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Optimization of Interference Suppression Algorithm for Polarization Sensitive Conformal Array in Complex Electromagnetic Environment

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Abstract. With the development of modern electronic technology, the electromagnetic environment is becoming increasingly complex, which poses a severe challenge to the normal work of radar, communication and other systems. Polarization sensitive array can more effectively distinguish and suppress interference signals by using polarization information of electromagnetic waves, and improve the signal-to-noise ratio (SNR) and anti-interference ability of the system. Conformal array can be closely attached to the carrier surface, reducing space occupation and improving signal receiving efficiency and accuracy. However, at present, polarization-sensitive conformal arrays still face technical problems in interference suppression, especially in complex electromagnetic environment, how to optimize interference suppression algorithms to improve system performance has become the research focus. In this paper, an adaptive interference suppression algorithm combining spatial-polarization domain processing is proposed. The algorithm digitally processes the received signal, extracts spatial and polarization domain information, constructs the joint feature vector of the signal in spatial and polarization domain, and designs a joint filter in spatial and polarization domain. The minimum mean square error (MMSE) criterion and the least mean square (LMS) algorithm are used to update the weight vector of the filter in real time, enabling the filter to automatically adapt to changes in the electromagnetic environment and achieve optimal interference suppression. Simulation experiments show that the algorithm exhibits good stability and adaptability under different electromagnetic environments, effectively suppressing interference and extracting the desired signal. Compared with traditional interference suppression algorithms based solely on spatial domain, the joint spatial-polarization domain adaptive interference suppression algorithm significantly improves the interference suppression ratio (ISR) and signal-to-interference-plus-noise ratio (SINR) performance indicators, verifying that the introduction of polarization domain information can enhance the effect of interference suppression.

Keywords: Complex Electromagnetic Environment; Interference Suppression; Polarization Sensitive Conformal Array; Combining Spatial-polarization Domain Processing.

1. Introduction

With the rapid development of modern electronic technology, the electromagnetic environment is becoming increasingly complex, and the electromagnetic interference generated by various electronic devices is increasing. This complex electromagnetic environment poses a severe challenge to the normal work of radar, communication and other systems. Especially in military and civil fields, how to effectively suppress interference and improve signal reception quality in complex electromagnetic environment has become an urgent problem to be solved.

As an advanced signal processing technology, polarization sensitive array shows its unique advantages in anti-interference [1-2]. By using the polarization information of electromagnetic waves, it can more effectively distinguish and suppress interference signals, thus improving the signal-to-noise ratio (SNR) and anti-interference ability of the system. As a special array layout, conformal array can be closely attached to the carrier surface, which not only reduces the space occupation, but also improves the efficiency and accuracy of signal reception to a certain extent [3]. However, there are still some technical problems in interference suppression of polarization-sensitive conformal arrays, especially in complex electromagnetic environment, how to optimize the interference suppression algorithm to further improve the performance of the system has become a hot and difficult research. The purpose of this study is to deeply discuss the optimization of interference suppression algorithm of polarization-sensitive conformal array in complex electromagnetic environment, in order to provide theoretical support and practical guidance for technological progress in related fields.

2. Interference analysis in complex electromagnetic environment

In the current electronic age, complex electromagnetic environment has become a reality that all kinds of electronic systems must face. The characteristics of this environment are mainly reflected in the diversity and density of electromagnetic signals, including various communication signals, radar signals and electromagnetic radiation generated by other electronic equipment. These signals are intertwined in space, forming a complex electromagnetic background, which has a serious impact on the normal work of radar, communication and other systems.

According to the types of interference, the interference in complex electromagnetic environment mainly includes narrowband interference, broadband interference and pulse interference. Narrow-band interference usually comes from specific radio sources, such as radio stations and television signals, which will produce strong interference at specific frequencies [4]. Broadband interference comes from the overlapping working frequency ranges of various electronic devices, which leads to interference in the whole frequency band. Pulse interference is transient electromagnetic interference caused by lightning and switching operation. Although it lasts for a short time, it has high intensity and may cause damage to electronic equipment.

The influence of these interferences on polarization-sensitive arrays is mainly reflected in reducing the signal reception quality, increasing the false alarm rate and missed alarm rate, and even leading to system failure. Especially in radar detection, wireless communication and other fields, the existence of interference seriously affects the performance and reliability of the system.

However, it is not easy to achieve effective interference suppression in complex electromagnetic environment. On the one hand, there are many kinds of interference sources, which makes it difficult to identify and separate interference signals; On the other hand, the dynamic change of electromagnetic environment requires that the interference suppression algorithm must have good adaptive ability. These technical problems pose a higher challenge to the existing interference suppression algorithms, and also promote the continuous exploration and optimization of interference suppression strategies.

3. Research on optimization of interference suppression algorithm

3.1. Algorithm optimization idea

For polarization-sensitive conformal arrays, this study proposes the following optimization ideas of interference suppression algorithm:

(1) Joint spatial-polarization domain processing: Traditional interference suppression methods often only process in spatial domain or polarization domain. By combining the information of spatial domain and polarization domain, we can describe and distinguish the signal and interference more comprehensively, thus improving the effect of interference suppression.

(2) Adaptive filtering: Considering the dynamic change of electromagnetic environment, the parameters of the filter can be adjusted in real time by using adaptive filtering technology to adapt to different interference environments. This can ensure that the interference suppression algorithm can maintain good performance in various complex electromagnetic environments.

3.2. Optimization algorithm design

Based on the above ideas, an adaptive interference suppression algorithm is designed in this study (Figure 1). The specific principle is to digitize the received signal and extract the spatial and polarization information of the signal. According to the arrival angle and polarization state of the signal, the joint feature vector of spatial-polarization domain of the signal is constructed. Using the minimum mean square error (MMSE) criterion, a joint spatial-polarization filter is designed. The weight vector of the filter consists of spatial weight and polarization weight, which are used to adjust the response of the filter in space and polarization state respectively [5-6]. The least mean square (LMS) algorithm is used to update the weight vector of the filter in real time. Through continuous iterative optimization, the filter can automatically adapt to the changes of electromagnetic environment and achieve the best interference suppression effect [7].

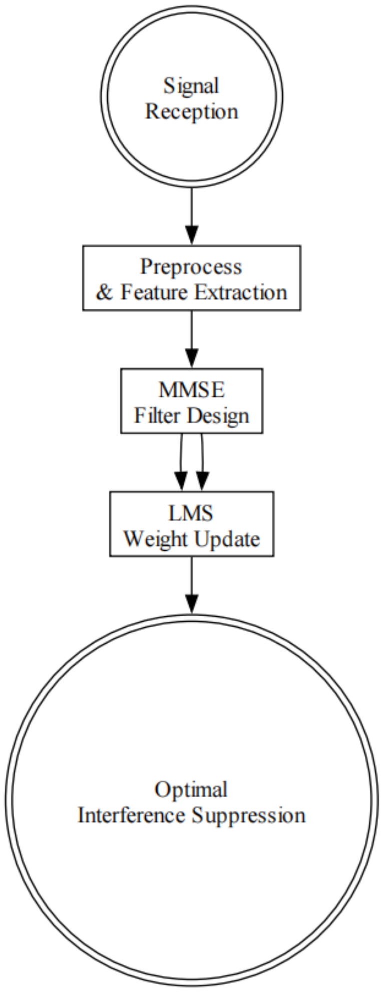

Figure 1 Structure of adaptive interference suppression algorithm in joint space-polarization domain

Let the received signal vector be $x(t)$, which contains the expected signal and the interference signal. If the weight vector of the filter is w, the output $y(t)$ of the filter can be expressed as:

$$y(t) = w^H x(t) \tag{1}$$

Where w^H represents the conjugate transposition of the weight vector.

Under the MMSE criterion, the optimal weight vector w_{opt} is solved by minimizing the mean square error between the desired signal and the filter output [8-9]:

$$w_{opt} = \arg\min_{w} E\left|d(t) - wHx(t)\right|^2 \tag{2}$$

Where $d(t)$ is the sample value of the desired signal and $E|\cdot|$ represents the desired operation.

In order to solve the above optimization problems, the standard MMSE solution is used. Firstly, the autocorrelation matrix R_{xx} of the received signal and the cross-correlation vector r_{xd} of the received signal and the expected signal are defined:

$$R_{xx} = Ex(t)x^H(t) \tag{3}$$

$$r_{xd} = Ex(t)d^*(t) \tag{4}$$

Where $*$ represents complex conjugation. Then, the optimal weight vector is solved by the following formula:

$$w_{opt} = R_{xx}^{-1} r_{xd} \tag{5}$$

It should be noted that the autocorrelation matrix R_{xx} and cross-correlation vector r_{xd} in the above formula need to be estimated by the actually received signal samples. In addition, because signal vector $x(t)$ contains information in spatial domain and polarization domain, it is necessary to consider the characteristics of both spatial domain and polarization domain when calculating autocorrelation matrix and cross-correlation vector.

In the process of weight updating, LMS algorithm is a common method, which is famous for its simplicity and easy implementation [10]. LMS algorithm updates the weight vector of the filter by iteration to minimize the mean square error between the desired signal and the output of the filter.

Calculation error signal:

$$e(t) = d(t) - y(t) \tag{6}$$

Where $e(t)$ is the error between the desired signal and the filter output.

Update weight vector:

$$w(t+1) = w(t) + \mu x(t) e^{(t)} \tag{7}$$

Where, μ is the step parameter, which is used to control the update rate of the value, and $e^{(t)}$ represents the complex conjugate of the error signal.

The selection of step size parameter μ is very important to the performance of LMS algorithm. If the step size is too large, the algorithm may be unstable; If the step size is too small, the convergence speed of the algorithm may be very slow. Therefore, in practical application, it is necessary to select appropriate step parameters according to specific conditions.

In addition, LMS algorithm may be affected by the eigenvalue distribution of signal autocorrelation matrix in the convergence process. If the autocorrelation matrix of the signal has a large eigenvalue spread (that is, the ratio of the maximum eigenvalue to the minimum eigenvalue is large), the convergence speed of LMS algorithm may be very slow [11]. In order to improve this situation, the normalized LMS algorithm (NLMS) is further studied.

4. Simulation experiment and result analysis

In order to verify the effectiveness of the joint space-polarization adaptive interference suppression algorithm designed in this study, MATLAB is chosen as the simulation platform, because it provides a rich signal processing toolbox and flexible programming environment, which is convenient for us to simulate complex electromagnetic environment and signal receiving process.

In the simulation environment, set one expected signal source and three interference sources. The expected signal power is set to 1, and the interference signal power is set to 0.8, 0.6, and 0.4, respectively, to simulate interference of different intensities. The expected arrival angle of the signal is set to 30 °, and the polarization state is vertical polarization. The arrival angles of the three interference signals are set to 60 °, 120 °, and 180 °, respectively, and the polarization states are horizontal polarization, 45 ° linear polarization, and right-handed circular polarization. Added additive Gaussian white noise (AWGN) with an SNR of 10dB to simulate actual noisy environments. Generate signal sources and interference source signals with specific power, arrival angle, and polarization state using MATLAB. The signal adopts QPSK modulation method with a symbol rate of 1Mbps. Simulate an array receiving system with multiple receiving antennas, with antenna spacing set at half wavelength, to fully utilize spatial diversity. The received signals include expected signals, interference signals, and noise.

After digitizing the received signal, the spatial and polarization domain information of the signal is extracted. Based on the angle of arrival and polarization state of the signal, a joint spatial-polarization domain feature vector of the signal is constructed. The joint spatial-polarization domain adaptive interference suppression algorithm designed in this study is applied, using the LMS algorithm to update the filter's weight vector in real time. The performance of the algorithm is evaluated by calculating the interference suppression ratio (ISR) and the signal-to-interference-plus-noise ratio (SINR) performance indicators.

In different electromagnetic environments, the adaptive interference suppression algorithm of joint space-polarization domain shows good stability and adaptability. No matter in strong or weak interference environment, the algorithm can effectively suppress interference and extract the desired signal (Figure 2).

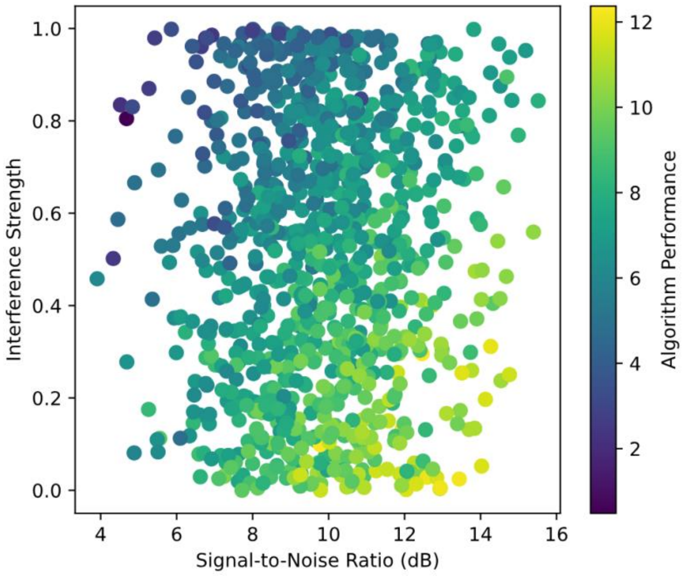

Figure 2 Performance distribution in different electromagnetic environments

With the increase of SNR, the overall performance of the algorithm shows an upward trend. This shows that the algorithm can extract the desired signal more effectively and suppress interference and noise in a higher SNR environment. When the interference intensity is low, the performance of the algorithm is generally good. With the increase of interference intensity, the performance of the algorithm decreases, but even in a strong interference environment, the algorithm can still maintain a certain level of performance, which reflects the robustness and adaptability of the algorithm. Most of the sample points are concentrated in the middle performance area, but there are also many points distributed in the high performance area, especially in the areas with high SNR and low interference intensity. This shows that the algorithm can provide good performance in most cases and achieve higher performance level in ideal electromagnetic environment.

Through comparative experiments, it is found that the joint space-polarization adaptive interference suppression algorithm is superior to the traditional space-based interference suppression algorithm in ISR and SINR performance indicators. This shows that the introduction of polarization domain information can really improve the effect of interference suppression (Table 1).

Table 1 Performance comparison

algorithm	ISR (dB)	SINR (dB)
Only based on airspace	15.3	12.8
Joint space-polarization domain	23.5	18.7

The joint space-polarization adaptive interference suppression algorithm is superior to the traditional space-based interference suppression algorithm in ISR and SINR indexes. Specifically, the ISR of the joint space-polarization domain algorithm is 23.5 dB, which is higher than the 15.3 dB; based on the spatial domain algorithm only. At the same time, the SINR of the joint space-polarization domain algorithm is 18.7 dB, which is also higher than the 12.8 dB based on only the space domain algorithm. By introducing polarization domain information, the joint space-polarization domain adaptive interference suppression algorithm can suppress interference more effectively and improve signal quality. This also verifies the viewpoint mentioned in the study, that is, introducing polarization domain information can really improve the effect of interference suppression.

5. Conclusion

The algorithm designed in this study can adjust the filter parameters in real time to adapt to the changing electromagnetic environment by processing the spatial and polarization information jointly and adopting adaptive filtering technology. The simulation results show that the algorithm has good stability and adaptability in different electromagnetic environments, and effectively improves the SINR and ISR performance indexes of the system. By introducing polarization domain information, the algorithm not only enhances the ability to identify and separate interference signals, but also improves the overall anti-interference ability of the system. This discovery verifies the effectiveness of the joint space-polarization domain processing strategy, and also shows the superiority of adaptive filtering technology in dynamic electromagnetic environment. The joint space-polarization adaptive interference suppression algorithm proposed in this study provides an effective solution for the application of polarization-sensitive conformal arrays in complex electromagnetic environment. Future work can further explore the application effect of the algorithm in actual scenes and the possibility of expansion in other related fields.

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