© 2015
Scienceline Publication
www.science-line.com

ISSN: 2322-5114
Journal of World's Electrical Engineering and Technology
J. World. Elect. Eng. Tech. 4(1): 13-20, April 25, 2015

JWEET

Studying an Improved Interval-Only Algorithm for the De-Interleaving of Radar Pulses

Navid Daryasafar and Hamid Dehghani

Malek Ashtar University, Tehran, Iran

*Corresponding author's Email: navid_daryasafar@yahoo.com

ORIGINAL ARTICLE
PII: S232251141500003-4
Received 26 Oct. 2014
Accepted 15 Jan. 2015

Abstract – *In the electronic intelligence system (ELINT) in the process of identification radar signals are used both technical and tactical parameters. The detailed analysis of radar signal parameters was made in conjunction to radar applications. The paper presents an improved method for the deinterleaving of radar signals, based on a time of arrival analysis and the use of the sequential difference histogram (SDIF) for determining the pulse repetition interval (PRI). In this paper, mathematical modeling of interval-only algorithms, their block diagrams and implementations steps as well as their ability in Deinterleaving of radar pulses are analyzed.*

Keywords*: Radar Identification, Electronic Intelligence Systems (Elint), Deinterleaving, Time of Arrival.*

INTRODUCTION

The present electronic intelligence system (ELINT) must be able to fulfill these specific requirements. One of the most principal functions of ELINT system is gathering basic information from the entire electromagnetic spectrum and its analysis.

A main function of ESM system is to threat detection and the area surveillance so as to determine the identity of surrounding emitters. This system must be able to recognize emitters from the pulse-by pulse measurements made by receiver in order to indicate the presence of known (friendly or hostile) radar, as well as to provide emitter tracking, threat assessment and platform identification. The ELINT/ESM data processing, with response time constantly decreasing, presents one of the most complex and time-domain critical problem for current technology [1].

To ensure rapid system response in a dense and complex electromagnetic environment of a future conflict, the search, interception, analysis and identification functions have to be automated. The special software concerning measurements, processing, analysis and recognition of radar signals consists of the following parts [2]:

- Control of radar signals measurement in ESM receiver,
- De-interleaving of the pulse trains which are then compared with an emitter library,
- Analysis of intercepted signals to determine the set of radar parameters,
- Calculation of a specific signal measurement signature to emitter database,

The first step in the process of examine the properties of radar signals is analysis of the measured data set and allows to determine: A) The type and range of changes of basic radar signal parameters, such as RF, PRI, PD; B) The type of intra-pulse modulation for complex signals and values of changes for signals with frequency modulation.

Deinterleaving of radar pulses as a part of surveillance radar systems consists of radar diagnosis and detection which are active simultaneously. Essentially, separation algorithms are based on analysis of arrival pulses parameters such as time of arrival, angle of arrival, pulse amplitude, pulse width and frequency of carrier. To cluster the radar signals including clustering based on DOA parameters [3], neural network [4] and specifications of frequency modulation [5], efforts have been made before.

The proposed algorithm is among the so-called "interval-only" algorithms which only makes use of time of arrival information.

"Interval-only" algorithms

The original version of this algorithm is based on cumulative difference histogram algorithm (CDIF) of pulses arrival time. Then the upgraded version of this algorithm will be developed that is based on sequential difference histogram (SDIF).

Introduction to the basic algorithm

The initial algorithm is based on histogram analysis CDIF. In this method, difference histogram of various orders of TOAs calculated. It means that the first order difference can be obtained from calculating the value of sequential pulse differences and the second order from

To cite this paper: Daryasafar N and Dehghani H. 2015. Studying an Improved Interval-Only Algorithm for the De-Interleaving of Radar Pulses. *J World Elec. Eng. Tech.*, 4 (1): 13-20.
Journal homepages: http://www.jweet.science-line.com/

calculating the difference of arrival time of each pulse with two pulses after it. Finally, frequency of each histogram with the same order summed up and developed the final histogram of that order difference. The peaks of these histograms can be the main PRI representative of radar. For each TOA difference from c order, forming a new histogram and introducing a new threshold is necessary and if no peaks exceed from threshold, then it is calculated the difference histogram of c+1th order with new value of threshold.

After determining the PRI it is need to run the sequence search algorithm, searching a group of pulses that have a periodic pulse train with alternation equal to obtained PRI value. Such a group of pulses is known as a sequent of PRI. If this search is successful, then sequent of PRI omitted from input buffer and a new histogram CDIF created (starting from first difference). This process will continue as long as there is enough pulse to create PRI in input buffer. But, if no PRI founded (pulses do not form the PRI sequence), then it is need to calculate the next order difference. If none of the histogram peaks exceed from threshold, again the next order difference must be calculated. If more than one PRI exceeds from threshold value, it is run to search the sequent for each PRI and starting from minimum value. This method is less sensitive to disorder and missed pulses than other techniques such as histogram of all differences (ADIF). Algorithm diagram block of CDIF and sequence search block is shown in Figures 1 and 2 respectively.

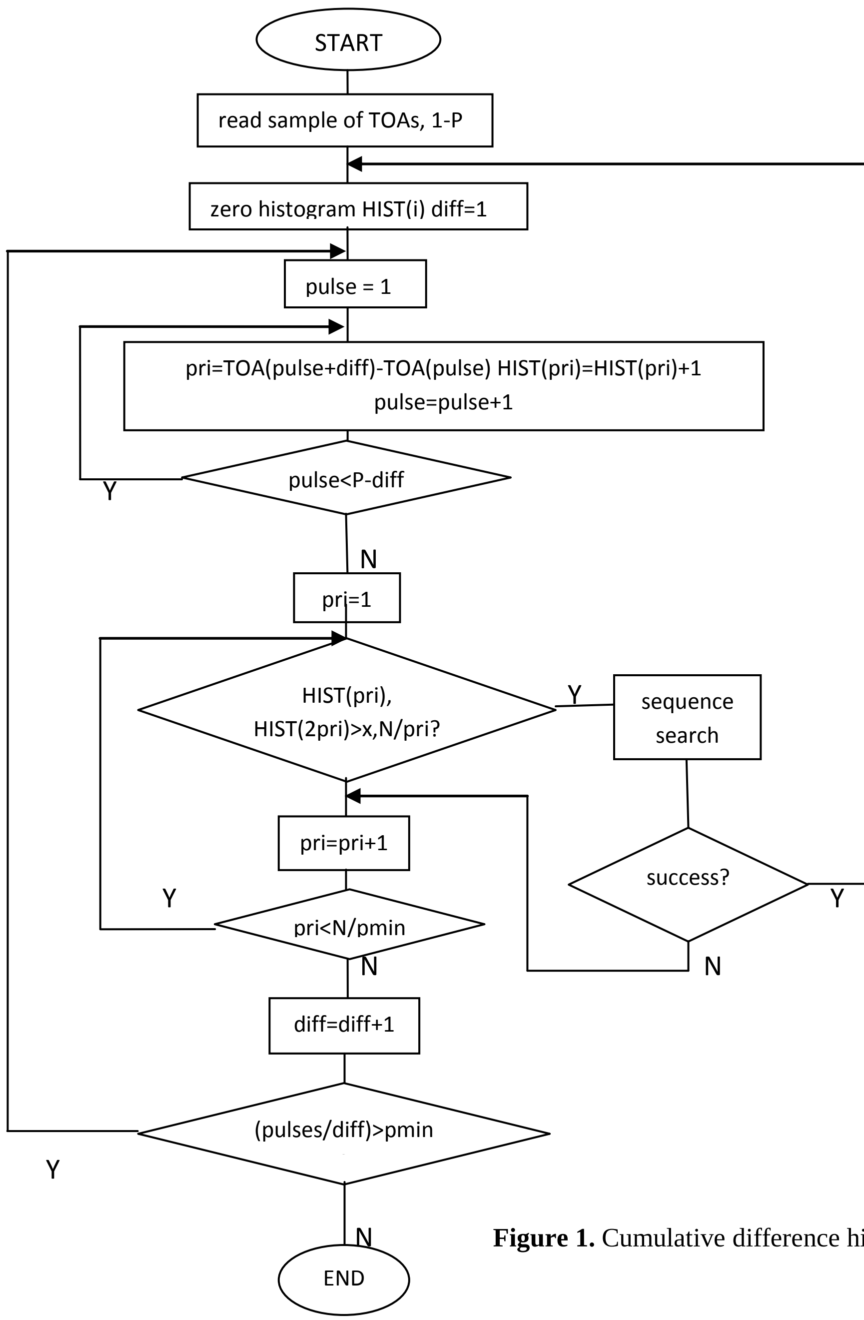


Figure 1. Cumulative difference histogram flowchart.

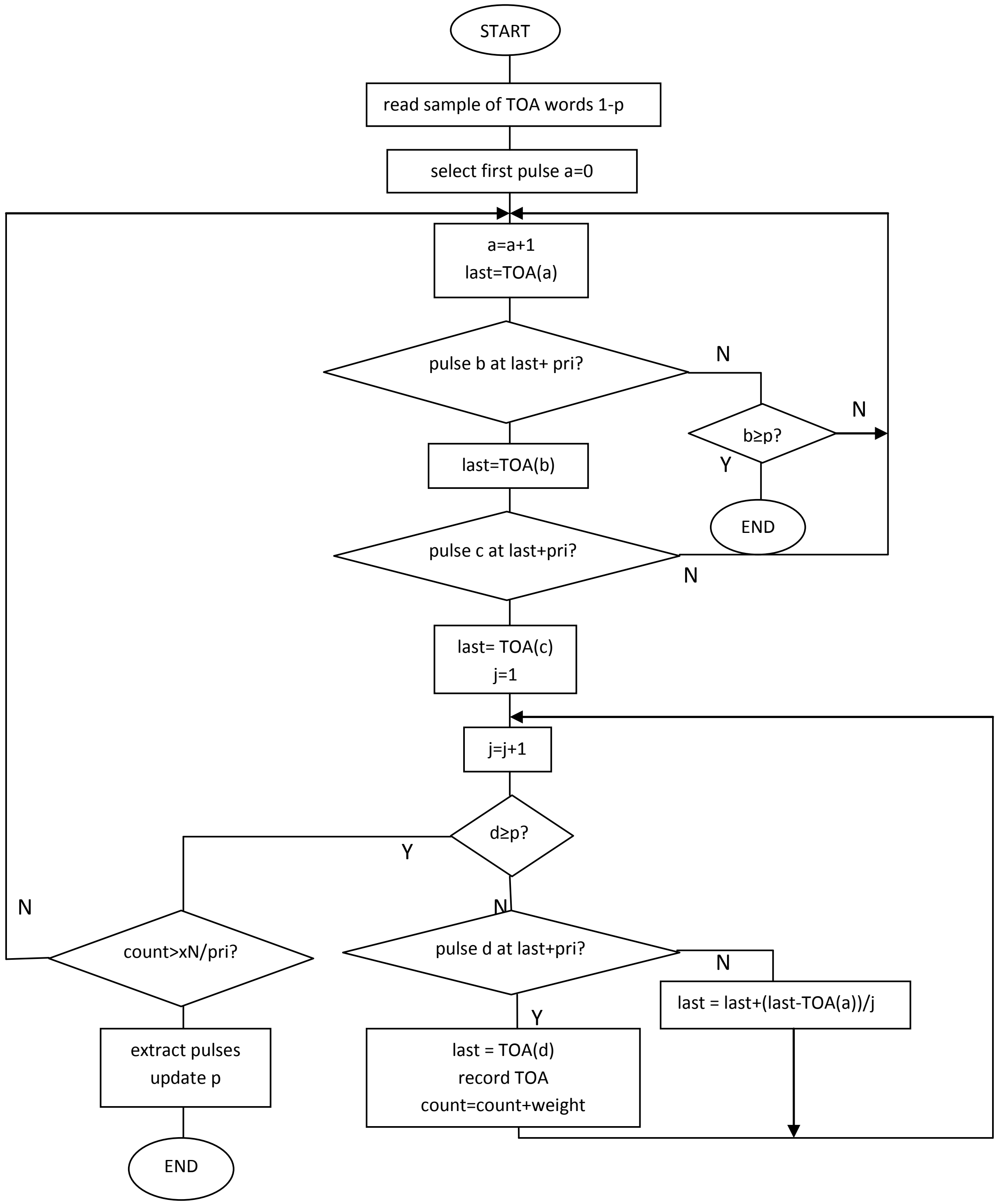


Figure 2. Weighted sequence search flowchart.

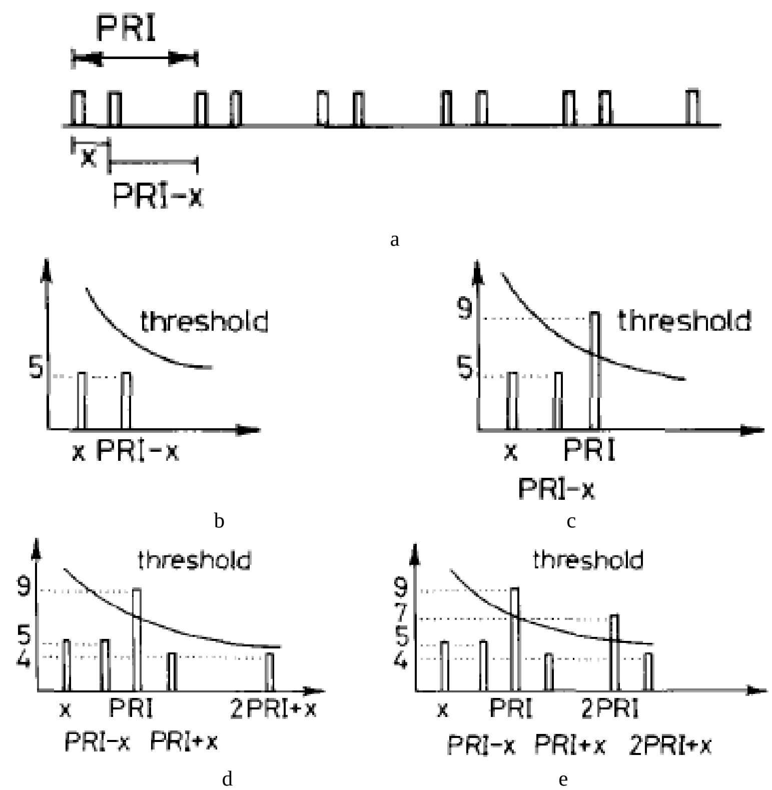


Figure 3. CDIF histogram of two interleaved radar signals. a) Pulse sequence represents two radar signals with the same PRI or radar with a PRI from Stagger type; b to e) Differences of one to four orders.

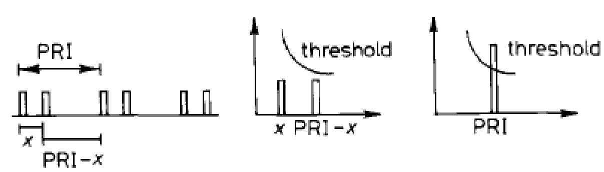
The most important problem of this method is that the different orders differences, even at very simple modes, must be calculated. If it is need to second harmonic of main PRI, then its calculation limited to the modes that a sequence of three events (not only two) occurs in. But such thing in the second part of algorithm (sequence search) is obtainable with imposing a condition. In fact, if the presence condition of second harmonic be excluded, then there is no need to summing up in other difference histogram and this is the main idea of using the algorithm SDIF that it is not necessary calculating the sum in sequential difference levels in its structure.

The main point of each detection technique is based on the threshold function histogram. It can be proved that for CDIF histogram, optimum threshold is proportional to the bin ordinal number. However, it can be stated that for SDIF, this function is in the exponential form.

Description of the Improved Algorithm

This novel algorithm is composed of two parts: PRI estimation and sequence search. PRI estimation, as a main part of separation algorithm, will be addressed later. However, sequence search part is considered similar to basic algorithm in order to compare this technique with the original algorithm.

In Figure 4, histogram of SDIF of two radar signals with the same PRI drawn that is the same as Figure 3. The current difference exists in this histogram simply and this histogram is so cleaner than the basis algorithm histogram. As we can see in the Figure, to extract the correct value of PRI, it is enough to calculate the difference of second order and compare with threshold; meanwhile it is no need to compare two times PRI with threshold. Thus the time of calculation is a little more than half of the previous mode.



a b c

Figure 4. a) Histogram of SDIF of two interleaved radar signals; b) First difference; c)Second difference.

Figure 5 shows the improved algorithm flowchart. For any difference from *c* order, histogram SDIF formed and its threshold function calculated. Then all peaks that exceed from threshold introduced to process as candidate of PRI. If extracting the PRI is successful, then extracting the pulses train continuous till only 5 pulses remain in buffer. If the sequences of PRI no obtain in search sequence, then the next difference and its consequence the new threshold function calculated and the process starts again. At the end of analyzing the PRI it is need to identify the Stagger modulation.

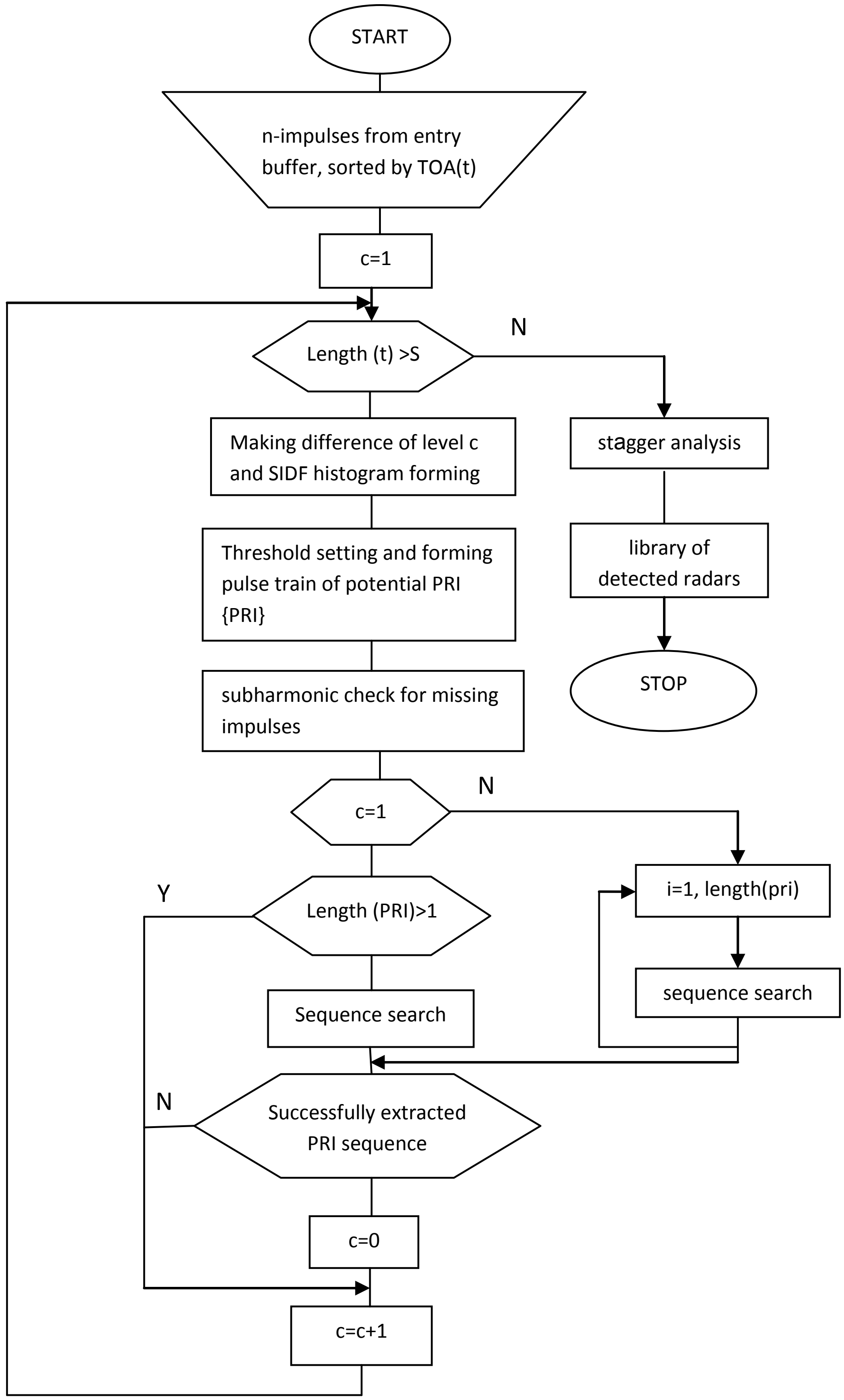


Figure 5. Flowchart of modified 'interval-only' algorithm based on SDIF histogram of TOA.

The optimal detection threshold for SDIF histogram

Depending on the number of bins in SDIF histogram, it is required to find the optimum threshold function in order to determine which histogram peak can be a candid for real PRI. It may be easily observed that threshold function is proportional to the inverse of bins number (τ). Due to proportionality of a histogram's bins with pulse intervals, time of observation is also limited. In a limited observation time, the more are the intervals of pulse observations, the less is the number of that time interval observations. Such threshold can be stated as follows:

$$P(\tau) = \frac{xE}{\tau} \quad (1)$$

Which,

E is the collective observed pulses and x is a constant less than 1.

If the number of observed pulses is big enough and several radiators are active simultaneously, the intervals of consecutive pulses can be considered as a random process. That is, ascending edge of pulses is considered as Poisson points [6]. Moreover, each limited observed interval, e.g. T, is divided into *n* sub-interval. As we know, the probability of k of n points to be in the range of interval $\tau=t_2-t_1$ is based on Poisson distribution [6]:

$$P_K(\tau) = \frac{(\lambda\tau)^K}{k\,!} e^{-\lambda\tau}, k = 0,1,2,... \quad (2)$$

Which,

λ is Poisson process parameter, indicating the medium number of events occurred in time unit. If a pulse train is observed from several radiators, the number of arrived pulses will be proportional to the total observation time or total number of bins (N).

The probability of placing one of the Poisson points in interval τ is achievable for k=0:

$$P_0(\tau) = e^{-\lambda\tau} \quad (3)$$

This is proportional to the consecutive pulses interval,τ. That is, the histogram of first differences will be in the form of the above equation. Regarding that the estimation histogram of a probability distribution function is a random event, high order histograms will be also in the exponential form. Maximum peak of histogram will be decreased with the increase in orders, because the number of pulses produced by c-histogram is E-c. If the time delay is proportional to the number of samples, or total number of histogram's bins, Poisson distribution parameter will be λ=(1/kN); where k is a constant less than 1. Thus, it can be concluded that the optimum threshold function is:

$$\text{threshold}(\tau) = x\,(E - c)e^{\frac{-\tau}{(kN)}} \quad (4)$$

Where,

E is the aggregate number of pulses, N is the number of available bins in histogram, and c is the order of difference. The optimum values for x and k are obtained empirically. Given that the probability of loss of pulse is considered as a random event with uniform distribution, and in turn increases the threshold, it might be stated that parameter x is proportional to the maximum number of lost pulses.

As it was seen, exponential threshold is much better than two other thresholds because exponential function proportionality to a process's essence is high. Using this novel threshold the time of analysis will be significantly decreased as this algorithm introduces only several limited PRIs into the sequence search process.

RESULTS

The results of applying introduced threshold s are drawn in Figure 8. In this figure, the red, green and yellow curves are related to $\frac{1}{x}$ and exp (-x) and $\frac{1}{\sqrt{x}}$ functions respectively and blue curve represents the PRI values. The existing problem here is that it is not easy to regulate these thresholds, so that if a threshold with specific data results in a desire answer there is no guarantee that other data leads to same results.

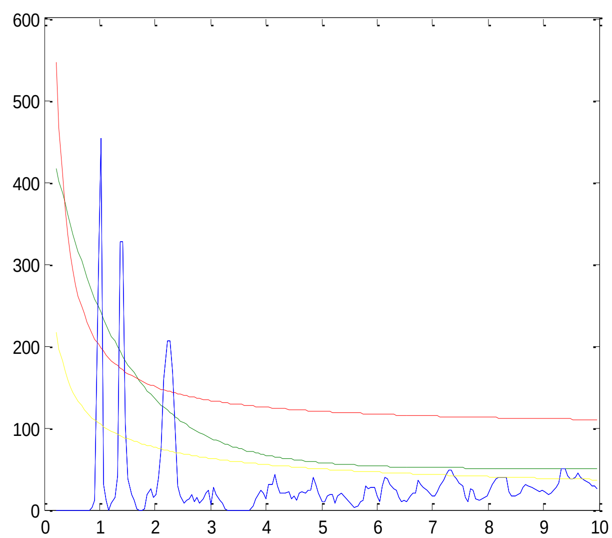


Figure 6. Deinterleaving algorithm output with assumption of three different PRIs and various thresholds.

Thus, using the other features in PDW is a better way. These, generally, are: angle of arrival (AOA), pulse width (PW), time of arrival (TOA), radio frequency (RF), amplitude (Amp) and so on.

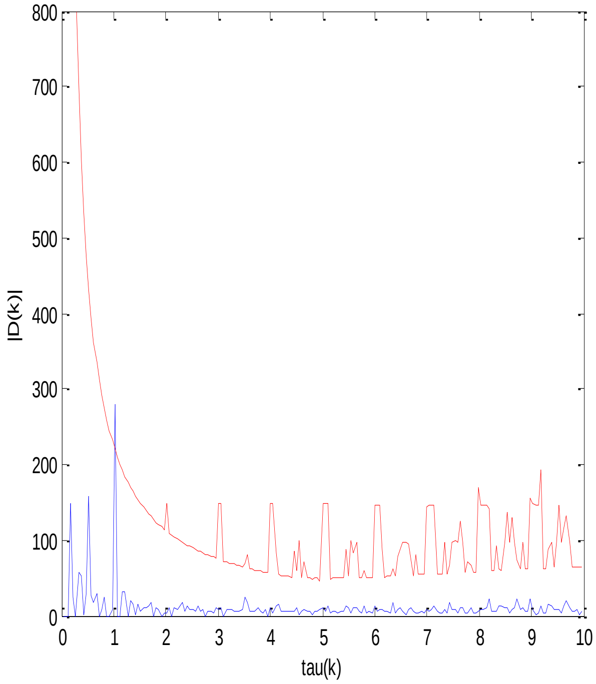


Figure 7. Improved algorithm for estimating PRIs applies to interleaved pulse (trains with PRI jitter).

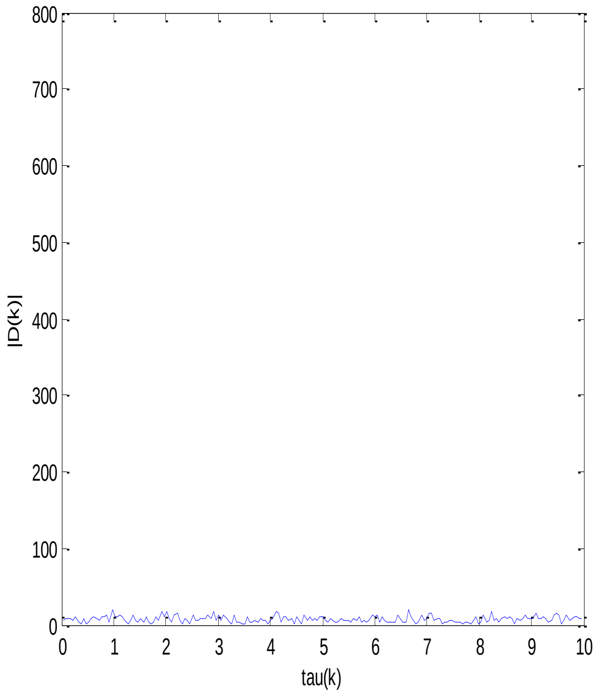


Figure 8. Original algorithm based on PRI transform applies to interleaved pulse (train with PRI jitter. Mean PRIs are 1, $\sqrt{2}$ and $\sqrt{5}$).

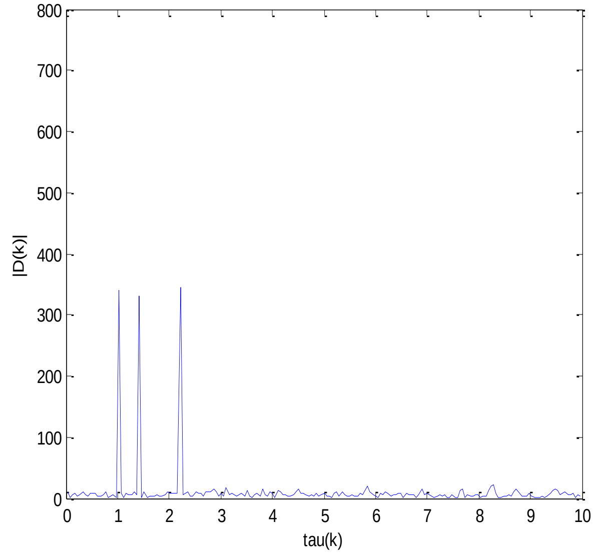


Fig. 9- Original algorithm based on PRI transform applies to interleaved pulse (train with constant PRIs 1, $\sqrt{2}$ and $\sqrt{5}$).

DISCUSSION

Time-of-arrival (TOA) deinterleaving is employed in ESM processing to identify and extract the pulses of each radar signal.

A cumulative TOA difference histogram gives an indication of probable pulse repetition intervals (PRIs) with a minimum number of computations. Validation and identification is given by searching for a sequence of these pulse intervals. The technique presented is less sensitive to interfering pulses and more robust to missed pulses than conventional published techniques. This TOA deinterleaver has been incorporated into an ESM receiver simulation combined with an adaptive clustering process [7].

The improved algorithm is shown that the new method is very successful in high-pulse-density radar environments and for complex signal types.

CONCLUSION

The capability of an ESM/ELINT system to correctly identify detectable radar emissions in a dense environment is a key to their application in modern command, communication and control system. The recording data and results of their analysis help us to extract some facts to constructing the knowledge base and design the expert systems in the last stage of radar identification.

This paper presents a modified and improved algorithm for interleaving radar pulses, based on TOA analysis using the SDIF histogram and its application to a multiple-parameter interleaving algorithm. Computer simulation shows that the presented algorithm based on TOA analysis produces very good results multiple-parameter interleaving algorithm, which includes the new SDIF histogram analysis of TOA.

REFERENCES

[1]. R. G. Wiley, "Electronic Intelligence: The Analysis of Radar Signals, 2nd Edition", Artech House, Inc., 1993.

[2]. J. Matuszewski, K. Banasiak, S. Wnuczek. Some aspects of radar signals acquisition, analysis and recognition. *Proceeding of "Sensors & Electronics Technology Panel". SET Symposium*, Warsaw, Poland, 23-25 April 2001, RTO-MP-070 AC/323 (SET-047) TP/17, pp. 44-1 – 44-12.

[3]. J. Dudczyk, A. Kawalec, J. Cyrek "Applying the Distance and Similarity Functions to Radar Signals Identification", *IEEE Xplore*, 2007.

[4]. H. C. Shyu, C. C. Chang, Y. J. Lee, C. H. Lee, "Radar Signal Clustering and Deinterleaving by a Neural Network"**,** *IEICE Trans Fundamentals of Electronics, Communications and Computer Sciences* Vol. E80-A, No. 5, 1997, pp. 903-911.

[5]. D. W. Lee, J. W. Han, K.H. Song, Y.J. Ryoo, "Radar Signals Clustering Method Using Frequency Modulation Characteristics And Combination Characteristics of Signals, And System For Receiving And Processing Radar Signals Using The Same", *Patent application*, No. 20100283666, 2010.

[6]. Papoulis, A.: 'Probability, random variables and stochastic processes' (McGraw Hill, 1986).

[7]. Mardia, H.K.: 'Digital signal processing for radar recognition in dense radar environments'. PhD thesis, Electrical Eng. Dept., Leeds University, 1988**,** pp. 3248, 108-115.