# Anti-electromagnetic interference method based on high-order cumulant method and PRI sorting

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**Abstract.** Facing the increasingly complex electromagnetic environment, how to make the detection instrument still have better detection performance is one of the current research hotspots. This paper proposes an anti-electromagnetic interference method based on high-order cumulant and PRI sorting. The former identifies the modulation type of the signal, the latter sorts the signals with different modulation parameters of the same modulation type, and finally selects the signal to be processed. The simulation results show that the algorithm is accurate and effective.

**Keywords:** Higher order cumulants, PRI sorting, Electromagnetic interference.

## 1 Introduction

In daily life, the popularization of communication equipment such as mobile phones has brought great convenience to people's lives, but for some measuring instruments, these are one of the main sources of electromagnetic interference. This kind of signal interference will have different degrees of influence on the measuring equipment. Therefore, how to reduce the influence of electromagnetic interference is one of the main tasks in the research and development of many measuring instruments. Reference [1] Improved LOR filtering algorithm and parallel processing, and achieved good results. Reference [2] describes various measures to suppress EMI from the hardware side. Sorting algorithms based on pulse repetition interval (PRI) are usually used in the field of radar signal sorting. There are many such algorithms, such as sequential difference histogram (SDIF) and sequential difference histogram cumulative[3], etc. At the same time, we noticed that the improved PRI transform method still has good performance when the signal has large jitter. Reference [4] uses the PRI transform method to achieve better sorting performance. However, when the semaphore density is too large, this method will be greatly constrained[5]. Therefore, this paper proposes a PRI sorting algorithm based on high-order cumulants. The signal is first classified by the modulation type using the high-order cumulant method, while the arrival time of each pulse is recorded. Then, based on TOA, PRI sorting is performed on the received signals of different modulation types. At this time, the amount of signals decreases sharply, and a better sorting effect can be achieved.

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## 2 Methods

### 2.1 Signal model

When considering Gaussian noise interference, the complex expression of digital modulation signal is as follows:

$$x(t)=\sum_k a_k\sqrt{E}q(t-kT)e^{j(2\pi f_c t+\theta_c)}+n(t) \tag{1}$$

$k=1,2,3,...,N$ , $N$ is the number of transmitted symbol sequences, $q(t)$ is the baseband symbol waveform, $a_k$ is the symbol sequence, $T$ is the symbol width, $E$ is the energy of the transmitted symbol waveform, $f_c$ is the carrier frequency, $\theta_c$ is the initial phase of the carrier, and $n(t)$ is white Gaussian noise with zero mean.

Assuming that the carrier frequency, phase, and timing of the received signal are synchronized, the complex baseband signal processed by down-conversion can be expressed as:

$$x(t)=s(t)+n(t)=\sum_k a_k\sqrt{E}q(t-kT)e^{j\Delta\theta_c}+n(t) \tag{2}$$

$\Delta\theta_c$ is the carrier phase difference.

### 2.2 Modulation type identification

High-order cumulants include second-order and higher-order statistical information, and high-order cumulants of different orders contain different modulation characteristics of modulation signals, so modulation type identification can be performed according to high-order cumulant characteristics. At the same time, since the cumulant of Gaussian noise is zero at the second order and above, for the received signal, the influence of additive white Gaussian noise can be ignored when calculating the cumulant of the second order and above, which has better robustness.

For a zero-mean complex random process $x(k)$, its $p$ -order mixing moment can be expressed as:

$$M_{pq}=E(x(k)^{p-q}x^*(k)^q) \tag{3}$$

where * denotes conjugation.

The relationship between moments and cumulants of random vectors is:

$$cum(x_1^{k_1},x_2^{k_2},...,x_n^{k_n})=\sum(-1)^{q-1}(q-1)!\prod_{p=1}^{q}E\{\prod_{l=U_p}S_l\} \tag{4}$$

The above expression sums all possible divisions in $X=\{x_1,x_2,...,x_n\}$ , Among them, $x_1,x_2,...,x_n$ is a random vector, $k_1,k_2,...,k_n$ represents the order of $x_1,x_2,...,x_n$ respectively, $q$ represents the number of subsets that may be divided, and $U_p$ represents the set of all subsets and the p-th subset. From the formula, the calculation formula of the second-order to sixth-order cumulant of $x(k)$ is as follows:

$$\begin{cases} C_{20} = \mathrm{M}_{20} \\ C_{21} = \mathrm{M}_{21} \\ \mathrm{C}_{40} = \mathrm{M}_{40} - 3M_{20}^2 \\ C_{41} = \mathrm{M}_{41} - 3M_{21}M_{20} \\ C_{42} = \mathrm{M}_{42} - \left|M_{20}\right|^2 - 2M_{21}^2 \\ C_{60} = \mathrm{M}_{60} - 15M_{40}M_{20} + 30M_{20}^3 \\ C_{63} = \mathrm{M}_{63} - 6M_{20}M_{41} - 9M_{42}M_{21} + 18M_{20}^2M_{21} + 12M_{21}^3 \end{cases} \quad (5)$$

Assuming that the energy of the modulated signal is E, the theoretical cumulative value of each modulation type is shown in table1:

**Table1.** Higher-order cumulant theoretical value of the signal.

| Modulation | $\lvert C_{20} \rvert$ | $\lvert C_{21} \rvert$ | $\lvert C_{40} \rvert$ | $\lvert C_{41} \rvert$ | $\lvert C_{42} \rvert$ | $\lvert C_{60} \rvert$ | $\lvert C_{63} \rvert$ |
|---|---|---|---|---|---|---|---|
| BPSK | E | E | $2E^2$ | $2E^2$ | $2E^2$ | $16E^3$ | $13E^3$ |
| QPSK | 0 | E | $1E^2$ | 0 | $1E^2$ | 0 | $4E^3$ |
| 8PSK | 0 | E | 0 | 0 | $E^2$ | 0 | $4E^3$ |
| 8QAM | 0 | E | $1.36E^2$ | 0 | $1.03E^2$ | 0 | $56.177E^3$ |
| 16QAM | 0 | E | $0.68E^2$ | 0 | $0.68E^2$ | 0 | $2.08E^3$ |
| 32QAM | 0 | E | $0.19E^2$ | 0 | $0.69E^2$ | 0 | $2.11E^3$ |

It can be seen from the table that the high-order cumulative value of each modulation type will be different, so the modulation types can be distinguished according to the calculated data.

### 2.3 Improved PRI transform

Let $t_n (n = 0,1,2,..., N-1)$ be the arrival time of the leading edge of the pulse, the pulse sequence can be expressed as:

$$g(t) = \sum_{n=0}^{N-1} \delta(t - t_n) \quad (6)$$

Define the integral transform $D(\tau)$ of $g(t)$ as the PRI transform of $g(t)$:

$$D(\tau) = \int_{-\infty}^{\infty} g(t)g(t+\tau)\exp(\frac{2\pi it}{\tau})dt \quad (7)$$

Substitute the above formula into the autocorrelation function to get:

$$D(\tau) = \sum_{n=1}^{N-1}\sum_{m=0}^{n-1} \delta(\tau - t_n + t_m)\exp\left[2\pi i t_n (t_n - t_m)\right] \quad (8)$$

$D(\tau)$ represents a PRI spectrum, At the potential PRI, there will be a peak at the corresponding position in the PRI spectrum. In the formula, $\exp\left[2\pi i t_n(t_n - t_m)\right]$ is the phase factor, which can largely prevent the generation of sub-harmonics and can estimate the real PRI very accurately.

The PRI transform method needs to be discretized in use, so it is necessary to obtain the discrete form of the PRI transform. Set the observed PRI range, denoted by $[\tau_{\min}, \tau_{\max}]$, and evenly divide the observation interval into K equal intervals, which are called PRI boxes.

The discrete PRI transform formula can be expressed as:

$$D_k = \int_{\tau_k - b/2}^{\tau_k + b/2} D(\tau)\mathrm{d}\tau = \sum_{\tau_k - b/2 < t_n - t_m < \tau_k + b/2} \exp\left[2\pi i t_n(t_n - t_m)\right] \tag{9}$$

$|D_k|$ represents the corresponding number of pulses at the PRI. When the peak value of $|D_k|$ exceeds the threshold, it is considered that the interval corresponding to the peak value at this position is a possible PRI value.

Detection threshold setting method:

$$A_k = \max\{\alpha \frac{T}{\tau_k}, \beta C_k, \gamma\sqrt{T\rho^2 b_k}\} \tag{10}$$

α, β, γ are all adjustable parameters, where $\gamma \geq 3$.

The PRI transformation method is not suitable for occasions with large signal jitter, First, as the arrival time sequence of the pulse sequence deviates from the initial time larger and larger, the phase error of its phase factor is also larger and larger. Second, due to the jitter of the signal, the pulse signal that should have been in the same cabinet is scattered into several adjacent cabinets, so that the peak on the PRI spectrum is weakened, and when it is lower than the set threshold, it cannot be detected[6].

The literature [7] improves it. The main idea is to use a variable starting time, move the starting time continuously, and eliminate its accumulated error to reduce the error of the phase factor. At the same time, the width of the PRI box is expandable, so as to prevent the signal of the box from being scattered into the adjacent boxes.

## 3 Results

From the above analysis, it can be seen that the high-order cumulant method can identify the modulation type of the signal, but cannot identify the signal with different modulation parameters under the same modulation type. The PRI transformation algorithm cannot identify the modulation type, which will have an impact when the signal density is too large. Therefore, this paper combines the two methods. First, the high-order cumulant method is used to identify the modulation type. After reducing the signal amount, the improved PRI transform method is used for signal sorting under the same modulation type. The experimental flow chart is shown in Figure 1.

First check the accuracy of the high-order cumulant method to identify the modulation type, assuming that the carrier frequency of the six modulation signals is 10 kHz, the number of symbols is N=2000, the sampling frequency is 40 kHz, and the noise is additive white Gaussian noise. 200 independent experiments were performed on the signal when the ratio environment was the same. The recognition accuracy is shown in Figure 2.

The sorting performance of the improved PRI sorting method in the case of signal jitter is checked again. It can be seen from the results that the improved PRI method still has better performance at 20% jitter. The experimental results are shown in Figure 3:

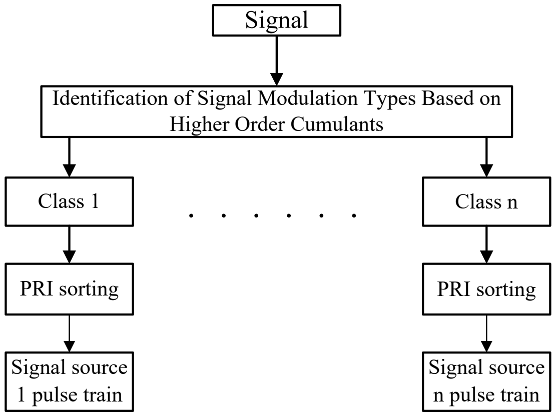


**Fig. 1.** Algorithm flowchart.

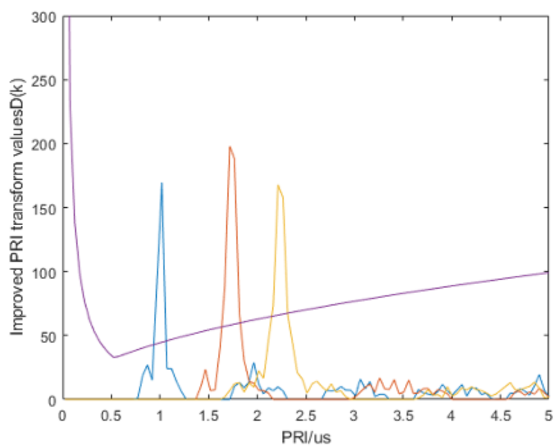


**Fig. 2.** Modulation identification accuracy.

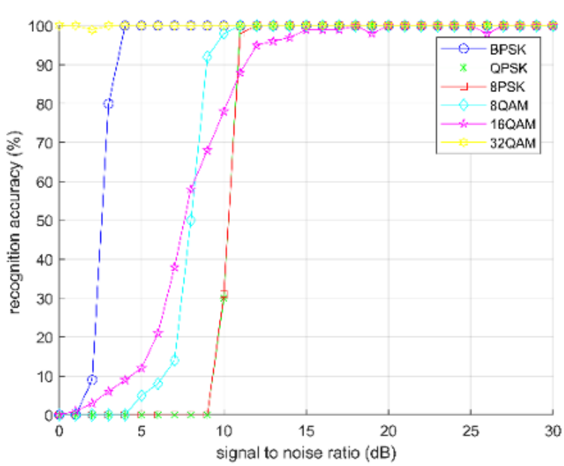


**Fig. 3.** PRI sorting at 20% jitter.

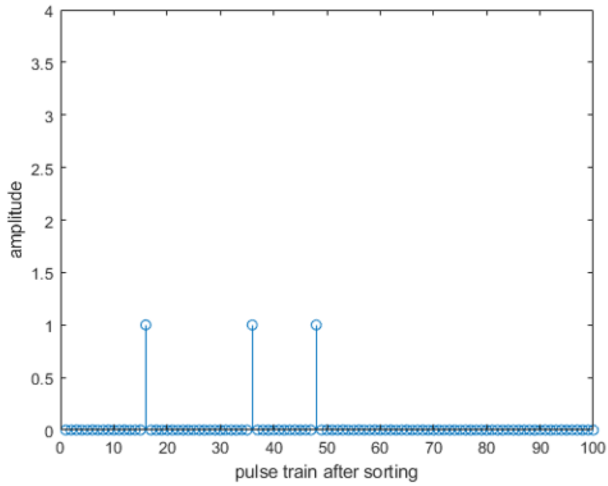


**Fig. 4.** Pulse sequence before sorting.

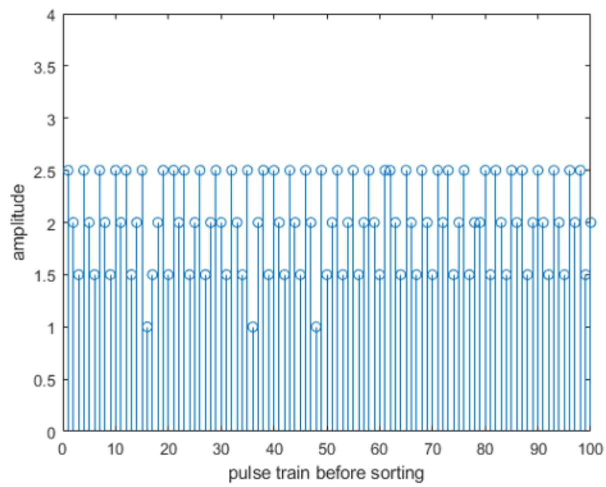


**Fig. 5.** Pulse sequence after sorting.

Combining the two methods on the basis of the above experiments, three periodic pulse sequences are set, the TOA of the signal is recorded at the same time of sorting, and then it is separated from the received signal. The pulse sequence before and after sorting is shown in the figure:

## 4 Conclusion

For the study of anti-electromagnetic interference, this paper proposes a signal sorting method. This algorithm integrates the high-order cumulant and the improved PRI sorting algorithm. First, the signal is classified into the modulation type based on the high-order cumulant algorithm. When the number of samples is reduced, the improved PRI algorithm is used for further sorting. The experimental results show that the algorithm is accurate and reliable.

## References

1. Biao Chen, Qingdong Yao and Ming Shen 2002 Composite Disturbance Filtering Algorithm and Realization for Slow Variation Signals Application Research of Computers vol 6, pp20-51.
2. Ping Wang, Yi Xie and Xuesong Guo 2012 Research on EMC Shielding Technology of Nuclear Instrumentation Nuclear electronics & detection technology vol 7, p32.
3. Bingxin Yi and Wansheng Ling 2014 Radar Signal Sorting Technology in Complex Electromagnetic Environment Electronic Information Warfare Technology vol 6, pp 57-59.
4. Yu Wang 2010 Research on rapid algorithm for sorting and identification of unknown radar signal.
5. Danfeng Cai and Wei Lin 2017 New algorithm for sorting in tra-pulse modulated signals based on PRI Experimental Technology and Management Vol 4, pp59-63.
6. Bailin Cheng and Jun Han 2010 Sorting of Unknown Radar Emitter Based on WPT-PRI PIEZOELECTRICS & ACOUSTOOPTICS vol 3, pp375-378.
7. Guowen Yu Jun Han and Mao Yan 2008 A new method for sorting unknown radar emitter signals 2008 9th International Conference on Signal Processing.