# An Approach of Self-Defense Mainlobe Interference Suppression

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**Abstract.** Self-defense mainlobe interference and radar echo signals generated by real targets are same spatial angle, which seriously affect the radar performance, so self-defense mainlobe interference suppression is one of the hot spots and difficulties in the current radar field. In order to solve this issue, an approach of self-dense mainlobe interference suppression is proposed. Firstly, the pulse signals suffered self-dense mainlobe interference are rejected. Then, based on modified iterative method with adaptive threshold, the interfered pulse signals are reconstructed along slow time. Simulation results indicate that the proposed approach not only could effectively suppress the self-dense mainlobe interference, but also has high robust to the amount and periodicity of the interference pulses, which has a promising engineering application prospect.

**Keywords:** Self-dense mainlobe interference suppression; intermittent interference; pulse rejection; signal reconstruction

## 1. Introduction

With the rapid development of high-speed integrated circuit technology and digital signal processing technology, digital radio frequency memory (DRFM) technology [1] and direct digital synthesis technology have gradually made modern radar interference technology agility, diversity, and intelligence, which may lead to a serious threat for radar systems. Therefore, the interference suppression ability of radar in complex electromagnetic interference environments has always been one of the focus researches at home and abroad [2].

Electromagnetic interference signals can be divided into sidelobe interference and mainlobe interference based on spatial angles. There is a significant difference in spatial angle between sidelobe interference signals and real target signals. Traditional adaptive sidelobe cancellation algorithms, sidelobe masking algorithms and receiver beam ultra-low sidelobe designs can achieve good performance of sidelobe interference suppression. Mainlobe interference can be further divided into pure mainlobe interference (referring to self-defense interference where the target angle and interference angle are the same) and near mainlobe interference (referring to interference angle within the main lobe but with a certain angle difference from the target angle). Based on the eigen-projection matrix preprocessing and covariance matrix reconstruction methods, [3] uses normalized correlation coefficients to improve the accuracy of preprocessing matrix, thereby enhancing the robustness against mainlobe interference. Based on prior information, [4] adds constraint conditions to maintain the shape of mainbeam, ensuring the depth of interference angle null without losing target angle energy. [5] combines subarray structure and sparse theory to suppress mainlobe interference based on blind source separation (BSS) method. However, as the angle difference between real target and interference decreases, the effectiveness of the spatial null method or the BSS method will gradually deteriorate. For self-defense mainlobe interference, waveform diversity or frequency agility usually can be used to actively suppress interference. However, with the rapid development of DRFM technology and the increasing intelligence of jammer, it is difficult to counter the complex electromagnetic interference environments through a single approach. Therefore, self-defense mainlobe interference is a difficult problem that urgently needs to be solved in radar field, and has important research value.

In order to solve the issue mentioned above, this paper proposes an approach of self-dense mainlobe intermittent interference suppression. Firstly, the approach selects real echo signals from the time periods without mainlobe interference, and then reconstructs real echo signals affected by mainlobe interference based on these signals. Namely, the proposed approach first removes the pulses affected by mainlobe interference, and then reconstructs the interfered pulse signals along slow time using a modified iterative method with adaptive threshold (MIMAT). Unless otherwise specified, the intermittent interference refers to non continuous interference in time domain, and the interference signal could be either noise signal or a deceptive signal.

## 2. Problem Description and Signal Model

### 2.1 Interference Problem Analysis

Assume that the airborne self-defense jammer adopts time division mode of transmission and reception, and releases intermittent noise interference. The expression of the interference signal in time domain is

$$\mathrm{J}(t,m)=\mathrm{rect}\left(\frac{t-(m-1)T_{\mathrm{J},r}}{T_{\mathrm{J},p}}\right)*\gamma(t) \tag{1}$$

where

$$\mathrm{rect}\left(\frac{t-(m-1)T_{\mathrm{J},r}}{T_{\mathrm{J},p}}\right)=\begin{cases}1, & (m-1)T_{\mathrm{J},r}\le t\le (m-1)T_{\mathrm{J},r}+T_{\mathrm{J},p}\\ 0, & \text{others}\end{cases} \tag{2}$$

is rectangular window function, $T_{\mathrm{J},p}$ is interference pulse width, $T_{\mathrm{J},r}$ is interference signal period, $m$ is the index of interference pulse and $\gamma(t)$ is the released interference signal. Different modulation methods of the jammer release different interference signals. If the modulation method of jammer is radio frequency noise interference, it can be expressed as

$$\gamma(t)=U(t)*\cos\left[2\pi f_0 t+\varphi_0(t)\right] \tag{3}$$

where $U(t)$ is noise signal used for amplitude modulation and follows a Rayleigh distribution, $f_0$ is the center frequency of noise signal and phase $\varphi_0(t)$ follows a uniform distribution.

The expression of radar transmitting signal in time domain is

$$\mathrm{S}(t,n)=\mathrm{rect}\left(\frac{t-(n-1)T_r}{T_p}\right)*\exp\left[\mathrm{j}\left(2\pi f_0 t+\pi\mu t^2+\phi\right)\right] \tag{4}$$

where $T_p$ is radar signal pulse width, $T_r$ is radar signal period, n is the index of radar pulse, $\mu$ is the slope of linear frequency modulation signal and $\phi$ is the initial phase of signal.

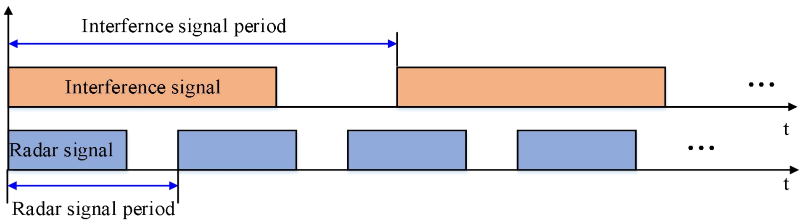



Fig.1 The schematics of radar signal and interference signal

In order to intuitively illustrate the impact of self-defense mainlobe interference on radar systems, the difference in power will be analyzed next. Assume that the distance between the target and radar is $R$, the target echo power ($P_r$) and interference power ($P_I$) received by radar can be expressed as

$$P_r=\frac{ERP_{\mathrm{r}}G\lambda^2\sigma}{(4\pi)^3R^4},P_I=\frac{ERP_{\mathrm{I}}G\lambda^2}{(4\pi)^2R^2} \tag{5}$$

where $ERP_r$ ($ERP_I$) is the effective power radiated by the radar (jammer), $G$ is the gain of radar receiving antenna, $\lambda$ is the wavelength of signal, and $\sigma$ is radar cross section (RCS). Assuming that the radar $ERP_r = 1000\text{kW}$, jammer $ERP_I = 1\text{W}$, RCS $\sigma = 1\text{m}^2$, wavelength $\lambda = 1\text{m}$, radar receiving antenna gain $G = 30\text{dB}$, echo signal power and interference power received by radar are as follows

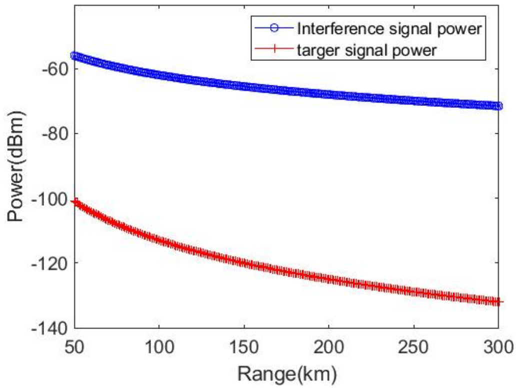



Fig.2 Power comparison of echo signal and interference signal with different distances

From Fig.2, it can be seen that as the distance between the real target and the radar increases, the echo signal power and interference power gradually decrease and the echo signal power decreases rapidly.

## 2.2 Interference Suppression

From Fig.2, it could be inferred that if the mainlobe interference signal is not effectively suppressed, the radar power will suffer severe losses. For self-defense mainlobe interference, the angle between the target and the interference signal is the same, making it difficult for the radar to suppress the interference signal in the airspace. Assume that the interference signal released by the jammer in the time domain is not continuous, it is possible to suppress the self-defense mainlobe interference signal in the time domain.

To eliminate the influence of interference, the pulse of the mainlobe interference can be set to zero. Next, we will analyze the impact of only zeroing method, which involves setting pulse signal suffered by the mainlobe interference to zero, namely,

$$\mathrm{S}_{\text{zero}}(t) = A_0 \exp(\mathrm{j}2\pi f_\mathrm{d}\,\mathrm{t}) * \left[ \mathrm{rect}\left(\frac{t}{MT_r}\right) - \sum_{i=1}^{K} \mathrm{rect}\left(\frac{t}{T_{\text{Interf},i}}\right) \right] \quad (6)$$

where $A_0$ is the signal amplitude, $f_\mathrm{d}$ is the Doppler frequency, $M$ is the total number of pulses in a frame, $T_{\text{Interf},i}$ is the interference duration for the $i$ time interference, and $K$ represents the total number of interferences in a frame.

The interference appears periodically in the echo signal may have different effects on the signal spectrum envelope, as shown in Fig. 3. In practical applications, if the radar signal and the interference signal are both periodic signals, the position of interference signal in target echo signals may have periodicity, otherwise it may not have periodicity.

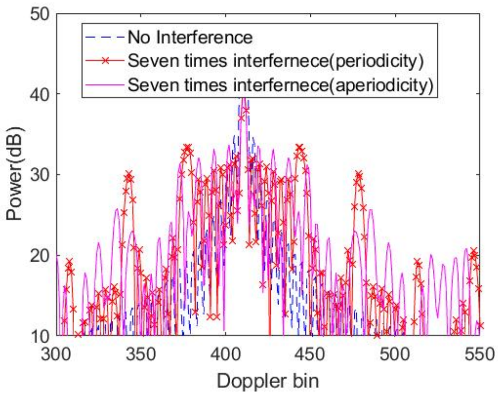



Fig.3 The impact of periodic interference on signal spectrum envelope

## 3. Interfernce Suppression and Signal Reconstruction

From Fig. 3, it can be seen that if the self-defense mainlobe interference signals are only zeroed, not only the power loss of the target signal may be large, but also the envelope (i.e., sidelobe level) may lead to rise, which may affect the detection of weak targets and trigger false alarms. In order to solve the problems mentioned above, this paper proposes an approach of self-defense mainlobe interference suppression based on signal reconstruction. The specific flowchart is shown below

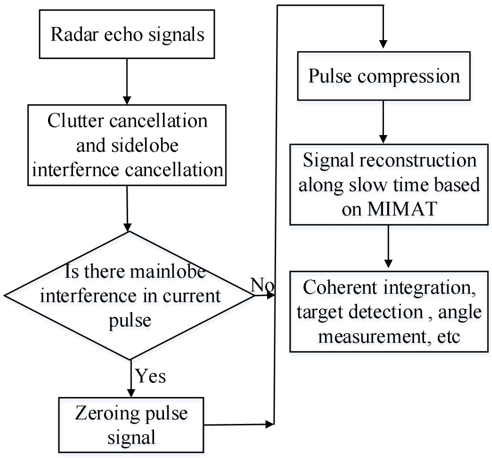



Fig.4 Flow chart of self-defense mainlobe interference suppression

The IMAT algorithm in [6] gradually improves the accuracy and signal to noise ratio (SNR) of the reconstructed signal as the number of iteration increases. However, the literature does not provide methods of specific parameters for the threshold and setting the total number of iterations. When the threshold is lower than the noise power, the accuracy and SNR will deteriorate. In order to solve this problem and adapt to practical engineering applications, this paper will adjust and modify the IMAT steps, namely, the modified iterative adaptive threshold (MIMAT) algorithm.

The setting of threshold parameters in MIMAT algorithm mainly considers two aspects: iteration step size and iteration times. For the iteration step size, make the signal after zeroing through fast Fourier transform (FFT) and obtain $S(f)$. Then, obtain the local maximum value and sort it in descending order to obtain the vector $\mathbf{x}$ and calculate $\alpha_{\mathrm{Len}} = \mathbf{x}(1) - \mathbf{x}(2)$. Let $\alpha = \min(\alpha_{\mathrm{Len}}, \alpha_0)$, where $\alpha_0$ is the parameter corresponding to the minimum step size for iteration, such as when the minimum iteration step length is 3dB, $\alpha_0 = 0.6931$. For the maximum iteration times $K$: the iteration threshold cannot be lower than the internal thermal noise power of the receiver. So if it falls below the noise power, the termination condition is reached.

The detailed steps of the signal reconstruction algorithm based on MIMAT are as follows:

1) Input the iteration step size $\alpha$, maximum number of iterations $\kappa$, and threshold for the minimum energy drop between adjacent iterations $\varepsilon$;

2) Perform FFT on the signal $s_{\text{zero}}(t)$ to be reconstructed and obtain the maximum value $\beta_i$ of the $i$ iteration and the signal total energy $P_i$;

3) Calculate the threshold $\delta_{\text{thres}} = \beta_i e^{-(i-1)\alpha}$ of the $i$ iteration, and retain signals that exceed the threshold while setting signals below the threshold to zero;

4) Perform inverse Fourier transform on the signal obtained in step 3) to obtain the reconstruction signal $s_{\text{est}}(t)$, and fill the signal $s_{\text{zero}}(t)$ in the index zero position with signal $s_{\text{est}}(t)$ at the corresponding position, while keeping the signal unchanged at other positions.

5) If $|P_{i-1} - P_i| \le \varepsilon$ or the number of iterations is greater than or equal to $\kappa$, obtain the final optimization result. Conversely, let $i = i+1$, return to step 2).

## 4. Simulation Results

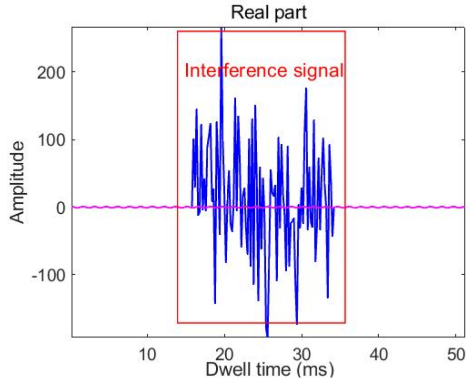
This section will analyze the effectiveness of the proposed approach of self-defense mainlobe interference suppression from multiple perspectives through simulation experiments. The performance evaluation indicators are the SNR, root mean square error (RMSE) and relative error (RE) of the signal. In the simulation experiments, if not explicitly mentioned, the radar and target parameters are shown in Table 1. Assume that the self-defense interference aircraft releases aiming intermittent noise interference, and the noise type is Gaussian white noise.

Table 1 Simulation parameters

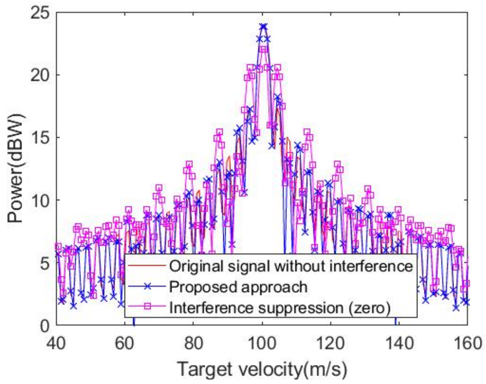
| Parameters | Value |
|---|---|
| Radar frequency | 1 GHz |
| Pulse period $T_r$ | 200 us |
| Pulse number $M$ | 256 |
| Target number | 1 |
| Target velocity | 200 m/s |
| Target RCS | 1 m2 |

**Experiment 1: Interference suppression performance**

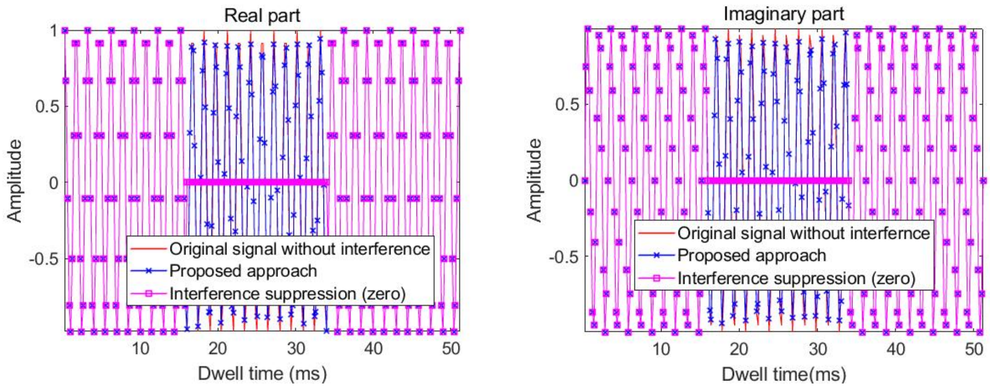
The zeroing method in Fig.5 refers to directly zeroing the pulse signal interfered by self-defense mainlobe interference. From Fig.5, it can be seen that the zeroing method can effectively suppress interference signals. The zeroing method is achieved by adding an inverse rectangular window method, which raises the sidelobe level and may cause small targets to be submerged or trigger false alarms. In addition, the zeroing method suppresses some of real target echo signals, resulting in a loss of target power. But the proposed approach in this paper could effectively suppress the self-defense mainlobe interference signal and reconstruct the real target signal of zeroing, obtaining better performance.



(a) Echo signal (along slow time dimension)



(b) Comparison of Doppler frequency spectrum

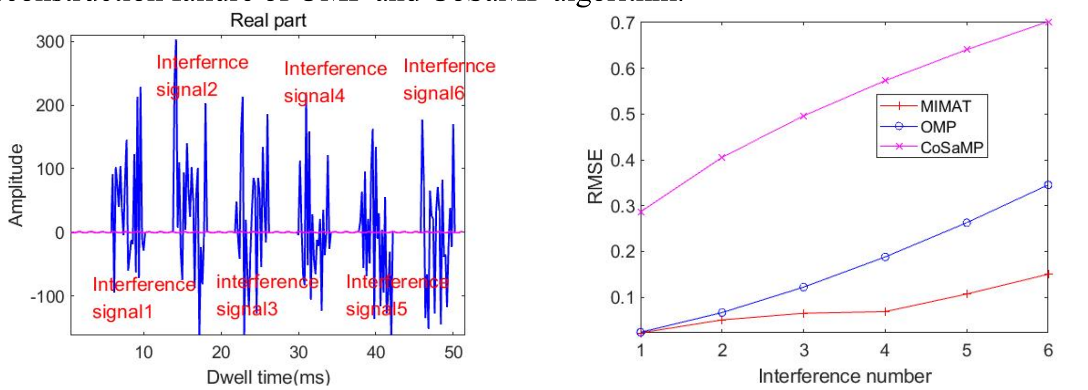



(c) Comparison of signal real part (d) Comparison of signal imaginary part

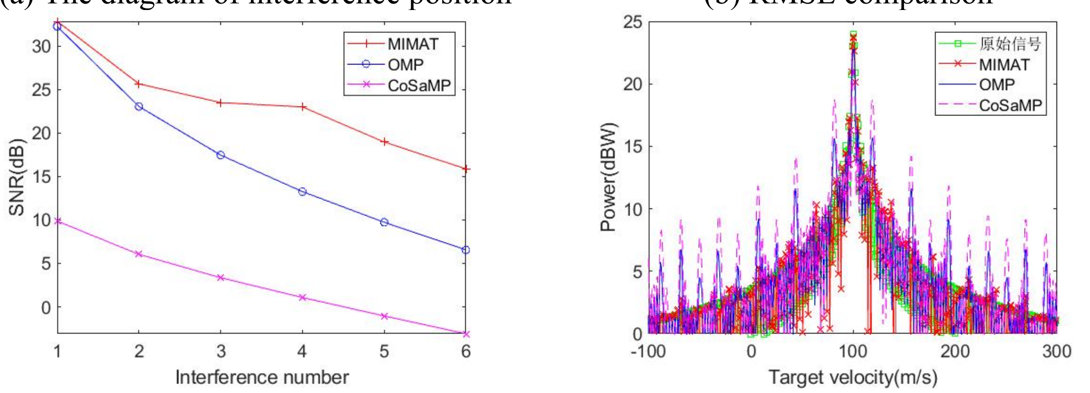
Fig.5 Comparison of interference suppression performance between the proposed approach and the zeroing method

**Experiment 2: Performance comparison under multiple interference scenarios**

From Fig. 6, it can be seen that under multiple mainlobe interference conditions, the MIMAT algorithm still can reconstruct target echo signals well and has strong robustness when the position of self-defense mainlobe interference has periodicity. Moreover, the performance of MIMAT algorithm is superior to orthogonal matching pursuit (OMP) [7] algorithm and compressive sampling matching pursuit (CoSaMP) [8] algorithm. As the number of interferences increases, the advantage of MIMAT algorithm gradually increases. In addition, when the interference position has periodicity, the Doppler spectra of OMP and CoSaMP algorithm exhibit grating lobe, this is because that when the interference position exhibits periodicity, similar to equidistant sampling, it does not satisfy the constraint equidistant condition of compressive sensing theory, resulting in the signal reconstruction failure of OMP and CoSaMP algorithm.




(a) The diagram of interference position (b) RMSE comparison




(c) SNR comparison (d) Comparison of Doppler frequency spectrum

Fig. 6 The performance comparison under interference location periodicity conation

## 5. Summary

This paper proposes an approach of self-defense mainlobe interference suppression based on signal reconstruction. The approach removes the suffered mainlobe interference pulses and then reconstructs the signal along slow time using MIMAT algorithm. This approach not only can effectively suppress the self-defense mainlobe interference signal, but also reconstruct the interfered real target signals well, ensuring that the radar detection performance is not affected by interference. Simulation results indicate the effectiveness of the proposed approach of suppressing self-defense mainlobe interference. Meanwhile, it is verified that the MIMAT algorithm has better signal reconstruction performance than that of the OMP and CoSaMP algorithm in different interference environments and has high robustness to the number and periodicity of interference pulses.

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