Global optimized BAS algorithm based on Powell local search strategy

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Abstract

In order to overcome the shortcomings of BAS algorithm including slow convergence speed, low accuracy and falling into local optimum value easily, a global optimization algorithm (named as Powell-IBAS) based on Powell local search strategy is proposed. The algorithm combines the global search ability of Powell and the local optimization performance of the BAS algorithm. It ensures the speed of searching solution while improving the accuracy of BAS algorithm. Through the test of 8 typical functions, the simulation results show that the Powell-IBAS algorithm obtains relatively good mean, the worst value, the optimal value and the variance. The results show that the algorithm not only improves the optimization accuracy and optimization efficiency, but also has a strong adaptability and good robustness compared with the standard BAS algorithm.

Keywords

Beetle search algorithm, Powell local search strategy, global optimization, function optimization.

1. Introduction

The meta heuristic algorithm [1], also known as the intelligent optimization algorithm [2], is a new search technology proposed by human through the simulation of natural phenomena and the learning of biological intelligence. Because of its simplicity and flexibility, it can be used to guide the traditional heuristic algorithm to search for spaces that may contain high quality solutions, and become popular in solving optimization problems. The commonly used metaheuristic algorithms mainly include tabu search algorithm, simulated annealing algorithm, genetic algorithm, ant colony optimization algorithm, artificial neural network and so on. Subsequently, inspired by nature, various new heuristic algorithms have emerged. In 2001, the Korean scholar Geem and others proposed an intelligent optimization algorithm, [3], for the harmonic search algorithm. In 2005, India scholar Krishnanand and Ghose were inspired by the firefly's information communication in nature, and put forward the firefly algorithm FA (Firefly algorithm) [4]. In 2009, the DEB at Yang and Raman at Engineering University of Cambridge proposed the Cuckoo Search (Cuckoo Search) by simulating cuckoo bird finding behavior [5]. In 2017, the Beetle Antennae Search-BAS (Search-BAS) [6] was proposed, inspired by the search behavior of the beetle. It is similar to genetic algorithm, particle swarm optimization, simulated annealing and other intelligent optimization algorithms, this algorithm doesn't need to know the specific form of functions, and does not need gradient information and can achieve efficient optimization. Compared with particle swarm optimization (PSO), the beetle search requires only one individual, the amount of operation is greatly reduced, and there are not many parameters to be adjusted. But the algorithm has slow convergence and low convergence accuracy and falls into local optimum value easily. Aiming at solving these problems, we use local optimization ability of Powell method as a local search operator that embedded into the algorithm. So, a method of local optimization of Powell beetles to search algorithm is proposed. The test results show that the new algorithm in solving complex function has better performance than the beetle shall.

2. Beetle search algorithm and Powell

2.1 Beetle search algorithm

(1) Bionic principle

The Beetle Antennae search (BAS), also known as the Beetle, is an intelligent optimization algorithm inspired by the principle of foraging of the cattle. The cattle don't know the exact location of the food when they foraging, but can forage according to the strength of the smell of food. The beetle has two long antennae, and if the left antenna receives a stronger odor than the right, the next step is to search the left, else to the right. According to this simple principle, the beetle can find food effectively. The heuristic of the beetle search for the optimization: the strength of the smell of the food is equivalent to a function, so the function value is different in three-dimensional space sawyer. The two must of beetle pick up the smell of the two values near itself in order to find the value of the largest global smell. By imitating the behavior of the beetle, the function can be optimized efficiently.

(2) Model:

For the n-dimensional space, the left whisker coordinates are expressed as x_l , the right whisker coordinates are expressed as x_r , the centroid coordinates are expressed as x , and the distance between the two tentacles is expressed as d_0 . We propose a random direction of beetle searching as follows,

$$dir = rands(n,1)$$

$$dir = dir / normal(dir) \tag{1}$$

Furthermore, we present the searching behaviors of both right-hand and left-hand sides respectively to imitate the activities of the beetle's antennae:

$$\begin{cases} x_l = x + d_0 * dir / 2 \\ x_r = x - d_0 * dir / 2 \end{cases} \tag{2}$$

For the objective function f , the values of two tentacles are respectively: $f_l = f(x_l)$, $f_r = f(x_r)$. Compare the two values and determine the direction and next step of the beetle.:

$$x = x - step * normal(x_l - x_r) * sign(f_l - f_r) = x - step * dir * sign(f_l - f_r) \tag{3}$$

(Note: normal is a normalized function, and sign is a symbolic function).

The initial step size can be as large as possible and is best to be equal with the maximum length of the independent variable. The two method of setting the step length:

a. Set $step = \alpha * step$, it is close to 1 and ranges in 0-1, which $\alpha = 0.95$ is usually advisable;

b. Introducing new variable and final resolution ratio, $temp = \alpha * temp, step = temp + step_0$;

(3) Solution:

The BAS algorithm flow is as follows:

BAS algorithm
Step 1:Initialization parameters: maxgen, x, d_0 ; Step 2:According to(2), calculate x_l, x_r and evaluate the fitness. Record the current optimal solution x_{best} and optimum fitness f_{best} ; Step 3:If the total iteration number is greater than maxgen, the iteration is stopped and the maximum point is found; otherwise, it is turned to Step4; Step 4:The position update is carried out according to the formula (3); Step 5: If $f(x) < f_{best}$, x_{best} is replaced by x ; Step 6:use formula (4) to update step and turn to Step2;

2.2 Improved search algorithm for the beetle(IBAS)

The step setting of BAS algorithm makes the algorithm converge very fast, but it is easy to fall into local optimum in the later stage of optimization, so it is necessary to improve the setting of step size and improve the overall optimization ability of the algorithm. The performance of the optimization algorithm depends on the balance between the global exploration and the local development ability of the algorithm. In the different stages of the process, the algorithm should have different global exploration ability and exploitation ability. Generally, in the early stage, algorithm should have global exploration ability, in the latter part of the optimization process; the algorithm should have strong ability of local development. Therefore, we redesign an adaptive step adjustment mechanism for BAS algorithm (named as IBAS), which provides enough local development capability and global exploration capability. Set step of IBAS as following:

$$step = \omega * step\,,\ \ \omega = 2^{\left(1-\frac{\lambda g}{\max gen}\right)} \tag{4}$$

Where, the step length adjustment coefficient ω gradually decreases with the increase of the number of optimized iterations. The initial value is set as 2 and the final value is 0.25. In (4): g is the current generation; maxgen is the largest iterative number; $\lambda = 3$.

2.3 Powell

The Powell search method, also known as the direction acceleration method [7], is a direct local search method that doesn't need to calculate derivatives but only uses function values. It is considered as one of the most effective strategies for finding the minimum value of functions in direct search method. The Powel search algorithm divides the optimization process into several stages, in which the optimization of each round is composed n+1 times one dimensional search. In every iteration process of Powel search algorithm, we first search along the known n direction in order to get the best location. A direction is determined from the initial point of this iteration to the best point found by the search, and then it is searched in that direction. In this direction, we get the best point of this stage, then replace one of the first n directions with the last determined search direction. Based on that, we start the iterative optimization of the next stage.

2.4 Powell-IBAS

The Powell-IBAS hybrid algorithm combines the advantages of the BAS and Powell algorithms to avoid its shortcomings and emphasizes the balance of accuracy, reliability and computing time. The Powell-IBAS algorithm flow is as follows:

Powell-IBAS
Step 1:Parameter initialization: maxgen, x, d_0, step parameter λ, accuracy of Powell method ε,the probability of Powell method search P_p;
Step 2:According to(2), calculate x_l, x_r and evaluate the fitness. Record the current optimal solution x_{best} and optimum fitness f_{best};
Step 3:If the total iteration number is greater than maxgen, the iteration is stopped and the best solution is found; otherwise, it is turned to Step4;
Step 4:The position update is carried out according to the formula (3);
Step 5:If $rand < P_p$, the location of the BAS search is used as the initial point to search the extreme points by using the Powell method;
Step 6:If $f(x) < f_{best}$, x_{best} is replaced by x;
Step 7:Use formula (4) to update step and turn to Step2.

3. Algorithm simulation

In order to verify the optimization performance of the IBAS algorithm, 8 benchmark functions (see Table 1) are applied to compare the basic BAS algorithm and Powell-IBAS algorithm. The experimental results are shown in Table 2. The parameters are set as follows: BAS method maximum iteration number maxgen is set as100, initial step step is set as 1, initial whisker distance $d_0 = step / c, c = 5$, step parameter $\lambda = 3$, Powell accuracy $\varepsilon = 10^{-3}$ and Powell search probability $P_p = 0.3$.

3.1 Search probability of Powell method

Theorem [8] set f is continuous and differentiable uniformly convex function. If the level set $\Omega(x^{(0)}) = \{x \mid f(x) \le f(x^{(0)})\}$ is bounded, then the point set $\{x^{(k)}\}$ generated by Powell search method converges to the unique minimum value f in $\Omega(x^{(0)})$.

The theorem shows that different initial points are likely to converge to the same global or local extreme value by Powell search method, which leads to missing peak value and the decreasing of possibility of finding all extreme points. Therefore, we set Powell search probability $P_p = 0.3$ in this algorithm.

3.2 Test functions [9]

Tab1 Test function

Function name	Functional formula	Dimension	Domain	Theoretical Extreme Values
Sphere	$f = \sum_{i=1}^{n} x_i^2$	2	[-100,100]	0
Axis parallel hyper ellipsoid	$f = x^2 + 2y^2$	2	[-5.12,5.12]	0
Becker and Lago	$f = (\lvert x \rvert - 5)^2 + (\lvert y \rvert - 5)^2$	2	[-10,10]	0
Booth's	$f = (x + 2y - 7)^2 + (2x + y - 5)^2$	2	[-10,10]	0
Sum of different power	$f = \sum_{i=1}^{N} \lvert x_i \rvert^{i+1}$	2	[-1,1]	0
Eggcrate	$f = x^2 + y^2 + 25(\sin^2 x + \sin^2 y)$	2	$[-2\pi, 2\pi]$	0
Ackley	$f = -20\exp(-0.2\sqrt{\frac{1}{n}\sum_{i}^{n} x_i^2}) - \exp(\frac{1}{n}\sum_{i}^{n} \cos 2\pi x_i) + 20 + e$	2	[-5,5]	0
Rosenbrock	$f = \sum_{i=1}^{n-1} [100(x_{i+1} - x_i^2)^2 + (x_i - 1)^2]$	2	[-2.048,2.048]	0

3.3 Result analysis

The experimental results are evaluated from two aspects of convergence speed and convergence accuracy. In order to prevent the accidental error of the experiment, the Powell-IBAS and BAS algorithm was used by two independent experiments for 50 times. Compute the optimal value, the worst value, the mean and standard deviation of two algorithm's results. The mean value is obtained by averaging the optimal results which can reflect the effect of two kinds of optimization algorithm; variance can be used to reflect the stability of the algorithm: the smaller of variance, the better stability of the algorithm otherwise the stability of the algorithm is poor. The results of the experiment are shown in Table 2. The convergence curves of the 8 test functions at 100 times iteration are shown in Figure 2 - 9.

Tab 2 Algorithm test index

function name	algorithm	mean value	worst value	optimal value	variance
Sphere	BAS	1.66E-02	4.06E-01	6.59E-09	4.479276E-03
	Powell-IBAS	0	0	0	0
Axis parallel hyper ellipsoid	BAS	6.13E-06	2.78E-05	2.49E-07	3.83369E-11
	Powell-IBAS	0	0	0	0
Becker and Lago	BAS	3.44E-06	1.09E-05	6.64E-08	8.77457E-12
	Powell-IBAS	0	0	0	0
Booth's	BAS	1.05E-04	1.80E-03	1.99E-07	1.5158E-07
	Powell-IBAS	0	0	0	0
Sum of different power	BAS	1.51E-06	8.45E-06	2.09E-08	3.86488E-12
	Powell-IBAS	8.59266E-11	4.41474E-10	2.14358E-13	1.59365E-20
Eggcrate	BAS	1.08E-04	5.11E-04	1.38E-06	1.76814E-08
	Powell-IBAS	1.10718E-09	5.20468E-09	1.42364E-11	1.84194E-18
Ackley	BAS	3.725 E-03	7.5 E-03	4.451 E-04	4.1124E-06
	Powell-IBAS	1.078 E-03	2.164 E-03	1.722E-05	3.6217E-07
Rosenbrock	BAS	1.852 E-01	6.575 E-01	3.912 E-03	1.910 E-02
	Powell-IBAS	1.4168 E-01	3.365 E-01	6.54 E-03	7.959 E-03

1) Analysis of convergence

From the above table, we can conclude that Powell-IBAS has obtained relatively better average result, worst result, best result and variance compared with the BAS algorithm in the 50 experiments that conducted on each test function independently. For the Sphere function and the Booth's function, the Powell-IBAS algorithm has reached its theoretical value in the 50 experiments. For the other three test functions, the two algorithms can't reach their theoretical values, but in terms of convergence accuracy, the Powell-IBAS algorithm is better than the standard BAS algorithm. For the first four test functions, each optimization experiment can reach the theoretical value and the optimization effect is remarkable. In terms of stability, it can be seen from table 2 that the variance of Powell-IBAS algorithm for eight test functions is lower than that of BAS algorithm. For some complicated functions, the stability of the algorithm is increased by at least one order of magnitude.

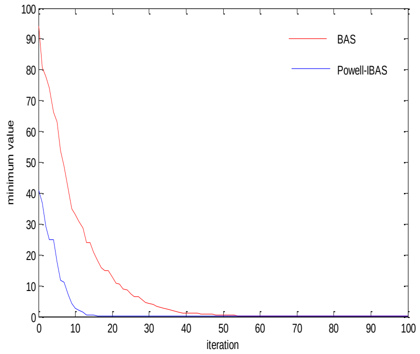

Fig.2 Sphere convergent curve

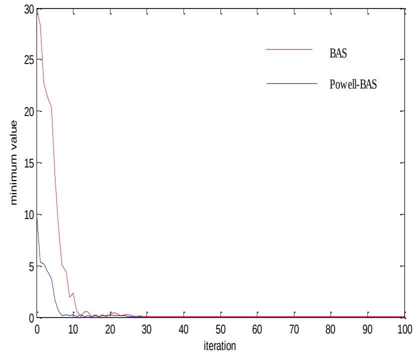

Fig.3 Axis parallel hyper-ellipsoid convergent curve

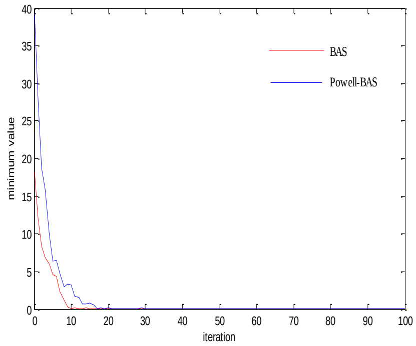

Fig.4 Becker and Lago convergent curve

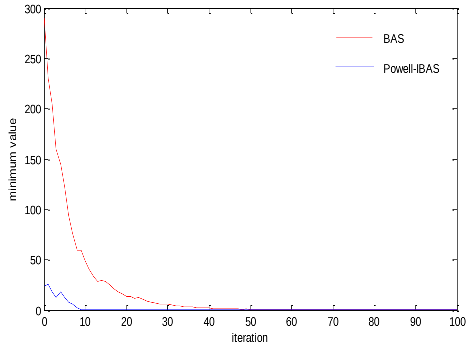

Fig.5 Booth's convergent curve

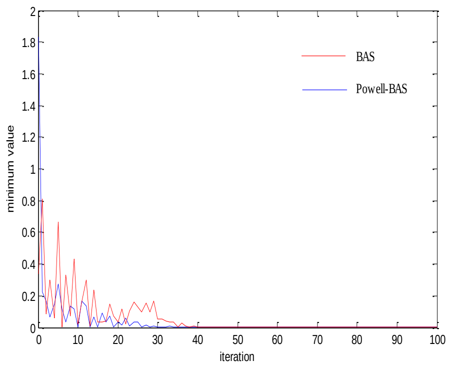

Fig.6 Sum of different power convergent curve

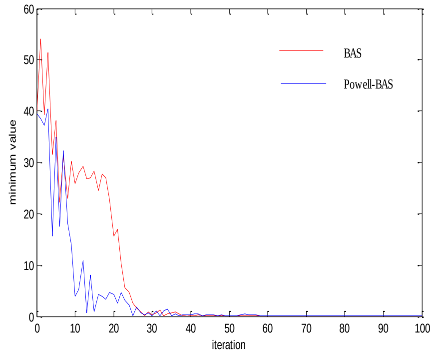

Fig.7 Eggcrate convergent curve

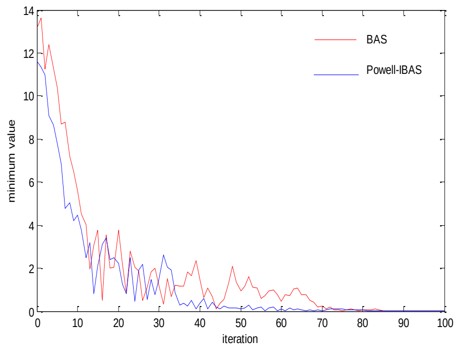

Fig.8 Ackley convergent curve

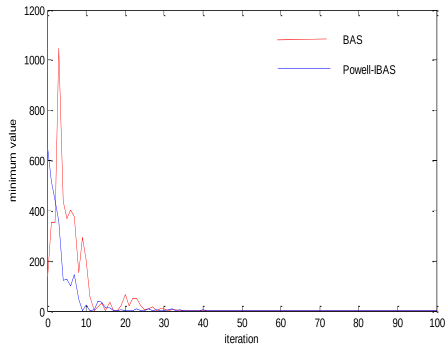

Fig.9 Rosenbrock convergent curve

2) analysis of convergence rate

In the convergent curve of the eight test functions, the maximum iterations of the two algorithms are set as 100 times, but the Powell-IBAS algorithm always achieves a stable minimum value than the BAS algorithm. Especially for the first four test functions, Powell-IBAS achieves a stable minimum value of about 10 times experiments, while the BAS algorithm needs about 40 times experiments. For the other four test functions, two algorithms achieve stable minimum within 100 times experiments. It shows that the Powell-IBAS algorithm has a remarkable improvement in the convergence and speed, and the practical performance is very good.

4. Conclusion

Based on the optimization process of BAS algorithm, a Powell-IBAS algorithm is proposed based on IBAS and adding Powell search operators, aiming at eliminate the shortcomings of the low convergence accuracy and easy to get stuck at local optimal value. The new algorithm uses the variable optimization step which changes with the current iteration to generate individual, which can enhance the global exploration ability of the algorithm and take into account the balance of global exploration and the local exploitation ability. The experiment results of 8 test functions show that the Powell-IBAS algorithm can effectively improve the convergence precision and convergence speed of the standard BAS algorithm.

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