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Synthetic aperture radar radio frequency interference suppression technology

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Abstract. Radio frequency interference (RFI) can easily hinder the data collection, imaging and interpretation of the initial echo of synthetic aperture radar, which has always been a difficult problem affecting the accuracy of synthetic aperture radar. In this paper, the radio frequency interference suppression technology of synthetic aperture radar is analyzed and studied. It can be concluded that in today's complex and changeable electromagnetic environment, although many literature have proposed and established different objective functions and constraints for more specific application environments, there is still room for further improvement. Therefore, the future SAR system needs to select the most appropriate interference suppression method according to the dynamic changes of RFI environment. The development trend of interference suppression technology in the future is obtained from the comprehensive analysis of the RFI interference sources, RFI models and existing SAR interference suppression technologies, which provides a certain reference for future research.

Keywords: Synthetic Aperture Radar (SAR), Radio Frequency Interference (RFI), Interference Suppression, Jamming.

1. Introduction

SAR is an active microwave remote sensing system that offers crucial information to comprehend environmental changes on a worldwide scale. It can realize all-day and all-weather high-resolution imaging, and play the role of visible light, hyperspectral, infrared and other earth observation sensors in battlefield reconnaissance, disaster monitoring, disaster assessment and early warning, resource exploration, terrain mapping and other aspects [1-3]. SAR is therefore frequently employed in the sectors of science, commerce, and national defense. The likelihood of interference in the channels of active remote sensing systems has significantly grown due to the quick development of radio technology. Radio Frequency Interference (RFI) signals are electromagnetic radiation produced in the same frequency band as other radiation sources. SAR systems in low frequency bands such as P, L, and C are more susceptible to these RFI signals [3]. RFI sources are densely distributed all over the world, but the distribution varies with a different regions, such as developed regions with relatively dense population. SAR mainly uses information about amplitude, frequency, delay, polarization, Doppler shift and phase. RFI can destroy radar measurements in a variety of ways, including the original echo capture, imaging and image interpretation processes. In this paper, the current situation of its development is summarized and its development direction is prospected. Firstly, several main

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interference sources are introduced and the basic principle of interference is explained. Moreover, the signal model of a typical RFI type is given and the SAR interference suppression technology is explained as well. This paper also introduces the different current interference suppression methods and their advantages and disadvantages are expounded. Finally, the problems existing in SAR interference suppression technology are analyzed based on the above contents, and the future development trend of this technology and how to solve the problems are analyzed. With the wide application of synthetic aperture radar, it is accompanied by a more complex electromagnetic environment, so the interference suppression technology of synthetic aperture radar gradually becomes the key, which has important practical significance in improving the suitability and practical efficiency of synthetic aperture radar systems in complex electromagnetic environments.

2. Main interference sources and RFI models

2.1. Ground RFI Source

Most sources of RFI are related to human activities on land. Ground-based commercial or industrial radio equipment, including but not limited to radio location radars, wind profilers, telecommunications equipment, television networks, and ham radio, is considered the primary RFI source for SAR. Since ground interference propagates only one way, receiving strong RFI signals will greatly improve the noise base and reduce the signal-to-noise ratio [3,4]. As shown in figure.1, SAR images with and without RFI pollution are compared, and it can be found that under strong interference, the image will generate stripes, thus covering the real scene.

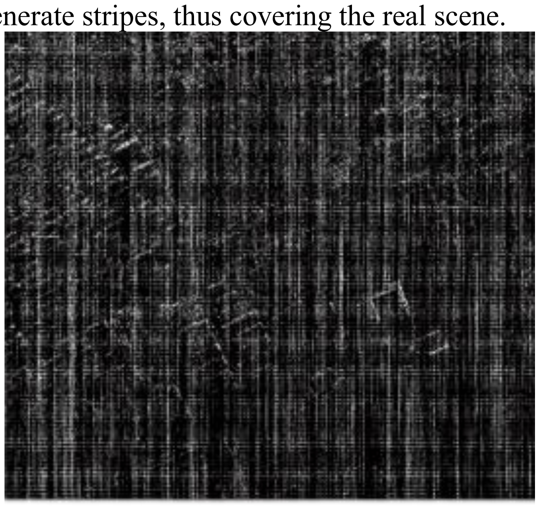

Figure 1(a). Image with RFI [5].

Figure 1(b). Image without RFI [5].

3. Existing SAR interference suppression techniques and their advantages and disadvantages

3.1. Suppression Interference Suppression Technology

With the development of synthetic aperture radar (SAR), the electromagnetic environment is becoming more and more complex. No matter what the jamming style is, the destruction of SAR imaging mainly depends on the suppression effect formed by the strong jamming power in the time domain, frequency domain, or space domain. The current anti-interference methods can be divided into several categories according to the different processing methods.

3.1.1. Frequency Domain Notch Method. The use of notch filtering in the range spectrum of a radar echo is the direct way of RFI detection and suppression. Because RFI typically exhibits spikes in the

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frequency domain that are many dB louder than the background signal level and is narrow band relative to the transmitted pulse bandwidth, interference suppression can be accomplished by merely removing the portion that exceeds the energy threshold. This method is simple and efficient, but it will cause spectrum fracture when repaired, which means it cannot avoid signal loss due to broadband interference [4, 5, 8].

3.1.2. Parametric Modeling Method. Another method of incoherent jamming trap is the coherent estimation and subtraction of interference, which mainly includes the coherent estimation and in-phase subtraction of interference sources. In theory, this approach can lead to better performance. However, due to the complexity and variability of the modulation patterns of the existing RFI sources, this assumption is no longer very valid. As a result, achieving accurate modeling and parameter estimation remains a major issue affecting the performance of such methods [9,10].

3.1.3. Adaptive Filtering. Adaptive filtering method can realize interference separation in the time domain, frequency domain, space domain and polarization domain by constructing appropriate filters. A typical example is the recursive adaptive filter, which models radio frequency interference as an autoregressive process and has a good compromise between convergence speed and narrowband interference suppression performance. But its convergence rate is limited by the ratio of the maximum and minimum eigenvalues of the autocorrelation matrix of the input signal [5, 11].

3.1.4. Decomposition and Reconstruction. The RFI potential components or subspaces are extracted using the decomposition method based on the power and statistical differences between RFI and SAR echoes. The disadvantage is that the iterative optimization calculation is large and is not suitable for wideband interference [12]. The reconstruction method can reduce the signal distortion introduced by the suppression of wideband interference and is suitable for processing non-sparse RFI scenarios. However, it has the same disadvantages as the decomposition method, a large amount of computation for iterative optimization and involves fine-tuning of hyper-parameters.

3.2. Spoofing Interference Suppression Technology

The signal intensity of spoofing is similar to that of real echo, and its main characteristic is to form deceptive false targets in the process of synthetic aperture radar imaging, which can be well fused with the synthetic aperture radar image and has high concealment. Spoofing jamming is highly similar to synthetic aperture radar echo in multiple characterization domains, so it is difficult to suppress the jamming.

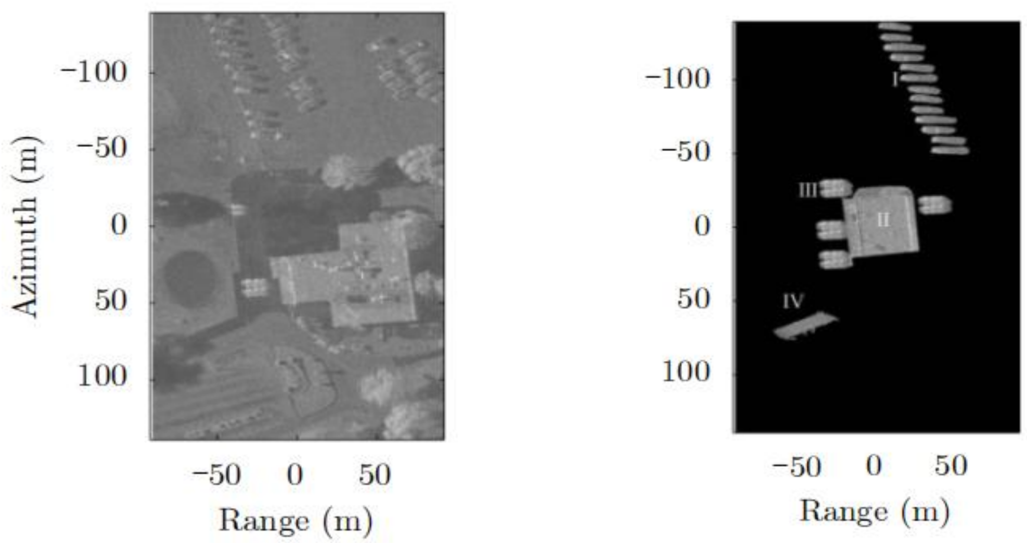

Figure 2(a). True Scene. **Figure 2(b).** Deceptive Scene.

3.2.1. Spoofing and Jamming Suppression Technology of Multi-channel SAR System. Multi-channel synthetic aperture radar (SAR) system can provide more spatial freedom and is a common method to suppress spoofing. Due to the different positions of the channels, there is a fixed phase deviation between the SAR echoes received by them. Although the jammer can generate false targets in large scenes by Doppler modulation, due to the fixed transmitting position of jammer, the phase deviation of spoofing in multiple SAR channels changes with the change of the false scene, which is obviously different from the SAR echo. Therefore, the fixed phase difference between multiple channels can be used to construct the guidance vector, and the interference cancellation between different channels can be carried out through the Space Time Adaptive Processing (STAP) technology to achieve the purpose of suppressing spoofing interference [13].

3.2.2. Spoofing and Jamming Suppression Technology of Single-channel SAR System. Now there are a lot of agility by emitting parameters of the waveform active anti-interference method to suppress the deception jamming. In general, agile techniques primarily employ two methods to improve the performance of deception jamming prevention. Firstly, consider using noise frequency modulation signal, noise, and sinusoidal signal and random two phase coding form, reduce the probability of being intercepted signal. Secondly, by transmitting orthogonal waveform signals at different slow moments, the forward spoofing interference can be suppressed. Under the current technical conditions, this method increases the complexity of the synthetic aperture radar system, but it can achieve a better spoofing suppression effect. However, jamming and anti-jamming techniques are developing in competition with each other. With the further development of spoofing modulation theory and technology level, the above interference suppression methods will also face the problem of upgrading and perfecting [13, 14].

4. Existing Problems and Development Trends

Through the above review and introduction of SAR suppression and spoofing suppression methods and their advantages and disadvantages, existing suppression methods rely on expert knowledge to maximize the difference between RFI and useful echoes. Some super parameters are mostly selected according to experience and are only applicable to interference of specific modulation type. This occurs in the implementation of the algorithm. However, the heterogeneous RFI environment that SAR systems will face in the future is a challenging task, as they will encounter various types of RFI signals simultaneously. The development trend of synthetic aperture radar jamming suppression technology is as follows: Most active interference suppression methods almost assume the existence of interference, and rarely mention the setting of an adaptive threshold to determine whether there is interference. If there is no interference, there is no need to adopt any interference suppression method. Therefore, in the future, SAR system is required to select the most appropriate interference suppression method according to the dynamic changes of the RFI environment, and this can provide more waveform optimization ability, and make adaptive adjustments in time, space, frequency, and other aspects. Synthetic aperture radar interference suppression technology is still the data processing of object. Under the background of the current development of science and technology, the form of jamming is also very complex, which increases the amount of data received and used by radar. Therefore, as a popular technology in today's era, how to apply big data and jamming suppression technology can also become the development direction of SAR anti-jamming technology in the future. Nowadays, interference suppression and deception interference are developing alternately in competition with each other. In addition to the independent cognitive ability, deception interference suppression methods can automatically detect the weakness of current deception interference methods, so as to seek the most effective deception interference suppression methods. Due to the gradual enrichment of deception interference and anti-interference means, the opposing parties also need to adjust their own strategies in real time according to the opposing methods, so that the confrontation becomes a dynamic game process, so that the technology has a higher degree of freedom and as many possibilities as possible. The dominant position in a dynamic game is an important problem for SAR anti-spoofing technology.

5. Conclusion

In this paper, the existing synthetic aperture radar jamming suppression techniques are summarized, common jamming sources and RFI models are sorted out, the research progress of different anti-jamming methods is introduced, and the advantages and disadvantages of these methods are summarized. It serves as a guide for applying the best RFI suppression strategy in future airborne or spaceborne SAR systems. Any interference suppression technique's performance is influenced by a variety of variables, including as the SAR system's architecture, the observation mode, the type of RFI present, and the available computational power. Finally, this paper points out the possible development trend of this field in the future, and provides ideas for researchers to explore potential research topics and locate new research directions. However, there is a lack of actual data observed in real situations in this paper, and the analysis may be inaccurate in some aspects. Therefore, future studies should focus on the collection of real and effective data, and more detailed characterization and inhibition of RFI remain to be further studied.

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