커널 밀도 윈도우를 이용한 레이더 펄스 클러스터링

*이동원, 한진우, **이원돈
*국방과학연구소, **충남대학교 전기정보통신공학부
e-mail : *jg2mlee@hotmail.com*

Radar Pulse Clustering using Kernel Density Window

***Dong-Weon Lee, Jin-Woo Han, **Won-Don Lee**
***Agency for Defense Development**
****Chungnam National University**

Abstract

As radar signal environments become denser and more complex, the capability of high-speed and accurate signal analysis is required for ES(Electronic warfare Support) system to identify individual radar signals at real-time. In this paper, we propose the new novel clustering algorithm of radar pulses to alleviate the load of signal analysis process and support reliable analysis. The proposed algorithm uses KDE(Kernel Density Estimation) and its CDF(Cumulative Distribution Function) to compose clusters considering the distribution characteristics of pulses. Simulation results show the good performance of the proposed clustering algorithm in clustering and classifying the emitters.

I. Introduction

An ES system measures pulse characteristics of received RF signals and discriminates the pulse trains that have a rule, correlation, continuance from collected data. ES system analyzes the characteristics of the data and identifies the emitters through comparison with EID(Emitter Identification Data). In dense and complex signal environments, the capability of high-speed and accurate signal analysis is required to identify individual radar signals at 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. This paper presents a clustering algorithm of radar pulses considering the distribution characteristics of pulses.

Ⅱ. Clustering concept in ES

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).

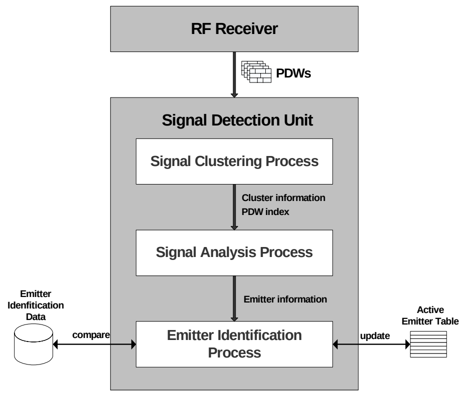

Fig.1 Signal processing flow in a general ES system

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 ES system because it affects to the capability of signal analysis directly.

Ⅲ. Proposed algorithm

The proposed algorithm uses KDE and CDF to discriminate the pulses with fixed frequency modulation and the pulses with agile frequency modulation. Also, they are used to identify whether the pulses in the specific area which is composed of cells are from single emitter or not. The algorithm makes the two dimensional cells for AOA and RF, and accumulates pulses to the cells. The size of the cell should be determined with care because it affects to 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. We define the size of cell using the standard deviation σ of parameters in ES system as the following:

$$cell\,size = 6\sigma_{AOA} \times 6\sigma_{RF} \quad (1)$$

where σ_{AOA} and σ_{RF} are the standard deviation of AOA and RF respectively.

After all pulses are assigned to the cells, then KDE of the cells are calculated. If the △CDF of KDE is greater than TH_{fixed} which is the threshold to classify the pulses with fixed frequency modulation, all pulses in the cell are single group. Because the distribution of the pulses with fixed frequency modulation is normal distribution, while the distribution of the pulses with agile frequency modulation is uniform distribution. The △CDF of KDE is following:

$$KDE(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x - X_i}{h}\right) \quad (2)$$

$$\triangle CDF = \int_{i=c-\sigma_{RF}}^{c+\sigma_{RF}} KDE(i)\,di \quad (3)$$

where n is the number of pulses in a cell, h is the window size and c is the index of peak point in the KDE.

After all pulses with fixed frequency modulation are identified as single emitter respectively, all pulses with agile frequency modulation are remained. Then, we use the window W which means the max area of a emitter which has the pulses with agile frequency modulation. For example, W is fifty times bigger than cell size in a RF domain. If △CDF of KDE in W is in TH_{agile}±10%, all pulses in W are one agile emitter. Otherwise, two or more agile emitters are in W. To tell In detail, if △CDF of KDE in W is greater than TH_{agile}+10%, two or more agile emitters are overlapped. And if △CDF of KDE in W is smaller than TH_{agile}-10%, two or more agile emitters are splitted in W.

Ⅳ. Experimental Results

A computer program is constructed to apply the clustering algorithms described in the previous section to interleaved multiple radar signals. The input data consisted of various emitters which have AOA, RF, PRI individually. Simulation results show that the proposed algorithm has good performance in clustering and classifying the emitters as shown in Fig.2. Consequently, we believe the proposed algorithm will be very useful for signal processing in ES system.

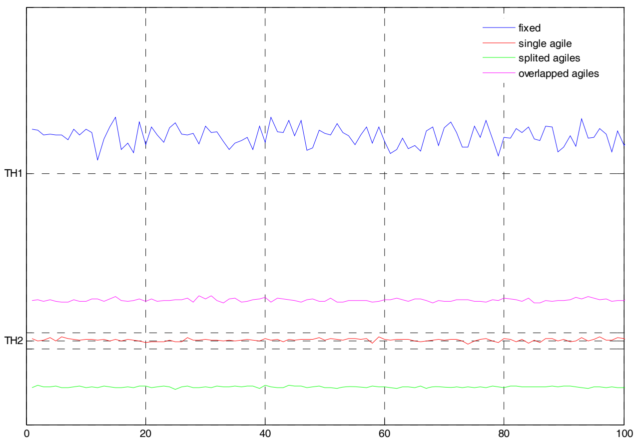

Fig.2 Simulation Results(△CDF for pulses)
($TH1$ = TH_{fixed}, $TH2$ = TH_{agile})

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