Class-based compression algorithm for hyperspectral images

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Abstract: The huge amount of hyperspectral images creates challenges for data storage and transmission, thus it is necessary to employ efficient algorithm for hyperspectral images compression. An efficient lossy compression algorithm based on spectral classification was presented in this paper. The C-means algorithm was performed on the hyperspectral images to realize the unsupervised classification. According to the classification map, an adaptive Karhunen-Loève transform was performed on each class vector with the same spatial location in the spectral orientation to remove the spectral correlation, and then two dimensional wavelet transform was performed on each principle component. In order to achieve the best rate-distortion performance, the embedded block coding with optimized truncation coding was performed on all the principle components to produce the final bit-stream. Experimental results show that the proposed algorithm outperforms other state-of-the-art algorithms.

Key words: lossy compression; hyperspectral images; spectral classification; spectral decorrelation
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基于分类的高光谱图像压缩算法

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摘　要: 高光谱图像庞大的数据量给存储与传输带来巨大挑战,必须采用有效的压缩算法对其进行压缩。提出了一种基于分类的高光谱图像有损压缩算法。首先利用 C 均值算法对高光谱图像进行无监督光谱分类。根据分类图,针对每一类数据分别采用自适应 KLT(Karhunen-Loève transform)进行谱间去相关;然后对每个主成分分别进行二维小波变换。为了获得最佳的率失真性能,采用 EBCOT(Embedded Block Coding with Optimized Truncation)算法对所有的主成分进行联合率失真编码。实验结果表明,所提出算法的有损压缩性能优于其它经典的压缩算法。

关键词: 有损压缩; 高光谱图像; 光谱分类; 光谱去相关

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0 Introduction

With the increase of the spectral, spatial and radiometric resolution of the instrument, the number of collected hyperspectral images has increased rapidly, and such a huge amount of data creates challenges for data storage and transmission. To address this problem, efficient compression algorithms should be used. Lossy compression generates images with different quality levels by introducing a certain distortion, which can better exploit the typically limited downlink bandwidth. Therefore, there has recently been renewed interest in lossy compression.

As for the transform-based algorithms, Discrete Wavelet Transform (DWT), Discrete Cosine Transform (DCT) and Karhunen-Loève transform (KLT) are the three main methods used for spectral decorrelation. Lee proposed an algorithm that combined JPEG2000 with a spectral correlation approach, and experimental results showed that the spectral decorrelation approach using KLT outperforms DWT and DCT[1]. Due to the high complexity of KLT for real time application, Penna presented a low complexity version of spectral KLT for hyperspectral images with virtually no performance loss[2]. Wang proposed a new transform scheme, including Reversible Time-Domain Lapped Transform (RTDLT) for spatial decorrelation and reversible integer low-complexity KLT for spectral decorrelation, which can realize progressive lossy-to-lossless compression from a single embedded code-stream file[3]. Despite KLT's excellent performance for spectral decorrelation, the method fails to take advantage of local correlation because there are various classes and complicated textures in hyperspectral images. In Ref. [4], Fang proposed an efficient lossy compression based on cluster KLT, which achieves better compression performance than that of DWT-based algorithm. In Ref. [5], Cagnazzo proposed a region-based compression algorithm, which employs region-based KLT or class-based KLT for spectral decorrelation of multispectral images. Based on Ref. [4] and [5], we propose an efficient compression algorithm based on spectral classification, which employs class-based adaptive KLT for spectral decorrelation with proper rate allocation, followed by Embedded Block Coding with Optimized Truncation (EBCOT) coding. Experimental results show that the proposed algorithm is competitive with state-of-the-art compression algorithms.

1 Hyperspectral images classification

The classification techniques for hyperspectral images can be divided into two categories: unsupervised classification and supervised classification. Unsupervised classification techniques perform classification naturally according to the spectral distribution rule of each class without any prior knowledge of each class. Supervised classification techniques take into account the training information that is available for a given classification problem, and the classification results depend on the training level of the samples. In general, a supervised classifier can provide better classification results than an unsupervised classifier. However, the complexity of the supervised classifier is much higher than that of the unsupervised classifier. Moreover, prior knowledge of each class is usually difficult to obtain. As a preprocessing step of the compression problem, the goal of classification is not to pursue the highest classification accuracy. In practice, an unsupervised classifier is preferred for the sake of simplicity. As a matter of fact, unsupervised classification of hyperspectral images is a prevalent processing method that is easy to achieve. In this paper, a C-means algorithm is introduced and carried out on the selected bands resulting from the band selection procedure to partition hyperspectral images into C classes. Classifications provided by C-means are represented by a map specifying which class the corresponding pixel belongs to.

2 Proposed algorithm

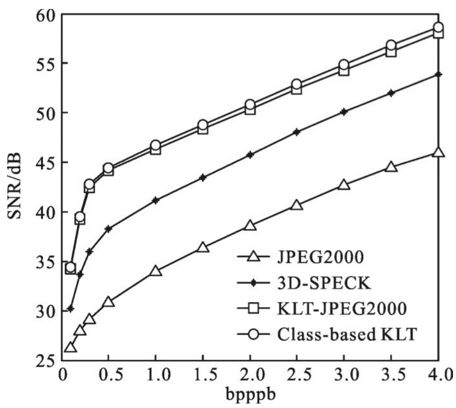
Most existing algorithms usually perform KLT for the entire image followed by two-dimensional DWT for each principle component (PC), which is adapted to the statistics of the entire image and does not take advantage of the characteristics of the local statistics. To further improve the performance of spectral KLT, the proposed algorithm uses a different KLT for spectral decorrelation of each class[4-5]. The proposed algorithm includes two steps: the requirement of a classification map and class-based compression. For the first step, a band selection algorithm is used to realize dimensionality reduction, and then, a C-means algorithm is performed on the selected bands to obtain the classification map. As for the second step, KLT is performed on each class in the spectral orientation according to the classification map, and then spatial DWT is performed on each PC. Finally, EBCOT is employed to generate the ultimate bit-stream. Note that the classification map needs to be compressed losslessly and transmitted to the decoder. In practice, the classification map is coded by a rice coder and added to the output bit-stream as side information.

Note that the rate allocation is an important part of the transform-based coding technique. Given the target bit-rate, the encoder must determine how to allocate this total rate appropriately across all of the PCs. As we know, Post-Compression Rate-Distortion (PCRD) plays an important role in the excellent rate-distortion performance of the EBCOT[6] algorithm. To code a single band, the image in the wavelet domain is further partitioned into much smaller rectangular blocks, referred to as code-blocks, with a typical size of 32×32. PCRD optimization is performed simultaneously across all of the code-blocks from the image, producing an optimal truncation point for each code-block, and then, the truncated code-blocks are concatenated together to generate the final bit-stream. As a matter of fact, the PCRD optimization distributes the target rate across all the code-blocks in an optimal rate-distortion fashion such that the code-blocks with higher energy tend to be given a higher rate.

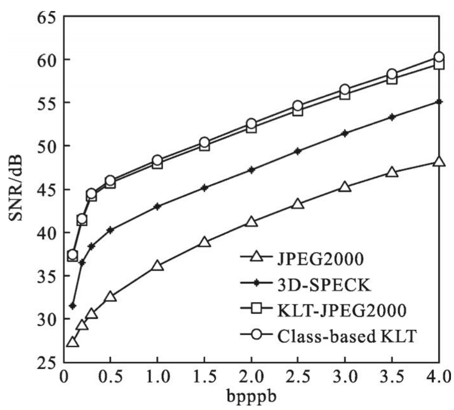
3 Experimental results

The hyperspectral images used in the experiments were acquired by the Airborne Visible Infrared Imaging Spectrometer (AVIRIS) sensor in 1997. The AVIRIS sensor collects hyperspectral images in 224 contiguous bands within the 0.41-2.5 μm spectral range. In particular, test images used in the simulations were from two scenes: Cuprite and Lunar Lake, each pixel is represented by two bytes.

The proposed compression algorithm has been compared with the other state-of-the-art lossy compression algorithms. Both bpppb (bit per pixel per band) an SNR are use to measure the compression performance. The results reported in Fig.1 are a comparison of RD performance between JPEG-2000, 3D-SPECK (three-dimensional set partitioned embedded block)[7], KLT-JPEG2000 and the proposed class-based KLT algorithm. As mentioned before, the JPEG2000 standard compresses each band of hyperspectral images separately without exploiting spectral decorrelation between bands. 3D-SPECK is a popular compression



(a) Cuprite



(b) Lunar lake

Fig.1 RD performance for the AVIRIS images algorithm based on a three -dimensional wavelet transform and is widely applied to compress image sequences, such as video images and hyperspectral images. KLT-JPEG2000 employs KLT to remove the spectral correlation, followed by JPEG2000 compression. As seen from Fig. 1, the RD performance of JPEG2000 is the worst due to the lack of spectral decorrelation. 3D-SPECK exploits both spectral and spatial correlation by using DWT, which performs better than JPEG2000 by providing a higher SNR. KLT-JPEG2000 clearly achieves higher performance than 3D-SPECK due to the excellent performance of spectral decorrelation compared with DWT. Note that the proposed algorithm outperforms the KLT-JPEG2000 algorithm, especially at high bit-rates, which shows that the class-based KLT is superior to the single KLT. Moreover, the class-based KLT can be easily parallelized by having different classes transformed at the same time, which is advantageous to improving operation efficiency.

4 Conclusion

In this paper, to further improve the performance of spectral decorrelation, we have proposed an efficient lossy compression algorithm based on classification. Different from the conventional algorithm, the proposed algorithm first performs C-means on the bands resulting from a band selection algorithm to obtain the classification map, and then, spectral KLT is carried out on each class in the spectral orientation. PCRD optimization is introduced to perform rate allocation for all code-blocks partitioned from PCs in the wavelet domain to achieve optimal RD performance. Finally, the EBCOT algorithm is applied to all of the code-blocks to produce the final bit-stream. Compared with the conventional KLT-based algorithm, the proposed algorithm can make full use of the local statistics of each class in hyperspectral images. Experimental results show that the proposed algorithm provides better RD performance and classification accuracy compared with the other classical algorithms. At present, classification or segmentation is an important practical application for hyperspectral images. Under this point of view, the proposed algorithm is one of the best choices for the compression of hyperspectral images.

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