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Synthetic aperture radar image compression using tree-structured edge-directed orthogonal wavelet packet transform

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ABSTRACT

Currently, wavelet-based coding algorithms are popular for synthetic aperture radar (SAR) image compression, which is very important for reducing the cost of data storage and transmission in relatively slow channels. However, standard wavelet transform is limited by spatial isotropy of its basis functions that is not completely adapted to represent image entities like edges or textures, which means wavelet-based coding algorithms are suboptimal to image compression. In this paper, a novel tree-structured edge-directed orthogonal wavelet packet transform is proposed for SAR image compression. Inspired by the intrinsic geometric structure of images, the new transform improves the performance of standard wavelet by filtering along the regular direction first and then along the orthogonal direction with directional lifting structure. The cost function of best basis selection is designed by textural and directional information for tree-structured edge-directed orthogonal wavelet packet transform. The new transform including speckle reduction can be used to construct SAR image coder with the embedded block coding with optimal truncation for transform coefficients, and arithmetic coding for additional information. The experimental results show that the proposed approach outperforms JPEG2000 and Fast wavelet packet (FWP), both visually and item of PSNR values.

1. Introduction

Synthetic aperture radar (SAR) [1] is a remote sensing technology that uses the motion of radar transmitter to synthesize an antenna aperture much larger than the actual antenna aperture in order to yield high spatial resolution radar images. However, the volume of data collection is increasing rapidly, the ability to transmit it to the ground, or to store it, is not ascending as fast. Thus, there is a strong interest in developing data compression algorithms [2] that can obtain higher compression ratios, while keeping image quality to an acceptable level for SAR image data.

Since the introduction of wavelet transform [3,4] as a tool for image representation, its use has become popular in images compression, such as wavelet-based JPEG2000 – international standard for still image compression [5]. The existing coding algorithms for SAR image compression mostly base on the wavelet transform or only have a little change [6]. In spite of its success, standard 2-D (two-dimension) discrete wavelet transform (DWT) is not completely adapted to represent image entities like edges or textures. 2-D images can be viewed as certain 2-D signals but with unique properties, which are neither the stack of 1-D (one-dimension) signals nor some completely random 2-D signals. There usually exist a large amount of edges or textures (weak edges), and the discontinuity points are typically positioned along smooth curves owing to smooth boundaries of physical objects. It is known that standard 2-D separable wavelet is implemented by separable 1-D filtering in horizontal and vertical directions, which has been proved that it is capable of detecting horizontal, vertical and punctual singularities. Whereas, the analysis of edges that are not straightly horizontal or vertical direction with separable wavelet bases is not optimized. The disappointing performances indicate that wavelet cannot provide a compact representation for edges and lines of images, which results in large-magnitude high-frequency coefficients. That is to say, standard wavelet bases are suboptimal to approximate natural and SAR images. At low bit rates of compression, the quantization noise from these coefficients is visible clearly, in particular causing annoying block artifacts around edges, which will reduce the visual quality of compressed image. Meanwhile, SAR images have some special characteristics [7] different from the natural images which affect the design of compression algorithms. The first is the speckle phenomena, which results from the coherent radiation and processing. The second is that there is detailed texture information as well as large homogeneous regions in SAR images. The third is the very high dynamic range of SAR images. All

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characteristics require that the methods for SAR image compression should be improved upon the traditional image compression techniques.

In order to promote the development of image processing technology, many researchers have done some excellent work to find the new theories and tools for image sparse representation, which is foundation of image compression. Their work can mainly be classified into two categories: fixed representation and adaptive representation. The former provides more directional information through producing more directional component images with high-frequency components, including curvelet [8], complex wavelet [9], contourlet [10], etc. These transforms propose to preserve fine directional information in transform domain, extensively applied in feature extraction, image enhancement, image denoising, and even retrieval. However, they are not suited to compression for lack of efficient entropy coding to exploit directional information in each transform region. The later includes bandelet [11], curved wavelet [12], etc. The key development is adding the direction predicted before the transform. Bandelet transform first applies the standard 2-D DWT to the image, followed by the bandeletization procedure that further removes the directional correlation in the high-pass wavelet coefficients. The low-pass image remains the same as in the standard 2-D DWT, and blocking artifacts are not observed since the block-wise operations are performed in the wavelet domain. Curved wavelet proposes an overlapped extension to prevent coding artifacts around the boundaries of different directional region, while looses the orthogonal property and the sub-pixel interpolation should be improved. These problems potentially prevent the above scheme from further improving the coding efficiency for the images with rich textures. Meanwhile, the traditional pyramid wavelet transform, which just recursively decomposes the low-frequency channel image, may not be optimal for SAR images. As described ahead, SAR images contain rich textures, which mean that there exist rich middle and high-frequency components. In order to improve the representation ability for SAR image data, the tree-structured wavelet packet transform was proposed for SAR image compression [13].

In this paper, a novel tree-structured edge-directed orthogonal wavelet packet transform (TS-EDOWPT) is proposed for SAR image compression, which is an efficient coding architecture fitting the characteristics of SAR image data, and improves the performance of the peak signal-to-noise ratio (PSNR) values and visual quality together. Inspired by the intrinsic geometric structure of images, the new transform improves the performance of standard wavelet by filtering along the regular direction first and then along the orthogonal direction with directional lifting structure. Compared with curved wavelet, the proposed method can efficiently capture the geometric regularity of sub-image, constrain the contamination of quantization noise, and reduce the additional information. The cost function for the best basis selection is established based on the textural and directional information analysis. The coding algorithm is developed using embedded block coding with optimal truncation (EBCOT) and arithmetic coding (AC) for transform coefficients and additional information respectively. Compared with the popular JPEG2000 and fast wavelet packet (FWP) [16] schemes, experimental results show that our method is very promising for image sparse representation and compression, which gains higher PSNR values and better visual quality.

In the remainder of the paper, we will describe our proposed method for SAR image compression in detail. Section 2 introduces the edge-directed orthogonal wavelet transform (EDOWT) with adaptive directional lifting structure and shows its improvement upon standard wavelet transform for image sparse representation by some experiments. Section 3 shows the best basis selection with the textural and directional information analysis for TS-EDOWPT, and new SAR image coder including speckle reduction proposed in Section 4. Section 5 provides the experimental results to demonstrate the advantage of our proposed method for SAR image compression. The conclusion of this paper is described in Section 6.

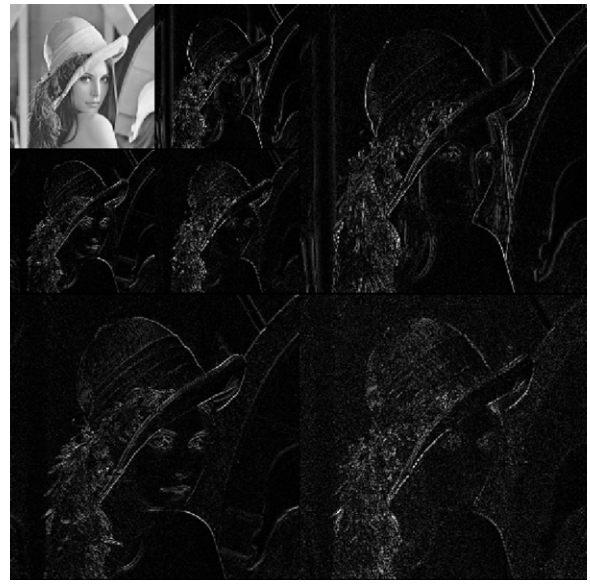

Fig. 1. Decomposed image of Lena.

2. Edge-directed orthogonal wavelet transform

Although wavelet transform has become an important tool for image processing and achieved a series of successes in both theory and practice. It is found that the wavelets in 2-D obtained by a tensor-product of one dimensional wavelets is suboptimal to image representation as cannot capture geometric structures of image, which limits its performance in higher dimensions.

The main shortcoming of standard 2-D wavelet is the limited and fixed direction, which is ill-suited to approximate image features with arbitrary direction that is neither vertical nor horizontal. Fig. 1 shows a decomposed image after two levels of 2-D Haar wavelet transform [3]. It can be seen from Fig. 1 that the large-magnitude high-frequency coefficients obviously exist in transform domain. Fig. 2 shows a portion of decoded Lena image obtained

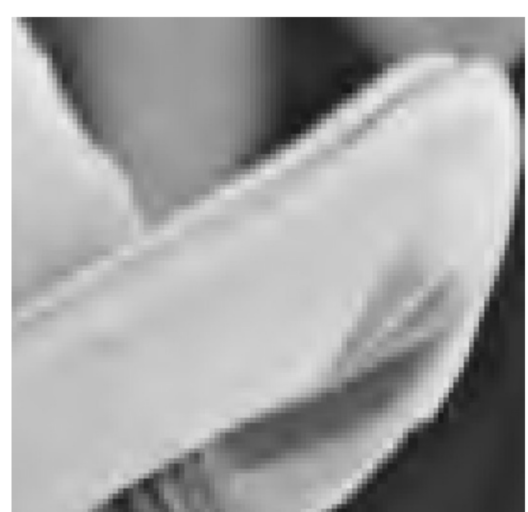

Fig. 2. Example of JPEG2000.