An Effective Refinement Artificial Bee Colony Optimization Algorithm Based On Chaotic Search and Application for PID Control Tuning

Gaowei YAN†, Chuangqin LI

College of Information Engineering, Taiyuan University of Technology, Taiyuan, 030024, China

Abstract

Artificial Bee Colony algorithm is a global optimization algorithm which is motivated by the foraging behavior of honey bee swarms. Basic Artificial Bee Colony algorithm (ABC) has the advantages of strong robustness, fast convergence and high flexibility, fewer setting parameters, but it has the disadvantages premature convergence in the later search period and the accuracy of the optimal value which cannot meet the requirements sometimes. In this paper the Chaotic Local Search method is applied to solve the accuracy problem of global optimal value. The premature convergence issue of the Artificial Bee Colony algorithm has been improved by increasing the number of scout and rational using of the global optimal value and Chaotic Search. The application of the Chaotic Search ABC (CABC) algorithm in the PID Control parameters tuning is also simulated in this paper.

Keywords: Artificial Bee Colony Algorithm; Chaotic Local Search; CABC; PID Control Tuning

1. Introduction

Recent years, with the development of computer technology, Swarm Intelligence (SI) has become a hot research subject to many scientists of related fields. The emergence of SI algorithms extended the use of optimization techniques and improved the reliability of the optimization results obtained by classic approaches [1].

Honey bees have been also a source of inspiration for different algorithms to solve optimization problems [12]. There are two main behaviors found in bees which have been modeled as optimization algorithms: The mating behavior and the foraging behavior [8]. The artificial bee colony meta-heuristic algorithm has been introduced as a new method in the field of Swarm Intelligence. ABC (Artificial Bee Colony) algorithm was proposed by Dervis Karaboga in 2005, which is based on the intelligent behavior of honeybee swarms finding nectar and sharing the information of food sources with each other [2]. ABC algorithm has the advantages of strong robustness, fast convergence and high flexibility, fewer control parameters. ABC algorithm can be used for solving multidimensional and multimodal optimization problems [3][17][25].

† Corresponding author.
Email addresses: yangaowei@tyut.edu.cn (Gaowei YAN).

1553-9105/ Copyright © 2011 Binary Information Press
September, 2011
This paper is organized as follows. In section 2 we will review the classical ABC algorithm. In section 3 we will introduce our improved algorithm Chaotic Search ABC (CABC). The application of the CABC on the PID parameters tuning is simulated in section 4. The conclusions are given in section 5.

2. ABC Algorithm

The artificial bee colony contains three groups: employed bee, onlooker bee and scout. The bee going to the food source which is visited by itself previously is employed bee. The bee waiting on the dance area for making decision to choose a food source is onlooker bee. The bee carrying out random search is scout bee. The onlooker bee with scout also called unemployed bee [2][4].

In the ABC algorithm, the collective intelligence searching model of artificial bee colony consists of three essential components: employed, unemployed foraging bees, and food sources. The employed and unemployed bees search for the rich food sources, which close to the bee's hive. The employed bees store the food source information and share the information with onlooker bees. The number of employed bees is equal to the number of food sources and also equal to the amount of onlooker bees. Employed bees whose solutions cannot be improved through a predetermined number of trials, specified by the user of the ABC algorithm and called “limit”, become scouts and their solutions are abandoned [1].

The model also defines two leading modes of behavior which are necessary for self-organizing and collective intelligence: recruitment of foragers to rich food sources resulting in positive feedback and abandonment of poor sources by scout causing negative feedback [3].

2.1. The Procedure of ABC

The classical ABC includes four main phases [6].

**Initialization Phase:** The food sources, whose population size is SN, are randomly generated by scout bees. The number of Artificial Bee is NP. Each food source $x_m$ is a vector to the optimization problem, $x_m$ has D variables and D is the dimension of searching space of the objective function to be optimized. The initiation food sources are randomly produced via the expression (1).

$$ x_m = l_i + rand(0,1)*(u_i - l_i) $$

where $u_i$ and $l_i$ are the upper and lower bound of the solution space of objective function, rand(0,1) is a random number within the range [0,1].

**Employed Bee Phase:** A employed bee flies to a food source and finds a new food source within the neighborhood of the food source. The higher quantity food source will be selected. The food source information stored by employed bee will be shared with onlooker bees. A neighbor food source $v_{mi}$ is determined and calculated by the following equation (2)

$$ v_{mi} = x_{mi} + \phi_{mi} (x_{mi} - x_i) $$

where $x_i$ is a randomly selected food source, $i$ is a randomly chosen parameter index, $\phi_{mi}$ is a random number within the range [-1,1]. The range of this parameter can make an appropriate adjustment on specific issues.

The fitness of food source is essential in order to find the global optimal. The fitness is calculated by the
following formula (3). After that a greedy selection is applied between \( x_m \) and \( v_m \).

\[
fit_m(x_m) = \begin{cases} 
1 & f_m(x_m) > 0 \\
1 + |f_m(x_m)| & f_m(x_m) < 0 
\end{cases}
\]  

(3)

where \( f_m(x_m) \) is the objective function value of \( x_m \).

**Onlooker Bee Phase:** Onlooker bees observe the waggle dance in the dance area and calculate the profitability of food sources, then randomly select a higher food source. After that onlooker bees carry out randomly search in the neighborhood of food source.

The quantity of a food source is evaluated by its profitability and the profitability of all food sources. \( P_m \) is determined by the formula

\[
P_m = \frac{\text{\( fit_m(x_m) \)}}{\sum_{m=1}^{\text{SN}} \text{\( fit_m(x_m) \)}}
\]  

(4)

where \( \text{\( fit_m(x_m) \)} \) is the fitness of \( x_m \).

Onlooker bees search the neighborhood of food source according to the expression (5)

\[
v_{mi} = x_{mi} + \phi_{mi}(x_{mi} - x_{li})
\]  

(5)

**Scout Phase:** If the profitability of food source cannot be improved and the times of unchanged greater than the predetermined number of trials, which called "limit" and specified by the user of the ABC algorithm, the solutions will be abandoned by scout bees. Then, the scouts start to randomly search the new solutions. If solution \( x_i \) has been abandoned, the new solution \( x_m \) will be discovered by the scout. The \( x_m \) is defined by expression (6)

\[
x_m = l_i + \text{rand}(0,1) \times (u_i - l_i)
\]  

(6)

Where \( x_m \) is the new generated food source, \( \text{rand}(0,1) \) is a random number within the range \([0,1]\), \( u_i \) and \( l_i \) are the upper and lower bound of the solution space of objective function.

### 2.2. The Main Concepts of ABC Algorithm

**Food sources:** According to different problems, the initial food sources are randomly generated in the search space.

**Local optimization strategy:** In the employed bee phase, employed bees look for the local optimization value in the neighborhood of food source. Generally, different local search strategies will be used for different problems.

**Random selection strategy in accordance with probability:** In the onlooker bee phase, the random selection strategy will be used to looking for local optimization value in the neighborhood of food source and the higher probability solution will be chosen by onlooker bees.

**Feedback strategy:** In scout bee phase, food sources which are initially poor or have been made poor by exploitation will be abandoned, this means that if a solution cannot be improved and the unchanged times greater than the predetermined “limit” parameter, the new solution will be discovered by the scout using the
negative feedback strategy\(^5\).

**Global optimization strategy**: After local optimization and random selection carried out, the global optimization strategy will be used to obtain global optimal value.

3. Chaotic Search ABC

In the basic Artificial Bee Colony algorithm, the best solution founded by onlooker bee which adopted the local search strategy is unable to reach the ideal level of accuracy\(^7\)[8][16]. In order to improve the accuracy of optimal solution and obtain the fine convergence ability, we use the chaotic search method to solve this problem\(^15\). In the Chaotic Search ABC algorithm (the improved ABC is also called CABC), onlooker bees apply chaotic sequence to enhance the local searching behavior and avoid being trapped into local optimum\(^20\). In onlooker bee phase, chaotic sequence is mapped into the food source. Onlooker bees make a decision between the old food source and the new food source according to a greedy selection strategy.

In this paper, the well-known logistic map which exhibits the sensitive dependence on initial conditions is employed to generate the chaotic sequence\(^27\).

The chaos system used in this paper is defined by

\[
x_{i+1} = \mu x_i (1 - x_i)
\]

where \( \mu \) is a chaotic attractor, If \( \mu \) equal to 4 then the above system enters into a fully chaos state, \( x_{i+1} \) is the value of the variable \( x_i \) in \( i \) iteration\(^15\). After the chaotic sequence generated, the new food source will be obtained by equation (8)

\[
x = x_{nf} + R \cdot (2 \cdot x_i - 1)
\]

Where \( x \) is the new food source and \( x_i \) is the chaotic variable, \( R \) is the radius of new food source being generated. The food source \( x_{nf} \) is in the central of searching region. After the food source has been generated, onlooker bee will exploit the new food source and select the higher profitable one using a greedy selection.

Chaotic search method includes the following steps:

**Step1.** Setting the iterations (cycle parameter) of chaotic search and produce a vector \( x_0 = [x_{0,1} \ x_{0,2} \ x_{0,3} \ldots] \), which is the initial value of chaotic search;

**Step2.** The chaotic sequence is generated according to expression (7) and a new food source, which combining the chaotic sequence with the original food source, is obtained following the equation (8);

**Step3.** Calculating the profitability of the new food source and using the greedy selection select the higher profitability food source;

**Step4.** If the number of chaotic search iterations greater than maximum, the artificial bee algorithm will enter the scout bee phase, or else enter the next chaotic search iteration.

3.1. Global Search Strategy

In the basic Artificial Bee Colony algorithm only one scout, but we added another one into the modified Artificial Bee Colony algorithm in order to improve the global convergence ability. When a scout bee find the food source unchanged times greater than the limit parameter, it will produce a new food source and
replace the original one. Scout bee discovery the new food source using the best optimal value strategy which accelerate the global convergence rate.

Assume that the solution $x_i$ has been abandoned and the scout bee will generate the new solution $x_m$ using the following equation

$$x_m \equiv x_{best}$$

$$x_m(i) = x_{best}(i) + \phi_m \cdot (x_{best}(i) - x_{neighbor}(i))$$

Where $x_m$ is new food source produced by scout bee using the global optimal value $x_{best}$ and $\phi_m$ is a random number within the range $[-1,1]$.

3.2. The Procedure of CABC

The procedure of CABC is as following:

% Initial Phase
According to equation (1) discovering the initial food sources
Itertime = 1;
while ( Itertime $\leq$ MaxCycle )
% Employed Bee Phase
Step1. According to expression (2) searching the neighborhood food source;
Step2. Calculate the function value;
Step3. According to formula (3) evaluate fitness of the food sources.
% Onlooker Bee Phase
Step1. According to expression (4) calculate the profitability;
Step2. Onlooker bee in the guide of equation (7) and (8) exploiting the local optimal solution;
Step3. Calculating the function value of new food source;
Step4. Evaluating the new food source fitness according to equation (3).
% Scout Bee Phase
if (trial>limit)
Step1. The first scout randomly discovering the new food source;
Step20 The second scout bee updating the food source, which hit the limit parameter, according to formula (9) and (10).
% Search the global optimal value
GlobalMin
End while

4. PID Control Tuning Based on CABC

Objective Function

In industrial process control system, PID control strategy has been widely used for its simple structure and robust performance within a wide range of operating conditions. Unfortunately, it is quite difficult to properly tune the parameters of PID controller, because many industrial plants are often burdened with problems such as: high orders; time delays; and nonlinearities and the fact that mathematical model of plant
is difficult to determine. In this situation, the controller must have the function of parameter self-tuning and
good tuning effect. So in the optimal control, the control parameter tuning and optimization is vital to
whole control system. Conventional PID control parameters tuning method uses the first proportional, second the integral, then
the derivative three steps and changes the parameters until a satisfactory effect obtained. But conventional
PID parameter tuning method has its own limitations. In recent decade, several heuristic methods have been
proposed for the tuning of PID controllers. The emergence of intelligent optimization methods provides a
new approach to tuning PID parameters. Artificial Bee Colony algorithm can be used to optimize PID parameters. The most crucial step in
applying Artificial Bee Colony algorithm is to choose the objective functions that are used to evaluate
fitness of each food source. In engineering, there are two selections, the first is the functions that
represent the quality indicators the system required; second is the error functions, when the error objective
function value is minimum, the quality of system is the best. There are several common types of
error objective function: Mean of the Squared Error (MSE), Integral of Time multiplied by Absolute Error (ITAE), Integral of Absolute Magnitude of the Error (IAE), and Integral of the Squared Error (ISE).
In this paper, using the following objective function based on the error function:
\[ Q = \text{Itae} + T_r + M_p \]  
where \( Q \) is the objective function, \( \text{Itae} \) is the integral of time multiplied by Absolute Error, defined by formula, \( T_r \) is Rising time and \( M_p \) is Overshoot.
\[ \text{Itae} = \int_0^t |e(t)| \, dt \]

The transfer function of the selected plant in this paper is defined by equation
\[ G(s) = \frac{400}{s^2 + 500s + 1} \]
The searching space of the PID parameter \( K_i, K_p, K_d \) with the range of \([0,20]\) and \([0,1]\) and
\([0,1]\), respectively.

4.2. PID Control Parameters Tuning Based on CABC

PID control parameters tuning based on CABC (Chaotic Search ABC) algorithm include two parts:

**CABC control parameters setting:** The setting of the control parameters for the CABC algorithm is
listed on the Table 1.

**Optimization results:** After three consecutive tests, the system's unit step response curve is shown in
Figure 1 and the red one is the best curve.

The optimal parameters corresponding to the red curve: \( K_p = 17.3524; K_i = 0.012; K_d = 0.1981 \)

The dynamic response index of the control system: Risetime = 0.017s; SettingTime = 0.062; OverShoot =
0.06.

5. Conclusion

PID control parameters optimization based on CABC algorithm not require the system to be tuned giving
the constraints related to the dynamic response and CABC algorithm also can obtain the best group of
parameter. The CABC algorithm has a great adaptability to the actual control system. Regardless of the plant’s transfer function, PID control system based on CABC can realize the optimization and tuning of parameters. CABC algorithm has a higher accuracy and the PID control systems adopt optimal parameters can obtain the quantity that low rise time, overshoot as well as quickly achieve steady state.

<table>
<thead>
<tr>
<th>Table 1 CABC Control Parameters Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Food Sources SN = 10</td>
</tr>
<tr>
<td>Times of Robust Test</td>
</tr>
<tr>
<td>runtime = 3</td>
</tr>
<tr>
<td>Iteration Cycle</td>
</tr>
<tr>
<td>MaxCycle = 100</td>
</tr>
<tr>
<td>Limited Parameter</td>
</tr>
<tr>
<td>limit =100</td>
</tr>
<tr>
<td>Iteration times of Chaotic Search</td>
</tr>
<tr>
<td>Nlimit = 4</td>
</tr>
</tbody>
</table>

Fig 1 The Step Response of PID Controller

Acknowledgement

This paper is supported by the National Natural Science Foundation Project of China (No.60975032), the Youth Science Foundation’s Project of Shanxi Province (No. 2006021016).

References

Efrén Mezura-Montes, Mauricio Damián-Araoz and Omar Cetina-Domínguez, Smart Flight Dynamic Tolerances in the Artificial Bee Colony for Constrained Optimization.


Chunfan Xu, Haibin Duan, Artificial bee colony (ABC) optimized edge potential function (EPF) approach to target recognition for low-altitude aircraft, Pattern Recognition Letters, 2010.

Adil Baykasoğlu, Lale Özbakır and Plnar Tapkan, Artificial Bee Colony Algorithm and Its Application to Generalized Assignment Problem, Swarm Intelligence: Focus on Art and Particle Swarm Optimization.

Dušan Teodorović, Tatjana Davidović and Milica Šelmić, Bee Colony Optimization Overview.


Adil Baykasoğlu, Lale Özbakır and Plnar Tapkan, Artificial Bee Colony Algorithm and Its Application to Generalized Assignment Problem, Swarm Intelligence: Focus on Art and Particle Swarm Optimization.


Adil Baykasoğlu, Lale Özbakır and Plnar Tapkan, Artificial Bee Colony Algorithm and Its Application to Generalized Assignment Problem, Swarm Intelligence: Focus on Art and Particle Swarm Optimization.


Dušan Teodorović, Tatjana Davidović and Milica Šelmić, Bee Colony Optimization Overview.


Adil Baykasoğlu, Lale Özbakır and Plnar Tapkan, Artificial Bee Colony Algorithm and Its Application to Generalized Assignment Problem, Swarm Intelligence: Focus on Art and Particle Swarm Optimization.


