Neurocomputing 191 (2016) 330–340

Contents lists available at ScienceDirect

Neurocomputing

journal homepage: www.elsevier.com/locate/neucom

Content-based onboard compression for remote sensing images

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ARTICLE INFO

Article history:
Received 7 August 2015
Received in revised form
8 December 2015
Accepted 17 January 2016
Available online 8 February 2016

Keywords:
Onboard compression
Content-based
Adaptive scanning
Remote sensing image
Binary tree coding

ABSTRACT

New-generation instruments on spacecraft are collecting a large amount of information at an increasing rate, which makes the onboard data compression a challenging task. Moreover, existing compression methods usually scan an image in a fixed way without considering the content of the image, which makes the performance improvements of these methods often marginal at best. In this paper, we present a novel, content-based, adaptive scanning (CAS) scheme for onboard compression. For a remote sensing image, first, the wavelet transform is performed. Second, an adaptive scanning method is proposed, which can provide different scanning orders among and within subbands, respectively. The former aims at organizing the codestream according to the importance of subbands, and the latter focuses on preserving the texture information as much as possible. Finally, the binary tree codec is utilized to code the 1-D coefficient array after scanning. Experimental results demonstrate that compared with other scan-based compression methods, including CCSDS, JPEG2000, and even the state-of-the-art adaptive binary tree coding (BTCA), the proposed compression method can effectively improve the coding performance. In addition, the method does not use entropy coding or any complicated components, which makes it extremely suitable for onboard compression.

1. Introduction

Along with the development of sensor technology, the spatial and spectral resolutions of remote sensing images have been greatly improved, which enhances the applicability of remote sensing images. However, there is cost of the large amount of data in that the data storage and transmission of onboard equipment is highly difficult. To alleviate this issue, a compression method with high coding performance and low complexity is very desirable. In general, the compression of remote sensing images involves some traditional compression schemes, such as EZW [1], SPIHT [2], SPECK [3], and JPEG2000 [4]. These compression schemes can effectively compress natural images because the details of natural images are often limited. After the discrete wavelet transform (DWT), a compact representation can be obtained. However, compared with natural images, remote sensing images have their own unique characteristics. They usually contain a large number of ground objects, which leads to a considerable number of details, such as geometric information, edge and texture information, and outlines of small targets. As a result, it is difficult to achieve high coding performance for remote sensing images because the coefficients of the high frequency subbands are still very large after the DWT. In recent years, some compression schemes specifically designed for remote sensing images have been proposed [5–8]. These compression schemes compress remote sensing images from several aspects, such as oriented wavelet transform (OWT) or sparse representation. Moreover, several machine learning methods are also adopted [9–12]. However, for onboard compression, the compression method should also be of low complexity. Therefore, some additional onboard compression methods have been proposed [13–19]. These onboard compression methods are designed based on several aspects, such as prediction, vector quantization, or distributed source coding (DSC). Because remote sensing images are often captured by sensors in a push-broom fashion and are quite large, the scan-based approach is also very desirable when handling onboard data [20].

In 2006, a scan-based method using JPEG2000 with incrementally acquired data was proposed [21]. However, the cost of the high-quality coding performance of JPEG2000 is its high complexity. The Consultative Committee for Space Data Systems (CCSDS) published a recommended standard for onboard image compression, and published the CCSDS-IDC Blue Book [22] for specific compression algorithms in 2005 and Green Book [23] for guidance of the IDC Recommendation in 2007. The standard of CCSDS is a scan-based algorithm, but it does not allow for interactive decoding. Furthermore, the level of DWT is fixed to three. In 2009, [14] presented some prominent extensions to the CCSDS, which allowed any number of wavelet decomposition levels and supported several forms of remote sensing image coding.

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http://dx.doi.org/10.1016/j.neucom.2016.01.048
0925-2312/

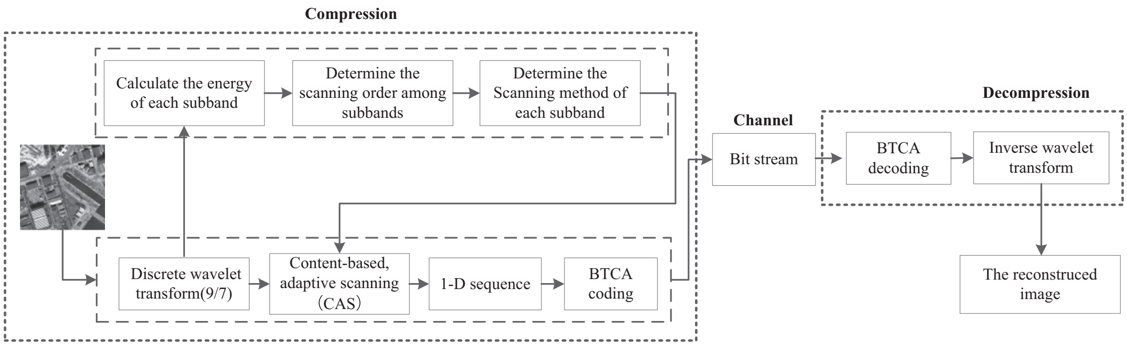

Fig. 1 The overall framework of the proposed compression method.

However, all of these methods are based on fixed scanning, which do not take the content of an image into consideration.

In 2012, the state-of-the-art compression method based on scanning for remote sensing images, known as adaptive binary tree coding (BTCA), was proposed [20]. The main concept of this method is that for a binary tree, it scans the significant nodes and their brothers before other nodes. This method can significantly improve the coding performance.

Although the process of BTCA is somehow related to the content of the image, it does not take an important procedure into account, i.e., the process of scanning an image. The BTCA directly converts a 2-D transformed image into a 1-D sequence by morton scanning. However, different remote sensing images are of different contents. In other words, for different remote sensing images, the spatial distribution of important coefficients is different. Thus, from the perspective of scanning, the morton scan may not be suitable for all images. In addition, remote sensing images are often rich in details, which leads to substantial amounts of information left in high frequency subbands after the wavelet transform. Moreover, for a given level of decomposition, the energy of HL, LH, and HH may be quite different. Therefore, the scanning order among these subbands is very important.

Focusing on the problems mentioned above, in this paper, a low-complexity, content-based, adaptive scanning (CAS) approach for onboard compression is proposed. The content of an image can be described from different perspectives, such as color, texture, shape and structure. In this paper, the content of an image refers to the energy distribution of different wavelet subbands. For different images, the direction information is different and can be reflected from the energy distribution of subbands. If the direction information can be utilized to determine the scanning order and scanning method, then those coefficients that can make a greater contribution to the reconstructed image can be preserved more effectively.

The paper is organized as follows. In Section 2, the novel content-based adaptive scanning scheme for the remote sensing image is designed. Firstly, some common scanning strategies are analyzed. Then, a detailed description of the proposed CAS-based compression scheme is provided. Finally, the computational complexity of the proposed method is analyzed. Section 3 describes the binary tree codes. Section 4 overviews some quality evaluation indices used in this paper. In Section 5, we present some numerical experiments and demonstrate the validity of the proposed method. Finally, a discussion of the results and conclusions is provided in Section 6.

2. Proposed content-based adaptive scanning method

The overall framework of the proposed content-based adaptive scanning compression method is shown in Fig. 1.

For the proposed method, the scanning order among the subbands is determined by the content of the image, and the scanning method within a subband depends on the characteristics of the current subband. When the scanning of a transformed image is finished, a 1-D coefficient sequence is generated. Finally, the binary tree codec is exploited to encode the 1-D coefficient sequence. The proposed method is not complicated, but it can provide a high-quality coding performance.

2.1. Features of the remote sensing images

Based on the type of remote sensor, remote sensing images can be classified into different categories, including optical images, synthetic aperture radar (SAR) images, infrared images, multispectral images and hyperspectral images [15]. For each type of remote sensing image, some compression methods have been proposed according to its features [24–29]. Optical remote sensing images[1] are often characterized by a high degree of randomness, weak local correlation, and multiple small targets [18], which result in a larger amount of non-zero coefficients in high frequency subbands after the wavelet transform. Four images, including two well-known natural images (Airplane, Goldhill) and two remote-sensing images (Europa3 and Ocean in Fig. 2), are chosen to compare the energy distribution of high frequency subbands (5-level DWT by the 9/7 biorthogonal filters); the result of comparison is shown in Fig. 3.

It has been demonstrated in Fig. 3 that the energy of almost every high-frequency subband of the remote sensing images is higher than that of the natural images. In addition, for these remote sensing images, the energy fluctuation among subbands is greater than that of natural images. This suggests that for remote sensing images, a different scanning order among subbands will have a greater impact on the coding performance. Therefore, the coding performance improvement is usually very marginal by using the traditional compression methods because they do not take the characteristics of the remote sensing images into consideration. To address this problem, developing a compression method that applies to remote sensing images is ideal.

2.2. Analysis of some common scanning strategies

For an image X, with a size of $M \times N$, the process of scanning the image can be defined as a bijection f from a closed interval $[1, 2, \ldots, M \times N]$ to the set of ordered pairs $\{(i,j) : 1 \le i \le M, 1 \le j \le N\}$,where the latter set represents the locations in the image [30]. After scanning, the two-dimensional (2-D) image is converted to a one-dimensional (1-D) sequence that

[1] For convenience, the optical remote sensing image in this paper is referred to as a remote sensing image hereafter.