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Deinterleaving pulse trains in unconventional circumstances using multiple hypothesis tracking algorithm

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A B S T R A C T

The main function of Electronic Support Measure (ESM) is to receive, measure and deinterleave pulses, and then identify alternative threat emitters. Among these processes, pulse deinterleaving is vitally important because dense electromagnetic environments could cause an ESM system to receive a seemingly random pulse stream consisting of interleaved pulse trains with high noise levels. Only when we segregate different radar pulse trains from the pulse stream can we proceed with further processing. Traditional deinterleaving algorithms have demonstrated instability in unconventional circumstances (such as agility of pulse repetition interval (PRI), large noise and jitter, missing of intercepted pulses). Based on the dynamic process of different emitters, a new Statistical Association Pulse Deinterleaving (SAPD) approach is proposed based on the Multiple Hypothesis Tracking (MHT) algorithm in Multiple Target Tracking system. Simulation results have shown that the proposed algorithm can successfully identify pulse trains with constant, jittered and staggered PRI, and provide much greater accuracy in PRI estimation and pulse classification than traditional algorithms, with the presence of large noise, frequency jitter, and many missing pulses.

1. Introduction

Radar reconnaissance equipment, known as Electronic Support Measure (ESM) [1], is one of the most important parts in Electronic War (EW), performing threat detection and area surveillance to determine the bearing and identity of surrounding radar emitters. In the dense electromagnetic environments encountered during war, a large number of surrounding emitters can cause an ESM to receive a seemingly random pulse stream consisting of interleaved pulse trains with high noise levels. Only when we segregate different radar pulse trains from the pulse stream can we proceed with the measurement, analysis, and identification of the signal parameters and types, and then impose countermeasures on the threatening radar emitters, such as blanket jamming or deceptive jamming. The process of associating every received pulse with its emitter is known as pulse train deinterleaving.

Broadly speaking, an automatic ESM system consists of three subsystems [1]: the ESM receiver, the deinterleaver, and the main processor. The ESM receiver, which is a passive radar receiver, picks up the pulses emitted by surrounding radars in the environment and measures their five identifying parameters: angle of arrival (AOA), radio frequency (RF), pulse width (PW), pulse amplitude (PA), and time of arrival (TOA). The receiver is designed to cover a parameter range wide enough to ensure detection of all radars of interest. And a threshold is used to declare the reception of a radar pulse [2].The measurement parameters of every pulse successfully intercepted are encoded in a digital format called the pulse descriptor vector (PDV). Then, the deinterleaver sorts the PDVs and forms pulse cells, each containing a set of PDVs assumed to belong to the same emitter. The pulse cells are encoded as emitter descriptor vectors (EDVs) whose components are emitter characteristics such as AOA, RF, PW, pulse

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repetition interval (PRI), agility, and scan period. Finally, the main processor compares the estimated EDVs with those stored in the threat library of the EW system to identify known emitters or determine unknown emitters [3,4].

Ideally, there will be a one-to-one relationship between cells identified by the deinterleaver and emitters in such an environment; however, as Electromagnetic Spectrum is utilized more sufficiently, there exists three primary issues: dense electromagnetic environment, agility of pulse parameters, and the low probability of interception (LPI) technique. The density of the pulse stream has come to be 10^6 pulses per second, which places greater demands upon the computational capability of the reconnaissance equipment. Moreover, the agility of various pulse parameters of radar emitter signals, such as RF and PRI, also aggravates the difficulty of pulse deinterleaving and increases the error rate. Furthermore, the universal adopted technique, LPI, by emitters, which greatly reduces the detection probability of pulses, can lead to a large number of missing pulses. In a word, all these techniques drive the development of radar pulse deinterleaving.

Generally, deinterleaving algorithms are classified on the basis of whether they use parameters of more than one pulse, such as PRI [5–15], or only a pulse, such as AOA, RF, and PW [16–19]. The former is denoted as the interval-only algorithm, while the latter is denoted as the multiple-parameter deinterleaving algorithm. The simplest in the family of ''interval-only'' algorithms is TOA difference histogram [5], in which each TOA is subtracted from every subsequent TOA and a count is accumulated for each TOA difference. Since this method is based only on subtractions, it is widely used in modern ESM Receivers [6]; however, this histogram is quite sensitive to interference and missing pulses. Therefore, the CDIF (cumulative difference) histogram technique [7] is proposed, which assumes the accumulation of histogram values for each difference level and potential values of PRI will correspond to the histogram peak. Once the potential PRI is identified, the algorithm performs a sequence search [7], i.e., it looks for a group of pulses that form a periodical pulse train with a period equal to the potential PRI. The most significant drawback of the CDIF technique concerns the large number of difference levels required even in very simple cases. Thus, the modified version is proposed as the SDIF (sequential difference) histogram technique [8], which does not include accumulation in the successive difference levels. Other similar methods are also proposed based on the numerical characteristics of the matrix of the differences of TOA [9]. For a uniform PRI, this matrix is a symmetrical harmonic Toeplitz matrix. All algorithms [5–9] above are based on the differences of TOA, whereas other time-domain techniques for deinterleaving pulse trains have been proposed. One method is to formulate the problem as a stochastic discrete-time dynamic linear model (DLM) [10] with fixed look-ahead and a probabilistic teacher Kalman filtering for the estimation task. Another method is to optimally combine the hidden Markov model and binary time series estimation techniques and yield maximum likelihood parameter estimates of the sources [11]. Someone also uses the fast Fourier transform technique to determine the number of pulse trains and estimate their periods without actually deinterleaving them [12]. At the same time, the method to estimate the interleaved pulse train phase is still proposed in [13]. Moreover, when the signal model from [10] is modified by a smoothing of its inherent discontinuities, the deinterleaving task can be also performed using the extended Kalman filter [13,14]. In 2004, several Japanese researchers have also used the Multiple Hypotheses Testing technique to perform pulse deinterleaving by evaluating every hypothesis by two parameters: the similarity of during of call and the period of TOA [15].

Refs. [5–15] discuss the interval-only algorithm while the multiple-parameter deinterleaving algorithm improves the reliability and the processing speed. This improvement is expected since the interval-only algorithms process only one pulse at a time, whereas the algorithms presented in [16–19] are applied to all received pulses synchronously. The multiple-parameter deinterleaving algorithms first sort the input pulses into a number of radar cells based on their mono-pulse parameters, and then the interval-only algorithms could be used to analyze each individual cell much faster. However, when identifying complex radars with agile PRI and RF, the multiple-parameter deinterleaving algorithms [16] may generate some false cells. That is why AOA is usually chosen as the only available parameter for primary deinterleaving, as it is difficult for any emitter to change over a very short time interval [17]. Furthermore, evaluating the quality of each deinterleaved cell with a confidence level [17] can also conserve the limited resources of the EW system that can be used against false radars. Finally, other algorithms [20–22] that have been recently proposed will not be individually discussed in this work.

All the algorithms stated above rely on five parameters to deinterleave the intercepted pulse trains. Unfortunately, the multiplication of intricate PRI and RF patterns has spurred the complexity and error in deinterleaving algorithms, which aggravates the radar emitter recognition based on the five parameters. Furthermore, the five parameters are far from describing a complex radar signal, such as BPSK or LFM. So, the analysis of modulation mode plays an important role and a lot of research has been made on intrapulse modulation to perform automatic emitter recognition, which is the same in both communication and radar system [23–27]. And this part will be discussed in the next paper in detail.

Until now, we have concluded the traditional algorithms for pulse deinterleaving completely. There exist two main problems for the traditional algorithms. The first is that the accuracy of pulse deinterleaving is not high enough in the unconventional circumstances with tremendous noise, jitter and missing. The second is that most of them need to estimate PRI first, and then perform a sequence search to separate pulses with the estimated PRI, but not accomplish them synchronously. Aiming at these two problems, a new approach is proposed in this paper, known as the Statistical Association Pulse