Research on Real Radar Pulse Signal Sorting Technology Based on Machine Learning

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Abstract. With the rapid development of radar technology, various new systems and new modes of radar are emerging, and radar signal sorting technology is undoubtedly an important part of studying radar signals. This article introduces the radar pulse characteristic parameters and the basic theory of machine learning. And for the radar pulse signals of known categories, PDW is used as the sorting feature, and the supervised algorithm in the machine learning algorithm is used for sorting. The supervised algorithm selects the algorithm based on the probability-based decision tree and the distance-based KNN algorithm to sort the radar signals, and the sorting accuracy rate is more than 95%, which shows the great sorting effect.

Keywords: Radar sorting · Pulse description words · KNN · Decision tree

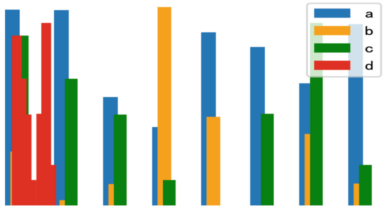
1 Introduction

With the rapid development of radar technology, various new systems and new modes of radar are emerging one after another. The electromagnetic signals they radiate are complex and changeable, which causes great difficulties in radar signal identification and feature analysis. By sorting the radar signals, the dense radar pulse signal can be diluted, which provides convenience for further identification and functional discrimination of the radar radiation source.

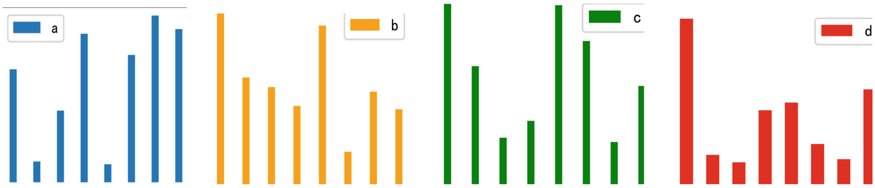
The processing of radar signal sorting can be understood as accurately sorting the pulse sequences of different radar systems from overlapping and random pulse signal streams, or it can be understood as a form of signal processing. The following Fig. 1 is an image display of radar signal sorting. The overlapping radar pulse signal streams captured at the signal receiver end can be sorted out after the radar signal sorting processor sorting operation. Pulse signal.

This article is to sort the real and known types of radar pulse signals. The pulse description word of the radar pulse signal can accurately represent the parameter characteristics of the pulse signal, and the parameter characteristics of different types of radar pulse signals are also different, so the radar signal pulse description word is used as the sorting feature. Since the specific class of radar pulses to be sorted is known, the supervised algorithm in the machine learning algorithm is used to sort the radar signals.

Y. Wang et al. (Eds.): *Signal and Information Processing, Networking and Computers*, LNEE 677, pp. 861–869, 2021.
https://doi.org/10.1007/978-981-33-4102-9_103



(a) Radar signals mixed together



(b) Radar signal after sorting

Fig. 1. Schematic diagram of radar signal sorting

2 Related Work

With the rapid development of radar signal processing technology, the research of the radar signal sorting algorithms has also been continuously deepened. As early as the 1970s, Campbell et al. Have begun to study complex signal recognition algorithms [1]. Later, Rogers et al. Studied the sorting algorithm of real-time signals in the 1990s for the radar signal environment with high density and complexity [2]. After further research on the traditional histogram algorithm and sequence search method of PRI sorting, the cumulative difference histogram algorithm (CDIF) and sequence difference histogram (SDIF) algorithms were successively proposed [3]. However, the histogram statistical method has poor ability to suppress harmonics, so the PRI transformation method was proposed, and then scholar Zhao Yongsheng made two improvements to the transformation method [4], and proposed an improved transformation method, improved the transform method has a good suppression effect on sub-harmonics, but it is not suitable for re-frequency stagger a sorting technology for the unknown radar radiation source signals based on complexity, which opened up new ideas for the radar sorting technology [5].

With the improvement of machine learning algorithm theory and the popularization of applications, in 2014, Chen Changxiao et al. Studied the extraction algorithm of five in-pulse feature parameters of entropy, likeness coefficient, fuzzy function, complexity and bispectrum, which broadened the range of available parameters for radar radiation source signal sorting [6]. Techniques such as artificial neural network, independent component analysis, and intra-pulse feature analysis have been applied to radar signal sorting by scholars at home and abroad, and have achieved a relatively good sorting effect [7].

3 Pulse Description Word

Pulse Description Word (PDW) consists of five parts: pulse arrival time (TOA), carrier frequency (RF), pulse width (PW), pulse amplitude (PA), and pulse arrival angle (DOA). PDW can accurately express the physical parameters of radar pulses. Radar signal sorting is achieved through the correlation of signal parameters.

3.1 TOA

The time when the leading edge of the radar pulse signal is captured by the receiver is defined as the pulse arrival time, or TOA.

$$TOA_n = TOA_{n-1} + PRI_{n-1} + s_i(n), n = 2, 3\ldots \tag{1}$$

3.2 RF

The carrier frequency change modes are various, the specific form is as follows.

1) Fixed frequency radar signal

$$f_t = f_0 + f(N) \tag{2}$$

2) Frequency agile radar signal

$$f_t = f_0 + (\frac{B}{2}) \sin(2\pi m(\frac{T_p}{T_r}) + \theta_0) \tag{3}$$

3) Frequency hopping radar signal

$$RF_n = rand\{RF(1), RF(2), \ldots RF(m)\}, n = 1, 2, \ldots m \tag{4}$$

3.3 PW

The variations of the pulse width that can be touched are mainly fixed type, jitter type, and agile type, but most of the fluctuation range of jitter or agile will not exceed 20% of the existing pulse width center value.

3.4 DOA

The spatial characteristics of the radar signal are represented by the parameter pulse arrival angle, that is, the angle of the radar signal return wave.

3.5 PA

The value range of this parameter fluctuates greatly and is not unique. For sorting problems, this parameter cannot be the only feature for sorting.

4 Machine Learning

Analyzing and designing algorithms that allow computers to learn autonomously is undoubtedly the core idea of machine learning. Models, strategies and algorithms are the three essential factors that make up machine learning [8]. Only by grasping the meanings of the three and using them reasonably can the best machine learning effect be achieved.

4.1 Algorithm Classification

Machine learning algorithms include supervised learning algorithms, unsupervised learning algorithms, integrated learning algorithms and reinforcement learning algorithms [9]. Supervised learning can predict a new result based on the original function (model). Unsupervised learning algorithm can't determine the correct output. For reinforcement learning, it uses the reward function as the basis for decision-making.

4.2 Evaluation Index

(1) Accuracy

$$ACC = \frac{TP + TN}{TP + TN + FP + FN} \tag{5}$$

The proportion of the correct sorted sample number in the total sample number is defined as the accuracy rate.

(2) Precision

$$P = \frac{TP}{TP + FP} \tag{6}$$

The proportion of the positive samples divided into the positive samples is defined as the accuracy rate.

(3) Recall

$$Recall = \frac{TP}{TP + FN} \tag{7}$$

The proportion of the samples divided into positive examples in the actual positive samples is defined as the recall rate.

(4) F1-Score

$$F1 = \frac{2 * Precision * Recall}{Precision + Recall} \tag{8}$$

F1-score combines the characteristics of the two evaluation indicators, accuracy rate and recall rate.

5 Experiment Analysis

Since this paper is aimed at real radar pulse data and the actual category of the pulse is known, the supervised learning algorithm in the machine learning algorithm will be used to sort the radar pulse signal. The decision tree algorithm based on probability [10] and the KNN algorithm based on Euclidean distance in sorting performance of real radar pulse signal.

5.1 Experiment Data

Real radar pulse data contains 7 types of signals, Table 1 is the data distribution.

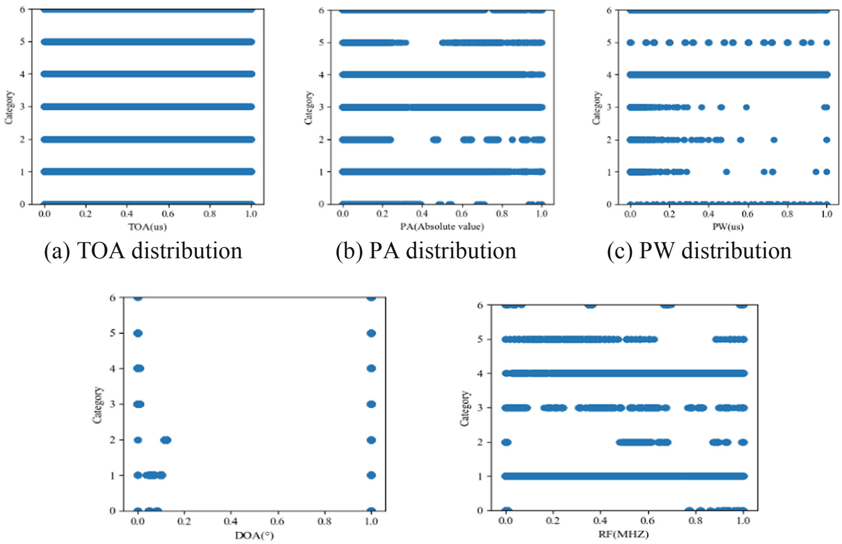
Table 1. Radar pulse number distribution

Category	Number
1	63544
2	101737
3	6954
4	40816
5	114050
6	3288
7	99130

Standard each dimension parameter to the variation range of the 0–1 distribution to achieve the effect of dimensional elimination according to the following formula.

$$\mathrm{a}_{ik} = \frac{a_{ik} - \min(a_{ik})}{\max(a_{ik}) - \min(a_{ik})} \tag{9}$$

Where a_{ik} is represented as the value of the i-th pulse feature of the k-th radar signal pulse. Figure 2 shows the normalized radar pulse signal characteristic distribution.



(a) TOA distribution (b) PA distribution (c) PW distribution

(d) DOA distribution (e) RF distribution

Fig. 2. Radar pulse characteristic distribution

5.2 Experimental Algorithm Selection

The decision tree uses the CART algorithm, which has the advantages of efficiency, ease of use, robustness, etc. The leaf node does not affect the construction of the entire decision tree, and the decision tree constructed by the CART algorithm is a binary tree. The information uncertainty of the algorithm is measured by Gini index. The smallest Gini index will be used as the classification feature.

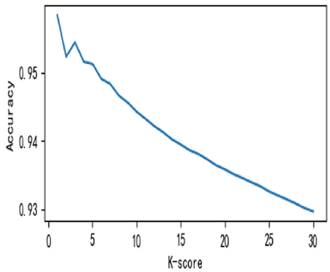
$$G(p) = \sum_{m=1}^{M} p_m(1 - p_m) = 1 - \sum_{m=1}^{M} p_m^2 \tag{10}$$

KNN algorithm is a typical algorithm commonly used in processing classification problems. The core content of the algorithm is to calculate the distance between different samples in the feature space and select the k samples closest to the sample to be classified. This article uses Euclidean distance as a measure of the distance between objects. The mathematical formula is as follows:

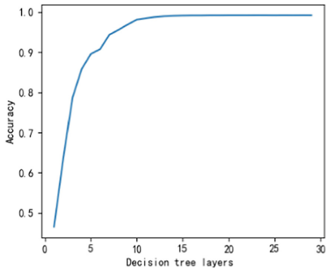
$$d(x, y) = \sqrt{\sum_{k=1}^{n} (x_k - y_k)^2} \tag{11}$$

5.3 Experimental Results

In the experiment of sorting radar pulse signals, in order to select the optimal K value in the KNN algorithm and the optimal number of layers of the decision tree algorithm, this paper uses the accuracy of sorting as the standard, and designs the cycle program to select The best K value and the best decision tree layers, the experimental results are shown in the Fig. 3.



(a) KNN k value



(b) Decision tree layers

Fig. 3. Algorithm parameter selection

It can be seen from the above figure that the optimal K value of the KNN algorithm is selected as 1, and the optimal number of decision trees is 15. Set the training set and test set ratio to 7: 3, and use the generalization ability of the 10-fold cross-validation model. The sorting results of decision tree and KNN algorithm are shown in Table 2 and Table 3.

Table 2. KNN algorithm sorting results

	Accuracy	Recall	Precision	F1-score
Fold 1	0.9645	0.9524	0.9558	0.9539
Fold 2	0.9648	0.9512	0.9531	0.9520
Fold 3	0.9640	0.9488	0.9559	0.9521
Fold 4	0.9638	0.9465	0.9563	0.9511
Fold 5	0.9643	0.9478	0.9530	0.9501
Fold 6	0.9665	0.9476	0.9582	0.9526
Fold 7	0.9659	0.9487	0.9569	0.9526
Fold 8	0.9658	0.9523	0.9582	0.9551
Fold 9	0.9655	0.9498	0.9580	0.9537
Fold 10	0.9628	0.9479	0.9526	0.9501

Table 3. Decision tree sorting results

	Accuracy	Recall	Precision	F1-score
Fold 1	0.9916	0.9824	0.9877	0.9849
Fold 2	0.9918	0.9838	0.9903	0.9870
Fold 3	0.9913	0.9784	0.9890	0.9836
Fold 4	09915	0.9837	0.9896	0.9866
Fold 5	0.9919	0.9857	0.9908	0.9882
Fold 6	0.9920	0.9819	0.9899	0.9858
Fold 7	0.9917	0.9841	0.9895	0.9868
Fold 8	0.9920	0.9868	0.9903	0.9885
Fold 9	0.9929	0.9882	0.9936	0.9909
Fold 10	0.9916	0.9816	0.9883	0.9849

It can be seen from the table-results that the KNN algorithm and the decision tree algorithm are very good for the sorting of known radar pulse signals, and the sorting accuracy has reached more than 95%. And through the comparison of machine learning evaluation indicators, the sorting effect of the decision tree algorithm is better.

6 Conclusion

This paper mainly studies the real radar pulse signal sorting based on machine learning algorithm. Firstly, the pulse descriptors of radar signals and related concepts and evaluation indexes of machine learning are introduced. And according to the radar pulse signal of the real known category, the KNN algorithm and the decision tree algorithm in the supervised algorithm are used for sorting. Through experimental design, the optimal K value selection of the KNN algorithm and the optimal number of decision tree constructions are determined, and the accuracy of the two algorithms for radar signal sorting is more than 95%.

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