AN EFFICIENT COMPRESSION ALGORITHM FOR HYPERSPECTRAL IMAGES BASED ON CORRELATION COEFFICIENTS ADAPTIVE THREE DIMENSIONAL WAVELET ZEROTREE CODING*

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ABSTRACT

In this paper, we propose an efficient compression algorithm for hyperspectral images. It is based on the correlation coefficients adaptive AT-3DSPIHT coding in the domain of WPT (wavelet packet transform). According to the characteristics of correlation coefficients between spectral bands, a binary tree spectral band grouping algorithm is carried out to divide the adjacent spectral bands into different mode groups. Along with this, WPT with the corresponding decomposition levels and a proper AT-3D zerotree are determined adaptively. Several AVIRIS images are used to evaluate the proposed algorithm. Compared with the existing 3D-based algorithms, the proposed adaptive AT-3DSPIHT achieves the best compression performance at lower rates. Moreover, at the low correlated adjacent bands, our proposed algorithm also beats the 2DSPIHT and JPEG2000-MC algorithm respectively.

Index Terms—Hyperspectral image, correlation coefficient, binary tree spectral band grouping, WPT, AT-3DSPIHT.

1. INTRODUCTION

Due to the huge sizes of the three-dimensional (3D) hyperspectral data sets, efficient compression is required for their transmission to the ground station for the limited available downlink bandwidth.

Recently, the three-dimensional wavelet transform based lossy compression algorithms for hyperspectral images have been proved promising. Both the 3DSPIHT [1] and the 3DSPECK [2] algorithms use a conventional symmetric 3DWT and they are very close in the rate-distortion performance. For more efficiently employing the higher correlation in the spectral direction than in the spatial domain for the hyperspectral images, some asymmetric 3DWT based methods have been proposed recently. An AT-3DSPIHT (asymmetric tree based 3DSPIHT) was presented in [3] and [4], and AT-3DSPECK for hyperspectral images compression was proposed in [5]. JPEG2000-MC proposed in [6] [7] has also been proved to be a good choice for hyperspectral images compression, which supports the multi-component image.

There usually exist high correlations between the adjacent spectral bands for hyperspectral images. However, there are occasionally some discontinuities along the spectral bands, where the correlations are very weak. These discontinuities tend to make the 3D-based algorithms less efficient. A hybrid algorithm was proposed in [8] to improve the compression performance for such cases, in which the 2DSPIHT is applied in each of the spectral bands where the correlations between adjacent bands are relatively low.

In this paper, a correlation coefficients adaptive AT-3DSPIHT lossy compression algorithm is proposed for hyperspectral images. Making use of the correlation coefficients, a binary tree spectral band grouping algorithm is performed to bind the higher correlated adjacent bands together in longer groups and to cluster the lower correlated adjacent bands in shorter groups. The main consideration of the grouping algorithm is to adaptively carry out WPT (wavelet packet transform) with different levels and the corresponding AT-3DSPIHT for the respective mode group. Combining with the fast grouping algorithm, the proper WPT and the corresponding AT-3DSPIHT coding, our lossy compression algorithm for hyperspectral images is expected to achieve a better coding performance.

The paper is organized as follows: The idea and the components of the proposed compression scheme are introduced in Section 2. Section 3 is devoted to the formal description of the proposed lossy compression algorithm. Section 4 presents the experimental results. Finally, Section 5 concludes this paper.

2. THE IDEA AND THE COMPONENTS OF THE PROPOSED COMPRESSION SCHEME

The compression algorithm has four major components: the binary tree spectral band grouping, WPT, the adaptive AT-3D zerotree selection and the corresponding 3DSPIHT

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coding. The two components proposed here are detailed as follows.

2.1. The Binary Tree Spectral Band Grouping

The correlation coefficient is chosen to characterize the inter-band linear similarity due to its simplicity. The correlation coefficient $\rho(k,r)$ between the *k-th* and *r-th* band *X(i, j, k)* and *X(i, j, r)* is calculated as:

$$\rho(k,r) \overset{\Delta}{=} \frac{E[X(i,j,k)X(i,j,r)] - E[X(i,j,k)]E[X(i,j,r)]}{\left\{\left[E\left(X^2(i,j,k)\right) - E^2\left(X(i,j,k)\right)\right] \times \left[E\left(X^2(i,j,r)\right) - E^2(i,j,r)\right]\right\}^{\frac{1}{2}}} \quad (1)$$

Where i, j are the row and the column coordinates of the images respectively. The correlation coefficient returns a real number in the range *[-1.0, 1.0]*.

The binary tree spectral band grouping algorithm:

Initialization: Partition sequentially all the spectral bands into $\{S_1, S_2, S_{rem}\}$. Each S_i consists of consecutive 16 bands $\{X_{S_i,1}, X_{S_i,2}, \cdots X_{S_i,16}\}$ for *i=1* and *2*, and S_{rem} is the subset of the left spectral bands. Let $\rho_{S_i}(k,k+1)$ denote the correlation coefficient between the adjacent bands $X_{S_i,k}$ and $X_{S_i,k+1}$.

Step 1: Start with S_1 and S_2, and calculate all the correlation coefficients $\rho_{S_1}(k,k+1)$ and $\rho_{S_2}(k,k+1)$.

Step 2:

- ***If*** $\min_{1 \le k \le 15}\left(\rho_{S_1}(k,k+1)\right) < 0.5$
  - Spit the root node S_1 from the midpoint into two subsets S_{11} and S_{12} with the same size of 8.
  - ***If*** $\min_{1 \le k \le 7}\left(\rho_{S_{12}}(k,k+1)\right) < 0.5$

    Both the child node S_{11} and S_{12} of S_1 belong to the group with the mode $\{00\}$ as Fig.1 (a).
  - ***Else*** Set $S_{11} = \{00\}$; Split the root node S_2 into $\{S_{21}, S_{22}\}$; merge S_{12} into S_{21} to produce a new node S_2^{new}; eliminate the root nodes S_1 and S_2; and update S_{rem} as $S_{rem} = \{S_2^{new}, S_{22}, S_{rem}\}$ as Fig.1 (b).
- ***If*** $0.5 \le \min_{1 \le k \le 15}\left(\rho_{S_1}(k,k+1)\right) < 0.9$
  - The root node S_1 is no longer split.
  - ***If*** $\min_{1 \le k \le 15}\left(\rho_{S_2}(k,k+1)\right) < 0.5$
    - Spit the root node S_2 as above.
    - ***If*** $\min_{1 \le k \le 7}\left(\rho_{S_{21}}(k,k+1)\right) \ge 0.5$

      Merge S_1 into S_{21} to produce a new node S_1^{new} of size 24; eliminate the root nodes S_1 and S_2; set $S_1^{new} \in \{01\}$ and $S_{22} \in \{00\}$ as Fig.1(c).
    - ***Else*** set $S_1 = \{01\}, S_{21} \in \{00\}$, let $S_{rem} = \{S_{22}, S_{rem}\}$.
  - ***Else*** set $S_1 \in \{01\}$; $S_{rem} = \{S_2, S_{rem}\}$.
- ***If*** $\min_{1 \le k \le 15}\left(\rho_{S_1}(k,k+1)\right) \ge 0.9$
  - The root node S_1 is no longer split.

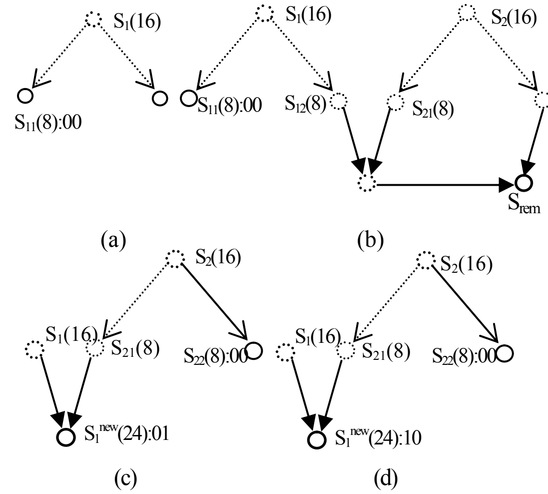

Fig. 1. Binary tree spectral band grouping algorithm.

  - ***If*** $\min_{1 \le k \le 15}\left(\rho_{S_2}(k,k+1)\right) < 0.5$
    - Spit the root node S_2 as above.
    - ***If*** $\min_{1 \le k \le 7}\left(\rho_{S_{21}}(k,k+1)\right) \ge 0.5$, set $S_{22} \in \{00\}$;

      merge S_1 into S_{21} to produce a new node S_1^{new}; and the mode of S_1^{new} is determined by the minimum correlation coefficients in S_{21}.

      If $0.5 \le \min_{1 \le k \le 7}\left(\rho_{S_{21}}(k,k+1)\right) < 0.9$,

      set $S_1^{new} \in \{01\}$ as Fig.1(c).

      If $\min_{1 \le k \le 7}\left(\rho_{S_{21}}(k,k+1)\right) \ge 0.9$,

      set $S_1^{new} \in \{10\}$ as Fig.1(d).
    - ***Else*** set $S_1 \in \{10\}, S_{21} \in \{00\}$ *and* $S_{rem} = \{S_{22}, S_{rem}\}$.
  - ***Else*** set $S_1 \in \{10\}$; let $S_{rem} = \{S_2, S_{rem}\}$.

Step3:

- ***If*** S_{rem} is not empty
  - ***If*** there exist 8 band images in S_{rem}, set $S_{rem} \in \{00\}$.
  - ***If*** there exist 16 band images in S_{rem}
    - ***If*** $\min_{1 \le k \le 15}\left(\rho_{S_{rem}}(k,k+1)\right) < 0.5$,

      split S_{rem} into $\{S_{rem1}, S_{rem2}\}$ with the same size of 8, set $S_{rem1} \in \{00\}$ *and* $S_{rem2} \in \{00\}$ as Fig.1 (a).
    - ***If*** $0.5 \le \min_{1 \le k \le 15}\left(\rho_{S_{rem}}(k,k+1)\right) < 0.9$, set $S_{rem} \in \{01\}$.
    - ***If*** $\min_{1 \le k \le 15}\left(\rho_{S_{rem}}(k,k+1)\right) \ge 0.9$, set $S_{rem} \in \{10\}$.
  - ***Otherwise***, re-divide S_{rem} using the same method as for the original S, and go to step1 repeating the process.
- ***Else*** the grouping process is finished.

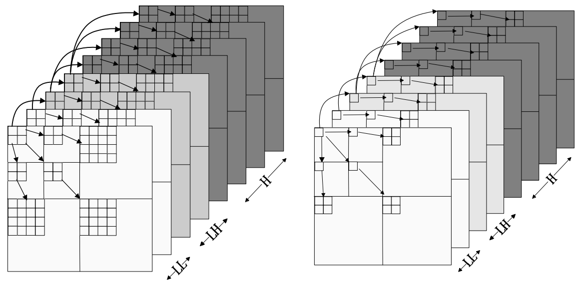

Fig.2. Two different zerotrees. (a) AT-3D zerotree1 (b) AT-3D zerotree2

2.2. Two Asymmetric 3D Tree Structures

3DSPIHT is a tree based coder. Unlike the symmetric tree structure, the asymmetric tree extends longer along the spectral axis. This should result in larger clusters of zero coefficients and therefore could provide a better compression performance. A scalable spatial-temporal wavelet tree for embedded MC-3DSPIHT video coding was proposed in [9] [10]. Tang and Pearlman [3] redefined this tree, denoted an asymmetric tree for 3DSPIHT (AT-3DSPIHT) in hyperspectral image compression. An optimal 3D tree structure for the 3D wavelet video compression was designed and its efficiency under different conditions was demonstrated in [11]. We use zerotree1 to denote the AT-3D zerotree defined in [9], [10] and [3] and zerotree2 to identify the AT-3D zerotree in [11]. The two AT-3D zerotrees are shown in Fig.2 (a) and (b) respectively, where an arrow indicates the respective parent-offspring relationship. Some similarities and differences exist between them. Besides all the desired features such as the computational efficiency, the scalability and the automatic growth feature, the nodes in the middle frequency subbands in the spatial dimensions have the same children in the two trees. But, for the lowest spatial subband of WPT, the case is totally different. Each of the root nodes in the AT-3D zerotree1 with even coordinates has four children in the next spectral subband, while each of the root nodes with at least one odd coordinates has four children in the next corresponding spatial subband. For AT-3D zerotree2, each root node also has four children, but three of them are in their next corresponding spatial subbands and only one in the next corresponding spectral subband. The case of the children of a node, which are in the spatial low frequency and spectral middle frequency subbands, are similar to those of the root nodes of the respective tree. AT-3D zerotree1 makes better use of the parent-offspring dependence relation but wider and shorter in spectral direction, on the contrary, AT-3D zerotree2 is narrower and longer than AT-3D zerotree1 in the spectral axis but the parent-offspring dependence is slightly worse. The lopsided distribution towards more spectral direction of the AT-3D zerotree1 gives good performance at the high correlated GOBs for its better utilization of the dependence of the middle subbands on the root subband, but results in rate distortion (RD) performance reduction a certain extent for the low correlated GOBs. The direction would result in a faster increment of the probability for a coefficient value being zero when moving from the root to the leaves, and consequently would provide a better coding efficiency for the low correlated GOBs. According to the above analysis, we can adaptively choose the desirable AT zerotree for hyperspectral images coding.

3. FORMAL DESCRIPTION OF THE PROPOSED LOSSY COMPRESSION ALGORITHM

Beginning with the original spectral bands triple $\{S_1, S_2 S_{rem}\}$ namely the S, the whole binary tree grouping algorithm is accomplished by means of dividing and updating the subsequence S_{rem} iteratively, and after each of the iteration steps is finished, the WPT, AT-3D zerotree choice and 3DSPIHT coding are consequently implemented. The whole compression scheme consists of the following 5 steps.

Step1: Execute the binary tree spectral band grouping algorithm. According to the outcome, we redefine the size and the coding mode of the processing GOB.

Step2: Implement WPT in the new GOB. If the coding mode is $\{01\}$ or $\{10\}$, do 3 levels 9/7 lifting wavelet transform along the spectral direction, otherwise, 1 level is carried out. After the spectral direction transform, 5 levels 9/7 lifting wavelet decomposition is done for the spatial dimensions.

Step3: Adaptively choose the AT-3D zerotree according to the coding mode. If the coding mode is $\{10\}$, apply the AT-3D zerotree1, otherwise, use the AT-3D zerotree2.

Step4: Execute the AT-3DSPIHT coding under the WPT and the selected AT-3D zerotree.

Step5: Finally, the size of new GOB, the coding mode and the output bit stream of the AT-3DSPIHT are further packetized to generate final bit-stream by a context-based adaptive arithmetic encoder.

4. EXPERIMENTAL RESULTS

Coding experiments are carried out on the three signed *16*-bit reflectance *AVIRIS* (*http://aviris.jpl.nasa.gov*) images Jasper Ridge, Lunar Lake and Cuprite, all of scene 1. We crop the scene to $512\times512\times224$ pixels. The SNR is used as the quality metric.

First we test the performance of the adaptive AT-3DSPIHT algorithm at different rates. From the RD curves in Fig.3 for the "Cuprite" images, it can be seen that AT-3DSPECK, AT-3DSPIHT and JPEG2000-MC outperform both 3DSPECK and 3DSPIHT at all the rates. Except for the highest bit rate (i.e. at 2.0bppp rate), our method performs substantially better than the other techniques, which is attributed to the suitable WPT and the proper AT-3D zerotree choice in the corresponding mode group. For example, the gains of 0.75db, 1.28db and 1.72db are achieved by the proposed algorithm compared to AT-3DSPIHT, JPEG2000-MC and AT-3DSPECK

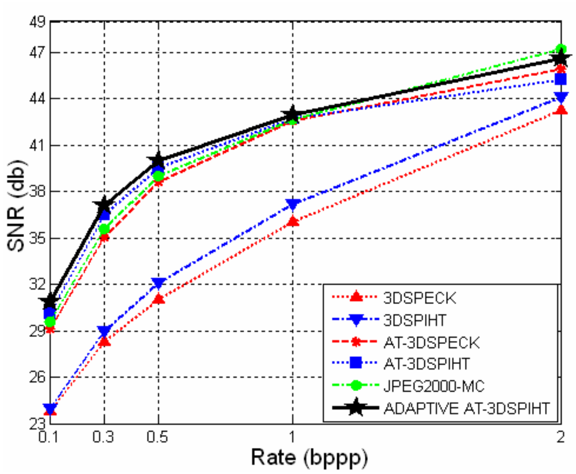

Fig.3. Performance comparisons for the "Cuprite" scene 1 images

Table I. SNR comparison at the low correlated spectral bands

Image	Scheme	Bit Rate				
		0.1	0.3	0.5	1.0	2.0
Jasper S1	3DSPECK	-1.77	1.69	3.42	7.08	11.06
	3DSPIHT	-1.07	2.38	4.31	7.38	11.60
	AT3DSECK	-2.10	1.90	4.76	9.12	12.79
	AT3DSPIHT	-5.26	-0.41	3.49	9.29	11.97
	2DSPIHT	5.52	7.12	8.37	10.89	15.96
	JPEG2000MC	6.21	7.29	8.10	10.20	14.82
	Our Method	**7.14**	**8.47**	**9.43**	**11.40**	**16.09**
Cuprite S1	3DSPIHT	-0.33	5.05	7.81	10.83	15.87
	3DSPECK	-0.06	5.78	8.17	11.61	16.11
	AT3DSPIHT	6.01	7.22	8.22	13.64	17.62
	AT3DSPECK	3.40	5.41	10.78	13.02	18.91
	2DSPIHT	11.49	12.63	13.66	15.94	21.15
	JPEG2000MC	10.67	12.64	13.57	16.22	20.99
	Our Method	**12.31**	**13.59**	**14.62**	**16.63**	**21.10**
Lunar lake S1	3DSPIHT	2.84	7.75	9.90	11.92	16.32
	3DSPECK	2.40	8.16	10.25	15.13	15.59
	AT3DSPIHT	6.97	10.68	12.89	15.30	20.83
	AT3DSPECK	5.16	9.66	12.27	14.55	18.66
	2DSPIHT	11.84	12.86	13.72	15.80	20.88
	JPEG2000MC	12.35	13.37	14.16	16.35	**21.05**
	Our method	**12.57**	**13.53**	**14.49**	**16.39**	20.91

respectively at lowest bit rate. JPEG2000-MC is slightly better than our scheme at the highest rates, but at other rates, ours substantially outperforms others.

Next we further show the performance improvement of our method for all the GOB groups belong to the groups with the mode $\{00\}$. The SNR results for 2DSPIHT are obtained by first coding each of the bands separately, and then averaging over all the bands. As can be seen from Table I, both the 3DWT-based and the WPT-based algorithms are considerably weak at those low correlated spectral bands. And 2DSPIHT is better than 3DSPECK, 3DSPIHT, AT-3DSPECK and AT-3DSPIHT, but not as good as the JPEG2000-MC scheme. The RD results indicate that our method exhibits substantial performance gains over the other six algorithms, which is contributed to the eliminating of the redundancy still existing in the low correlated spectral bands and the proper zerotree choice.

5. CONCLUSION

In this paper, we propose an efficient compression algorithm for hyperspectral images, using two powerful techniques, namely the binary tree spectral band grouping and the adaptive AT-3D zerotree choice followed by AT-3DSPIHT coding. The binary tree spectral band grouping algorithm is designed to make better use of the different correlation between adjacent bands. The proper WPT and asymmetric zerotree are efficiently combined in the proposed compression algorithm for the RD improvement. Experiments show that the proposed adaptive AT-3DSPIHT method not only outperforms state-of-the-art lossy compression techniques at the lower rates, but also performs better than 2DSPIHT and JPEG2000-MC at the low correlated spectral bands.

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