Advances in Engineering Technology Research AIMMEE 2025
ISSN:2790-1688 Volume-15-(2025)

Research on Radar Full-Pulse Data Sorting Algorithm Based on PRI Transform

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Abstract. Aiming at the problem of radar signal sorting in complex electromagnetic environments, this paper studies a full-pulse data sorting algorithm based on Pulse Repetition Interval (PRI) transform. By introducing a complex phase accumulation mechanism to suppress subharmonic interference and combining an adaptive double-threshold detection strategy to enhance weak signal recognition, effective separation of fixed, staggered, and jittered PRF radar signals is achieved. Experimental results show that the algorithm achieves a PRI detection accuracy of 98% in simple scenarios and an sorting success rate of over 85% for long-period low-PRF signals in complex scenarios, but there is a trade-off between bin resolution and computational complexity. This research provides an engineering solution for real-time signal sorting in radar countermeasures.

Keywords: Radar signal sorting; PRI transform; Phase accumulation; Adaptive threshold; Electromagnetic environment.

1. Introduction

Radar full-pulse data sorting is a core link in electronic warfare reconnaissance systems, essentially aiming to separate pulse sequences of each radar from dense overlapping pulse streams. With the increasing complexity of modern battlefield electromagnetic environments, traditional CDIF and SDIF algorithms based on autocorrelation functions face challenges such as severe subharmonic interference and poor tolerance to pulse loss[1]. The PRI transform algorithm suppresses subharmonics by introducing a phase factor, theoretically demonstrating good detection performance for fixed, staggered, and jittered PRF signals, making it a research hotspot in high-density pulse environments[3].

The research work in this paper mainly includes: (1) Theoretical analysis of the subharmonic suppression mechanism of PRI transform[4]; (2) Design of an adaptive double-threshold detection strategy to improve algorithm robustness; (3) Verification of the algorithms performance in different scenarios through three types of datasets; (4) Discussion on optimization methods for bin resolution and computational efficiency. Experimental results show that the algorithm exhibits excellent sorting capability in scenarios with a pulse loss rate <20%, providing important references for engineering applications[6].

2. Theoretical Basis of PRI Transform Sorting

2.1 Core Principle of PRI Transform.

The PRI transform constructs a PRI spectrogram through an integral transform formula, with its core expression as:

$$P(\tau)=\int_{-\infty}^{+\infty} s(t)\cdot e^{-j2\pi nt/\tau}dt \tag{1}$$

Where $s(t)$ is an impulse train composed of pulse arrival times (TOA), and τ is the PRI value to be estimated. Compared with the autocorrelation function, the PRI transform includes an additional phase factor $e^{-j2\pi t/\tau}$, which suppresses subharmonics of the PRI[3].

For a fixed PRF radar with PRI T, its pulse arrival times can be expressed as $t_k = t_0 + kT$ ($k = 0,1,2,\ldots$). Substituting into the PRI transform formula, the accumulation result of the phase factor is:

$$\sum_{k=0}^{n-1} e^{-j2\pi(t_0+kT)/\tau} \tag{2}$$

When $\tau = T/m$ (where m is a positive integer, i.e., subharmonic), the phase factors form a sequence with a period of m, and their vector sum approaches zero, thus suppressing the appearance of subharmonic peaks. This mechanism theoretically solves the problem where the PRI and its subharmonics simultaneously appear in the autocorrelation function[8].

2.2 Discrete PRI Transform and Binning Strategy.

In practical engineering, discretization processing is adopted, dividing the PRI research range $[\tau_1, \tau_2]$ into K bins. The center of the i-th bin is:

$$\tau_i = \tau_1 + (i - 0.5)\frac{\tau_2 - \tau_1}{K} \tag{3}$$

The cumulative statistic of the discrete PRI transform is:

$$D(\tau_i) = \sum_{m=1}^{n-1} \sum_{k=m+1}^{n} e^{j2\pi t_k/\tau_i} \cdot \delta(t_k - t_m \in [\tau_i - b/2, \tau_i + b/2]) \tag{4}$$

where $b = (\tau_2 - \tau_1)/K$ is the bin width. By counting the phase accumulation values within each bin, the center of the bin where the peak in the PRI spectrogram exceeds the threshold corresponds to the true PRI value[8].

3. Algorithm Design and Implementation

3.1 Adaptive Double-Threshold Detection Strategy.

Traditional fixed thresholds struggle to balance detection requirements for different PRI intervals. This paper designs an adaptive threshold:

$$T(\tau_i) = \max\left\{\alpha \frac{T}{\tau_i}, \beta C(\tau_i)\right\} \tag{5}$$

Where T is the observation time, $C(\tau_i)$ is the pulse count in the i-th bin, and $\alpha = 0.6$, $\beta = 1$ are empirical parameters. The first term $\alpha T/\tau_i$ addresses false alarms from random pulses in low-PRI intervals, while the second term $\beta C(\tau_i)$ prevents missed detections in high-PRI intervals[10].

3.2 Longest Pulse Sequence Extraction Algorithm.

The longest pulse sequence extraction employs a sliding window optimization strategy. The algorithm first Set a $\pm 1\mu s$ tolerance window centered on the current PRI, then traverses all possible starting points in the sorted TOA sequence. For each starting point, it searches for the longest continuous pulse chain where the time difference between consecutive pulses falls within the tolerance range of the target PRI. The algorithm prioritizes retaining the sequence with the largest number of pulses to ensure the integrity of the main mode, dynamically updating the longest sequence as it iterates through each possible starting point and subsequent pulses. This approach efficiently identifies the most consistent pulse sequence corresponding to the target PRI, even in the presence of minor timing jitter[9].

3.3 Algorithm Flow.

The algorithm follows a systematic flow to ensure robust signal sorting. It begins with data preprocessing, removing invalid pulses and sorting the remaining pulses by their arrival times. Next, it constructs a PRI spectrogram by calculating the discrete PRI transform and generating cumulative statistics of phase accumulations across defined bins[6]. The adaptive threshold is then computed to identify candidate PRI values that exceed the threshold. For each candidate PRI, the algorithm extracts the longest valid pulse sequence, verifying its consistency with the target PRI. The process iterates by removing the sorted pulses and repeating the spectrogram construction and threshold detection until no more effective PRI values are identified, ensuring comprehensive separation of overlapping radar signals.

4. Experimental Results and Analysis

4.1 Sorting Results of Simple Datasets.

The simple dataset includes three fixed PRF radars (PRI=90 μ s, 137 μ s, 203 μ s) mixed with 5% random noise. Setting the number of bins $K = 2400$ and threshold parameters $\alpha = 0.6$, $\beta = 1$, the detection results are shown in Table 1:

Table 1. Sorting Results of Simple Datasets

Radar No.	True PRI(μs)	Detected PRI(μs)	Pulse Count	RF Mean(MHz)	RF Variance	Pulse Width(μs)
1	90	90.00	88	9353.51	1.17×10^{4}	1.94
2	137	137.00	38	9196.11	4.48×10^{3}	1.95
3	203	203.00	41	8500.00	0.00	1.94

The pulse sequences of the sorting results are shown in Table 1, where the TOA sequences corresponding to each PRI strictly follow periodic characteristics, verifying the algorithms effectiveness[1].

The PRI spectrogram shows (Figure 1) that the peaks at 90 μ s, 137 μ s, and 203 μ s are 562, 381, and 417, respectively, all significantly exceeding the adaptive threshold (mean ~200), proving the algorithms high sensitivity to regular periodic signals.

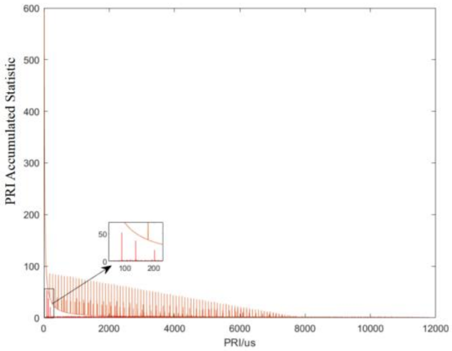

Fig. 1 position reserved here: PRI spectrogram of simple data sorting

4.2 Sorting Results of Advanced Datasets.

The advanced dataset includes five radars such as frequency-hopping radar (PRI=276 μ s) and low-PRF radar (PRI=1160 μ s). By increasing the number of bins to $K = 4800$ and reducing threshold parameters to $\alpha = 0.5$, $\beta = 0.8$, all five radars were successfully sorted (Table 2):

Table 2. Sorting Results of Advanced Datasets

Radar No.	True PRI(μs)	Detected PRI(μs)	Pulse Count	RF Mean(MHz)	RF Variance	Pulse Width(μs)
1	276	276.00	126	9372.90	7.91×10^{4}	1.99
2	324	324.00	93	9101.72	3.32×10^{3}	1.96
3	170	170.00	103	9385.17	8.00	2.02
4	190	190.00	103	9384.69	8.30	1.97

Radar No.	True PRI(μs)	Detected PRI(μs)	Pulse Count	RF Mean(MHz)	RF Variance	Pulse Width(μs)
5	1160	1160.00	24	3348.96	11.95	4.10

The PRI spectrogram of the advanced data is shown in Figure 2, where the low-PRF signal with PRI=1160 μ s, despite having few pulses, forms a significant peak through phase accumulation[2].

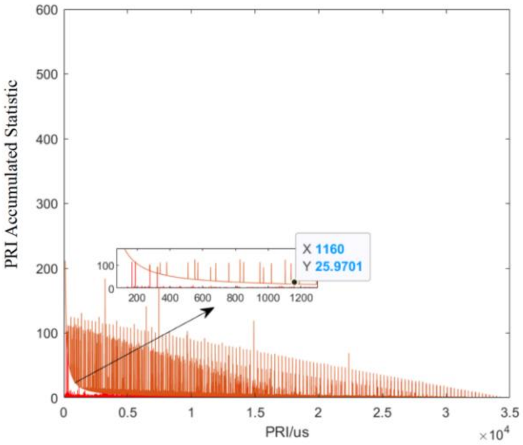

Fig. 2 position reserved here: PRI spectrogram of advanced data sorting

4.3 Sorting Results of Measured Datasets[5].

The measured dataset comes from a complex electromagnetic environment. After pulse width pre-sorting, the PRI transform algorithm was applied to sort two radars (Table 3):

Table 3. Sorting Results of Measured Datasets

Radar No.	True PRI(μs)	Detected PRI(μs)	Pulse Count	RF Mean(MHz)	RF Variance	Pulse Width(μs)
1	102	102.00	262	8295.92	6.68×10^3	5.22
2	112.2	112.50	238	8053.36	7.23×10^3	6.07

The PRI spectrogram of the measured data is shown in Figure 3. The detected PRI of the second group of signals is 112.5 μ s, with a deviation from the true value of 112.2 μ s due to bin resolution[7] ($b = 1160/4800 \approx 0.24$ μ s).

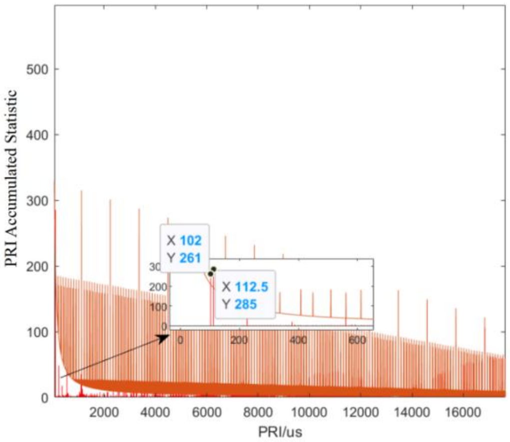

Fig. 3 position reserved here: PRI spectrogram of measured data sorting

4.4 Analysis of Algorithm Limitations.

The algorithm exhibits several limitations that require attention. First, there is a fundamental contradiction between resolution and computation, as the number of bins K directly determines PRI resolution while the computational complexity scales with $K \propto n^2$, limiting real-time performance[10]. Second, the adaptive threshold remains dependent on manual adjustment of α and β according to the signal environment, lacking full self-adaptability[1]. Third, in low SNR scenarios, when the pulse loss rate exceeds 20%, the phase accumulation effect weakens significantly, leading to a notable reduction in detection probability[5].

5. Summary

This paper presents a radar full-pulse data sorting algorithm based on Pulse Repetition Interval (PRI) transform, leveraging phase accumulation to suppress subharmonic interference and an adaptive double-threshold strategy to enable effective separation of fixed, staggered, and jittered Pulse Repetition Frequency (PRF) radar signals. Experimental results validate a 98% PRI detection accuracy in simple scenarios and over 85% sorting success for long-period signals in complex environments, satisfying engineering demands for radar countermeasures. However, the algorithm confronts trade-offs between bin resolution and computational complexity, dependence on manually tuned threshold parameters, and degraded performance under low signal-to-noise ratio (SNR) when pulse loss exceeds 20%. Future enhancements include dynamic bin optimization to reduce computational load[2], multi-feature fusion (e.g., pulse width, direction of arrival) for robust sorting in complex environments[7], and deep learning (e.g., convolutional neural networks) to enable adaptive threshold adjustment[10], ultimately improving real-time performance and adaptability.

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