Adaptive radar pulses clustering based on density cluster window

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Abstract: As radar signal environments become denser and more complex, the capability of high-speed and accurate signal analysis is required for an ES(Electronic warfare Support) system to identify individual radar signals in real-time. This paper presents the adaptive clustering algorithm of radar pulses to alleviate the load of signal analysis process and support reliable analysis. The proposed clustering algorithm determines the size of cluster window based on the type of frequency modulation of received radar signals. Simulation results show the superior performance of the proposed algorithm over conventional sequential histogram and scan model.

1. Introduction

In general, ES involves receiving enemy signals to identify and locate threat emitters and to help determine the enemy's force structure and deployment. Its primary functions are detection of threat signals, identification of threat types and operating modes, location of threat emitters, display or handoff of threat information to support situation awareness[1]. ES systems measure pulse characteristics of received RF signals and discriminates the pulse trains from collected data. Then ES systems analyze the characteristics of the data and identify the emitters through comparison with Emitter Identification Data(EID). In dense and complex signal environments, the capability of high-speed and accurate signal analysis is required to identify individual radar signals in real-time. For this, the clustering algorithm of radar pulses as a preprocessing technique in ES should be developed to alleviate the load of signal analysis and support reliable analysis.

Clustering in ES is a special application of data clustering to classify unknown radar emitters from received radar pulse samples. Compared with ordinary data clustering, radar emitter classification has some unique challenges. First of all, the radar pulse samples are of high dimension and the pulse sample vectors may be as high as several hundreds in dimension. Second, in hostile environments, the number of received pulses may be small, e.g., a couple of tens for each radar. Third, the radars may be of the same type from the same manufacturer, making it likely that the pulses from them are very similar. In other words, the radar pulse clusters may be close together[2]. Therefore, it is necessary to consider these factors for the clustering algorithm in ES.

Clustering of radar pulse samples which are PDW(Pulse Descriptor Word) of collected radar pulses is performed between radar signal measurement process and signal analysis process. Clustering process should report reliable cluster information to signal analysis process. For this, clustering algorithm is required to carry out following tasks: 1) to avoid scattering pulses of radar into different clusters, 2) to avoid forming excessively huge clusters and 3) to minimize the processing time.

Fig. 1 shows the general ES system which has a built-in signal clustering process. The signal receiving unit measures individual pulses transmitted by multiple radars and generates PDWs fitted to the predefined form for each measured pulse sample. PDWs consist of parametric information such as PW(Pulse Width), PA(Pulse Amplitude), RF(Pulse Radio Frequency), AOA(Angle of Arrival), and TOA(Time of arrival)[3]. Signal clustering process tries to cluster the received pulse data using specific parameters. After clustering process, the signal detection unit analyzes the radar pulse trains based on the cluster information, and identifies emitters through comparison with EID and updates the active emitter table. Clustering process is very important in an ES system because it affects the capability of signal analysis directly.

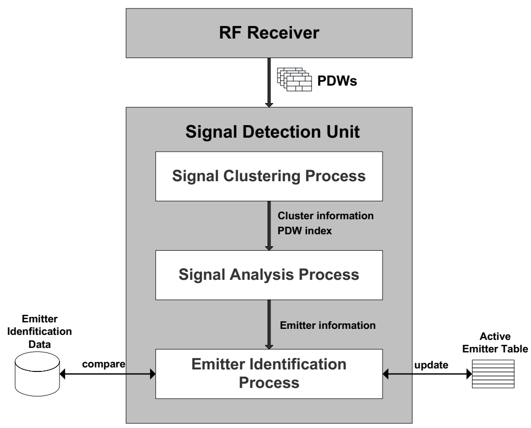

Figure 1. Signal processing flow in a general ES system

Fig. 2 shows a histogram representation of the data which might be received in the RF and AOA domain over a period of time. Pulses from different radars may be interleaved, and parameter measurements made on pulses from the same radar may not be constant from pulse to pulse. Even if there are no above distortions in received pulse data, the histogram distribution of the data may be spread out according to the type of frequency modulation of radar signals. In other words, the pulse data can be spread out extensively in case of a signal with agile frequency modulation, on the other hand, most of the pulse data from a signal with fixed frequency modulation get together in the narrow regions. Therefore, clustering algorithm should consider the type of frequency modulation as well as distortions to determine the proper range of clusters.

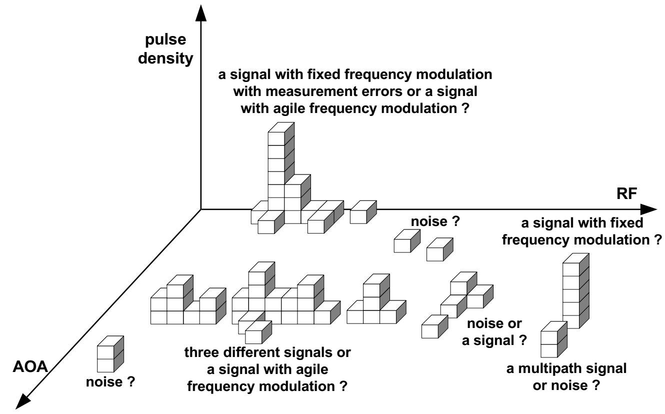

Figure 2. Clustering Problem in ES

The output from the signal receiving unit is in the form of PDWs consisting of PA, PW, RF, AOA and TOA for each received radar pulse. All of those parameters are entitled to consider for clustering of radar pulses except TOA. But, clustering using those parameters in PDW causes the 'curse of dimensionality' that means the problem caused by the exponential increase in volume associated with adding extra dimensions to a space. Consequently, the minimum number of parameters which affect decisively to cluster radar pulses should be used in the clustering algorithm.

PA is changed by the distance between ES receiver and radar and the measurement errors and scan pattern such as circular, sector, conical, etc. Therefore, PA is not suitable parameter for clustering. PW is not constant even if received pulses are from the same radar owing to the overlapping of the pulses by multi-path, PA of received pulses and measurement errors. But PW can be applied to clustering because of the low probability of distortion. RF is the key parameter for clustering of radar signals because it represents the inherited feature of individual radar systems. But, there are several types of frequency modulation such as fixed, agile, hopping, and pattern, hence, the type of frequency modulation is considered with caution in clustering of radar pulses. AOA is only determined by the radar's location not by its system design, and hence AOA is the most appropriate parameter for clustering of radar pulses. If there are no reflected signals to cause confusion, a constant AOA will be present over rather long periods of time even when the platforms are moving[4],[5]. As discussed above, of them all, this paper uses AOA, RF and PW parameters to cluster the received radar pulses.

This paper presents an adaptive clustering algorithm of radar pulses based on the density cluster window. The proposed cluster window which means the boundary of a potential cluster is determined according to the type of frequency modulation of received radar signals.

2. Conventional clustering algorithm

In this section, we analyzed the two conventional clustering algorithms used in an ES system in view of operational concepts and features.

2.1 The sequential histogram algorithm[6]

RF and AOA are measured on a pulse to pulse from multiple radars and can be represented by the two dimensional histogram as illustrated in Fig. 3.

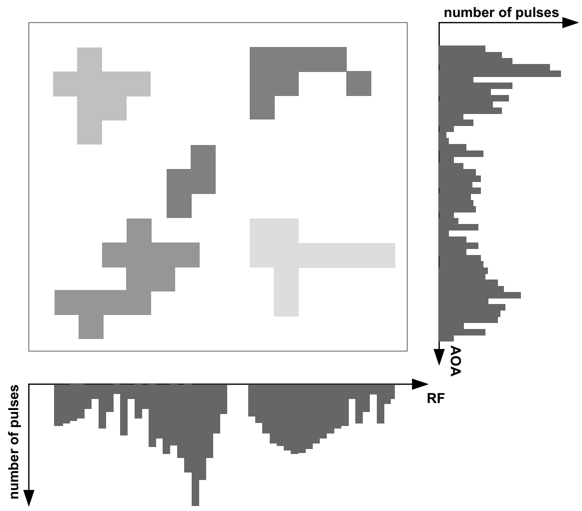

Figure 3. 2D histogram representation of radar pulses

In the sequential histogram algorithm, clustering for AOA is carried out by comparing histogram result with the threshold, and then clustering for RF is performed for each cluster made from prior clustering in the same way. In the clustering for RF, the separate thresholds are used to classify the clusters of signals with fixed frequency modulation and agile frequency modulation. This algorithm is easy to implement, but the signals with agile frequency modulation can be scattered into the two or more clusters in clustering for RF. Also, there are the problems of setting for threshold and the size of histogram bin.

2.2 The sequential scan algorithm[7]

The sequential scan algorithm is a two dimensional algorithm that is an application of labeling method used in image signal processing and pattern recognition. This algorithm sets the flags on the two dimensional cells corresponding to the AOA and RF of individual PDWs, and then scans sequentially in forward and reverse order. In forward scan, the label is assigned to the cells with flags to determine potential clusters as following. If any neighboring cell doesn't have the label, another label is assigned to the cells; otherwise, label is assigned to the cells as (1), where *a* is the index of AOA and f is the index of RF.

$$Label(a,f) = \min(\,Label(a-1,f),\,Label(a,f-1)) \quad (1)$$

In backward scan, the propagation of labels is performed to merge potential clusters which are closed by each other. Merging is performed similarly to the forward scan by (2). Through the backward scan, the one minimum label is assigned to discrimination cells of the same cluster.

$$Label(a, f) = \min(Label(a+1, f), Label(a, f+1)) \quad (2)$$

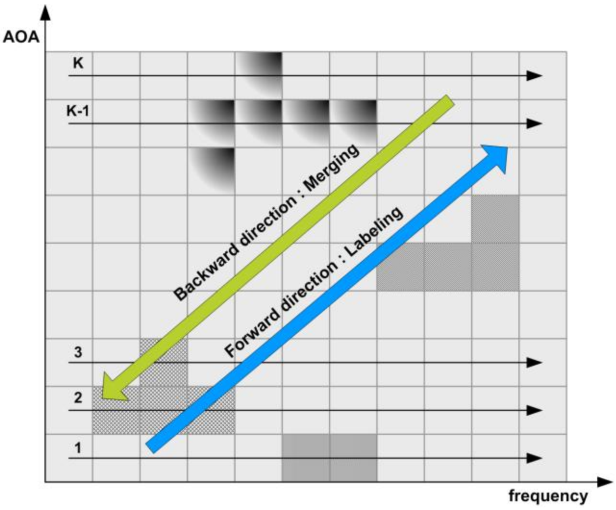

Figure 4. Clustering in the sequential scan algorithm

The sequential scan algorithm is the two dimensional approach of AOA and RF, and don't have decision variables such as threshold in the sequential histogram algorithm. But there are still some drawbacks. First, it can't discriminate the signals with the fixed frequency modulation and agile frequency modulation. If the cells of the signals with the fixed frequency modulation are in the cell domain formed by the signals with agile frequency modulation, two cells are merged in a cluster. Second, this algorithm is so time-consuming job, because it must scan all cells in twice irrespective of the number of pulses, N. Therefore, the sequential scan algorithm is not suitable for an ES system which requires real-time processing.

3. Proposed Algorithm

The proposed algorithm makes the three dimensional cells for AOA, RF and PW, and accumulates pulses to the cells, and then searches the candidates for the cluster headers based on the cell density. The cluster window that means the region of a potential cluster in the three dimensional cells is determined adaptively according to the cell density of each candidate for header. If the cell density of a header is higher than the threshold for the signals with agile frequency modulation, this header may be resulted from the signals with fixed frequency modulation, so the size of the cluster window will be reduced. Otherwise, this header may be resulted from the signals with agile frequency modulation, so the size of the cluster window will be expanded.

The size of the cell should be determined with care because it affects the clustering performance directly. If the cell size is too small, the pulses from a radar will be scattered to the several cells. And if the cell size is too big for clustering, the pulses from two or more radars will be clustered to a cluster. In this paper, the size of the cell is defined using the standard deviation σ of parameters in ES system as the following:

$$cell\ size = \sigma_{AOA} \times \sigma_{RF} \times \sigma_{PW} \quad (3)$$

where σ_{AOA}, σ_{RF} and σ_{PW} is the standard deviation of AOA and RF respectively. In this paper, the σ_{AOA}, σ_{RF} and σ_{PW} were determined as 5[˚], 10[MHz] and 50[ns] respectively through the computer simulations for better clustering result. This paper propose the size of the window W as (4) where H is the location of the cluster header in two dimensional cells, $2{\times}R_{AOA}$ is the length of the cluster window, $2{\times}R_{FreqFIX}$ and $2{\times}R_{FreqAGL}$ are the width of the cluster windows of the fixed and agile frequency modulation respectively and $2{\times}R_{PW}$ is the height of the cluster window.

$$\begin{aligned} W_{FreqAGL} &= (\mathrm{H} \pm R_{AOA}) \times (\mathrm{H} \pm R_{FreqAGL}) \times (\mathrm{H} \pm R_{PW}) \\ W_{FreqFIX} &= (\mathrm{H} \pm R_{AOA}) \times (\mathrm{H} \pm R_{FreqFIX}) \times (\mathrm{H} \pm R_{PW}) \end{aligned} \quad (4)$$

If the window for the signals with agile frequency modulation is used for the header for signals with fixed frequency modulation, large groups which impose a heavy load on the signal analysis process will occur without separating the signals with fixed frequency modulation. Therefore, it is necessary for clustering process to use adaptive density cluster window according to the frequency modulation types.

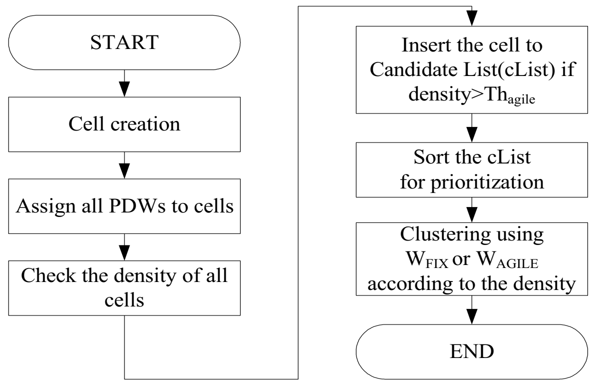

Figure 5. Flow Diagram of the propsed algorithm

4. Experimental Results

A computer program is constructed to apply the clustering algorithms described in the previous section to interleave multiple radar signals. The input data consisted of 2,048 pulses for various emitters which have AOA, RF, PRI, and PW individually. Performance evaluation is performed with changes in the input signals, and the results are followed at table 1. The results show that the sequential histogram and scan algorithm do not make clusters properly for the input signals. For sequential histogram algorithm, it has the more clusters than expected as the number of input signal increases, and many pulses which don't exceed the threshold remained unused.

Table 1. Performance Results

Algorithm	Type Classif-ication	Probability[%]		
		Clustering	Over Clustering	Under Clustering
Histogram	○	66.7	30	3.3
Scan	×	53.3	6.7	40
Density Cluster Window	○	96.7	0	3.3

On the other hand, the sequential scan algorithm has the fewer clusters, and also it can't discriminate the modulation type of carrier frequency. But in the proposed algorithm, most of the clusters are analyzed accurately to the input signals. Also, it can discriminate the modulation type of frequency accurately. Fig. 6 shows the sample clustering result of the proposed.

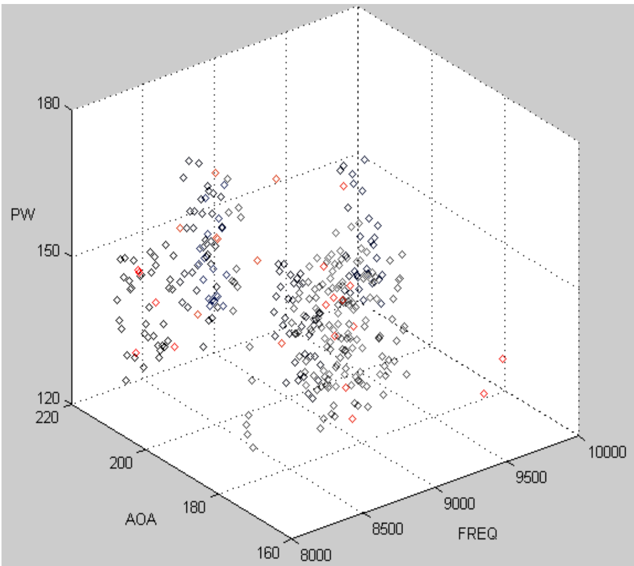

Figure 6. Clustering results for input signals

5. Conclusions

This paper proposes the novel clustering algorithm based on the three dimensional adaptive density cluster window. The proposed algorithm defines the cluster window which is changed adaptively through the decision on the variation or modulation characteristics of the parameters for clustering. Simulation results show that the proposed algorithm has good performance in clustering capability and processing time in comparison with the conventional algorithms. Consequently, the proposed clustering algorithm will be very useful for signal processing in ES systems.

References

[1] David L. Adamy, *Introduction to Electronic Warfare Modeling and Simulation*, Artech House, 2003.

[2] Lui Jun, J.O.Y. Lee, Lingjie Li, Luo Zhi-Quan and K.M. Wong, "Online clustering algorithms for radar emitter identification," *IEEE Transaction on pattern analysis and machine intelligence*, vol.27, pp.1185-1196, August 2005.

[3] Filippo Neri, *Introduction to Electronic Defense Systems*, Artech House, 1991.

[4] R. G. Wiley, *ELINT : The Interception and Analysis of Radar Signals*, Artech House, 2006.

[5] Jin-Woo Han, Kyu-Ha Song, Dong-Weon Lee, Si-Chan Lyu, "A novel clustering algorithm of radar pulses based on the adaptive cluster window," *2007 22nd International Symposium on Computer and Information Sciences*, November 2007.

[6] D.R. Wilkinson and A.W. Watson, "Use of metric tech--niques in ESM data processing," *IEE proceedings on F, Communications, radar, and signal processing*, vol.132, pp.229-232, July 1985.

[7] Sang-Yeol Lee, Kyu-Ha Song, The signal grouping technique using the frequency and angle of arrival information, *Technical Report*, ADD, 2000.