An efficient image compression method based on SPIHT algorithm using run-length coding

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Abstract

EZW (Embedded Zerotree Wavelets) coding algorithm has not only high compression rate but also some new features such as progressive coding/decoding, low computational complexity, etc. Based on EZW, many improved algorithms have been developed in recent years. SPIHT (Set Partitioning in Hierarchical Trees) is an outstanding one among them. Statistical experiments show that some directional and positional dependencies still exist between significant coefficients in each subband. Based on this structural characteristic, this paper incorporated RLC(Run-length Coding) into SPIHT and proposed a new scanning scheme to cluster significant coefficients' 1-D distribution, which reduced coefficients' such structural redundancy to the largest extent. Theoretic analysis and experiments indicate: after introducing RLC into SPIHT, not only is the low computational complexity preserved, but also increases the PSNR up to 2 dB at very high compression ratios, and the average improvement is about 0.1dB at 0.3-0.7bpp for standard test images used. The visual quality of reconstructed images is also significantly improved.

Keywords: remotely sensed image compression, wavelet transformation, zerotree, SPIHT, RLC coding

1 Introduction

Along with the transmission of satellite remote sensing image reconnaissance technology development, the image resolution and sampling rate become higher, cause remote sensing image data storage and transmission of data to sharply increase. At present, the urgent need for high fidelity, real-time compression ratio, satellite images of the data compression techniques to solve the input data bit rate and the transmission channel between bandwidth do not match the contradiction. The compression technology JPEG, MPEG-1, MPEG-2, and other international standards of the image compression is based on traditional "DCT + motion compensation + arithmetic coding" mode. But DCT-based coding scheme still exists square, ringing faults, making the coding efficiency limit. So people have been exploring more effective methods, such as the Wavelet Transform (Wavelet Transform) code rising in 1980s. Wavelet transform method can effectively overcome the square and DCT method ringing effect; people also found that the wavelet coefficient exists between the space self-similarity, which make wavelet transform can better use of human visual characteristics and adapted to the needs of the image compression. At present, the wavelet transform, the more classic coding algorithm has EZW [1] and SPIHT [2] algorithm.

Through the experiment, if the classic wavelet compression algorithm used directly in remote sensing image data compression, the compression ratio or compression performance cannot meet the requirements, because satellite remote sensing image detail is rich, the data quantity is so big, such as scanning of 25Km×25Km area, if the resolution for the 1 m2, it require 2500×2500 pixels to express the image. Usually a satellite remote sensing image of the corresponding 2-D array of data is very big, so for storage, processing and transmission with the many problems. In this paper the above characteristics of remote sensing image put forward the following improvement.

This paper is organized as follows. In section 2 we will introduce the run-length coding into SPIHT algorithm. In section 3, we will introduce our new scanning method of LIS and significant distribution of LIP node, in order to optimize the scanning path, followed by the experimental evaluations in section 4. The conclusions are given in section 5.

2 High rate compression Based on the remarkable wavelet coefficients of the structure characteristics

2.1 INTRODUCING RUN-LENGTH CODING INTO SPIHT ALGORITHM

In recent years, many scholars through the theoretical analysis and test results, proposed improved algorithm based on SPIHT algorithm [3-5]. For example, J. Zhu and S. Lawson put forward a zero tree structure which can cover more significant coefficient, and improve the operation of SPIHT nodes check order [3]. S. Jirachawang and V. Areekull use each sub-band coefficient between significant "direction relationship", proposed adaptive strategy to have many set [4]. Also some scholars (X. Yin, m. Fleury, A. C. Downton) put forward the adjacent the classification of merger bit plane operation, thus reduce

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registration code required bit consumption plane [5]. In short, through less bits to represent specific threshold T of all the significant coefficient, further compression significant coefficient positional information, is currently the main way of improving algorithm based on the structure of the compression efficiency in wavelet zerotree.

In addition mentioned above, statistical analysis shows that the image wavelet coefficients in every sub-band significant distribution has some direction and location correlation [6], so that the use of the image SPIHT during high ratio compression, the code will be a flow of continuous distribution 0, as shown in Figure 1. In this paper aim to cluster (clustering) phenomenon, bits in the output link SPIHT algorithm is proposed by introduction of the run-length coding (RLC), and based on performance analysis of run-length coding and original algorithm initialization and classification of operation. We adopted a new sorting pass in order to optimize the scanning sequence of significant nodes distribution. Keep the original algorithm in all excellent characteristics at the same time, this paper effectively in addition to compress the data structure of redundancy. The experimental data show that the compression performance is superior to original SPIHT.

```
00000000000000000000000000000000
00000000000000011000000001010000
01100000000001010000110000000000
00101000000000000000001100000000
00001000000000000110000000000000
00000000000000000000000000010110
00001100001100010110000011000000
00100001100110001000000001111100
00001000000001100000001000000000
00000000000000000000000000000000
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FIGURE 1 Coding bit-stream produced by SPIHT algorithm

Further analysis of RLC coding performance, for a given binary chart or a graphic character, scanning the binary sequence of the number of 0 and 1 is certain. However, the relative position of 0 and 1 appear has significant influence on compression efficiency of RLC [7].

Hypothesis coding sequence to each 1, there were a period before the length of 0 (d_j could be 0). If the sequence to 0 at the end, the end of the sequence with "imaginary" 1. The run-ticketing 0 length of number k and length sum n are constant, we have:

$$\sum_{j=0}^{k-1} d_j = n . \tag{1}$$

Obviously, just record all 0 run in the length of the information, and assume the decoding known the sequence's length (the assumption in this paper application is reasonable), the sequence can be fully restored. We approximately think that each 0 run after the compression of the amount of data that is the length of binary representation for the number of bits, the sequence of data compression by RLC after size S (bit) is:

$$S(d_0,...,d_j) = \sum_{j=0}^{k-1} \left\lceil \log_2\left(d_j+1\right) \right\rceil \tag{2}$$

Assume that the d_j continuous, $S(d_0, k, d_j)$ can differential. Using Lagrange multiplier method [8], and Equation (2) as constraint conditions, we can get the $S(d_0, k, d_j)$ minimum value. Make the objective function for:

$$L(d_0,...,d_j,\lambda) = S(d_0,...,d_j) - \lambda g(d_0,...,d_j) . \tag{3}$$

Constraint condition is:

$$g(d_0,...,d_j) = \sum_{j=0}^{k-1} d_j - n = 0 . \tag{4}$$

When $d_j > 0$, we have:

$$\frac{\partial L}{\partial d_j} = \frac{1}{d_j \ln 2} - \lambda = 0, \forall j . \tag{5}$$

With the Equation (4), simultaneous solution:

$$d_j = \frac{n}{k}, \forall j , \tag{6}$$

$$\lambda = \frac{k}{n \ln 2} \tag{7}$$

With the Cauchy inequality:

$$\frac{x_1 + x_2 + ... + x_n}{n} \geq \sqrt[n]{x_1 x_2 ... x_n} . \tag{8}$$

Equation is established when and only when $x_1=x_2=L=x_n$, we can get:

$$\sum_{j=0}^{k-1} \log_2(\mathrm{d}_j+1) = \log_2\left(\prod_{j=0}^{k-1}(d_j+1)\right) \leq k \log_2\left(\frac{n+k}{k}\right). \tag{9}$$

Equation was established when and only when $d_0=d_1=L=d_{k-1}$. So, when Equation (6) is established, $S(d_0, k, d_j)$ has a maximum in its internal domain. Because:

$$d_j \in [0, n], \forall j . \tag{10}$$

$S(d_0, k, d_j)$ must has the minimum [9], so the whole domain will be obtained at the edges of the minimum. Therefore, binary coding sequence, the more concentrated distribution of bit "1", the higher compression efficiency of RLC.

2.2 OPTIMIZATION OF LIS AND SIGNIFICANT NODE DISTRIBUTION OF LIP

SPIHT algorithm for image wavelet coefficients of the bit plane coding is a zero tree structure based on the depth of the priority scanning strategy. Review SPIHT algorithm, is not difficult to find that, the direct reason of SPIHT streaming appearing 0 bit cluster is the phenomenon that LIS and LIP is a large number of continuous distribution of the significant node [10, 11].

In a sense, this is the image wavelet coefficients of the distribution of the significant correlation structure in a one-dimensional particular scan path. Adjustment coefficient scanning sequence, and use the run-length coding to code list of nodes and the continuous significant followed by a significant nodes, can effective compress the distribution of wavelet coefficients of the narrow structure information, further removes the compressed data redundancies.

As shown in Figure 2, SPIHT algorithm will initialize wavelet tower from top HL_j, LH_j, HH_j sub-band coefficient, added coordinate to LIP LIS, in turn. Every subband of wavelet coefficients and wavelet zerotree are usually scanned in line mode.

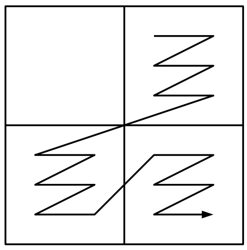

FIGURE 2 Domain initialization of scanning path

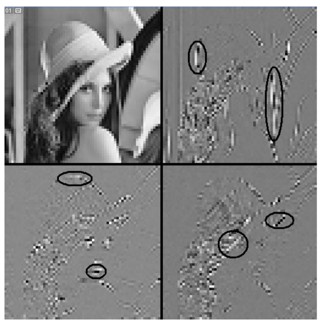

FIGURE 3 Domain amplitude of wavelet tower with the highest subband coefficient

As shown in Figure 3, wavelet coefficients cluster phenomenon obviously exits in the high frequency subband, and the appearing region is roughly the same (corresponding to the edge of the area). Further discovery found that, distribution of every subband has a certain direction. LH_j and HL_j subband in horizontal and vertical direction often has a continuous significant coefficient; and in HH_j subband, the significant coefficient is likely to delay the diagonal continuous distribution direction. In order to make the list of significant coefficient more gathered together, so that the original algorithm in introducing the maximum after RLC compression efficiency, a new algorithm is introduced in initialization LIP and LIS, based on 2×2 block "resolution" scanning strategy, and another three subbands of wavelet coefficients in the same path are synchronous scanning, as shown in Figure 4.

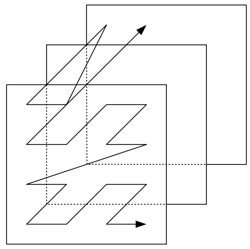

FIGURE 4 New scanning path

In order to show the 2×2 block scanning path, we firstly define: given a coefficient block of $B(i,j)$, if it can be divided into 4 sub-blocks(ratio of the original block is 1/2):

$$B(i,j)=\{S(i,j),S(i+1,j),S(i,j+1),S(i+1,j+1)\}, \tag{11}$$

where, B is original block, S is sub-block, i and j are the index of original B, then we called the coefficient block $B(i,j)$ can be divided. Based on the definition above, the entire wavelet sub-band coefficient can be seen as one block $B(0,0)$, and with the following recursively ways traversing all wavelet coefficients in subband:

```
ScanBlock(B(i,j))
{
    if (B(i, j) can be divided)
    {
    ScanBlock(S(i, j));
    ScanBlock(S(i+1, j));
    ScanBlock(S(i, j+1));
    ScanBlock(S(i+1, j+1));
    }
    else
    {
    scan all 2×2 sub-blocks in current coefficient blocks in line
    way;
    return;
   }
}
```

Note that before update current scanning, three 2×2 blocks (a total of 12 coefficients) located in the same position in HL_j, LH_j, HH_j is always placed in the list together (LIP, LIS) in turn. According to its place of different types, scanning sequence of every 2×2 coefficients block is as shown in Figure 5 shows.

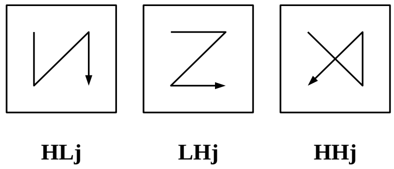

FIGURE 5 Scanning Path of 2×2 Block

In addition, when SPIHT algorithm is proposed in LIS checking, if the current node is A type, four "direct children" of the zero roots will be inserted into LSP, LIP in accordance with their significant; If the node is B type, it will be divided into four "direct children" marked with new type *A* node, inserted into LIS [2].

Experiments have tested that, differential method mentioned above has certain improvement on certain rate, but the result is no so significant, the reason is about the correlation of coefficients. We can find that the distance to the mass-center coefficient is farer, the correlation among adjacent coefficients is smaller, the redundancy of coefficients is little, as the formula has been proved as follows:

$$FWQI = \frac{\sum_{n=1}^{M} S(v,x_n)\cdot|c(x_n)|Q(x_n)}{\sum_{n=1}^{M} S(v,x_n)\cdot|c(x_n)|}. \tag{12}$$

The farer the coefficients to the reference coefficient, the little correlation of them have, the redundancy of other sub-blocks to reference is not significant, the quality can be hardly improved, differential coding needs to be optimized and the sorting pass needed to be adjusted. The evaluation of image quality, instead of using the traditional error summation methods, we designed a new method by modeling any sorting distortion.

Optimizing the method as follows:

(1) 8×8 DWT for the whole image data sequentially; store the result spectrum to *k*.

(2) Employ translation function *T* to *k* coefficient, resulting in: LL_i, LH_i, HL_i, HH_i.

(3) 4×4 IDWT for the LL_i, store the result spectrum to *k*'.

(4) Employ 8×8 DWT to *k'* coefficient.

The proposed methods applied the combined function to remove the correlation in the other subbands that are the leaf of the SOT tree. Those subbands include few significant coefficients, and the original SPIHT algorithm suggests the use of one bit to represent whether the significant coefficient is in the quad-tree.

Structure of zerotree is an effective method of describing the position of significant coefficients after wavelet transform. The fact that a quad-tree includes at least one significant coefficient is represents as 1. That all of the nodes in the quad-tree are insignificant coefficients is presented as 0. The subbands originally neglected by the SPIHT algorithm neglected exhibits quite a large correlation among the same level subbands, and the proposed algorithm presents the combined function to solve this problem. Utilize the correlation of insignificant coefficients in each sub-band.

By differential coding, the amount and distribution of zerotree in each quantization scale goes reasonable. The proposed algorithm differs from the SPIHT algorithm in transform and reducing redundancy of the same level subbands. For compression, it is favor for making more zero-trees, improving the compression efficiency, even more, it can avoid fluctuation of image quality when stop decoding in certain time in decoder.

3 Improved RLC+SPIHT algorithm

The improved algorithm still retain the whole framework of SPIHT algorithm, we add a "run-length count" to record the 0 run-length, and output the length in the end. In order to decompress correct run-length data at the decoding in the reconstruction, the experiment uses the first-order index Columbus code, such as Table 1.

TABLE 1 First-order index Columbus code

Code structure	Value range
1	0
01x_0	1-2
001x_1x_0	3-6
……	……

Using different methods to encode given run-length, the performance may not be the same. Specific coding procedure is as follows:

1) Initialization.

Use scanning path proposed in the paper to initialize LIP, LIS list, set the run length count *n* as 0. Other steps are with the original SPIHT.

2) Sorting process.

2.1) Test the node in LIP. If the current node is a significant node, add 1 to *n*; otherwise, output the first-order Columbus code of *n*, *n* reset to 0, and the node be moved to LSP;

2.2) Check the node in LIS in turn, If the current node is an insignificant node (set), add 1 to *n*, otherwise, output the first-order Columbus yards of *n*, *n* reset to 0, and:

2.2.1) If the node is *A* type, insert significant "direct children" into LSP with scanning path in turn, other with the original SPIHT.

2.2.2) If the node is *B* type, put the "direct children" of node to the end of LIS in turn, remove the original node.

3) Refine works with original SPIHT.

4) Quantization step.

Obviously, this algorithm retains the symmetry of original SPIHT coding and decoding, the decoding execution is the same as above. Also, we can use adaptive arithmetic coding to further improve the data compression ratio [10].

4 Experiment results

According to the same resolution, study is implemented in different direction and different between subband resolution, different subband nonlinear statistical rule, and Lena figure and is statistical analyzed after wavelet transform, the wavelet transform coefficients according to the corresponding relations between the space of three sets of data collection, on behalf of the HL, LH and HH sub-band coefficient of $a_{i,j}$, $b_{i,j}$, $c_{i,j}$, the same scale, different threshold different direction of the wavelet coefficients statistical distribution in the list below in Table 2.

We evaluate in PSNR the different algorithms we discussed above. When compression rate is 4, 8, 16, 32, we test a group of standard image. We use standard SPIHT compression algorithm to compare the tested image. It is well known that the more efficient an image compression technique is, the more complex it becomes, especially nonreversible or lossy techniques. That confirms a tenet of source coding: code for a source approaches optimality only through infinite computation. The image coding techniques Embedded zerotree Wavelet (EZW) in 1993 and Set Partitioning In Hierarchical Trees (SPIHT) in 1996, interrupted the simultaneous progress of efficiency and complexity. The tested results in different compression ratio based on SPIHT are listed below. Table 3 is in PSNR evaluation system while Table 3 is in SSIM system. Figure 2 is an original remote sensing image (1024×1024 pixels).

TABLE 2 Corresponding distribution coefficient of Lena

Situation	**Threshold**				
	4	8	16	32	64
$a_{i,j} > T, b_{i,j} < T, c_{i,j} < T$ $a_{i,j} < T, b_{i,j} > T, c_{i,j} < T$ $a_{i,j} < T, b_{i,j} < T, c_{i,j} > T$	25098 (29.77%)	13836 (15.90%)	7519 (8.64%)	3805 (4.37%)	1848 (2.12%)
$a_{i,j} > T, b_{i,j} < T, c_{i,j} < T$	40843 (46.92%)	64893 (74.56%)	75853 (87.15%)	81601 (93.75%)	84633 (97.23%)
$a_{i,j} > T, b_{i,j} > T, c_{i,j} > T$	7576 (8.70%)	3226 (3.58%)	1373 (1.58%)	499 (0.57%)	139 (0.16%)
$a_{i,j} > T, b_{i,j} > T, c_{i,j} < T$ $a_{i,j} < T, b_{i,j} < T, c_{i,j} < T$ $a_{i,j} < T, b_{i,j} > T, c_{i,j} > T$	13523 (15.54%)	5195 (5.97%)	2295 (2.64%)	1135 (1.30%)	420 (0.48%)
$a_{i,j} > T, b_{i,j} < T, c_{i,j} < T$ $a_{i,j} < T, b_{i,j} > T, c_{i,j} < T$ $a_{i,j} < T, b_{i,j} < T, c_{i,j} > T$	25098 (29.77%)	13836 (15.90%)	7519 (8.64%)	3805 (4.37%)	1848 (2.12%)
$a_{i,j} > T, b_{i,j} < T, c_{i,j} < T$	40843 (46.92%)	64893 (74.56%)	75853 (87.15%)	81601 (93.75%)	84633 (97.23%)

TABLE 3 Compare of reconstructed image in different compression rate in PSNR

Image File	**Threshold**			
	Compression Rate(4:1)	Compression Rate(8:1)	Compression Rate(16:1)	Compression Rate(32:1)
BigCity	31.2225	25.7486	22.5382	20.2216
Baghdad-1	38.2096	32.6498	28.8461	25.9817
Baghdad-2	39.3999	33.8379	30.1864	27.2784
Washsat	43.0531	38.4445	35.6317	33.5884
Zelda	45.5592	41.4101	39.0578	36.8412
Barb	42.6745	36.6416	31.3708	27.3010
Boat	43.8738	38.2023	33.4992	29.9689
Goldhill	40.8351	35.7558	33.3904	29.7980
Lena	44.1391	39.8141	36.6006	33.3358
Peppers	42.9193	37.8094	35.4492	32.8098

The improved algorithm is implemented in grayscale figure Lena and Goldhill, compared with standard algorithm. Experiment uses 9/7 bi-orthogonal wavelet filter to test image for five pyramidal decomposition, and PSNR image reconstruction quality measurement are set up. The improved algorithm rebuilding image is shown in Figure 6. To increase the efficiency of coding, the coefficients are coded by arithmetic coding algorithm. We compare the memory requirement and number of comparison operations required for compressing an image at various compression ratios. First an image is decomposed up to all possible decomposition levels using 9/7 bi-orthogonal filters. Then, we code the decomposed components using SPIHT. For limited space, we only give the map of Lena and Goldhill, other images are displayed with comparative data as shown in Table 3, which images' sizes are of 512×512 pixels.

Original image (Lena) Reconstructed image (Lena)

Original image (Goldhill) Reconstructed image (Goldhill)

FIGURE 6 Reconstructed image based on improved algorithm

5 Conclusion

With zero tree constantly split, distribution of significant node in LIS and LIP tend to be dispersed, so RLC compression efficiency also will decline. In addition, due to introduction of RLC, streaming of 0 and 1 will be more evenly distributed, the arithmetic coding will not significantly improve the efficiency of compression.

Considering the image understanding functions of human visual system, the image quality evaluation method based on image structural similarity, estimates the subjective feeling of human eyes to image quality by arithmetic modeling, so it accords with the application purpose of image processing. From Table 3, the algorithm based on structural similarity this paper proposed have certain capability superiority in reconstructing image perceptive quality. The computing model of structural similarity can improve the reconstructed image effectively.

It is worth noting that, this paper uses first-order index Columbus yards to express run-length is not dependent on probability characteristics of the object code. Therefore, we can consider of using appropriate RLC symbols entropy coding algorithm, further improve the algorithm performance, of course, the algorithm complexity also will increase.

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