Separation of signals with same frequency based on improved bird swarm algorithm

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***Abstract*—In view of the problem that the same frequency interference accrued to shipborne radar frequently in complex battlefield environment, a separation method of the same frequency signals based on improved bird swarm algorithm (IBSA) is proposed. The algorithm optimizes the initial value of the bird swarm algorithm (BSA) by using a "reverse learning" mechanism, and calculates the reverse population in the process of optimization dynamically, and increases the global search capability of the algorithm. The dynamic weight is introduced into the foraging formula of BSA to increase the search efficiency of the algorithm. And the improved bird swarm algorithm combined with independent component analysis of non-Gauss maximization is applied to the same frequency interference resistance for shipborne radar, and achieved good results. According to two criteria of signal separation and evaluation, giving a new evaluation criterion based on the set pair analysis, and the effectiveness of the improved bird swarm optimization model is proved to be effective in the solving problem of radar signal separation with same frequency. It provides a solution for problem that anti same frequency interference of shipborne radar.**

Keywords-anti same frequency interference; bird swarm algorithm; Independent component; reverse learning; dynamic weight; Set pair analysis and evaluation

I. INTRODUCTION

The modern battlefield environment is becoming more and more complex, especially the modern maritime battlefield environment. It is mainly manifested in complex natural environment elements, complex missile borne physical environment elements, complex physical environment elements, and complex electromagnetic environment elements[1] .The same frequency interference problem of shipborne radar belongs to a complex electromagnetic environment.

It is usually divided into the same-frequency synchronization interference and the same-frequency asynchronous interference in solving the problem of traditional anti-co-frequency interference of radar, most of the anti-co-frequency interference measures adopted are based on signal strength, modulation, and phase, and are usually developed in the frequency domain, air domain, time domain, and code domain. Paper [2] uses multi-pulse correlation to suppress the same-frequency asynchronous interference and achieved good results. Paper [3] provides a design reference for the formation of network formation of the same type radar, which combines fractional Fourier domain filtering and time domain anti asynchronous interference suppression. In [4], a method of dealing with the same frequency interference in time domain is presented, and paper [5] uses a coherent accumulation method, but these methods are only applicable to the case where there is no aliasing in the signal with same frequency. Paper [6] gives a design scheme for frequency modulation coding. By designing a coded signal with good orthogonality to achieve a good matching filtering effect, a reference scheme for the design of future radars is given. However, the existing service radar has the same frequency interference problem is still not resolved.

Blind source separation (BSS) algorithm is a hybrid signal separation method ,which has been applied in many fields[7]-[9]. The echo signal with same frequency interference received by shipborne radar is also a mixed signal, so it can be solved from the perspective of blind source separation. The fast_ICA algorithm based on the maximization of negative entropy has achieved good separation effect in [10]-[12],However, the algorithm involves the selection of nonlinear functions. So It is necessary to estimate the probability density distribution of the original signal, but which is complex. In this paper, we use the improved bird swarm algorithm to optimize the fourth-order cumulant (kurtosis) of signal to get the signal component with the largest kurtosis and separate the signals. It does not need to simulate the probability density of the original signal through nonlinear functions to achieve the Separation if the same frequency signal.

II. THEORETICAL MODEL

A. Blind source separation

BBS[13] separates and reconstructs source signals from the mixed signals observed. N independent source signals can be expressed as S .

$$S(t)=\left[s_1(t),s_2(t),\cdots,s_n(t)\right]^T$$

The hybrid system A makes the target radars get mixed observation signals X .

$$X(t)=\left[x_1(t),x_2(t),\cdots,x_m(t)\right]^T$$

That is： $X(t)=AS(t)$ (1)

Separating mixed signals is transformed into finding a matrix W , which is satisfied:

$$Y(t)=WX(t) \quad (2)$$

And $A\in R^{m\times n}$, m>n , $Y(t)$ is the source signals.

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The principle model of blind source separation is shown in Fig.1:

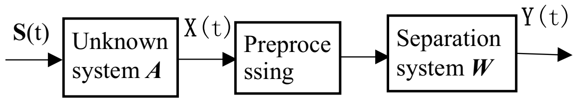

Figure 1. A schematic diagram of the principle of blind source separation.

There are two kinds of BSS objective functions: information theory and high-order cumulants. In this paper, an improved bird swarm algorithm combined with non-Gauss maximization is applied to independent component analysis. The objective function selects the four order cumulant of the signal, and optimizes the non-Gauss property of the mixed signal components. For the zero mean mixed signal Z, the four order cumulant of the source mixed signal is expressed as:

$$k_4(Z) = \left| E\{Z^4\} - 3\left(E\{Z^2\}\right)^2 \right| \qquad (3)$$

B. Improved bird swarm algorithm

Improved bird swarm algorithm is selected as the optimization algorithm in this paper. Bird Swarm Algorithm(BSA) is a new biological heuristic global optimization algorithm proposed by Meng Xian-Bing in 2015[14]. This algorithm mimics the vigilance, flying and foraging behavior of birds, and is applied to many fields due to its less parameters, high accuracy and good robustness[15]-[17].When the algorithm optimizes the multi extremum problem, However, there will occurs local convergence. and improve this algorithm for the shortcomings of this algorithm.

1) Optimization of initial population

At the selection of initial value in the algorithm, a reverse search strategy is introduced to optimize the initial value of the bird swarm algorithm, so as to Obtain a set of better initial candidate solutions. The reverse search strategy is a new concept that is widely used in the field of Computational Intelligence in recent years. The main idea is to reverse the operation of the feasible solution in the process of optimization, evaluate the original and reverse solutions, and select the feasible solution of the maximum corresponding value. Its definition is as follows:

Let $P = (p_1, p_2, \cdots, p_n)$ be a point in the n dimensional space, $p_1, p_2, \cdots, p_n \in R$, p_j belongs to (a_j, b_j), Then the reverse point $p^* = (p_1^*, p_2^*, \cdots, p_n^*)$ corresponding to p is defined as:

$$p_i = a_i + b_i - p_j \qquad (4)$$

2) Optimization of population position in iteration

In the iterative process of "foraging and vigilance", the reverse search is introduced selectively to increase the global search. The Selection probability b_0 is 0.5. Similarly, the reverse search is introduced selectively when updating the individual and the global optimum, and the inhibition algorithm falls into local optimum later. The Selection probability is 0.5, too.

3) Dynamic weight of individual renewal

The dynamic weight W is introduced into the algorithm of bird foraging, and its value varies with the number of iterations. In order to speed up the search, the initial individual should converge to the contemporary optimum value, and the corresponding individual proportion should be smaller, and the W take a smaller value. In the later period, individuals should be close to the global optimal value, and individuals should occupy a larger proportion. At this point, W take a larger value. Formula (5) gives the variation of W with iterations:

$$W = 1\text{-}W_{end}\left(W_{start} / W_{end}\right)^{1/\left(1 + c_{now} t_{now} / t_{\max}\right)} \qquad (5)$$

Reformate the formula (7) shown in [18].And $W_{start} = 1$, $W_{end} = 0.5$, t_{now} represents the number of current iterations, c_{now} =10, $t_{\max}$ represents the total number of iterations. The modified bird swarm algorithm for foraging is expressed as:

$$x_{i,j}^{k+1} = W \times x_{i,j}^t + \left(p_{i,j} - x_{i,j}^t\right) \times C_1 \times rand(0,1)$$
$$\times \mathrm{e}_1 + \left(g_j - x_{i,j}^t\right) \times C_2 \times rand(0,1) \times \mathrm{e}_2 \qquad (6)$$

Among them, $x_{i,j}^{k+1}$ represents the result of bird i at iteration of $k+1$, $j \in [1, 2, \cdots, D]$, D represents the dimension of data, $p_{i,j}$ represents the current optimal location of bird i, g_j represents the optimal location of the current population(iteration j). C_1 and C_2 express self-cognition coefficient and social acceleration coefficient respectively. And Weight coefficients are $\mathrm{e}_1 = \mathrm{t}_{now} / t_{\max}$, $\mathrm{e}_2 = \left(t_{\max} - \mathrm{t}_{now}\right) / t_{\max}$.

4) performance test of IBSA

In order to verify the performance of IBSA algorithm, five benchmark functions are selected to simulate and compare with basic bird swarm optimization (BSA), basic particle swarm optimization (PSO) and basic bat algorithm (BA). The test functions are shown in TABLE Ⅰ.

TABLE I. TEST FUNCTIONS

No.	Function name	search space	Optimal value
f1	Sphere	(-100,100)	0
f2	Schaffer	(-10,10)	0
f3	Rastrigin	(-5.12,5.12)	0
f4	Ackley	(-32,32)	0
f5	Griewank	(-600,600)	0

The parameters of BSA and IBSA are consistent. The parameters of BA are as follows: Both loudness and pulse are 0.5, frequency range is 0.9, the attenuation coefficient of Pulse intensity is 0.95, increasing coefficient of pulse frequency is 0.05. And the learning factor of PSO: $C_1 = C_2$ =2. The inertia weight is 0.7. To ensure fairness, all other parameters of the algorithm are consistent. Initial population is 30, and the number of iterations is 50, the dimension of data is 100. The optimal value, the worst value, the mean value and the mean square deviation of the optimization results of the 10 times of the four algorithms are recorded, and the experimental results are shown in TABLE Ⅱ.

From the above test function diagram, it can see that the improved IBSA algorithm performs better than PSO, BSA and BA algorithms in terms of convergence speed and search accuracy. Therefore, the improved IBSA algorithm is used to optimize the formula (3).

III. Experiment and Analysis

A. *Algorithm flow*

According to the BSA based optimization strategy proposed in part *A*, an improved BSA algorithm IBSA is obtained. The blind source separation algorithm combined with IBSA, which is used to separate the same frequency mixed signals of ship-borne radar. The main flow of the separation algorithm is as follows:

Step 1: Make the mixed signal $X(t)$ is centralization and whitening, and get the Processed mixed signal $Z(t)$.

Step 2: Initialize the parameter of IBSA and generate the components of the separation matrix w randomly as the initial individual of IBSA.

Step 3: The mix signal is separated by the components of the separation matrix, and separated signal is centralized and whitened. Then the fitness value of the fitness function is calculated according to formula (3).

Step4: optimize the initial separation matrix according to inverse learning mechanism.

Step5: According to the exposition of part *B*, the reverse population is dynamically calculated in the iterative process of IBSA algorithm, and the local optimal X_b and global optimal values X_g are recorded.

Step6: Iterate repeatly until the terminational condition of iterations is satisfied.

Step7: After separating a component of separation matrix, the component is removed from the separation matrix according to the formula (8) and the normalization is carried out according to the formula (9).

$$w_{k+1} = w_k - \sum_{j=1}^{k} w_{k+1}^T w_j w_j \tag{8}$$

$$w_{k+1} = \frac{w_{k+1}}{\left\| w_{k+1} \right\|} \tag{9}$$

w_k is the k component of the separation matrix.

Step8: After separating all the components of the separation matrix, it ends.

B. *Simulation experiment*

Suppose that there are four radars in the battlefield and start work at the same time. LFM signals are used in both the target echo signal and the jamming frequency signal of the jamming radar. Radar No. 1 is the target radar; the rests are the same frequency jamming radars. Among them, the radar No.3 is the same frequency synchronous jamming radar, No.2 and No.4 are the same frequency asynchronous jamming radar. The sampling frequency of all the radars is 6 MHz. The other parameters of the target radar and the jamming radars are shown in TABLE Ⅲ.

TABLE III. Radar Parameters of Each Radar

Radar number	**carrier frequency (MHz)**	**bandwidth (MHz)**	**pulse width (μs)**	**Signal amplitude**
1	3	1	300	3
2	2	1.5	180	1000
3	3	5	230	500
4	4	10	370	800

The algorithm is used to separate the radar signals from the mix signal with same frequency. The simulation results are shown in Fig.2 to Fig.5.

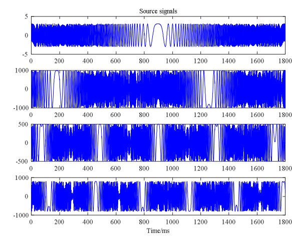

Figure 2. Echo and the signal of the same frequency interference source.

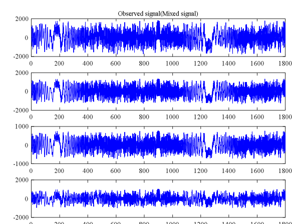

Figure 3. Mixed echo signal received by radar interference.

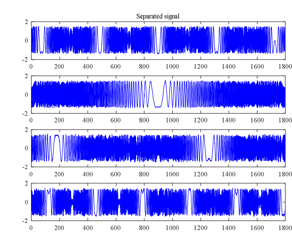

Figure 4. Echo signal after separating and the interference signals of same frequency after separating.

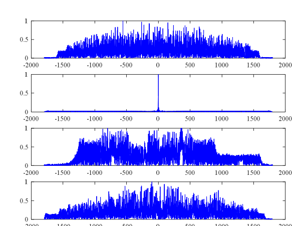

Figure 5. Matched filtering results of signal component after separating.

Fig.2 shows the simulation of radar source signals, the first radar signal is the echo signal, and the other three signals are the same frequency interference signals. Fig.3 shows the mixed echo signal received by the target radar. Fig.4 shows the echo signal after separating and the interference signals of same frequency after separating. Fig.5 shows the matched filtering results of signal components and target echo signals. From the simulation results of Fig.4 and Fig.5, it can be seen that the signal components are successfully separated. However, the amplitude and the separation order are different, which is caused by the uncertainty of the BBS algorithm, but does not affect the use of the signal. The matched filtering results show that the echo signal components have better matched filtering results, and the same frequency interference signals cannot be effectively matched and filtered, which shows the effectiveness of the algorithm.

C. Performance analysis

Based on the two evaluation criterions of signal separation, a set pair analysis comprehensive evaluation method is proposed to evaluate the separation effect of the algorithm. The formula for evaluating the separating degree. The two are separating degree evaluation[12] and similarity coefficient evaluation.

1) The formula of separating degree evaluation

$$F = 1 - \sqrt{\sum_{i=s}^{e} \eta(i)^2} \Big/ \sqrt{\sum_{i=s}^{e} p(i)^2} \tag{9}$$

The separating degree indicates how much of the energy of the radar signal is separated. $p(i)$ is the source signal, $\eta(i)$ is the energy difference between the separated signal and the source signal.

2) The formula of similarity coefficient evaluation

$$p = \left| \sum_{t=1}^{N} y_i(t) s_i(t) \right| \Big/ \sqrt{\sum_{t=1}^{N} y_i^2(t) \sum_{t=1}^{N} s_i^2(t)} \tag{10}$$

$y_i(t)$ and $s_i(t)$ denote separate signals and corresponding source signals respectively.

3) Singnal separation and evaluation based on the correlation number of set pair analysis

It can be seen from formulas of 1) and 2) that the two evaluation methods have each emphasis, so the difference between the evaluation results is too large and is not conducive to the description of the accuracy of the signal separation. Therefore, a comprehensive evaluation method based on the correlation number of set pair analysis is proposed.

The set pair analysis is the set pair analysis theory (set pair analysis, SPA), which was proposed by Zhao Keqin in 1989. It is a systematic analysis of the quantitative analysis of the relationship between the system and the identical different oppose (IDO). Use connection numbers to quantitatively describe the IDO relationship between things.

In this paper, based on the relation of the opposite IDO, the relation between the separation degree evaluation and the similarity coefficient evaluation is depicted, and the method of signal separation and evaluation based on the set pair analysis is proposed. According to [19] the description of IDO calculation is as follows:

$$U = a + bi + cj = \frac{s_1}{t_1} + \frac{s_1}{t_1\left(t_1^2 - 1\right)} i + \frac{t_1^2 - s_1 t_1 - 1}{t_1^2 - 1} j = \left(s_1, t_1\right) \tag{11}$$

Among them, s_1 represents similarity coefficient p, t_1 represents separation degree F, and U represents signal separation degree based on set pair analysis correlation number. The closer the U is to 1, the better the separation effect is. Under the simulation parameters of Table Ⅲ, the average result of the ten successful separation of this evaluation method is 0.870, and the results of calculation are shown in Table Ⅳ.

TABLE IV. SIGNAL SEPARATION COEFFICIENT U BASED ON THE CORRELATION NUMBER OF SET PAIR ANALYSIS

No.	1	2	3	4	5
U	0.870	0.862	0.852	0.864	0.860
No.	6	7	8	9	10
U	0.902	0.886	0.870	0.906	0.834

After extensive simulation tests and comparisons, it is found that the evaluation criteria of Signal separation effect based on the correlation number of set pair analysis are more precise.

4) Model performance analysis

In order to test the effectiveness of IBSA-BSS model, IBSA-BSS, PSO-BSS, BA-BSS and BSA-BSS models are used for simulation. The simulation results take the effective matching filtering as the standard. Figure 6 gives the result of signal separation effect based on the correlation number of set pair analysis.

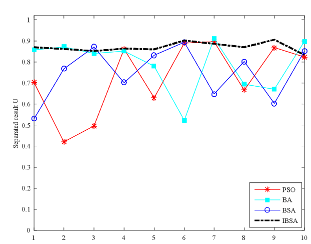

Figure 6. Evaluation results of signal separation effect based on correlation number of set pair analysis.

From Figure 6, it can be seen that the IBSA algorithm proposed in this paper has a good effect on separating radar signals with same frequency.

IV. CONCLUSION

In this paper, we introduced the research status of anti-same frequency interference of radar, and introduced the basic theory of BSS and BSA from the angle of signal separation, and proposed an improved bird swarm algorithm to optimize the four order cumulant of each signal component of the mixed signal. And it is applied to the study of anti-same frequency interference of radar, and the target radar signal and the same frequency interference signal are separated successfully. According to the two signal separation evaluation criteria of separating degree and similarity coefficient a method of signal separation and evaluation based on set pair analysis is proposed, and on this basis, the optimization results of IBSA algorithm are evaluated, and good evaluation results have been achieved. The simulation results show that the proposed IBSA algorithm can do well in the separation of the same frequency interference signals of radar and provide a solution for anti-same frequency interference of shipboard radar. Ship-borne radar is faced with a complex environment and often requires a combination of multiple anti-jamming technologies. This is the focus of the next step.

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TABLE II. THE COMPARISON OF ALGORITHMS

Function	Algorithm	Best	Worst	Mean	Std
f_1	PSO	2.977×10^{3}	3.3099×10^{4}	2.6170×10^{4}	4.3321×10^{3}
	BA	1.0302×10^{5}	1.6308×10^{5}	1.4161×10^{5}	1.8052×10^{4}
	BSA	5.8975×10^{-17}	4.4318×10^{-12}	2.2153×10^{-11}	8.8326×10^{-12}
	IBSA	1.7818×10^{-42}	1.4012×10^{-24}	1.4012×10^{-25}	4.4310×10^{-25}
f_2	PSO	0.0056	0.0100	0.0094	0.0013
	BA	0.0097	0.4147	0.1241	0.1389
	BSA	3.2752×10^{-15}	9.7433×10^{-4}	0.0097	0.0031
	IBSA	0	6.6563×10^{-13}	6.6563×10^{-14}	2.1049×10^{-13}
f_3	PSO	865.6312	1.0343×10^{3}	930.7036	54.9564
	BA	531.9543	872.5498	666.4425	99.1995
	BSA	0	6.8212×10^{-14}	3.4106×10^{-13}	1.2221×10^{-13}
	IBSA	0	0	0	0
f_4	PSO	13.5664	15.4977	14.7577	0.6067
	BA	17.8850	20.0155	18.9828	0.5959
	BSA	4.1166×10^{-12}	9.0145×10^{-10}	2.6424×10^{-9}	9.2430×10^{-10}
	IBSA	8.8818×10^{-16}	4.4409×10^{-15}	1.2434×10^{-15}	1.1235×10^{-15}
f_5	PSO	159.1440	365.8777	240.6030	58.1077
	BA	1.0513×10^{3}	2.2762×10^{3}	1.5488×10^{3}	398.0126
	BSA	0	1.3906×10^{-12}	1.3821×10^{-11}	4.3677×10^{-12}
	IBSA	0	0	0	0