A Novel Adaptive Particle Swarm Optimization Algorithm with Foraging Behavior in Optimization Design

Yan Liu[1] , Qi Wang[2] , Guoyi He[3], Li Zhang[1] and Jiao Wang[1]

[1] *Nanchang Hangkong University School of Aircraft Engineering,student,2017, China*
[2] *Nanchang Hangkong University School of Aircraft Engineering, professor,2017, China*
[3] *Nanchang Hangkong University School of Aircraft Engineering, associate professor,2017, China*

Abstract. The method of repeated trial and proofreading is generally used to the convention reducer design, but these methods is low efficiency and the size of the reducer is often large. Aiming the problems, this paper presents an adaptive particle swarm optimization algorithm with foraging behavior, in this method, the bacterial foraging process is introduced into the adaptive particle swarm optimization algorithm, which can provide the function of particle chemotaxis, swarming, reproduction, elimination and dispersal, to improve the ability of local search and avoid premature behavior. By test verification through typical function and the application of the optimization design in the structure of the reducer with discrete and continuous variables, the results are shown that the new algorithm has the advantages of good reliability, strong searching ability and high accuracy. It can be used in engineering design, and has a strong applicability.

1 Introduction

The gear reducer is the transmission between the prime mover and the working machine which can reduce the speed and increase the torque. It is widely used in industry, mining enterprises, transportation, construction and other departments of the mechanical parts[1].

The traditional design method of cylindrical gear reducer is used to compare existing reducers and develop an initial design, which is according to a variety of information, literature and combined with the design experience, then the program will be checked, if the check results are passed, the program can be determined ,otherwise, the reducer will be redesigned. In order to reduce the cost of the reducer and improve design efficiency, optimized design of cylindrical gear reducer is imperative[2]

Particle swarm optimization algorithm is a kind of stochastic optimization technique based on population, the basic idea is inspired by the behavior of birds with rapid and premature in the early stage. The other algorithm is the bacterial foraging, it is based on the foraging behavior model of Escherichia coli, which is not sensitive to the initial value and the parameter selection, and the local search ability is strong[3]. However, to combinate two algorithms can not only improve the optimization speed of complex problems, but also can solve the problem of premature convergence in engineer application.

2 Algorithm and improvement

Considering the advantages of the particle swarm optimization algorithm (PSO) and the bacterial foraging algorithm (BFA), the first is early rapidity and precocious puberty[4], and the second is strong local search ability[5]. So the combination of two algorithms can not only improve the optimization speed, but also solve the premature convergence of the complex problems.

This paper presents the particle swarm optimization algorithm based on bacterial foraging behavior(BFPSO). In this method, the bacterial foraging process is introduced into the adaptive particle swarm optimization algorithm(APSO) [6], which can provide the function of particle chemotaxis, swarming, reproduction, elimination and dispersal, improve the ability of local search and avoid premature behavior. The flow chart of the proposed algorithm is as figure 1.

3 Function test

In order to verify the optimization performance of BFPSO, we use 5 classical test functions to compare BFPSO with the simple PSO and APSO. Test times is 200.

The test functions are: f1 Rosenbrock function, f2 Rastrigrin function, f3 Shubert function, f4 Ackely function, and f5 Griewank function[5]. The basic features of these test functions are shown in table 1.

In the MATLAB simulation calculation, respectively, the number of 5 test lines for the 200 calculation, the reliability of the test results shown in table 2, the results of the convergence process are compared in figure 2.

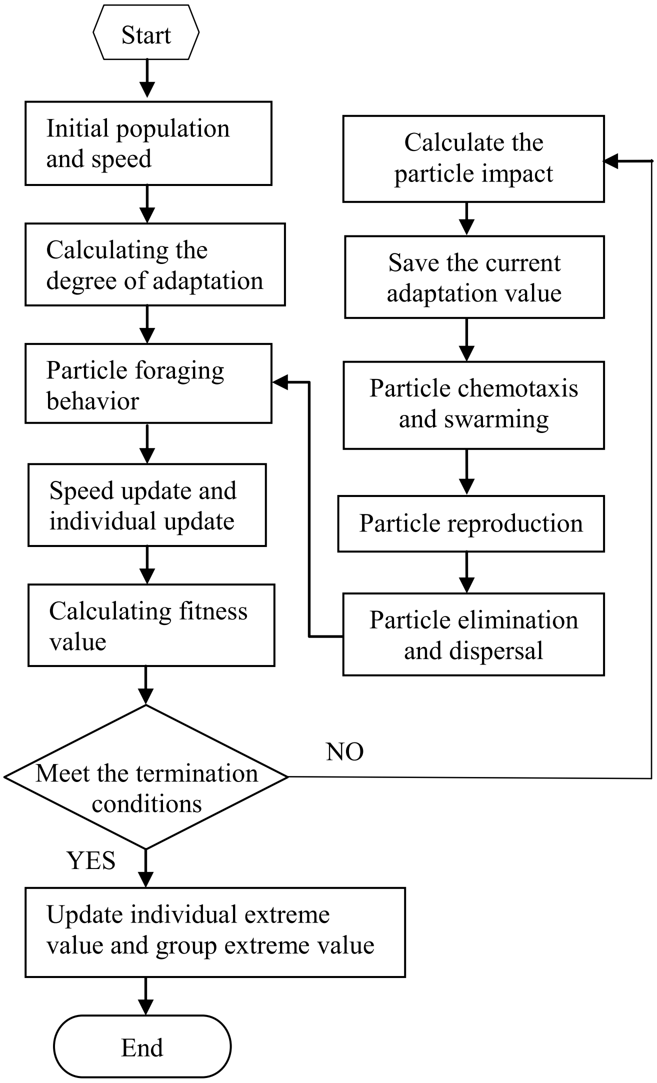


Figure 1. Flow chart of the proposed algorithm

The 200 reliability tests are shown in table 2, the accuracy of the improved algorithm is higher than the other two basic algorithms, and the accuracy requirements of the number is more, then the reliability and accuracy of the new algorithm are improved.

Compare to the convergence speed of the test functions f1,f2,f3, the new algorithm is significantly improved, the robustness is better.

For the test function f4, the convergence speed of the three algorithms is similar, because the f4 belongs to a single peak function and the extremum is at one point. The three algorithms can easily approch the extreme point, so the convergence speed is similar.

For the test function f5, the new algorithm converges slower than PSO and APSO, because the function f5 is uniform multi-peaked in the entire range of values, and the difference between the maximum absolute value point and the other extreme points is not obvious. When the PSO and APSO enter the local optimum, the BFPSO is still searching for the global optimal value. Therefore, the convergence speed of the BFPSO is slower than that of the PSO and the APSO, which shows that the global optimization capability of the BFPSO is stronger.

4 Optimization design of reducer

4.1 Design demand

This paper using the two-grade helical cylindrical gear reducer from references [7] as a analysis example. The design is to make sure the center distance is minimum in the require of bearing the design force.

Known conditions are: the input power of the high speed axle is R=6.2Kw, maximum rotate speed is n1=1450r/min, overall ratio is iΣ =31.5, the coefficient of facewidth of the gearwheel is φa=0.4, big wheel gear using No.45 steel, normalizing treatment, rigidity is ranging in(187~207)HBS, small wheel gear using No.45 steel, thermal refining rigidity is ranging in (228~255)HBS, total working time is designed not less than 10 years [7-9] .

4.2 Mathematical model

Using designing variable expression the center distance, the objective function is in Eq. (1).

$$f(x) = [x_1 x_3 (1 + x_5) + x_2 x_4 (1 + 31.5 / x_5)] / (2\cos x_6) \quad (1)$$

The constraint conditions from references [7] shown as in Eq. (2-8).

$$2 < x_1 < 5, \quad 3.5 < x_2 < 6, \quad 14 < x_3 < 22 \quad (2)$$

$$16 < x_4 < 22, \quad 5.8 < x_5 < 7, \quad 8 < x_6 < 15 \quad (3)$$

$$g(x) = \cos^3 x_6 - 3.079 \times 10^{-6} x_1^3 x_3^3 x_5 \le 0 \quad (4)$$

$$g(x) = x_5^2 \cos^3 x_6 - 1.701 \times 10^{-4} x_2^3 x_4^3 \le 0 \quad (5)$$

$$g(x) = \cos^2 x_6 - 9.939 \times 10^{-5} (1 + x_5) x_1^3 x_3^2 \le 0 \quad (6)$$

$$g(x) = x_5^2 \cos^2 x_6 - 1.706 \times 10^{-4} (31.5 + x_5) x_2^3 x_4^2 \le 0 \quad (7)$$

$$g(x) = x_5 [2(x_1 + 50)\cos x_6 + x_1 x_3 x_5] - x_2 x_4 (x_5 + 31.5) \le 0 \quad (8)$$

Where x_1,x_2 is the normal module of the high speed wheel gear and the low speed wheel gear, x_3,x_4 is the number of teeth of the high speed level wheel gear and the low speed level wheel gear, x_5 is the gear ratio of the high speed level, x_6 is the helical angle of the wheel gear.

4.3 Simulation

The operating parameters of BFPSO are: the initial number of particles m=80, the learning factor c_1=2， c_2=2, the Inertia weight w=0.729, the particle chemotaxis and swarming times N_c=50, the reproduction times N_{re}=4, the elimination and dispersal times N_{ed}=2, the elimination and dispersal probability P_{ed}=0.25.

In order to verify the effectiveness of BAPSO in the structural optimization design of reducer. Takes 10 times calculations and chooses the result (m_{n1}=2, m_{n2}=4, z_1=17, z_3=16, i_1=5.9, β=8.6334°, i_2=5.339, z_2=100, z_4=85, center distance is 323.8160,then corrected the center distance to 324, the helix angle is adjusted to β=10.0788°) which is the biggest center distance to compare with the

Table 1. Basic characteristics of test function

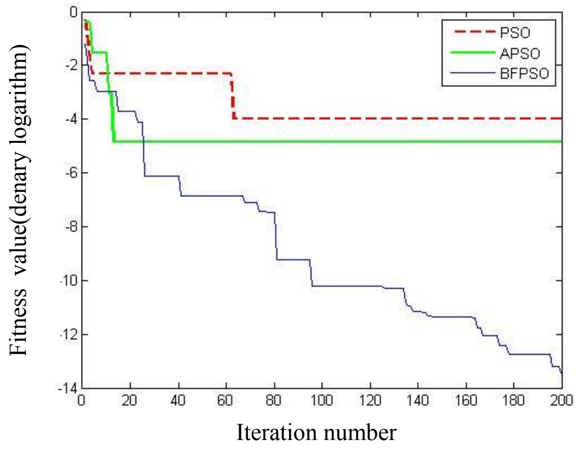
Test function	f1	f2	f3	f4	f5
Dimension	2	2	2	5	5
Optimal distribution	Single peak	Multi peak	Complex multi peak	Multi peak	Complex multi peak
Variable range	[-5.12,5.12]	[-5.12,5.12]	[-500,500]	[-10,10]	[-600,600]
Global optimal solution	[1,1]	[0,0]	[420.9687, 420.9687]	[0,0,0,0,0]	[0,0,0,0,0]
Global optimal value	0	0	0	0	0
Accuracy requirements	1×10^{-3}	1×10^{-5}	3×10^{-1}	1×10^{-5}	1×10^{-3}

Table 2. Statistical table of reliability test results

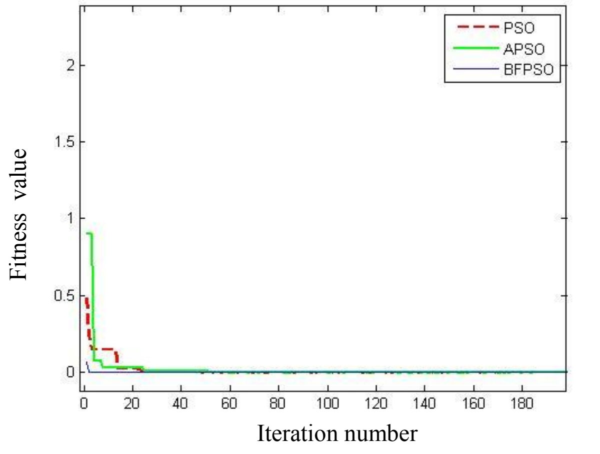
Function	Method	Meet the accuracy requirements	Control rates	Best	Mean
f1	PSO	195	97.5%	1.020962173183369e-4	0.0136434802252842
	APSO	189	94.5%	1.22455851741843e-5	0.001001051395270
	BFPSO	198	99.0%	1.86337017700319e-13	0.000253597371737501
f2	PSO	181	90.5%	0	1.54116880610374 e-5
	APSO	162	81.0%	0	1.46635488190231 e-5
	BFPSO	199	99.5%	0	5.24142685911032 e-6
f3	PSO	178	89.0%	0.172065452841252	0.622747078460316
	APSO	185	92.5%	0.0136952403170199	0.177770974202361
	BFPSO	191	95.5%	2.54551323450869e-5	0.0206438668787996
f4	PSO	154	77.0%	8.16946510440175e-9	8.19113710888889 e-5
	APSO	160	80.0%	7.29585281078471e-9	3.88195236493864 e-5
	BFPSO	162	81.0%	9.36495325731812e-10	2.64480185942740 e-6
f5	PSO	162	81.0%	6.51823898750270 e-4	0.0654890233968797
	APSO	195	97.5%	2.03284256395264 e-8	0.00435214963708608
	BFPSO	195	97.5%	6.34048369363427e-16	0.00303619265847559

Table 3. Parameters comparison of different design methods

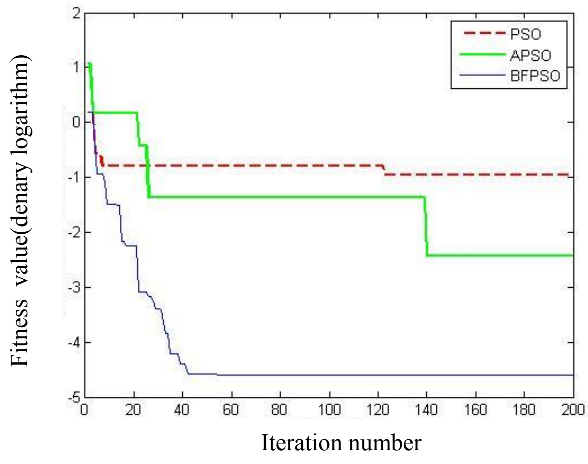
Design Method	m_{n1}	m_{n2}	z_1	z_3	i_1	β	Center Distance
Experience Design	3	5	19	17	6.3	11°	470
Paper[7]	2	4	19	16	5.8	9.8°	340
Present	2	4	17	16	5.9	10.1°	324



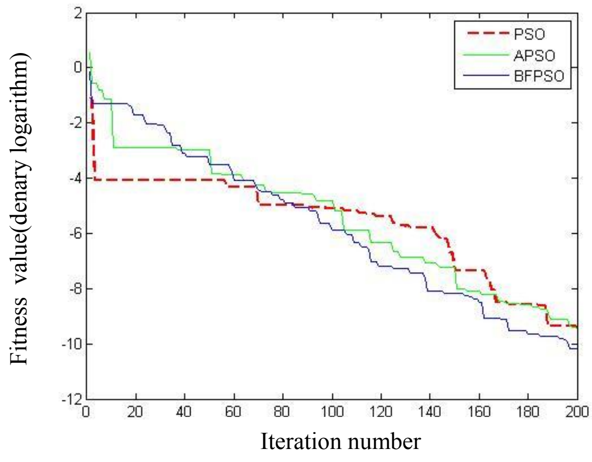
a. Convergence process of f1 function



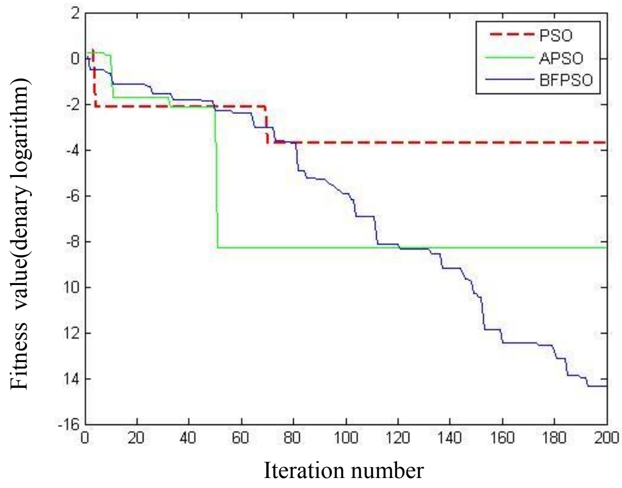
b. Convergence process of f2 function



c. Convergence process of f3 function



d. Convergence process of f4 function



e. Convergence process of f5 function

Figure 2. Comparison of convergence results of the three algorithms

experience method and traditional optimization methods introduced in reference [7]. The comparative results are shown in Table 3, The convergence process of center distance varying with the number of iterations shown in Figure 3.

The conclusion can be drawn in Table 3 :the optimization result about center distance using BAPSO in this paper decreases 31.06% compared to experienced design,and 4.71% compared to traditional optimization methods, which reflects its capability of solving complex optimization problems. This means that using the improved optimization algorithm in this paper for mechanical design can improve the design accuracy and design efficiency. At the same time, it shows that this optimization algorithm can effectively deal with the practical problems in the design after it is introduced into the design field.

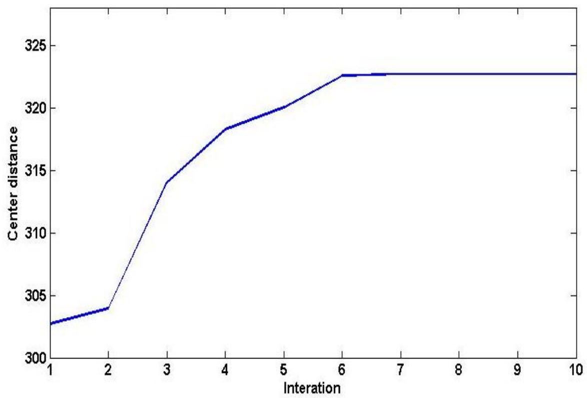


Figure 3. Iterative convergence process of center distance

5 Conclusions

In this paper, a particle swarm optimization algorithm based on bacterial foraging behavior(BFPSO) is proposed.

The performance of the BAPSO is tested by the classical test function, the results are shown that the BAPSO has better optimization ability, higher precision and reliability. Application the new algorithm for optimization design of gear reducer can get lesser center distance, the reducer structure is more compact. Indicating BAPSO has been more practical and better capacity for solving complex optimization problems. Further research in this area means that design accuracy and efficiency can be improved in solving practical problems in the areas of mechanical design, redundant allocation, flight control.

References

1. Deng X H. The method of optimizing design of cylindrical gear reducer[J].Journal of Minjiang University,2004，25（5）：38～40
2. Hu X H. Optimum design of single stage cylindrical gear reducer[J]. Combination Machine Tool and Automatic Machining Technology,2006(7)
3. Yang S Y, Zhang H. Group intelligence and bionic calculation[M]. Beijing. Electronic Industry Press, 2012
4. Yu S W. Case analysis and application of MATLAB optimization algorithm[M]. Beijing. Tsinghua University Press, 2014.
5. Hu J. Improvement of bacterial foraging optimization algorithm and its application[D]. Wuhan .Wuhan University of Technology, 2012.
6. Gong C,Wang Z L. Proficient in MATLAB Optimization[M]. Beijing. Electronic Industry Press, 2012
7. Zhang H P.optimization design of two-stage helical cylindrical gear reduce based on MATLAB[J]. Machinery Design and Manufacture,2010,(4):79-80.
8. Wen B C.Reducer and transmission[M].Beijing. China Machine Press,2015.
9. Wang D L,Ma Y L.Mechanical design[M]. Beijing.China Machine Press,2015.