Particle swarm optimization algorithm based on beetle antenna search optimization

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Abstract. For the standard particle swarm optimization algorithm, when optimizing multi-dimensional extreme value functions, it is easy to fall into the problem of local optimal solution and poor optimization effect. This paper proposes a particle swarm based on beetle antennae search optimization. This algorithm introduces beetle antenna search algorithm into particle swarm optimization algorithm. Each particle first updates its position according to the particle swarm optimization algorithm, and then takes the updated position as the initial value of the beetle antenna search algorithm. After iteration, a new location is obtained. By comparing the positions before and after the iteration, the optimal value is respectively compared with the individual history optimal value and the global optimal value, and the individual history optimal value and the global optimal value are updated. Joining beetles’ optimization strategy can better jump out of the local optimal value. Through simulation analysis of three different functions, it is concluded that the BASPSO algorithm has better optimization effect and better robustness.

1. Introduction

The swarm intelligence algorithm derived from the simulation of the life behavior of different species has been widely used in solving engineering problems, such as genetic algorithms and ant colony algorithms. The extensive application and research of particle swarm algorithm have found that its algorithm has low optimization precision when optimizing high-dimensional functions, or needs to introduce more particles. To solve these problems, some scholars have proposed the use of a hybrid algorithm, combining other optimization algorithms with PSO, extracting their respective advantages, and merging into a new hybrid algorithm. Zou D.L. et al. proposed a clustering and foraging behavior of artificial fish swarm algorithm based on particle swarm algorithm, so that the new hybrid algorithm after fusion has better global search ability[1]. Li S.X. et al. proposed the use of the mutation ability in simulated annealing to be introduced into the PSO algorithm to improve the diversity of the algorithm and make it easier to jump out of the local optimal solution[2].

Beetle Antennae Search (BAS) algorithm is a bionic algorithm simulated by Dr. Jiang et al.[3]. Compared with PSO algorithm, BAS algorithm has high optimization accuracy and strong robustness. Related work has been done to combine BAS algorithm and PSO algorithm to solve related problems. Wang T.T. proposed to combine BAS algorithm and PSO algorithm to form a new hybrid algorithm BSO [4]. In the algorithm, a speed increment was introduced according to the direction of left and right whiskers in the BAS algorithm, and the position updating formula of PSO was updated. Song L.N. proposed the application of BAS algorithm and PSO algorithm in sensor network coverage[5]. In the mentioned fusion algorithm, beetle optimization strategy is introduced into particle movement, and the particle optimization path is changed by judging the direction of the particle during particle optimization,
so as to search for the better direction, which can avoid falling into the local optimal solution to a certain extent.

Combining the advantages and disadvantages of BAS algorithm and PSO algorithm, this paper proposes a beetle search algorithm based on particle swarm optimization. After each particle is updated in position, it iterates through beetle optimization strategy, and then the fitness value is compared with the updated position of particle. The obtained optimal value is compared with the individual history optimal value and the population optimal value of the particle, and the individual optimal value and the global optimal value of the particle are updated. Through experimental simulation, this method is better than BAS algorithm and PSO algorithm in optimizing the extremum of multidimensional function.

2. Particle swarm optimization algorithm for beetle antenna search optimization

2.1. Beetle antenna search algorithm

The beetle antenna search algorithm is based on the process of beetle searching for food to form an intelligent search algorithm that achieves high efficiency for the location of unknown things in the global scope. The principle is that the location of the searched food is unknown to the beetle, and the odor concentration of the food is determined by the beetle antenna. When the odor concentration of a certain side is strong, the beetle moves to a certain side, and constantly compares the odor concentration. The beetle keeps moving until it finds the food.

The beetle's search for food is analogous to optimizing a function. The optimization function of the location of the food is \( f(x) \), the coordinates of the beetle's center of mass are \( x \), and \( xl \) and \( xr \) are respectively represented as the left and right sides of the beetle. The ratio of the beetle's step size in each iteration to the distance \( d0 \) between the beetle's left and right whiskers is a constant value \( c \). The step size of each iteration of beetle will constantly change with the update of position, expressed as \( \text{step} = \text{step} \times \eta (\eta = 0.95) \), and the orientation after each iteration of beetle is random. The random function \( \text{dir} = \text{rands}(n,1) \) is used to generate the random vector in the corresponding dimension and represent it by normalization.

The optimization process of the beetle antenna search algorithm for the function can be expressed as follows:

Step1: Initialization parameters of beetle antenna search algorithm: initialization parameters, distance between two antennas, beetle iteration step, maximum number of iterations, spatial dimension, randomization initialization solution, constant \( c \).

Step2: Calculate the position of the beetle's left and right antenna.

\[
X(l) = X(t) + d0 \times \text{dir}/2 \quad (1)
\]

\[
X(r) = X(t) - d0 \times \text{dir}/2 \quad (2)
\]

Step3: Calculate the fitness value of the beetle's left and right antenna.

\[
\text{fleft} = f(Xl) \quad (3)
\]

\[
\text{fright} = f(Xr) \quad (4)
\]

Step4: Update beetle location.

\[
X_i^{t} = X_i^{t-1} - \text{dir} \times \text{step} \times \text{sign}(\text{fleft} - \text{fright}) \quad (5)
\]

Step5: Repeat step 2 until the maximum number of iterations is reached.

2.2. Particle swarm optimization algorithm

Particle Swarm Optimization (PSO) is a random search algorithm based on foraging behavior of bird groups proposed by Eberhart and Kennedy in 1995. In other words, in the space of an unknown optimal solution, through the existing individual history optimal solution and global optimal solution, the particles continuously share their positions among each other, so as to realize the particle gradually flying towards the optimal solution. When optimizing the function of particle swarm optimization algorithm, \( X_i \) is used to represent the ith particle, then the position of the particle is expressed as \( X_i = (X_1, X_2, X_3, ..., X_n) \), the fitness value of each particle is obtained through fitness function \( f(x) \), and the
fitness value of each particle is compared to the optimal solution of individual history and the global optimal solution. Through the inertial weight value of omega, the value of inertial weight determines the global particle search. At the beginning of the iteration, a larger value of omega is needed to improve the global search ability of the algorithm, while at the later stage, a smaller value is needed for local search. Shi Y et al. proposed a weight evaluation method with linear decline\[6\]. The specific description is shown in formula seven. The influence factor \(c_1\) of the historical optimal solution on the velocity trend, and \(c_2\) of the global optimal solution on the velocity trend, obtained the velocity update formula:

\[
V^t_i = \omega * V^{t-1}_i + c_1 * \text{rand1} * (pbest^t_i - X^{t-1}_i) + c_2 * \text{rand2} * (gbest - X^{t-1}_i)
\]

\[
\omega = \omega_{\text{max}} - (\omega_{\text{max}} - \omega_{\text{min}}) * \left( \frac{i}{\text{maxgen}} \right)
\]

In the above formula, \(\text{rand1}\) and \(\text{rand2}\) are represented as random vectors of \(\text{rand}(0,1)\). According to the velocity update formula, the position update formula is obtained:

\[
X^t_i = V^t_i + X^{t-1}_i
\]

2.3. BAS and PSO hybrid optimization algorithms

In order to improve the particle swarm optimization algorithm (PSO) and beetles antenna search algorithm (BAS) the optimization of multi-dimensional extremum function optimization results, the BAS algorithm was formed in the beetle optimization strategy is introduced into the PSO a new hybrid algorithm (BASPSO), the particle as a beetle, each particle is updated get location, then uses the beetle optimization iteration to get a new position. The fitness value of the position obtained twice was compared, and the best position was selected to compare with the individual historical optimal value and the global optimal value, so as to update the individual historical optimal value and the global optimal value.

The overall flow chart of BASPSO algorithm is as follows:

Step1: In n dimensions, i particles were randomly generated to set the initial position and velocity of the particles, inertial weights, velocity trend factors \(c_1\) and \(c_2\), beetle step, Max iteration times, and constant \(c\) value.

Step2: Fitness function \(f(x)\) was used to calculate fitness values of all particles, and the individual historical optimal value (pbest) and the global optimal value (gbest) were obtained.

Step3: The updated position \(X\) was obtained by updating the position of the particle through formula 6 and 8.

Step4: Position \(X\) was taken as the initial position of the beetle, and a new position \(X_c\) was obtained after n iterations from formula 1 to formula 5.

Step5: By comparing the fitness values of \(X\) and \(X_c\), the optimal position is obtained.

Step6: Compare the optimal location with pbest and gbest, and update the pbest and gbest values.

Step7: Return to step 2 until the maximum number of iterations is reached.

The specific flow chart of BASPSO is as follows:
Initialize beetle and particle parameters
Calculate the fitness values of all particles and get the pbest and gbest values
Each particle updates its position according to the particle swarm optimization algorithm to obtain position X
Position X is iterated n times through beetle antenna search algorithm to get a new position Xc
The fitness values of position X, Xc, pbest and gbest were compared, and pbest and gbest values were updated
Whether the maximum search times are reached
The optimal solution of the optimization function is obtained
Start
End

Figure 1. Flow chart of BASPSO algorithm.

3. Algorithm simulation analysis
Three different test functions were selected for the simulation analysis of the BASPSO algorithm. The simulation was conducted in the environment of matlab2014a. Standard PSO algorithm and BAS algorithm were used for comparison. Parameter Settings are shown in table 1:

| parameter name          | value |
|-------------------------|-------|
| step                    | 10    |
| eta                     | 0.95  |
| c                       | 5     |
| iterations              | 1000  |
| number of particles     | 20    |
| spatial dimensions      | 5     |
| weight $\omega_{\text{max}}$ | 0.9   |
| $\omega_{\text{min}}$   | 0.4   |

Griewank, Ackley and Rastrigin were selected as three different multi-peak extremum functions, each of which had more minima, and the minimum value 0 was obtained at $x=0$. Expressed as $x_1, x_2, x_3, \ldots x_l=0$, $f(x_l)=0$. The function expression is shown in table 2:
Table 2. Functional expression.

| Number | Function name | Expression | Value range | Minimum value |
|--------|---------------|------------|-------------|---------------|
| F1     | Griewank      | \( F_1(x) = \frac{1}{4000} \sum_{i=1}^{n} x_i^2 + \prod_{i=1}^{n} \cos(\frac{x_i}{\sqrt{i}}) + 1 \) | [-300,300] | 0             |
| F2     | Ackley        | \( F_2(x) = -20 \exp \left(-\frac{1}{2} \sum_{i=1}^{n} x_i^2 \right) \) | [-32,32] | 0             |

Different algorithms optimize the same function under the same parameter conditions. Each algorithm runs 20 times when optimizing a function. The statistical results are shown in Table 3:

Table 3. Algorithm result statistics.

| Number | Algorithm type | Average | Best         | Log10 (average) |
|--------|----------------|---------|--------------|-----------------|
| F1     | BAS            | 1.1429E+00 | 2.3907E-01 | 0.0580          |
|        | PSO            | 3.8030E+00 | 2.0591E-01 | 0.5801          |
|        | BASPSO         | 2.9392E-02 | 2.4662E-03 | -1.5318         |
| F2     | BAS            | 3.0792E+00 | 2.4986E+00 | 0.4884          |
|        | PSO            | 3.8336E+00 | 2.2522E+02 | 0.5836          |
|        | BASPSO         | 2.0792E+00 | 5.5074E-10 | 0.3179          |
| F3     | BAS            | 1.1706E+01 | 1.0944E+01 | 1.0684          |
|        | PSO            | 2.6321E+00 | 2.0019E+00 | 0.4203          |
|        | BASPSO         | 1.6199E+00 | 0.9949E+00 | 0.2095          |

Figure 2. Each algorithm optimizes the convergence curve for the F1 function.

Figure 3. Each algorithm optimizes the convergence curve for the F2 function.
Figure 4. Each algorithm optimizes the convergence curve for the F3 function.

By comparing the above table 3 with the convergence curves of various algorithms when optimizing different functions, BASPSO algorithm has a better optimization effect in the face of different optimization functions. For the three different multi-peak functions, the optimization effect of the basic PSO algorithm and the BAS algorithm is not very ideal, and the combination of the two results in the BASPSO algorithm both in the convergence speed and the optimization accuracy is much better than the basic algorithm. This is mainly because the basic PSO algorithm introduces the beetle antenna optimization mechanism to update the position after the individual optimization, so as to obtain better individual optimal value and global optimal solution. When the particle moves to the global optimum, the beetle antenna optimization strategy can jump out of the local optimal solution to some extent, so that the BASPSO algorithm performs better in optimization.

4. Conclusion
BASPSO algorithm proposed in this paper introduces BAS optimization strategy on the basis of basic PSO algorithm. After optimization of each particle, BAS optimization of the obtained position is conducted to obtain better individual optimal value and global optimal solution. When the particle falls into the local optimal solution, it can jump out of the local optimal through beetle optimization, and get better optimization effect. Through the optimization simulation of three different multi-peak functions, it is concluded that the BASPSO algorithm has a better optimization effect than the two basic algorithms.

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