(t) + \Delta t\frac{dX_i}{dt} \tag{14}$$

Δt is a very important parameter which determines the effect of velocity on the new position of krill. This parameter is extremely affected by search space, so that it can be as the following equation:

$$\Delta t = C_t\sum_{j=1}^{NV}\left(UB_j - LB_j\right) \tag{15}$$

where NV is the number of variables and LB$_j$ and UB$_j$ are the lower and the upper limits of the jth variable. C_t is varied in the range [0,2]. It is obvious that small values of C_t results precisely search in the search space.