3D Wavelet Block Tree Coding for Hyperspectral Images

Shrish Bajpai, Naimur Rahman Kidwai, Harsh Vikram Singh

Abstract*: *A novel hyperspectral image compression scheme based on set partitioned compression scheme is proposed. This compression scheme uses the 3D wavelet transform to exploits the both, inter sub-band & intra sub-band correlation, among the wavelet coefficients of transformed hyperspectral images. The compression scheme is based on the spatial oriented trees (SOT) which is the basic unit in block. Block is in cube shape having the coefficients m*m*m in contrast to a single coefficient in three dimension set partitioning in hierarchical trees compression scheme. Each SOT has a root node in LLL band with the child and descendent blocks in high frequency sub-band. So, proposed wavelet based compression scheme uses the features of both zeroblock & zerotree base compression schemes.

Index Terms*: *Compression Schemes, Hyperspectral Imaging, Performance Comparison, Set Partition Compression, Wavelet Transform.

I. INTRODUCTION

Hyperspectral imaging (HSI) is a collection of a number of images of a single scene captured over continuous narrow frequency bands of visible spectrum (400 nm-1000 nm) to the infrared spectrum (1000 nm-1700 nm and over), for a single scene [1]. The images are placed in continuous narrow spectral frequency bands with the spacing of 2 nm to 10 nm [2]. HSI images have the high correlation between the two consecutive spectral dimension planes. HSI images can potentially recognize the differential characteristics of objects by detecting minor changes in chemical content, moisture, temperature etc. As a result, HSI has been successfully applied in a number of emerging applications such agriculture, biotechnology, environmental science, food processing, forensic science, medical, pharmaceutical, remote sensing (land cover analysis), space science, security, town planning etc. Remote sensing is the most active area of research in HSI where the researchers focused on developing algorithms for feature extraction, object classification, image compression and target detection [2]. Hyperspectral data are similar to video data where the third dimension of the hyperspectral image is 'wavelength' which corresponds to the third dimension of video data is 'time'. Due to these statistical properties of HSI data differ from the video data.

With this growing spatial and spectral data of hyperspectral images, it is a challenge to handle this large data for the transmission and storage process. Hyperspectral image compression in HSI is needed to reduce the data for transmission, to save channel bandwidth, channel capacity, memory storage requirement and data transmission time [3]. For the above-listed reasons, hyperspectral image compression is one of the growing fields in remote sensing. Compression ratio in HSI is stated in the terms of bits per pixel per band (bpppb).

There are many hyperspectral image compression schemes pro-posed, but the wavelet-based image compression schemes offer greater advantage with reference to the other compression schemes because they have excellent energy clustering in space and frequency due to the pyramid structure. The 3D dyadic wavelet transform is used in the compression schemes [4]. The wavelet transform is first applied to the row and column followed by the third spectrum dimension. In the last decade, many transform based compression schemes are proposed which are broadly divided into two group's zerotree & zeroblock based compression schemes [5]. Zerotree compression schemes work on the group of wavelet coefficients corresponding to the same spatial location and organize a spatial orientation tree (SOT). 3D-SPIHT (Set partitioning in hierarchical trees) [7] is a popular compression scheme for HSI to give attractive rate-distortion performance with low computation complexity which makes it a perfect solution for the noisy transmission channels. While, zeroblock compression schemes, partitioned the transformed image into the adjoining blocks & perform the test of significance on each individual blocks. A block under test is zeroblock when no significant coefficients are found above the threshold level. 3D-SPECK (set partitioning embedded block) is the well knows zero block compression scheme used in the HSI compression [6].

The two-dimension wavelet block tree coding (WBTC) uses the features of both zerotree and zeroblock image compression schemes, which improves the PSNR and complexity of the compression scheme is significantly reduced. The performance gains are more significant at the lower bit rates of WBTC than SPECK & SPIHT, which is useful where the less memory is available [8].

The proposed compression scheme 3D Wavelet Block Tree Compression (3D-WBTC) combines the useful features of tree-based compression schemes and block-based compression schemes. This compression scheme 3D-WBTC partitions the transformed image into the coefficient block, after that, it constructs the trees of the block with the root present in the topmost sub-band in a branch tree fashion.

Revised Manuscript Received on December 22, 2018.
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In the proposed compression scheme, significant block search using the tree partitioning concept of zerotree compression schemes while significant coefficient in the block is searched using the zeroblock compression scheme.
The paper is organized into four sections. Section II describes the proposed compression scheme which is adapted for hyperspectral images. Section III outlines the comparison result and analysis of 3D-WBTC with 3D-SPECK & 3D-SPIHT [6-7] on the parameters of peak signal-to-noise ratio (PSNR), new significant bit found in the first ten pass, memory consumed by compression schemes encoding time & decoding time. Conclusions are given in Section IV.

II. Proposed Compression Scheme

The extension from 2D to 3D transform based compression schemes uses the interband dependence or correlation that can be exploited automatically for spectrum domain. The encoding of the images is done at the transmitter and decoding of the images received from the transmitter is done at the receiver end. [9]. First, the transformed image is encoded according to the compression scheme and then the reverse process has been done for the decoding process. Wavelet transform gives an attractive result in hyper-spectral image compression. Wavelet block tree compression (WBTC) scheme is a wavelet-based compression scheme which exploits the redundancies among the sub-bands & along with the partial exploitation of redundancy within the sub-band. 3D-WBTC is the bit plane coding scheme similar to the 3D-SPIHT & 3D-SPECK in which trees or blocks are encoded starting from the most significant bit plane to the lower bit planes [6-7].

Zeroblock based compression schemes divide the transformed image into the contiguous blocks and perform the significance test on each block. If the block is significant, then it is partitioned into 8 equals sub-blocks (octuple partitioning). Each sub-block is tested for significant and, if any significant sub-block found then again, it uses the octuplet tree partitioning. In zerotree based composition schemes, the significant blocks are found using the tree partitioning concept, where the significant coefficients in each block are found using the octuple tree partitioning. The significant block tree recursively partitions till the significant coefficients are found.

Let consider the hyperspectral images of size M x M x M after 5 level of dyadic wavelet transformation exhibit a pyramidal sub-band structure which has the low-frequency component at the top left corner of the cube, while high frequency terms exist at the bottom level of transform image cube. The transform cube is represented by an index set of transform coefficients [$C_{i,j,k}$]. The coefficients are grouped in block cube of size m x m x m coefficient and then block trees from within the roots of the topmost LLL sub-band. The linear indexing scheme is used is used to represent the transform image coefficients in a linear indexed set [C_i]. The 3-dimensional coefficients are mapped into the one-dimensional array based on the Morton ordering. This ordering is best suited to the pyramid structure of wavelet coefficients.

3D-WBTC has three major advantages over the 3D-SPIHT. 3D-WBTC combines many partitioned zerotree which could occur in initial passes and thus, creating the zero tree with more elements. Secondly inter sub-band correlation can be also exploited by this scheme. Thirdly because due to its block-based nature compare to the other pixel-based compression scheme, memory requirement for the sorting of the list and the encoding time & decoding time are significantly reduced.

A block tree is a tree of all descendant block of a root block. Except for the lowest and highest resolution band, every block has eight offspring block that corresponds to the same spatial orientation in the high-frequency sub-bands. In LLL band, out of each group of 2*2*2 block cubes, the topmost left block has no descendant, and each of other seven blocks has eight different off-spring block in the high-frequency sub-bands of their corresponding spatial orientation. This will create a block tree in which many 3D-SPIHT's spatial oriented trees (SOTs) are combined into a single spatial orientation block tree which is the basic unit of this coding scheme. In this way, a block cube size of 2*2*2, eight SOTs of 3D-SPIHT are combined into a single 3D-WBTC's SOT. A set of descendent blocks refer as type 'A' block tree while the set of grand descendent blocks is referred as type ‘B’ block tree.

Significant information about the transformer image is stored in the three different ordered lists, a list of insignificant blocks (LIB), a list of insignificant blocks set (LIBS) and a list of the significant pixel (LSP). At the initialization step, the blocks in topmost left LLL band are added to the LIB and its associated descendants are added in LIBS as type 'A' entries. The LSP will start as an empty list. Since 3D-WBTC is a bit plane based compression schemes like 3D-SPIHT & 3D-SPECK [6-7], it has two stages within each bit plane: the sorting & refinement passes.

The encoding process started with the most significant bit plane and it proceeds towards the topmost left position. During the sorting pass encoder first, transverse through LIB and test the significance of the block, according to the threshold level of the bits of the block. For each block present in LIB is used to describe the significance by a single bit. If the block is not significant, then it is the zero-block and '0' is sent. The block will remain in LIB, there is no further partitioned for the same and no more bits will be generated. So, insignificant block information of m*m*m individual coefficients is conveyed using a single bit whereas in 3D-SPIHT it generates m x m x m zero bits. If the block is significant, then the block falls in nonzero block category and a '1' is sent. A significant block is partitioned into the 8 adjacent blocks using octuple partitioning. This partition is recursive be repeated until no further division is needed or smallest possible block size is obtained. At this stage, eight coefficients and their significance are individually tested. If a coefficient is insignificant then '0' is sent and the coefficient is moved to LIB as a single coefficient block. If a coefficient is significant then '1' is sent with it's sign bit and the coefficient is moved to LSP. After testing all eight coefficients individually in the block, then the block is moved out from LIB. All set present in LIBS, are examined by the encoder. The encoder performs the significance test on each set.

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Table 1 : PSNR (in db) comparison of 3D-WBTC with 3D-SPECK & 3D-SPIHT [6-7] at various bit rates for the three different hyperspectral images Washington DC, Jasper Ridge & Cuprite [10]

bpppb	Washington DC			Jasper Ridge			Cuprite		
	3D-SPECK[6]	3D-SPIHT[7]	3D-WBTC	3D-SPECK[6]	3D-SPIHT[7]	3D-WBTC	3D-SPECK[6]	3D-SPIHT[7]	3D-WBTC
0.1	38.53	38.28	**38.7**	35.08	35.11	**35.67**	**25.64**	24.67	25.57
0.2	41.54	41.34	**41.72**	39.35	39.13	**39.60**	30.92	29.44	**31.03**
0.3	43.51	43.3	**43.69**	41.72	41.89	**42.40**	34.55	33.36	**34.58**
0.4	45.26	45.11	**45.45**	44.52	44.41	**44.81**	38.05	37.04	**38.15**
0.5	46.81	46.6	**47.01**	45.91	46.33	**46.78**	41.27	40.51	**41.37**
0.6	48.45	48.24	**48.63**	48.17	48.19	**48.62**	43.46	42.58	**43.57**
0.7	49.76	49.53	**49.94**	49.94	50.06	**50.53**	45.55	45.00	**45.57**
0.8	51.12	50.84	**51.29**	51.13	51.74	**52.20**	47.12	46.43	**47.26**
0.9	52.24	52.06	**52.42**	52.97	53.09	**53.51**	48.74	47.95	**48.85**
1	53.52	53.32	**53.71**	54.77	54.72	**55.13**	49.83	49.24	**49.98**

Table 2 : New significant bit found in the first ten pass of 3D-SPECK, 3D-SPIHT [6-7] & 3D-WBTC for the three different hyperspectral images Washington DC, Jasper Ridge & Cuprite [10].

Pass	Washington DC			Jasper Ridge			Cuprite		
	3D-SPECK[6]	3D-SPIHT[7]	3D-WBTC	3D-SPECK[6]	3D-SPIHT[7]	3D-WBTC	3D-SPECK[6]	3D-SPIHT[7]	3D-WBTC
1	17	17	17	7	7	7	5	5	5
2	50	50	50	30	30	30	50	50	50
3	65	65	65	71	71	71	219	219	219
4	178	178	178	217	217	217	537	537	537
5	533	533	533	636	636	636	5099	5099	5099
6	1786	1786	1786	1671	1671	1671	10324	10324	10324
7	5558	5558	5558	5602	5602	5602	22424	22424	22424
8	18159	18159	18159	18286	18286	18286	46681	46681	46681
9	48342	48342	48342	37407	37407	37407	79986	79986	79986
10	108519	77842	71878	72574	72574	72574	120660	120660	112854

Table 3 : Memory use (kb) by the 3D-SPECK, 3D-SPIHT [6-7] & 3D-WBTC at different bppbp for the three different hyperspectral images Washington DC, Jasper Ridge & Cuprite [10]

bpppb	Washington DC			Jasper Ridge			Cuprite		
	3D-SPECK[6]	3D-SPIHT[7]	3D-WBTC	3D-SPECK[6]	3D-SPIHT[7]	3D-WBTC	3D-SPECK[6]	3D-SPIHT[7]	3D-WBTC
0.1	243.84	263.28	250.09	241.36	245.86	245.83	277.73	277.60	282.79
0.2	416.29	437.97	416.00	439.95	445.74	443.73	414.52	434.27	417.15
0.3	701.05	628.55	704.03	541.29	555.28	549.26	544.29	514.74	546.27
0.4	733.80	723.55	732.97	729.56	759.53	741.59	601.93	576.49	594.45
0.5	1048.80	1060.50	1049.00	821.57	808.88	827.94	671.18	701.89	674.51
0.6	1191.10	1222.60	1195.40	1099.85	1123.21	1106.71	854.01	783.74	857.57
0.7	1191.90	1222.60	1195.60	1099.85	1123.21	1106.71	854.02	783.74	857.57
0.8	1407.70	1415.30	1404.40	1178.85	1192.71	1189.12	1065.30	964.62	1057.30
0.9	1702.50	1725.50	1704.60	1443.24	1467.97	1450.32	1158.50	1182.40	1159.50
1	1802.50	1826.70	1724.60	1443.24	1467.97	1450.32	1158.50	1182.40	1159.60

Insignificant sets remain in the LIBS while significance sets are partition into the subset.

Let a type significant type set 'A' with the root blocks $X_{a,b,c}^{l,m,n}$ is partition into a 'B' set $Y_{a,b,c}^{l,m,n}$ and it has eight offspring blocks $Z_{a,b,c}^{l,m,n}$. The Set 'B' is added to the end of LIBS while that the eight offspring blocks which have the same dimension as root block, are immediately examined for their significance. A significant type set 'B' is partition into eight types 'A' set and all of these newly created sets are added to the LIBS. All newly created insignificant sets are added to the LIBS so that they can process in the same manner for a given threshold until they are examined. After the sorting pass, the coefficient present in LSP, except those just added at current bit plane, are refined with a single bit only. The compression scheme repeats the above procedure but decreasing the current threshold level by the factor of two until the desired bit rate is achieved. For a block size of single pixel (1x1x1) 3D-WBTC leads towards the 3D-SPIHT [8].

III. SIMULATION RESULTS & DISCUSSION

The performance of 3D SPECK, 3D SPIHT & proposed 3D WBTC hyperspectral image compression schemes are evaluated on the three standard hyperspectral images which are Washington DC (1280x307x191), Culprit (250x190x224) & Jasper Ridge (100x100x224). Images of taken in the size of the cube of 128x128x128 [10]. Padding has been done with '0' for the Jasper Ridge to get the cube size of 128x128x128. Washington DC & Culprit hyperspectral images are cropped from initial to get the desired cube size. The performance of the compression scheme is evaluated in the terms of coding efficiency, memory requirement and the encoder-decoder complexity parameters are calculated on the difference between bits per pixel per band.

Table 4 : Encoding Time (sec) by the 3D-SPECK, 3D-SPIHT [6-7] & 3D-WBTC at different bpppb for the three different hyperspectral images Washington DC, Jasper Ridge & Cuprite [10].

bpppb	Washington DC			Jasper Ridge			Cuprite		
	3D-SPECK[6]	3D-SPIHT[7]	3D-WBTC	3D-SPECK[6]	3D-SPIHT[7]	3D-WBTC	3D-SPECK[6]	3D-SPIHT[7]	3D-WBTC
0.1	24.98	7.47	6.51	21.10	7.62	6.36	17.26	6.29	4.69
0.2	57.94	25.76	24.81	54.19	20.56	17.71	55.82	26.01	16.61
0.3	92.12	37.47	32.03	100.62	39.43	42.77	107.91	45.52	39.06
0.4	269.74	117.89	195.46	150.94	47.77	70.67	182.28	75.55	68.19
0.5	414.80	140.13	194.19	315.28	101.56	182.38	276.14	95.44	93.32
0.6	576.03	166.40	247.89	355.95	115.33	227.51	298.42	161.67	155.69
0.7	887.48	405.70	625.02	426.13	232.29	480.85	438.80	179.18	202.24
0.8	1130.50	474.16	710.20	585.74	382.31	676.43	558.74	198.45	358.46
0.9	1334.60	555.72	746.00	701.17	415.02	771.90	656.09	282.84	370.97
1	1497.50	574.96	804.00	757.32	425.38	942.81	905.06	364.00	652.46

Table 5 : Decoding Time (sec) by the 3D-SPECK, 3D-SPIHT [6-7] & 3D-WBTC at different bppbp for the three different hyperspectral images Washington DC, Jasper Ridge & Cuprite [10].

bpppb	Washington DC			Jasper Ridge			Cuprite		
	3D-SPECK[6]	3D-SPIHT[7]	3D-WBTC	3D-SPECK[6]	3D-SPIHT[7]	3D-WBTC	3D-SPECK[6]	3D-SPIHT[7]	3D-WBTC
0.1	17.42	6.12	5.03	15.31	7.41	4.57	13.38	5.00	3.14
0.2	48.77	24.84	22.45	36.99	17.63	15.32	46.66	22.08	14.57
0.3	75.39	34.77	28.50	84.67	37.14	39.95	93.70	40.23	35.41
0.4	264.22	106.26	180.43	128.79	44.96	68.97	162.48	70.08	65.81
0.5	339.07	135.44	191.65	290.76	98.51	178.42	236.13	88.29	91.52
0.6	532.38	130.56	244.64	330.90	155.55	229.76	319.20	160.90	148.97
0.7	807.58	427.07	558.00	386.40	232.15	432.08	435.00	175.79	196.82
0.8	1058.10	468.88	675.31	487.76	382.18	608.44	525.89	195.33	315.96
0.9	1142.30	486.23	725.00	667.35	402.73	673.47	599.22	273.50	366.90
1	1289.66	503.96	874.00	726.86	421.31	923.14	884.44	346.64	595.98

Hyperspectral image compression schemes are implemented using Matlab (version 2016A) and are executed on Windows 8. 1 operating system with 4th generation i3 processor @ CPU speed of 1.6 GHz and 8GB RAM.

The coding efficiency of hyperspectral images is calculated by measuring in the terms of the average number of bits per pixel per band in the coded bit stream to achieve a minimum desired quality of the reconstructed hyperspectral images. The quality of reconstructed hyperspectral images is measured in the terms of peak signal noise ratio which is defined as the equation 1.

$$PSNR = 10log_{10}\left[\frac{(2^n-1)}{MSE}\right] \qquad (1)$$

where n is the number of bit plane involved for the concern hyperspectral images and MSE is a mean square error of the re-constructed image with respect to the original image.

For the fair comparison of this result, it is calculated without any arithmetic coding. It is observed that 3D-WBTC has excellent coding performance in general for the different bit rates with reference to 3D-SPIHT [7] and better performance with reference to 3D-SPECK [6] for all three hyperspectral image data set as shown in Table 1. 3D-WBTC compression scheme outperforms the range of 0. 4db to 0. 6 db for 3D-SPIHT [7] and 0.1db to 0.2 db for 3D-SPECK [6]. It has been observed that the performance of 3D-WBTC is significantly better at very low bit rates and also improves the coding efficiency at almost every bit rates. The main reason behind this remarkable performance is due to the fact that when the few high priority bit planes are coded, the majority of coefficients are insignificant and 3D-WBTC combines a large volume of insignificant coefficients together, represent in a single bit. Due to this, there is an improvement in coding efficiency.

In table 2, the new significant bits found in the first 10 passes of the hyperspectral image compression schemes have been presented. It has been observed that for the higher bit planes the 3D-WBTC has been successfully identified the significant bit and the result of identification of new significant bit is same as 3D-SPECK & 3D-SPIHT [6-7]. This has been done by 3D-WBTC by keeping the high PSNR with reference to the 3D-SPECK & 3D-SPIHT.

3D-WBTC has been the performance of better than 3D-SPECK [6] for generation of cumulative bits as represented in the table for all three images. It has been cleared that 3D-WBTC is more efficient in sorting of the significant options then 3D-SPIHT [7]. In the early passes, when the threshold is high, the volumetric cluster of zeros has occurred more and 3D-WBTC encodes this cluster more efficiently by the single symbol. It also exploits more efficiently by the single symbol. It also exploits the intra sub-band correlation partially in the form of zero block which is not happen for 3D-SPIHT [7].

Table 3 represents the memory requirement of the compression schemes for the different bit per pixel for the band. For all three compression schemes, the block size is a cube of 2 for the test images. It has been represented in the table that the memory requirement of 3D-WBTC is nearly less than 3D-SPIHT [7] for each bit per pixel for the band but it is more significant in the later passes.

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It is clear that memory requirement of all three-compression scheme in early passes is more significant, then later passes because at the lowest threshold level of later passes, more sets will be become significant and set partitioning will result in into more entries in LIB.

Table 4 and table 5 are the encoding and decoding time for the compression scheme this has been calculated for different bit per pixel per band. The timing associated with the wavelet transform and Inverse wavelet transform is not included in the encoding time & decoding time. It has been cleared at the 3D-WBTC is taking the more time than 3D- SPIHT [7] because of its block tree structure which leads to taking the more time for the calculation and identification of the significant bit. For the early passes, it is taking the similar decoding and encoding time with reference to the 3D-SPIHT [7] but in later passes it is taking more time because of getting more significant blocks in the higher order passes.

IV. CONCLUSION

This paper investigates the image compression scheme for hyperspectral data which exploits intra sub-band in the form of zeroblock and inter sub-band correlation in the form of zerotree. It has been observed that the proposed compression scheme gives the excellent performance at the low bit rates with reference to the tree based compression scheme 3D-SPECK. It also observed that 3D-WBTC has the less decoding & encoding time at the low bit rates which enable the images to be transmitted in less time which have been observed for the three hyperspectral images. Therefore this is an attractive compression scheme for on board hyperspectral sensors where the limited memory & data processing power.

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