Research on Optimized Design of Antenna Based on Improved Whale Optimization Algorithm

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Abstract

- In order to improve the efficiency of antenna design, various intelligent optimization algorithms are used for settling the complex nonlinear problems involved. The whale optimization algorithm (WOA) is one of the relatively novel and well-performing swarm intelligence optimization algorithms.
- In this article, an improved whale optimization algorithm (IWOA) is proposed in view of the shortcomings of WOA. First, the nonlinear control parameter, adaptive weight and Cauchy disturbance are introduced to improve algorithm performance. Then a CEC benchmark function set was selected to test the feasibility and effectiveness of IWOA.
- The results show that IWOA has obvious advantages in terms of convergence speed, convergence accuracy and stability. Finally, the algorithm is used for the optimization of structural parameters of two ultrawideband (UWB) antennas.

Introduction

The antenna synthesis problem can be classified as a black-box optimization problem, and the emergence of intelligent optimization algorithms makes it possible for nonergodic optimization. Since 1960s, a series of intelligent optimization algorithms has emerged inspired by various biological intelligence behaviors. There have been many achievements in applying these algorithms to solve antenna optimization problems. The WOA is a novel optimization algorithm based on swarm intelligence which was processed by Mirjalili and Lewis in 2016. The WOA has advantages of simple principle, fewer control arguments and strong robustness. However, the WOA is easily trapped into local optimum like other algorithms. In this paper, an improved algorithm is applied to design two kinds of antennas after performance tests.

Algorism Principle

A. Whale Optimization Algorithm (WOA)

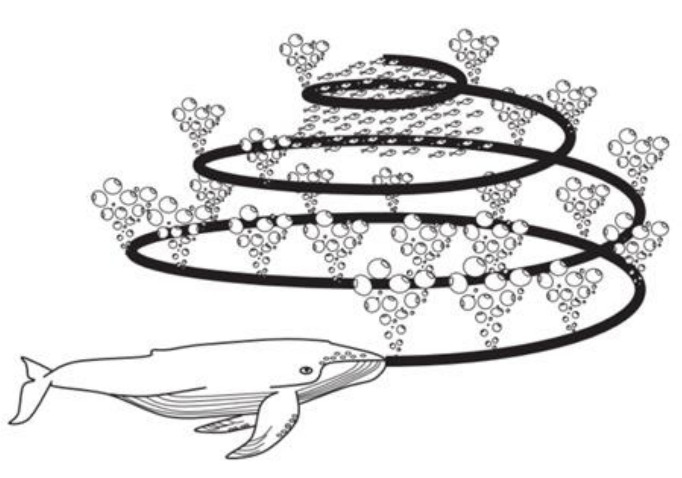

Fig.1. Bubble-net feeding behavior of humpback whales

$$\begin{cases} X(t+1) = X^*(t) - A\left|CX^*(t) - X(t)\right| \\ X(t+1) = X_{rand}(t) - A\left|CX_{rand}(t) - X(t)\right| \\ X(t+1) = X^*(t) + \left|X^*(t) - X(t)\right| \cdot e^{bl}\cos(2\pi l) \end{cases}$$

B. Improved Whale Optimization Algorithm (IWOA)

- (a) Nonlinear Convergence Factor

$$a(t) = 2\cos\left(\frac{\pi}{2}\cdot\frac{t}{T}\right)$$

- (b) Adaptive Weight Coefficient

$$\omega(t) = \frac{\pi}{2}\cdot\tan\left(\frac{t}{T}\right)$$

- (c) Caushy Disturbance

$$X_1^*(t) = X^*(t)\cdot\left[1 + cauchy(0,1)\right]$$

Simulation and Comparison

A. Benchmark Functions

- A CEC set consists of 23 classical benchmark functions
- Including unimodal (1-7), multimodal (8-13) and fixed-dimension multimodal (14-23)

B. Selection of Algorithms

- Gravitational Search Algorithm **(GSA)**
- Grey Wolf Optimizer **(GWO)**
- Improved Whale Optimization Algorithm **(IWOA)**
- Moth-Flame Optimization **(MFO)**
- Particle Swarm Optimization **(PSO)**
- Salp Swarm Algorithm **(SSA)**
- Whale Optimization Algorithm **(WOA)**

C. Experiment Settings

- Maximum number of iterations **(1000)**
- Initial population size **(30)**
- Experimental repetition times **(30)**

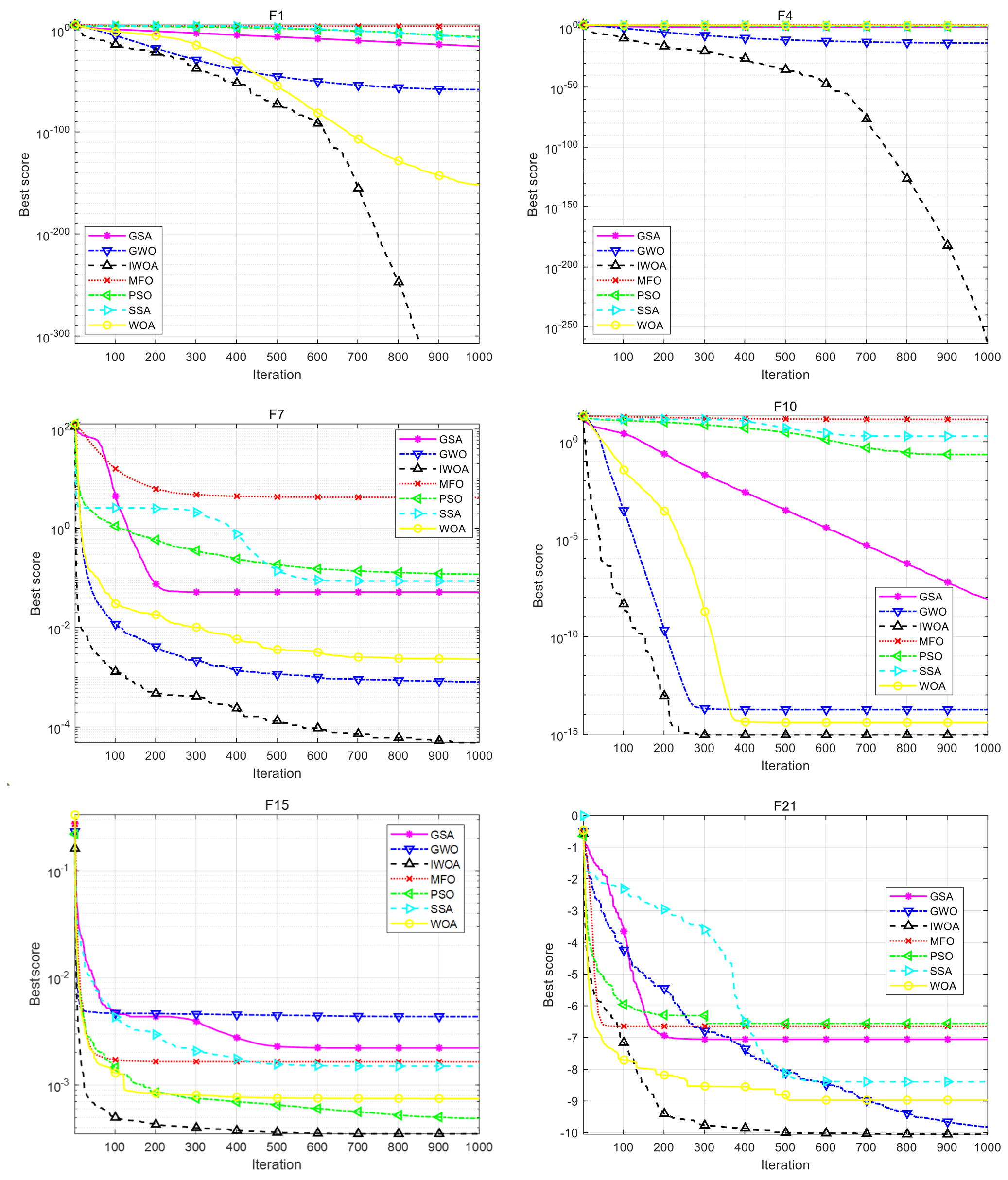

Fig.2. Examples of convergence curves

D. Analysis of Results

- By analyzing the graphs, it is obvious that IWOA is more competitive than similar algorithms.
- Summing up the average optimal results, it can be concluded that IWOA is able to obtain the optimal solution on 17 test functions, and can also get results close to the optimal value in the rest six functions (F6, F13, F14, F20, F22, F23).
- And IWOA could obtain the smallest standard deviation on 13 test functions which proves that the stability is also improved.

Antenna Optimization

A. Rectangular Angle Cut UWB Antenna

- Fabricated on a *30*17*0.8mm³* FR4 substrate and fed by *50Ω* microstrip line with a width of *1.5mm*.

$$Fitness = (S_{11\_1} + S_{11\_2}) * k_1 - (BW_1 + BW_2) * k_2$$

$$S_{11} = \begin{cases} 100, & S_{11} > -10dB \\ S_{11}, & -10dB > S_{11} > -20dB \\ -20, & S_{11} < -20dB \end{cases}$$

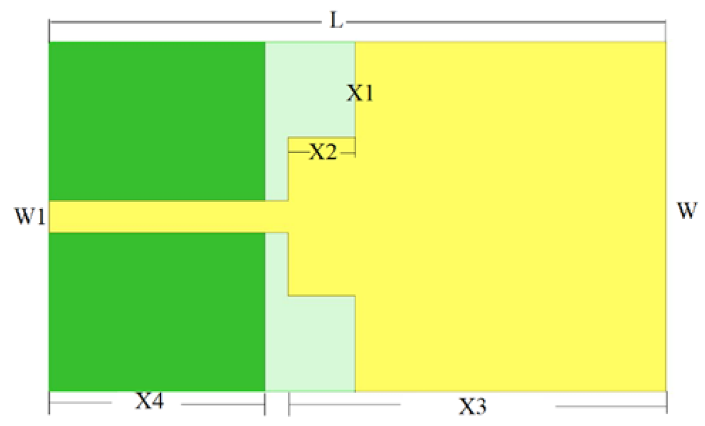

Fig.3. Top view

Variable name	X_1	X_2	X_3	X_4
Range	[3,5]	[3,5]	[10,14]	[9,12]
Before	4.2	4.0	18.0	11.0
After	4.6	3.3	18.4	10.5

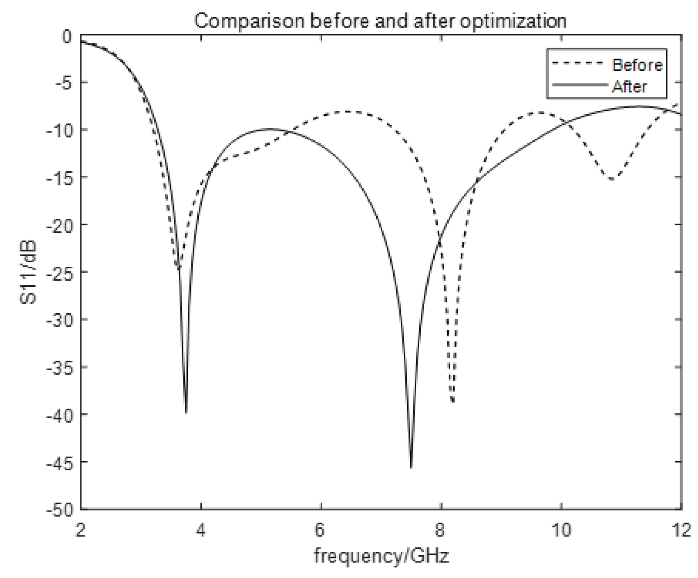

Fig.4. The return loss curves

B. Polygon UWB Antenna

- Fabricated on a *30*30*1.5mm³* FR4 substrate and fed by *50Ω* microstrip line with a width of *3mm*.

$$Fitness = \begin{cases} S_{11}, & S_{11} \geq -20dB \\ -20 - BW * 2, & S_{11} < -20dB \end{cases}$$

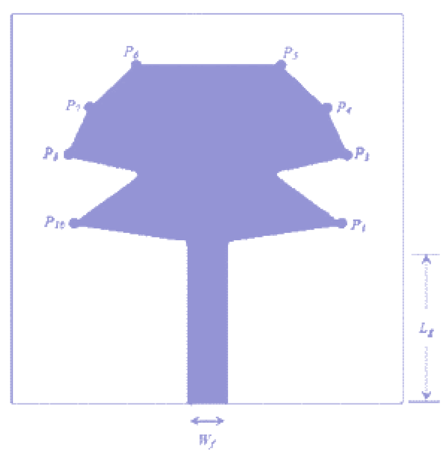

Fig.5. Geometry of the polygon patch

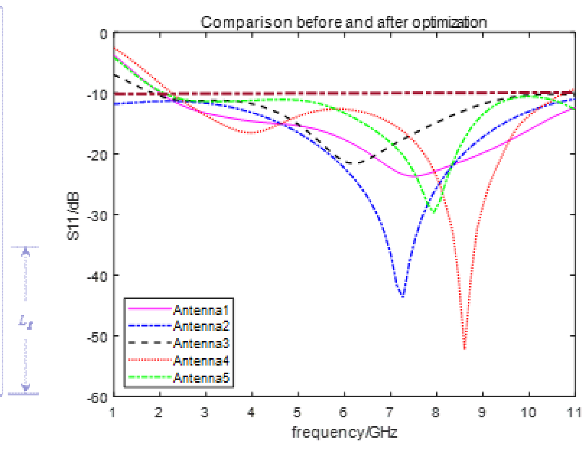

Fig.6. The return loss curves

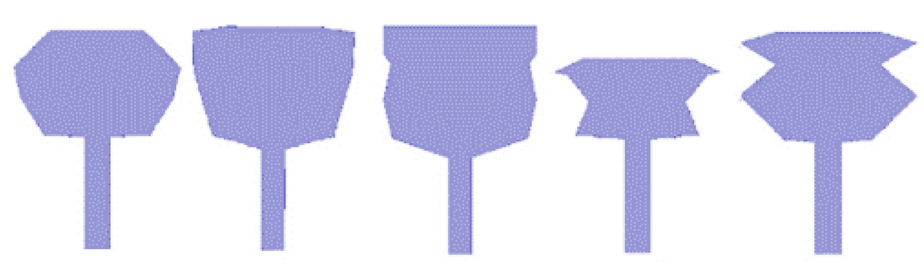

Fig.7. The shapes of antenna patch optimized by IWOA

Conclusion

In this paper, firstly, method aided by intelligent optimization algorithms is introduced based on the current sore point of antenna optimization design. Then three strategies are proposed to improve WOA. It is proved that IWOA is superior to other algorithms in convergence speed, optimization precision and stability. Finally, the IWOA is applied to optimize two different cases of microstrip antenna.

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