# Low Complexity Sensing Algorithm of Periodic Impulsive Interference

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**Abstract.** In this paper, a low complexity sensing algorithm based on power spectrum density (PSD) for periodic impulsive interference is proposed. First, the PSD is computed by modified periodogram. Then the time occupancy of spectrum by interference and time interval of interference is computed in multiple detections to determine the presence of impulsive interference. Finally, main parameters of impulsive interference, such as period, duty cycle, bandwidth, and the peak power, are estimated. The computation afford of the proposed algorithm is quite low. The simulation results show that the sensing performance can satisfy the requirement of spectrum sensing.

**Keywords:** Impulsive interference · Sensing · Low complexity

## 1 Introduction

Nowadays, numerous wireless communication systems are deployed for variety of different fields of applications. Without doubt, wireless communication may be exposed to various interference, and noise, due to the open nature of wireless channel [1]. Periodic impulsive interference is a kind of typical interference which can significantly impact the performance of wireless communication systems. For example, impulsive interference generated by high-voltage equipment such as transformers, power lines, and switch-gear within substations has a significant influence for wireless communication in a smart grid context [2]. Wireless DVB-T signals may be impaired by impulsive interference, which is caused by house appliances [3]. In aeronautical communications, L-band digital aeronautical communications system will be exposed to impulsive interference from distance measuring equipment (DME) [4]. In military applications, pulsed jamming can disrupt reliable data transmission or reception of military communication system [5]. Whether it is generated unintentionally or by an opponent, impulsive interference or pulsed jamming can cause a substantial increase in the bit error rate of a communication system relative to the rate caused by continuous interference with the same average power. Therefore, we focus on the detection and parameters estimation of impulsive interference as base of anti-impulsive-interference technology.

Recently, there has been a lot of research on the mitigation of impulsive interference. The popular method to compensate for the performance loss is concatenated


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forward error correction coding combined with frequency-domain block interleaving [6, 7]. Optimal power allocation with respect to sum capacity affected by additive independent Class A impulse noise is proposed [8]. The performance of frame synchronizer in Consultative Committee for Space Data Systems (CCSDS) under pulsed jamming conditions is researched [9]. An efficient statistical processing of impulsive interference of distance measuring equipment (DME) is proposed [4]. In [3], blanking nonlinearity for mitigating impulsive interference in OFDM systems is investigated. However, none of the existed references have researched the sensing algorithm of impulsive interference.

In this paper, we present a low complexity sensing algorithm based on power spectrum density (PSD) for periodic impulsive interference. Based on the sensing results, one can know the presence and main parameters of impulsive interference and exploit the spectrum hole in impulsive interference environment. The outline of this paper is as follows. Section 2 describes the system model under investigation. Section 3 present the impulsive interference sensing algorithm based on PSD in detail. Section 4 presents computer simulation results. Finally, in Sect. 5, some concluding remarks are provided.

## 2 System Model

Impulsive interference is interference that occurs periodically or sporadically for brief durations. Its characteristics are time-varying power with large peak power and low average power. In this paper, the sensing problem of periodic impulsive interference is researched. Some of the important design issues associated with the sensing algorithm for impulsive interference are as follows:

(1) Low complexity, in order to lower the calculation delay required to sense the impulsive interference.
(2) Not requiring prior knowledge, in order to account for the difficulty of acquiring prior knowledge of impulsive interference signals in wireless communication systems.
(3) Strong adaptability. The sensing algorithm should take wide range of period, duty cycle and bandwidth of impulsive interference into consideration.

Therefore, the sensing algorithm for impulsive interference based on PSD is investigated. The following assumptions are given in the paper.

(1) Sensing duration of one time is equal to PSD estimation interval $T_d$.
(2) The starting time of PSD estimation is assumed to be the starting time of impulsive interference.
(3) The interference time and interference-free time of impulsive interference is all the integral multiple of $T_d$.

The block diagram of sensing system of impulsive interference is shown as Fig. 1.

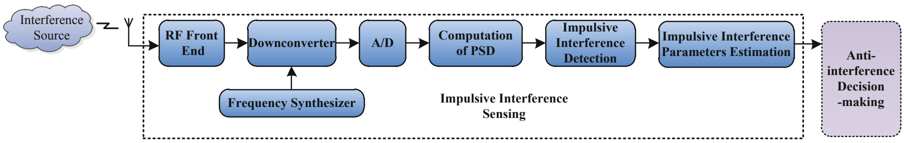


**Fig. 1.** Block diagram of impulsive sensing system

In the sensing system, a broadband radio frequency (RF) front end with a bandwidth $W$ that covers target spectrum should be equipped. The automatic gain control (AGC) is not exploited in the RF front end to detect the actual signal power. By designing the appropriate gain of RF front end, strong impulsive interference will fall on the linear range of RF front end. After the received signal is processed by the RF front end, downconverter, and ADC, impulsive interference is sensed at an intermediate frequency. Therefore, the discrete time received signal after processing by ADC is given by

$$r(n) = I_{pul}(n) + w(n) \tag{1}$$

where $w(n)$ is AWGN with zero mean and unknown variance $\sigma_w^2$, $I_{pul}(n)$ is impulsive interference denoted as

$$\begin{aligned} I_{pul}(n) &= AI(n)\sum_{i=0}^{\infty} D_\tau(n - iT) \\ &= AI(n)\sum_{i=0}^{\infty} [U(n - n_1 - iT) - U(n - n_2 - iT)] \end{aligned} \tag{2}$$

where $A$ is amplitude of impulsive interference, $I(n)$ is continuous interference waveform with zero mean and unknown variance $\sigma_I^2$, $D_\tau(n)$ is rectangular pulse with the duration $\tau = n_2 - n_1$, $T$ is the period of impulsive interference, $U(n)$ is the unit step function. $U(n) = 1$, $n \geq 0$, and $U(n) = 0$, $n < 0$.

## 3 Detection and Parameters Estimation of Periodic Impulsive Interference

In this section, the presence of periodic impulsive interference is determined by detection algorithm firstly. Then the parameters of periodic impulsive interference are estimated.

### 3.1 Detection of Periodic Impulsive Interference

The most popular PSD estimation algorithm is periodogram, which has very low complexity. Therefore, the modified periodogram is explored in the proposed scheme. Every $N$ received samples which correspond to the sensing duration $T_d$ are computed PSD. The modified periodogram is defined as follows [10]:

$$S(f_i) = \frac{\frac{1}{F_s N}\left|\sum_{n=1}^{N} win_n r(n) e^{-j2\pi f_i n}\right|^2}{\frac{1}{N}\sum_{n=1}^{N} |win_n|^2}, i = 1, 2, \ldots, N \tag{3}$$

where $win_n$ is a window, $F_s$ is the sample frequency. In the proposed sensing scheme, PSD is calculated every $T_d$. To smoothen the PSD with large fluctuation generated by the periodogram, a moving average filter is exploited, which has very low complexity and processing delay. The filter can be written as follows:

$$S_{sm}(f_i) = \frac{1}{2M+1}\sum_{j=-M}^{M} S(f_{i-j}) \tag{4}$$

where $S_{sm}(f_i)$ is the smoothened PSD in $f_i$. In this paper, $M = 2$ is used, which can reconcile good smoothening effect and low errors of PSD. The PSD vector after smoothening at $k$th PSD estimation interval is written as

$$\mathbf{S}_{smooth}(\mathbf{f}, k) = [S_{sm}(f_1, k), S_{sm}(f_2, k), \ldots, S_{sm}(f_N, k)] \tag{5}$$

The spectral resolution of every PSD point is

$$\Delta f = \frac{W}{N} \tag{6}$$

where $W$ is the bandwidth of RF front end.

To determine the presence of impulsive interference, the detection threshold $\alpha_{th}$ should be chosen. The PSD with a magnitude exceeding threshold are considered interference. However, the determination of the threshold is a sensitive task because of unknown $\sigma_w^2$. Therefore, we determine $\alpha_{th}$ by method in [11]. $\mathbf{S}_{smooth}(f, n)$ is sorted in descending order firstly. Then a mean value $\alpha_{mean}$ is computed by 20% largest values of PSD. Finally, the initial threshold $\alpha_{th}$ is set to be proportional to $\alpha_{mean}$. In general, $\alpha_{th} = 0.7\alpha_{mean}$ is obtained.

After $K$ detections, the PSD matrix $\mathbf{S}$ can be denoted as

$$\mathbf{S} = [\mathbf{S}_{smooth}(\mathbf{f}, 1),\ \mathbf{S}_{smooth}(\mathbf{f}, 2), \ldots, \mathbf{S}_{smooth}(\mathbf{f}, K)]^T \tag{7}$$

where the superscript $T$ denote transpose. $\mathbf{S}$ is also denoted as

$$\mathbf{S} = \left[\mathbf{S}_f(f_1, \mathbf{K}),\ \mathbf{S}_f(f_2, \mathbf{K}), \ldots, \mathbf{S}_f(f_N, \mathbf{K})\right] \tag{8}$$

where $\mathbf{S}_f(f_n, \mathbf{K}) = [S_{sm}(f_n, 1), S_{sm}(f_n, 2), \ldots, S_{sm}(f_n, K)]$. $\mathbf{S}$ is processed as a dual value according to $\alpha_{th}$, i.e.,

$$S_2(f_n, k) = \begin{cases} 1, S_{sm}(f_n, k) \geq \alpha_{th} \\ 0, S_{sm}(f_n, k) < \alpha_{th} \end{cases}, n = 1, 2, 3, \ldots, N, k = 1, 2, 3, \ldots, K \tag{9}$$

Then we compute the occupancy of spectrum by interference in $K$ detections.

$$\rho(f_n) = \frac{\sum_{k=1}^{K} S_2(f_n, k)}{K} \tag{10}$$

According to experience, we can set the upper and lower threshold of the occupancy of spectrum by interference as $\rho_1$ and $\rho_2$. Impulsive interference is considered as presence in the spectrum with occupancy between $\rho_1$ and $\rho_2$. The spectrum with occupancy below $\rho_1$ is considered as that only AWGN exist. That is

$$\begin{cases} \rho(f_n) < \rho_1, \text{ only AWGN exist} \\ \rho_1 \leq \rho(f_n) \leq \rho_2, \text{ impulsive interference and AWGN may exist} \\ \rho(f_n) > \rho_2, \text{ constant interference and AWGN exist} \end{cases} \tag{11}$$

Then the time slot and frequency range of impulsive interference can be determined initially. The $f_n$ with $\rho_1 \leq \rho(f_n) \leq \rho_2$ is the candidate frequency of periodic impulsive interference. $\mathbf{S}_2(f_n, \mathbf{K}) = [S_2(f_n, 1), S_2(f_n, 2), \ldots, S_2(f_n, K)]$ is dual-value PSD of $f_n$. If the index of element in $\mathbf{S}_2(f_n, \mathbf{K})$ begin from 1, the index of element "1" in $\mathbf{S}_2(f_n, \mathbf{K})$ can compose vector of interference index

$$\mathbf{IND1} = [index_1, index_2, \ldots, index_{M_1}] \tag{12}$$

$M_1$ elements are assumed to compose $\mathbf{IND1}$. Then the elements in $\mathbf{IND1}$ is performed self-difference operation:

$$\mathbf{IND}2 = [(index_2 - index_1 - 1), (index_3 - index_2 - 1), \ldots, (index_{M_1} - index_{M_1 - 1} - 1)] \tag{13}$$

The non-zero elements in $\mathbf{IND}2$ compose vector $\mathbf{IND}3$. We assume $\mathbf{IND}3$ is composed of $M_2$ elements, i.e. $\mathbf{IND}3 = [ind_1, ind_2, \ldots, ind_{M_2}]$. The mean of all elements in $\mathbf{IND}3$ is

$$Mean = \frac{\sum_{m=1}^{M_2} ind_m}{M_2} \tag{14}$$

The upper and lower threshold are set as $\beta_1$ and $\beta_2$.

$$\beta_1 = \mathrm{Ceil}(Mean) + 1 \tag{15}$$

$$\beta_2 = \mathrm{floor}(Mean) - 1 \tag{16}$$

where Ceil(•) and Floor(•) denote round toward positive infinity and negative infinity respectively. If

$$\beta_1 \leq 80\% \text{ elements of } \mathbf{IND}3 \leq \beta_2 \tag{17}$$

$f_n$ is determined as the frequency with periodic impulsive interference, and is kept a record. All the $f_n$ satisfied with (17) can compose the frequency vector of impulsive interference

$$\mathbf{f}_{im} = [f_{im1}, f_{im2}, \ldots, f_{imN_1}] \tag{18}$$

## 3.2 Parameters Estimation of Periodic Impulsive Interference

The parameters of periodic impulsive interference include period, duty cycle, the mean power, the peak power, etc. The interference-free time in a period is approximated as

$$T_{fr} = Mean \bullet T_d \tag{19}$$

During the total sensing time $KT_d$, the number of period is

$$M_3 = M_2 + 1 \tag{20}$$

Interference time in a period is approximated as

$$T_{in} = \frac{M_1}{M_3} T_d \tag{21}$$

A period of impulsive interference is approximated as

$$T_p = \frac{K}{M_3} T_d \tag{22}$$

The duty cycle of periodic impulsive interference is

$$DR = \frac{T_{in}}{T_p} = \frac{M_1}{K} \tag{23}$$

The average power of periodic impulsive interference can be calculated by the PSD $S_{sm}(f_n, k)$ corresponding to the interference index vector **IND1**.

$$P_{aver}(f_n) = \frac{\Delta f \sum_{k \in \mathbf{IND1}} S_{sm}(f_n, K)}{KT_d} \tag{24}$$

The peak power of impulsive interference can be estimated as

$$P_{peak}(f_n) = \frac{P_{aver}(f_n)}{DR} \tag{25}$$

The bandwidth of impulsive interference can be estimated as

$$B_{im} = f_{imN_1} - f_{im1} \tag{26}$$

## 4 Simulation Results

The simulation is performed in intermediate frequency. Sampling frequency, PSD detection duration, and PSD detection period are 20 MHz, 100 μs and 100 μs, respectively. The impulsive interference's central frequency and bandwidth is 5 MHz and 0.4 MHz. The impulsive interference period is 10 ms. AWGN exist in the wireless environment. The duty cycle is 0.1, 0.2 0.3 0.4, respectively. The 10000 trials are performed in simulation. NMSE (Normalized Mean Square Error) of parameters estimation is computed.

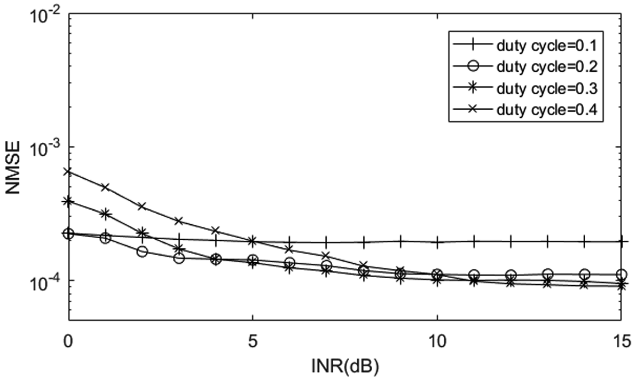


**Fig. 2.** The estimation performance of peak power of impulsive interference

Figure 2 shows the estimation performance of peak power of impulsive interference as a function of INR (Interference-to-Noise Ratio). From the figure, we can find that the NMSE of estimation value of peak power with duty cycle = 0.1 keeps steady. However, the NMSE deteriorates with the INR decrease when duty cycle = 0.2, 0.3 and 0.4. The small duty cycle is, the larger peak power is. Therefore, the noise has little effect on the estimation performance of peak power when the duty cycle is small.

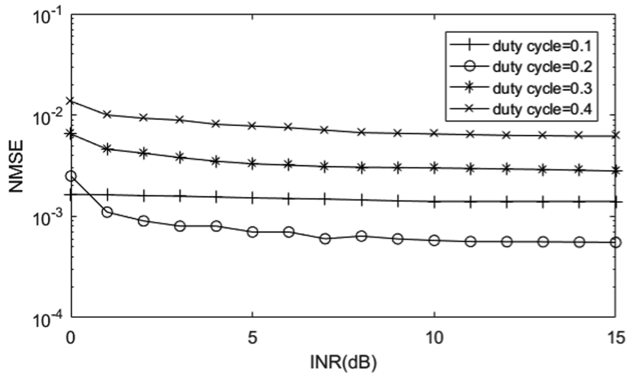


**Fig. 3.** The estimation performance of bandwidth of impulsive interference

Figure 3 shows the estimation performance of bandwidth of impulsive interference as a function of INR. Similar to Fig. 3, the NMSE of estimation value of bandwidth with duty cycle = 0.1 keeps steady. However, the NMSE deteriorates with the INR decrease when duty cycle = 0.2, 0.3 and 0.4. The larger duty cycle lead to the lower peak power, which is affected largely by noise when INR is low.

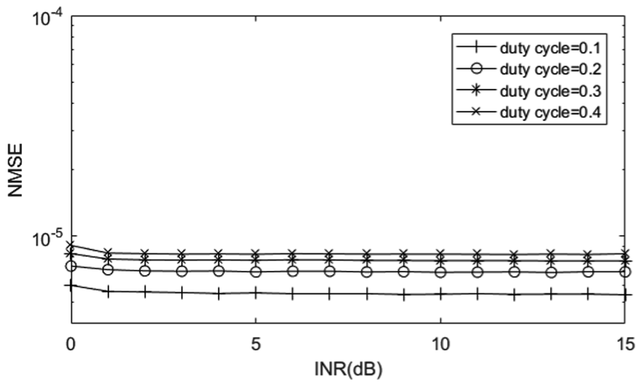


**Fig. 4.** The estimation performance of period of impulsive interference

Figure 4 shows the estimation performance of period of impulsive interference as a function of INR. Difference with Figs. 2 and 3, the NMSE of period is quite steady with INR. But with the increase of duty cycle, the NMSE deteriorates slightly.

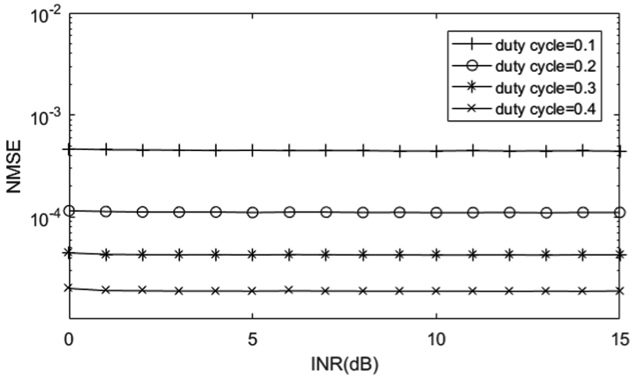


**Fig. 5.** The estimation performance of duty cycle of impulsive interference

Figure 5 shows the estimation performance of duty cycle of impulsive interference as a function of INR. Difference with all above simulation results, the larger duty cycle implies the better NMSE performance. The reason lies in the detection period is fixed. The large duty cycle includes more detection periods, which improve the estimation performance.

In summary, the NMSE of parameters estimation can satisfy the sensing requirement of interference.

## 5 Conclusion

In this paper, a low complexity sensing algorithm based on power spectrum density (PSD) for periodic impulsive interference is proposed. First, the modified periodogram is computed. Then the time occupancy of spectrum by interference and time interval of interference is computed in multiple detections to determine the presence of impulsive interference. Finally, main parameters of impulsive interference, such as period, duty cycle, bandwidth, and the peak power, are estimated. The computation afford of the proposed algorithm is quite low. The simulation results show that the sensing performance can satisfy the requirement of spectrum sensing.

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