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Radar target recognition using contourlet packet transform and neural network approach

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ABSTRACT

Contourlet is a "true" two-dimensional transform that captures the intrinsic geometrical structure and have been shown to be successful for many tasks in image processing. In this paper, a wavelet-based contourlet packet (WBCP) transform is investigated and an adaptive contourlet packet (ACP) transform based on genetic algorithm (GA) is proposed to extract the features of radar targets in synthetic aperture radar (SAR) images recognition. The features of the sampled targets are subsequently used to train a radical basis function neural network (RBFNN) that is then able to quickly and reliably recognize the objects. In comparison with WBCP, our proposed ACP has relatively low computational complexity and high recognition rate. Finally, we show some numerical experiments demonstrating the potential of this method for target recognition in SAR image processing.

1. Introduction

Many efficient techniques have been developed to recognize radar target type using one-dimensional (1D) or two-dimensional (2D) range profiles of radar returns [1,2]. In recent years, along with the development of radar technologies, as well as with increasing demands for target identification in radar applications, classifying targets with high-resolution radars has been well known to many researches and commonly used in radar target recognition [3–7]. For example, Zyweck et al. [3] proposed to classify the detected aircrafts using high-resolution signatures provided by the radar system. Another approach is to use 2D synthetic aperture radar (SAR) and inverse synthetic aperture radar (ISAR) images to recognize objects [5–7]. In this case SAR system provides 2D data, and the automatic target recognition (ATR) is based on the information in the received signal echoes, representing different geometrical structures of targets. Although the imaginary and retrieval approaches of SAR data have made an improvement by years of efforts, the subsequent comprehension technique of SAR images is still in their infancy, such as SAR image compression, fusion and ATR. However, the radar target recognition using SAR image is becoming an active research area, and some approaches to ATR ranging from template matching based on physical models to statistical techniques are proposed. General reviews of ATR concepts and technologies can be found in [8,9].

Different with regular electro-optical imagery, SAR systems collect huge amounts of complex data, which show 2D radar cross-section (RCS) distribution of a target in the down-range and cross-range domain. The raw complex SAR data has both the amplitude and phase information, and the SAR data has not only the geometric feature of optical imagery, but also the electromagnetic characteristic, which can both be used for ATR of SAR. In paper [7], the authors proposed a fully integrated ATR system, which made full use of the controllable parameters in imaging stage, and could select the illuminating

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and reflecting states of polarization of a radar signal to maximize the separation distance among targets and clutter using maximum average correlation height filters. However, the SAR target recognition is also operated on the amplitude of the synthesized SAR data for the inaccessibility of raw data and the scarcity of professional knowledge. The most important objective of ATR of SAR images is to separate various target classes apart. One of the key approaches to ATR of SAR imagery is based on the extraction of certain features of the objects in the images and the subsequent classifier. Currently the detection theory [10,11], pattern recognition [12–14] and neural network [15,16] approaches have been applied to SAR target recognition, which all tend to use effective features to get reliable recognition.

Commonly speaking, an ATR system of SAR images consists of four parts: speckle reduction, detection, extraction and recognition or classification. Because SAR images are often polluted by speckle or coherent noise, so firstly speckle reduction is a necessary procedure before detection. Several filters have been proposed for speckle reduction, such as the Lee filter and Frost filter. The detection stage aims to locate the possible region of interest (ROI) from the homogeneous background of SAR images. Constant false alarm ratio (CFAR) and its variants such as cell average CFAR (CA-CFAR), greatest of CFAR (GO-CFAR) and smallest of CFAR (SO-CFAR) are frequently used in detection. Recently region classification CFAR (RC-CFAR) is proposed to detect multiple targets in both homogeneous and inhomogeneous background [17]. Unlike in optical images, targets in SAR images have large dynamic range and don't have clear edges. So a preprocessing of ROI data is helpful to the subsequent feature extraction and recognition. To discard image chips that do not contain potential targets, it is first necessary to segment targets from noisy background and shadow. Since the radar reflection varies from chip to chip, we first equalize the intensity of the image to be in the interval from 0 to 1 using the standard histogram equalization method. Histogram equalization modifies the dynamic range and contrast of an image by employing a monotonic, non-linear mapping which reassigns the intensity values of pixels in the input image, such that the output image contains a uniform distribution of intensities. Then the images are smoothed and roughly segmented with a predefined threshold, and subsequent fine-target segmentation is performed by using the median of this target as a threshold.

The next step in ATR system of SAR is feature extraction and pattern recognition. Features represent the characteristics of objects in the SAR images and selecting or synthesizing effective composite features are the key to the performance of target recognition. The quality of target recognition is heavily dependent on the effectiveness of the features. For the segmented targets, there are many features that can be extracted. What are the appropriate features that are helpful to classification or recognition, and how to obtain the appropriate set of features from the image are the two fundamental questions in feature extraction. One of the most important differences of various classes of targets, such as ships, tanks and planes, is their geometric shapes, which also exist in different types of one class.

Apparently the fine details of the target geometrical structure are crucial for automatic recognition of SAR images. Recently wavelet transform (WT) have become one of the basic tools for feature extraction. Unlike Fourier transform, WT coefficients are partially localized in both spatial and frequency domains and form a multiscale representation of the image [18]. Therefore the transformed coefficients can be successfully selected as the features of images for classification. However, it is well known that the commonly used separable extensions of 1D transforms, such as WT, are limited in capturing the geometry of image edges. Efficient representation of image lies at the heart of many image processing tasks, where "efficient" refers to the ability to capture significant information about an object of interest using a small description. For practical applications, an efficient representation is crucial.

In the last decade, several "geometric" wavelets (e.g., ridgelet, curvelet, contourlet and bandelet) [19–23] have grown in popularity motivated by the need for finding better representations of nature images. The imaginative appeal of multiscale and localized representation may account for the popularity of "geometric" wavelets. A striking property of these "new wave" of multiscale transforms is their efficiency in dealing with particular singularities in images. For example, ridgelet basis/frames are optimal for representing smooth signals with singularities along straight lines, and contourlet basis can effectively capture smooth contours that are the dominant feature in natural images. Contourlet is a flexible multiresolution, local and directional image expansion using contour segments. It can provide a multiscale and directional decomposition for images, which is more suitable for catching the features in SAR images that are abundant in complex contours, edges, textures and background. However, contourlet transform (CT) does not give a further decomposition of the high frequency, which may lose some details of image. The latest theoretical developments in feature extraction using "geometric" wavelets quickly find applications in pattern recognition [24,25]. Joining these efforts, in this paper, an adaptive contourlet packet (ACP) transform is proposed based on the wavelet-based contourlet packet transform (WBCP), and a truncated contourlet packet decomposition tree (CPDT) is constructed through optimized selection of the contourlet atoms using genetic algorithm. Subsequently some related statistical parameters of nodes are computed as the features for recognition. These extracted features capture the characteristics of the object and are fed into a classifier, radical basis function neural network (RBFNN) to recognize the objects in SAR images.

The remainder of this paper is organized as follows. Section 2 introduces the mathematical foundation of contourlet. In Section 3, a WBCP transform is investigated, and an ACP based on an optimization selection of nodes with genetic algorithm (GA) is proposed. Then we provide the overall structure of the recognition system and give the technical details used in this paper. In Section 4, some experiments will be conducted and their results together