



Remote sensing image compression based on binary tree and optimized truncation [☆]



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ABSTRACT

The remote sensing image data is so vast that it requires compression by low-complexity algorithm on space-borne equipment. Binary tree coding with adaptive scanning order (BTCA) is an effective algorithm for the mission. However, for large-scale remote sensing images, BTCA requires a lot of memory, and does not provide random access property. In this paper, we propose a new coding method based on BTCA and optimize truncation. The wavelet image is first divided into several blocks which are encoded individually by BTCA. According the property of BTCA, we select the valid truncation points for each block carefully to optimize the ratio of rate-distortion, so that a higher compression ratio, lower memory requirement and random access property are attained. Without any entropy coding, the proposed method is simple and fast, which is very suitable for space-borne equipment. Experiments are conducted on three remote sensing image sets, and the results show that it can significantly improve PSNR, SSIM and VIF, as well as subjective visual experience.

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1. Introduction

Remote sensing images have wide applications such as object detection [1], environmental monitoring [2], and urban planning [3], etc. With the rapid development of sensor technology, high spatial resolution images are more easily acquired. Since the images will take up a great deal of storage space, and the hardware of space-borne equipments is limited, great efforts are made to seek low-complexity image compression algorithms.

Because wavelet transform expresses the local time-domain and frequency-domain characterization and provides excellent multi-resolution analysis features, most of the state-of-the-art coding systems are based on wavelet transform. The Embedded Zerotree Wavelet (EZW) [4] is the first successful compression algorithm based on wavelet transform, which constructs zero-tree by the correlations across scales in each bit-plane, so that a large number of no-significant coefficients are predicted successfully by a

root of zerotree. Set Partitioning in Hierarchical Tree (SPIHT) [5] is another famous algorithm, which can significantly improve the performance with lower complexity compared with EZW. In [6], the Set Partitioned Embedded Block (SPECK) coder was proposed to extend SPIHT.

EZW, SPIHT and SPECK exploit self-similarity across scales, while there are some algorithms that utilize the clustering characteristic within each subband. In [7], the QuadTree Coding (QTC) algorithm for wavelet image compression was proposed. It splits each node into four descendent nodes once it is significant with the current threshold. QTC produces an embedded data stream, supports quality scalability, and permits region-of-interest coding. The Embedded Block Coding with Optimized Truncation (EBCOT) algorithm [8], adopted in the JPEG2000 standard [9], combines layered block coding, rate-distortion optimization, and context-based arithmetic coding in an efficient and highly scalable way.

Presently, there are some methods which are specifically designed for remote sensing images. In [10], Li et al. proposed the two-dimensional oriented wavelet transform for remote sensing images based on JPEG2000. Kulkarni et al. [11] presented a scan-based JPEG2000 for large-scale images. However, JPEG2000 is too complex, which hinders JPEG2000 to be a compression standard for space-borne missions where the capacity of storage and transmission is limited.

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In [12], the Consultative Committee for Space Data Systems (CCSDS) [13] published an image data compression standard (CCSDS-IDC) based on wavelet transform. The recommendation specifically targets space-borne missions, and focuses more on complexity and less on compression performance. It has a limited set of options, supporting its successful application without in-depth algorithm knowledge. In [14], some extensions of CCSDS-IDC have been proposed. In [15], the directional lifting wavelet transform was used to improve the performance of CCSDS-IDC.

Besides JPEG2000 and CCSDS-IDC, the other compression algorithms were also applied for remote sensing image. In [16], a modified listless strip based SPIHT was proposed to reduce system complexity and minimize processing time and memory usage. In [17], an improved SPIHT was proposed for multispectral image compression for various band images with high resolution. In [18], a three dimensional SPECK was proposed for hyperspectral image compression. In [19], a SAR complex image data compression algorithm based on QTC in wavelet transform domain was proposed, showing that QTC achieves the best performance for SAR complex image compression. In [20], the cubic B-spline fuzzy transform was proposed for an efficient and secure compression in wireless sensor networks.

Recently, compressed sensing has been successfully used in many fields of computer vision [21,22], which also has been proved to perform well on image compression. In [23], a SAR image compression using multiscale dictionary learning and sparse representation was proposed, which is better for preserving the important features of SAR images with a competitive compression performance. In [24], an adaptive spectral-spatial compression of hyperspectral image with sparse representation has been proposed, which outperforms some state-of-the-art HSI compression methods in terms of the rate-distortion and spectral fidelity performances. For remote sensing image compression, the complexity of algorithm is very important. A new fast algorithm for image and video compression based on discrete Tchebichef transforms DTT has shown good performance [25]. The proposed DTT-based method is multiplication-free and only requires a reduced number of additions and bit-shifting operations, which is suitable for remote sensing image compression for its lower complexity.

In 2012, a fast remote sensing image coder, named binary tree coding with adaptive scanning order (BTCA) [26], was presented. It used the binary tree for coding remote sensing image in wavelet domain, and then developed an adaptive scanning order to traverse the binary tree, so that better performance and visual effect are attained. Unlike JPEG2000 or CCSDS-IDC, BTCA is very fast because it does not use any entropy coding. BTCA is very easy to implement in hardware and very suitable for on-board compression. Since BTCA was proposed, some improvements have been developed. In [27], an embedded image compression based on fractal and wavelet is proposed, where the lowest frequency subband of wavelet domain is coded by fractal first, and the coding error and other sub-bands are coded by BTCA. In [28], a Human vision-based Adaptive Scanning (HAS) for the compression of remote sensing image was proposed, which generates an importance weighting mask according to the human visual characteristics before applying BTCA. In [29], a content-based adaptive scanning scheme was proposed for remote sensing image compression, which provides different scanning orders among and within subbands based on BTCA.

However, BTCA needs a lot of memory to store the binary tree for large-scale remote sensing images, and does not provide random access property. In [26], BTCA is processed with a scan-based mode, named BTCAS, to deal with this problem. Nevertheless, BTCAS sacrifices in compression efficiency. In this paper, we propose a new coding method based on Binary Tree and Optimized Truncation (BTOT). Compared with BTCA, the proposed

BTOT method significantly improves the PSNR, while it requires less memory and has the random access property.

The main contributions of this paper are listed as follows:

- We propose an improved BTCA algorithm by optimized truncation. The wavelet image is first divided into several blocks which are encoded individually by BTCA. Then we apply rate-distortion optimization to get the higher compression ratio, less memory requirement and the random access property.
- We find that the distortion-rate almost decreases as the adaptive scanning level increases, so we record the bit rate and corresponding distortion as a candidate truncation point after each adaptive scanning level to get finer embedded bit-streams.

The remainder of the paper is organized as follows: In section 2, we introduce the BTCA algorithm briefly. In section 3, we describe the proposed method in detail. In section 4, we give the analyses about time complexity, memory requirement and the feature of the coding stream. The experimental results are presented in section 5. Finally, we provides the conclusion in section 6.

2. The BTCA algorithm

Because the coefficients in the high-frequency wavelet subbands are sparse, we can divide the subbands into several blocks and then check whether they contain significant coefficients. The tree structure is widely used in many fields of information sciences [30–32], and is also a good model for compression [33]. In [7], each block is split into four sub-blocks once it tests as significant with respect to the current threshold. However, the binary tree is more efficient than quadtree [34], so the binary tree coding in wavelet domain is proposed in [26]. Because our method is based on BTCA, we briefly describe BTCA as follows.

Suppose a wavelet image is of size $2^N \times 2^N$. We first transform it into an one-dimensional vector using Morton scanning order, denoted by V . Then we construct the binary tree $\Gamma(t)$ for $1 \leq t < 2 \times 2^N \times 2^N$. The bottom level of the binary tree consists of the absolute value of each coefficient:

$$\Gamma(t) = \left| V(t - 2^N \times 2^N) \right| \text{ for } 2^N \times 2^N \leq t < 2 \times 2^N \times 2^N. \quad (1)$$

The upper levels of the tree are defined iteratively:

$$\Gamma(t) = \max \{ \Gamma(2t), \Gamma(2t + 1) \} \text{ for } 1 \leq t < 2^N \times 2^N. \quad (2)$$

After constructing the binary tree, we can traverse the tree by depth-first, which can be expressed as a function $code = BTC(\Gamma, t, T_k)$ as Algorithm 1, where t is a tree node index of the binary tree, and T_k is a threshold where $T_0 = 2^{\lfloor \log_2 \Gamma(1) \rfloor}$ and $T_k = T_0 / 2^k$.

The coefficients on the edges are often large, so we can scan the neighbor of the previous significant coefficients before other regions are scanned. BTCA uses an adaptive scanning order, namely, from the bottom level to the top, if a coefficient's brother is a previous significant coefficient, then we traverse the coefficient and its descendants by depth-first. Based on Algorithm 1, the detail steps of BTCA can be described as a function $code = BTCA(\Gamma, T_k)$ as Algorithm 2.

3. Compression based on binary tree and optimized truncation

BTCA achieves state-of-the-art performance, but it needs a lot of memory to store the binary tree for a large remote sensing image, and does not provide random access property. In this section, we propose a new method based on binary tree and optimized

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