NOVEL RADAR SIGNAL SORTING METHOD BASED ON GEOMETRIC COVERING

Wan Jian(万建), *Guo Qiang*(国强), *Song Wenming*(宋文明)

(Information and Communication Engineering College, Harbin Engineering University, Harbin, 150001, P. R. China)

Abstract: With the increase of complexity of electromagnetic environment and continuous appearance of advanced system radars, signals received by radar reconnaissance receivers become even more intensive and complex. Therefore, traditional radar sorting methods based on neural network algorithms and support vector machine (SVM) cannot process them effectively. Aiming at solving this problem, a novel radar signal sorting method based on the cloud model theory and the geometric covering algorithm is proposed. By applying the geometric covering algorithm to divide input signals into different covering domains based on their distribution characteristics, the method can overcome a typical problem that it is easy for traditional sorting algorithms to fall into the local extrema due to the use of complex nonlinear equation to describe input signals. The method uses the cloud model to describe the membership degree between signals to be sorted and their covering domains, thus it avoids the disadvantage that traditional sorting methods based on hard clustering cannot deinterleave the signal samples with overlapped parameters. Experimental results show that the presented method can effectively sort advanced system radar signals with overlapped parameters in complex electromagnetic environment.

Key words: radar emitter; signal sorting; geometric covering

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INTRODUCTION

The development of electronic countermeasure technology leads to complex electromagnetic environment and diverse working modes of advanced system radars, which makes both the radar signals and their data banks of radiation sources have strong randomness and fuzziness. As a result, the data banks of traditional sorting methods cannot describe the signals clearly. Some methods were proposed to solved this problem, such as sorting methods based on neural network[1-2], and methods based on supporting vector machine (SVM). The methods based on neural network can handle the division of optimal boundary with multi-parameter well and have the advantages of parallel processing, strong fault tolerance ability and generalization ability[3], however, classification results of parameter space with overlapped boundary are not satisfactory. These methods use some kinds of optimal criteria to adjust network structure and to determine weights, which often fall into the local extrema and misconvergence[4]. The basic thought of methods based on SVM is that the linear unseparable problem in low dimensional space can become the linear separation by translating the low dimensional space to a higher dimensional space with nonlinear transformation. Compared with traditional neural network algorithm, these meth-

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Corresponding author: Wan Jian, Associate Professor, E-mail: wanjian@hrbeu.edu.cn.

ods use structural risk minimization rule to determine the optimal lineoid for maximizing the distance of adjacent samples, and can classify signal samples with a low error rate by determining decision rule with limited training samples[5]. However, these methods cannot deal with large-scale data, and the computational effort of these methods grows exponentially with the number of input data, which often leads to long training time and insufficient memory. And the sorting results are often vulnerable to the selection of parameters. Based on above problems, a novel radar signal sorting method based on cloud model and geometric covering algorithm is proposed in the paper.

1 NOVEL RADAR SIGNAL SORTING METHOD

1.1 Overall thought

Fully considering the randomness and fuzziness of radar signals, a novel radar sorting method is proposed based on cloud model theory[6] and geometric covering algorithm[7]. As we know, the essence of neural network algorithm and SVM algorithm is to divide the characteristic spaces by projecting them into corresponding lineoids, and how to divide different lineoids to make the division more reasonable and intuitive. However, when the dimension of input sample space is very large, the amount of lineoids will be very large, which makes the connected region of different kinds of samples hard to be described. By using geometric covering algorithm, the input sample is limited to a certain sphere, then according to the intersection of this sphere and a given lineoid, we can get the required sphere domain. Therefore, we can get a more intuitive method to deal with the samples. The new method introduces cloud model into radar signal sorting field, and the cloud model is an uncertain model that can implement the mutual transform between some qualitative concept represented by natural language and its quantitative expression. Cloud model integrates fuzziness and randomness on the basis of fuzzy set theory and probability statistics. As we mentioned above, because of the more complex electromagnetic environment and more fickle work mode of advanced radar system, cloud model is hard to get a complete data bank of radiation sources. However, using traditional algorithm such as membership function and rough set theory to classify the radar signals becomes unpractical, so the cloud model can describe parameter space with fuzzy qualitative concept, which exactly corresponds with current radar signal sorting problem.

1.2 Geometric description of signal characteristic parameters

The new method divides parameter space of input radar signals into different domains according to their characteristic of distribution with geometric covering algorithm, by which the optimal design problem of traditional neural network algorithms translates into optimal covering problem. Moreover, instead of radar source database, the new method just needs a certain number of radar signals, i.e., by working with cloud model algorithm, the geometric covering algorithm does not need complete binding radiation source-sink and fuzzy prior information.

Characteristic parameters (RF, PW, DOA) of a certain number of radiating-source signals are used as feature vector of radar signals to get their covering domains in geometric covering method, and the specific steps are as follows[5-7].

(1) Pretreatment: Firstly, project the characteristic parameters into spheres in a higher dimension space. Then, assume all the characteristic parameters as a set D, where the radar signal parameters should satisfy

$$f(\boldsymbol{X})=(\boldsymbol{X},(R^2-|\boldsymbol{X}|^2)^{1/2}) \tag{1}$$

where $R\geqslant\max\{|\boldsymbol{X}|\}$, $\boldsymbol{X}\in D$, which means radius R must be greater than the maximum norm of input feature vector. Thus the samples are projected into a sphere of radius R, with the origin as center.

(2) Randomly take a point a_i as the center of the sphere, and determine domain radius $d(\lambda)$ and domain center a_i according to Eq. (2).

$$d^1(\lambda) = \max_{x \notin X_k}\{\langle a_i, x\rangle\}$$

$$d^2(\lambda) = \min\{\langle a_i, x\rangle \mid \langle a_i, x\rangle > d^1(w)\}$$

$$d(\lambda) = a \cdot d^1(\lambda) + \beta \cdot d^2(\lambda) \tag{2}$$

where $d^1(\lambda)$ is the maximum inner product of different kinds of signal samples, which indicates the minimum distance between different kinds of samples; $d^2(\lambda)$ is the maximum distance of same kind of samples, which must be greater than $d^1(\lambda)$.

(3) Obtain domain's barycenter of all the radar signal samples covered by domain $C(a_i)$. Then project the barycenter into a sphere with a_i' as center, and get the new radius λ' according to Eq. (2), thus a new domain $C(a_i')$ is established.

(4) Calculate the amount of radar signals covered by domain $C(a_i')$, then let $a_i' \to a_i$, $\lambda' \to \lambda$ hold. If the amount is greater than number of radar signals covered by domain $C(a_i)$, return to step (3), otherwise, the covering domain of signals of category i is obtained.

(5) Repeat the above steps until all the radar signal samples are covered.

1.3 Impact on separation caused by fuzzy signals with overlapping boundary

If there is not explicit boundary of interleaved pulse train, it will be difficult to find a feature vector that can tell the difference of different kinds of signals. For using membership degree between different kinds as the reflection of uncertain division, fuzzy theory is introduced into radar signal sorting. However, in fuzzy theory, whether a clear membership function can be obtained absolutely depends on the expert's prior knowledge and statistical methods, which are all subjective.

Cloud model, proposed by Academician Li[8], is an uncertain model that can implement the mutual transform between some qualitative concept represented by natural language and its quantitative expression. It integrates fuzziness and randomness based on fuzzy set theory and probability statistics, and can give a better expression of the membership degree's randomness.

1.4 Radar signal sorting based on cloud model

After processing the radar signals with covering algorithm, we can establish cloud models for each covering domain. Assume that A is a set called linguistic register, and linguistic value a of linguistic register A means that any projection point x in data space X has a number of stable tendency $y=\mu_A(x)$, which is called the degree of certainty of point x to linguistic value a. Desired value E_x, entropy E_n and hyper entropy H_e can represent the numerical characteristics of cloud model, and the numerical characteristics can constitute the projection of qualitative concept to its quantitative expression. In the expression, E_x is the center of gravity position of cloud droplets in data space, and the point which can best represent the qualitative concept; E_n is the measure of the uncertainty of qualitative concept, which can reflect the range of data space accepted by the linguistic value a, i. e. the ambiguity of linguistic value a; H_e is the entropy of E_n, and it can represent the degree of dispersion of E_n and reflect that the cohesion of the certainty of each number corresponding to each linguistic value, i. e. the cohesion of the cloud droplet. The specific steps to establish cloud model are as follows:

(1) Consider each covering domain as a qualitative concept, and let centers of each domain be expected value E_x, where E_n is 1/6 of each domain's boundary. Randomly pick a constant, then obtain normal random number $E_{n_i'}$ with expected value E_n, and standard deviation H_e[9].

(2) According to cloud model theory and positive cloud generation algorithm[10], generate multi-dimensional cloud model, shown as

$$M_i = \exp\sum_{j=1}^{n}\left(-\frac{(x - E_{x_{ij}})^2}{2E_{n'^2_{ij}}}\right) \tag{3}$$

where M_i expresses membership cloud of signalx-to the ith domain, $E_{x_{ij}}$ the expected value of jth dimensional characteristic value in theithdomain.

(3) Once the maximum value $\mathrm{Max}(M_i)$ of each domain is obtained, each domain will be identified as the category of signals to be sorted.

In this way the method overcomes the limitation of fuzzy theory, and can deal with the randomness and fuzziness caused by measurement and reconnaissance[11]. Therefore, the presented method can accurately achieve real-time sorting of radar signals with serious overlapped characteristic parameters.

2 SIMULATION RESULTS

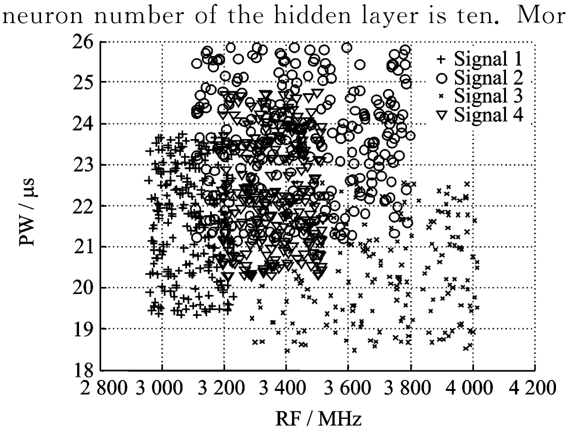
Let input signals be four kinds of radar signals with complex change, of which the parameters overlap seriously. According to the feature of radar emitter environment and signal models, without considering in-pulse characteristics of radar signals, select three basic parameters to form the input characteristic vector of signals to be sorted[12-13]. In the light of radar signal models, simulate the parameters DOA, RF, PW with Gaussian random variables, and simulation time is 50 ms[14]. The radar parameter information is shown in Table 1.

Table 1 Radar parameter information

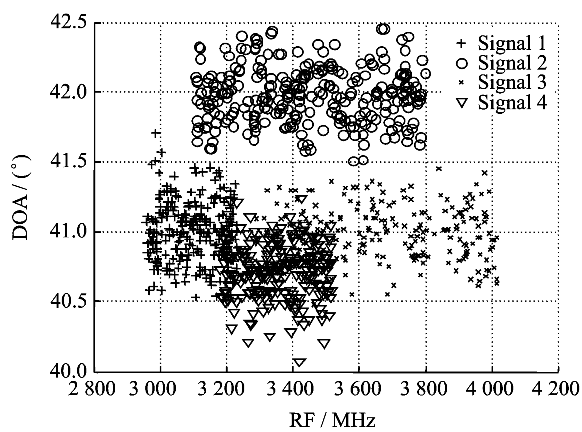
Category	RF/MHz	PW/s	DOA	PRI/μs	Signal number
1	2 960—3 236 Frequency agility	19.27—23.62 Pulse width jitter	40.3—41.4	194—207 Staggering PRF	249
2	3 110—3 791 Frequency agility	20.99—25.87 Pulse width jitter	41.4—42.5	176—234 Staggering PRF	277
3	3 289—4 015 Frequency agility	18.35—22.61 Pulse width jitter	41.3—41.7	218—287 Staggering PRF	226
4	3 185—3 516 Frequency agility	20.11—24.81	40.1—41.3	210,240,260 Staggering PRF	237

In order to make the experiment be more in line with actual situation, noise is added in all the signals to be sorted. Two-dimensional distribution maps of characteristic parameters RF and PW, RF and DOA, PW and DOA are shown in Fig. 1.

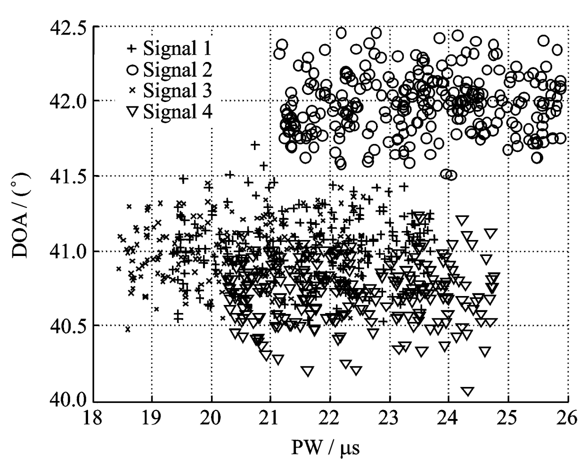
In Fig. 1, we can see that the characteristic parameters overlap seriously. Because sorting methods based on BP neural network (BPNN) are widely used in sorting of binding radiation source, we choose BPNN algorithm to compare sorting performance with the proposed method. The input layer of BPNN used here is four neurons, and neuron number of the hidden layer is ten. Moreo-



(a) RF and PW



(b) RF and DOA



(c) PW and DOA

Fig. 1 Two-dimensional distribution maps of characteristic parameters of radar signal samples ver, the transfer functions of input layer, hidden layer, output layer are tansig, purelin and trainlm, respectively. The tolerance is 0.05, and the error is 0.001. The signals are sorted by covering algorithm and BPNN algorithm. Sorting results are shown in Tables 2, 3.

Table 2 Sorting result by original covering algorithm

Serial number	Correct	Wrong	Correct rate/%
1	249	0	100
2	218	59	78.70
3	199	27	88.05
4	197	40	83.12
Average accuracy			87.26
Time needed/s			0.155

Table 3 Sorting result by BPNN algorithm

Serial number	Correct	Wrong	Correct rate/%
1	236	13	94.78
2	235	42	84.83
3	161	65	71.24
4	221	26	93.24
Average accuracy			85.24
Time needed/s			20.514

As can be seen from Tables 2, 3, sorting performance of geometric covering algorithm precedes that of BPNN algorithm, and there is one radar that is completely sorted. Moreover, its required time is much less than that of BPNN algorithm. In a word, simulation result shows that geometric covering algorithm overcomes the problem of BPNN algorithm. However, its average accuracy is not high enough for practical application. For this reason, the method based on cloud model joints with the geometric covering algorithm, and simulation results are shown in Table 4.

From Table 4, the average accuracy of the method based on cloud model and geometric covering algorithm is much higher than that of two other algorithm, and its required time is much less than that of BPNN algorithm. In conclusion the simulation verifies the validity of the method.

Table 4 Sorting result by the presented method

Serial number	Correct	Wrong	Correct rate/%
1	249	0	100
2	248	29	89.53
3	216	10	95.58
4	236	1	99.58
Average accuracy			95.96
Time needed/s			2.476

3 CONCLUSION

A novel radar sorting method based on geometric covering algorithm and cloud model theory is proposed in this paper. The method overcomes the defects of traditional algorithms, and can deal with complex and uncertain signals. In theory, efficiently handling the uncertainty of radar signals can reduce the required accuracy of training samples, which accords further with current electronic reconnaissance environment. Simulation results prove that the method can accurately sort radar signals with overlapped parameters in real-time.

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