

Summary of Research Progress on the Recognition of Ship Target from SAR Image

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Abstract. The technology of SAR image ship target detection and identification is pivotal for accurately guiding weapon to discover the specific target and locking it. Based on extensive research literature, classical processes of ship target detection and recognition in SAR images are summarized and reviewed, the research progress of each link included. And the advantages and disadvantages of the existing methods are analyzed. Finally, some specific problems encountered in the research are put forward, and the main direction of future development is looked forward, referring the current research results.

Keywords: SAR image; classifier; target detection and recognition; summary review; outlook.

1. Introduction

Synthetic Aperture Radar (SAR) is an active microwave imaging sensor with full-day, all-weather and multi-polarity observation capabilities in agriculture, forestry, geology, environment, hydrology, oceanography, disasters, mapping, Military and many other fields have unique application advantages. Since the first introduction of the concept of "synthetic aperture radar" by Wiley C. in 1951, SAR has developed over the past 70 years and has formed high resolution, multi-operation mode, multi-polarization and multi-band characteristics[1].

The American first carried out research on SAR imaging technology, and first obtained SAR images from SEASAT-I satellite in 1978, which opened the prelude to the exploration of SAR image processing technology[2]. Since the 1990s, the world has set off a climax of SAR remote sensing. The former Soviet Union, ESA and Japan have launched their own SAR satellites. In the 21st century, new SAR satellites from major countries in the world have emerged. Such as the famous "Lacrosse" series of military reconnaissance imaging satellites, the German Terra SAR-X spaceborne radar system and the SAR-Lupe military radar imaging satellite, Japan ALOS radar series and Canada's RADARSAT series satellites[3], and so on. The research on SAR imaging technology in China is relatively late. The airborne SAR imaging experiment was first carried out in 1979. After more than 30 years of development, the SAR satellite system represented by the "Environment and Disaster Monitoring and Forecasting Small Satellite Constellation" system has been formed [4].

Compared with SAR imaging technology, the interpretation and interpretation technology of SAR images is still lagging behind. With the improvement of SAR image resolution, the ship target reflects more abundant features, and the corresponding data volume also increases sharply. Under the conditions of modern warfare, the demand for automatic target recognition for the informationization and intelligent development of high-tech weapons is obvious. How to quickly and accurately detect and locate a typical marine ship target from a high-resolution SAR image containing background clutter, extract the characteristics of the target ship, and further identify the result, which has become an urgent application in military applications. The demand, this is also the hotspot and difficulty of the research of the research institutions in the world.

2. Image Preprocessing

The classic interpretation process of SAR image ship target is shown in Fig.1[5]. It mainly contains three modules: image preprocessing, feature extraction and selection, and classification recognition.

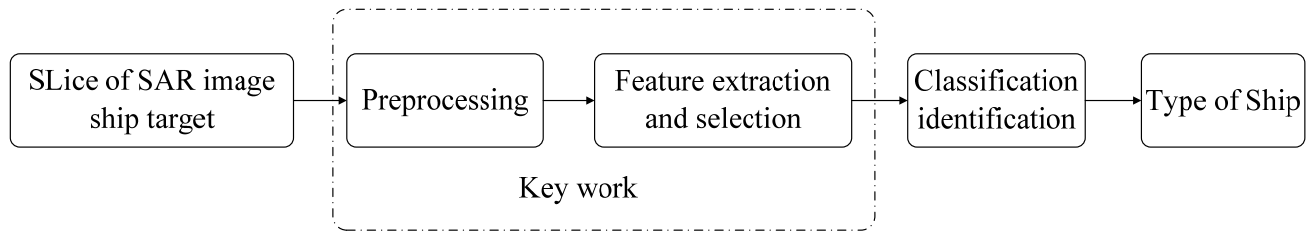


Fig.1 The classic process of SAR image ship target interpretation

Image preprocessing is the first step in the interpretation of SAR image ship targets, and its purpose is to remove the influence of background clutter on subsequent recognition performance and separate the target from the background. Preprocessing has the most rich connotations, including image denoising, image segmentation and morphological filtering.

2.1 Reduction of Image Noise

Reduction of image noise is to suppress the influence of speckle noise and target smear on subsequent processing [6]. In the early SAR image processing, the suppression of the speckle is mainly achieved by image filtering[7][8]. The classic RCS reconstruction filter is a typical representative, for example, the Lee filter and the Kuan filter[9] in which the multiplicative noise is approximated as a linear model. The Frost filter[10] which recovers the image by convolving with the impulse response is also included. And various enhancement filters built on this basis to preserve more image texture details are the main means of image noise reduction during this period.

Recently, the modern spectral estimation techniques have been widely used for preprocessing of SAR images. Studies have shown that spectral estimation methods can strike a better balance between scattering center resolution and noise and clutter suppression. In addition, new methods for improving resolution such as regularization methods, partial differential methods, and basis tracking methods have received increasing attention. The basic idea is to estimate the extrapolation of the spectrum and the resolution by estimating the relevant parameters of the target scattering center model under specific a priori constraints.

2.2 Image Segmentation

The purpose of image segmentation is to separate the target from the background clutter for subsequent feature extraction. The commonly used methods are Markov random field based segmentation (MRF), partial differential equation based segmentation (PDE) and threshold-based segmentation[11]. The well-known CFAR (constant false alarm) detection is a kind of threshold segmentation, which is widely studied and applied because of its simple and efficient algorithm, and CA-CFAR, VI-CFAR and GO/SO-CFAR[12]are derived. It has been greatly improved, and its shortcomings are also obvious. The selection of sea clutter model and parameter estimation largely determine the performance of the algorithm. In order to overcome the dependence of the segmentation algorithm on the background clutter statistical model, the threshold segmentation method based on the gray histogram[13] has received more and more attention from researchers. For example, the largest inter-class difference method proposed by Japanese scholars in 1979, which is to adaptively determine the segmentation threshold by maximizing the variance between the grayscale classes of the segmented target and the background. Similarly, the introduction of the Shannon entropy concept in information theory[15], the maximum entropy threshold method that maximizes the sum of target background information entropy is also an effective image segmentation method.

2.3 Morphological Filtering

Morphological filtering is to eliminate the isolated points and edge burrs in the binarized image. The main method is the erosion and expansion of the image morphology processing, and the open and closed operations of their composite.

3. Feature Extraction and Selection

In order to obtain a robust and compact description of the target of interest from the SAR image in order to improve the speed and performance of the classification recognition, the extraction and selection of the target feature is necessary. At present, the characteristics widely used by researchers mainly include geometric structure features, gray statistical features, electromagnetic scattering features and transformation features [16], as shown in Table 1.

Table 1. The typical characteristics of ship target recognition in SAR images

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|---|--|--|
| Typical Characteristics of Ship Target Recognition in SAR Image | Geometric feature | Perimeter, area, aspect-ratio, squareness, fractal dimension, moment of inertia, etc. |
| | Grayscale statistical feature | Mean, variance, standard deviation, variance coefficient, maximum undulation of gray scale, dispersion coefficient, etc. |
| | Electromagnetic scattering characteristics | Peak, scattering center. |
| | Locally invariant feature | Generalized invariant moments (Hu-moments, Zernike-moments), SIFT features, etc. |
| | Transformation feature | Fourier transform, wavelet transform, Radon transform, etc. |

Generally, there is no linear relationship between the performance of the classifier and the number of features. On the contrary, the feature of excessive redundancy may even cause the performance of the classifier to be seriously degraded, so further screening of features is required. Research on target feature selection methods Currently published literature is less, the mainstream feature selection strategy [17] has Filter and Wrapper. The Filter strategy does not depend on the recognition model, but through the analysis of the correlation coefficient between the features, mutual information and information entropy [18] and other mathematical relationships for screening. The advantage is that the speed is fast and the efficiency is high. The disadvantage is that it is separated from the subsequent classification algorithm. The result of the combination of the selected features for classification identification does not guarantee the accuracy of the results. On the contrary, the Wrapper strategy directly selects the feature with the correct rate of the classifier. The advantage is that the accuracy of the classification algorithm is guaranteed. The disadvantage is that the dependent classifier increases the computational overhead. Therefore, using the two strategies cascade [19] method to design the feature selection algorithm is the common idea of the researchers, that is, the Filter feature selector is used to greatly compress the target feature dimension, and then the Wrapper strategy is used for fine filtering, taking into account the characteristics. The speed and accuracy of the selection. However, the loss of target feature information caused by the two strategic cascades may make the final result a sub-optimal strategy, and the theory to prove its effectiveness has not been publicly reported, and the performance of the selector is also good or bad. Lack of generalized evaluation indicators.

4. Classification and Identification

Classifier design is the key to target recognition. Using the filtered target feature vector as the target descriptor, construct the training sample set, and use the machine learning method such as support vector machine [20] (SVM), extreme learning machine [21] (ELM), BP neural network [22] Recognition has become a major trend in the development of SAR image target recognition. Each type of machine learning model in this type of method can well establish its performance evaluation indicators. The published data show that the best BDA-KELM (discrete algorithm-core limit learning

machine) model is currently available [21] Its classification accuracy rate is 97%, which is far superior to the traditional Bayes classification model (87%) [23] and KNN model (92%) [24], and is also better than the SVM combined classifier accuracy of 95% [19].

In the case where the prior ship type is not available as a training sample, the unsupervised classification method is commonly used for SAR image ship target recognition. Gerard Margarit [25] used the Euclidean distance corresponding to the scattering center as a measure of the degree of similarity between the ship and the model, and classified the ship to obtain better classification performance. In addition, syntactic structures, fuzzy logic and other techniques have been applied in SAR image ship target recognition, and some research results have been achieved.

5. Compressed Sensing Technology

The classical SAR image processing method includes the above contents, and its effectiveness has been confirmed by a large number of experimental and theoretical studies. However, for different SAR images, the adaptive and generalization capabilities of the preprocessing algorithm are difficult to guarantee and identify. The algorithm also encounters bottlenecks in terms of speed and accuracy. The Compressed Sensing (CS) Theory [26] proposed by D. Donoho and E. Candes et al. in 2006 showed excellent performance in the field of signal processing. In 2009, John Wright and Nhat Vo[27] put it in person. The successful application of face recognition lays a theoretical framework for compressed sensing for pattern recognition, and also provides a new idea for SAR image ship target recognition.

5.1 Method Overview

SAR image target recognition is to identify the attribution problem of test samples by using known training samples. Compressed sensing theory by constructing a so-called over-complete dictionary containing all kinds of samples, theoretically any test sample y to be identified can be linearly represented by the column vector constituting, and only the coefficient of the column vector of its corresponding category is non-zero. That is, the sparse representation of the test sample y in the overcomplete dictionary A can be obtained. The problem of the SAR image ship target recognition is transformed into solving an optimal norm and reconstructing the sparse signal from its measured projection value [28].

This method does not pay attention to the two-dimensional structure of the SAR image itself, and generally stretches it into a one-dimensional vector by column. Therefore, there is no redundant process of pre-processing images, which avoids the influence of pre-processing on target recognition rate.

5.2 Algorithmic Tour

The core problem of CS theory is the signal reconstruction problem, and the signal reconstruction under the norm model is an NP-hard problem. There are two main types of approximation algorithms and heuristic algorithms. The typical approximation algorithms are greedy tracking and convex relaxation. (1) Greedy tracking adopts the method of iterative iteration, updating the support set and gradually approximating the original solution, such as: matching tracking (MP) [29], orthogonal matching tracking (OMP) [30], regularized orthogonal matching pursuit (ROMP) [31], piecewise orthogonal matching tracking (StOMP) [32], gradient tracking (GP) [33], subspace tracking (SP) [34]. (2) The convex relaxation algorithm is solved by transforming the nonconvex norm optimization problem into a convex norm optimization problem under certain conditions. Such as the well-known base tracking (BP) [35] algorithm, interior point method [36] and gradient projection method [37]. The representative of heuristic algorithms is group intelligence algorithm [38], such as ant colony algorithm (ACO), particle swarm optimization (PSO) and genetic algorithm (GA), tabu search. Greedy tracking has attracted much attention because of its simple algorithm and low computational cost. OMP class algorithm is the mainstream of it, and it has become the focus of researchers. Many researchers at home and abroad have studied and improved such algorithms.

6. Summary and Outlook

Thanks to the unremitting efforts of many researchers, SAR image ship target recognition technology has made great progress, the theoretical framework is getting better and better, and the performance of the algorithm is also improving. However, the technology is still immature at present, and there are still many problems to be solved:

(1) At the training sample level, the lack of real SAR data sets, the cost of acquiring various satellite-borne SAR data is relatively high, and the lack of data seriously hinders the progress of the research.

(2) At the feature selection level, there is a lack of generalized evaluation indicators for feature selection results.

(3) The classifier design level, over-reliance on machine learning, can not complete the identification in the absence of target a priori data, and hinders the practical application of these algorithms in engineering.

In response to these problems, there are two main lines for the development of SAR image ship target recognition. Firstly, field experiments should be widely carried out, SAR image data of various types of ships should be collected, and SAR image ship target sample libraries should be constructed. Secondly, the research on recognition algorithms based on target model driving should be actively carried out to promote the practical application of identification technology in engineering.

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