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Progressive Satellite Image Transmission Based on Integer Discrete Cosine Transform

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Abstract: This study proposes a progressive transmission method for satellite images based on the integer discrete cosine transform. It has two characteristics, low-complexity and lossless reconstruction ability. Besides, high quality intermediate image can be obtained at the early stage with a low bit rate. The reconstructed images visual quality at stage 4 is acceptable and the associated bit rate is approximately 0.2. In addition, when all stages transmission completed, the reconstructed image is accurately recovered. Experimental results demonstrate the effectiveness of the proposed method and show it outperforms the classical low-complexity progressive transmission method based on BPM. Our method can be used in many practical applications of satellite image transmission.

Key words: Satellite image, progressive transmission, integer discrete cosine transform

INTRODUCTION

With the development of astronautics and remote sensing techniques, a large quantity of satellite images are produced and transmitted. Meanwhile, satellite images have been widely used in applications such as military scout, weather forecast, minerals exploration, environmental investigation and so on. However, satellite images transmission usually requires massive time and channel resources. Thus, techniques those are able to fast access remote satellite images are highly desirable, especially in some military real-time processing applications (Park *et al*., 2004). Progressive Image Transmission (PIT) (Baeza *et al*., 2005) is an efficient solution to mitigate the latency caused by the limited bandwidth channels. The PIT means transmitting a coarse version of the original image at an early stage and this coarse image is progressively refined in the successive stages. If the reconstructed image quality is good enough, the receiver can interrupt the transmission.

Available PIT techniques can be divided into spatial domain, transform domain and pyramid-structured methods. For example, a PIT scheme based on quadtree and shading approach is developed by Chung and Tseng (2001). Later, Hu and Jiang (2005) proposed a improved PIT scheme based on quadtree segmentation with low computational complexity required. For another example, a progressive image transmission technique based on using blocked wavelets is proposed in 2008 (Chang *et al*., 2008). In 2007, a prototype named CASANDRA is introduced by Villanueva-Oller *et al*. (2007) for progressive transmission of medical digital images.

Most existing PIT methods have two properties, lossy reconstruction and/or high computational complexity. However, transmitted satellite images are always required to be accurately reconstructed at the receiving end. For example, to transmit a high-resolution military satellite map, even one pixel distortion decoded by the receiver may cause hundreds of meters error in trim size. This may further leads to serious problems in practice. Moreover, in many military applications real-time processing is important. Therefore, many available time-consuming PIT methods are is inapplicable. In other words, it is quite necessary to develop a low-complexity and lossless reconstruction PIT method for satellite images. This study aims to propose a transform domain PIT method for satellite images with these two characteristics. On one hand, computational complexity of this method is small for the original image encoding and decoding is quite simple. On the other hand, the original image can be losslessly reconstructed until all encoded information received.

PROPOSED SCHEME

Obviously, high correlation exists among neighboring image pixels and the Discrete Cosine Transform (DCT) exhibits high efficiency in energy compaction of highly correlated data. As a result, higher frequency corresponds to smaller coefficient amplitude in the statistics for high correlated image pixels. However,

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the conventional floating-point DCT is not reversible and therefore not able to guarantee the lossless recovery of the original image.

Our method is based on the integer discrete cosine transform (IntDCT). IntDCT maps an image to integer coefficients instead of floating-point coefficients as the conventional DCT. As a reversible transform (Yang *et al.*, 2004), it can ensure lossless reconstruction of the original data. Our method can be divided into encoding and transmission phase and decoding and reconstruction phase. Suppose the satellite image S is an 8-bit gray level image. Details of the two phases are described below.

Encoding and transmission: The encoding and transmission phase is described as follow:

- **Step 1: Image partition:** Partition S into non-overlapping 8×8 pixel blocks b = (b_1, b_2, Y, b_m)
- **Step 2: Forward IntDCT:** Perform forward IntDCT to each 8H8 block and the associated coefficients of b_k' ($1 \le k \le m$) are obtained. The Zig-Zag ordered coefficients DC, AC_1, Y, AC_{63} are arranged as shown in Fig. 1
- **Step 3: Bit assignment map construction:** The produced IntDCT coefficients are binary encoded and an 8H8 bit assignment map (M) is used to store the bit lengths l_0, l_1, Y, l_{63} of coding DC, AC_1, Y, AC_{63}. The element of M is obtained as:

$$l_j = \begin{cases} \text{length}(DC_{max})_2 & \text{if } j = 0 \\ \text{length}(|AC_j|_{max})_2 + 1 & \text{if } j = 1,...,63 \end{cases} \quad (1)$$

where, max denotes the maximum value of all coefficients at the same component and length(•) 2 denotes the length of binary encoded component. Obviously DC is always a positive integer while AC may be negative and thus one more bit is added to store AC = s sign. An example M (including the signs) of test satellite image (Fig. 6a).

- **Step 4: Binary encoding and transmission:** This operation is to binary encode the bit assignment map

DC	AC_1	AC_5	AC_6	AC_{14}	AC_{15}	AC_{27}	AC_{28}
AC_2	AC_4	AC_7	AC_{13}	AC_{16}	AC_{26}	AC_{29}	AC_{42}
AC_3	AC_8	AC_{12}	AC_{17}	AC_{25}	AC_{30}	AC_{41}	AC_{43}
AC_9	AC_{11}	AC_{18}	AC_{24}	AC_{31}	AC_{40}	AC_{44}	AC_{53}
AC_{10}	AC_{19}	AC_{23}	AC_{32}	AC_{39}	AC_{45}	AC_{52}	AC_{54}
AC_{20}	AC_{22}	AC_{33}	AC_{38}	AC_{46}	AC_{51}	AC_{55}	AC_{60}
AC_{21}	AC_{34}	AC_{37}	AC_{47}	AC_{50}	AC_{56}	AC_{59}	AC_{61}
AC_{35}	AC_{36}	AC_{48}	AC_{49}	AC_{57}	AC_{58}	AC_{62}	AC_{63}

Fig. 1: IntDCT coefficients arrangement with the Zig-Zag order

and integer coefficients. For example, the M shown in Fig. 2 can be binary encoded as Fig. 3. Similarly, all blocks = coefficients are binary encoded with the corresponding length listed in the M. Note that in our case if AC>0, sign = 1, otherwise sign = 0. We divide the information transmission into ten stages as that does in JPEG compression standard. Figure 4 shows the transmission stages classification associated with coefficient components

Next, concatenate the binary encoded M and coefficients sequentially with the raster scanning manner, i.e., line by line from top to bottom. At last transmit the packaged content to the receiver stage by stage. The transmission sequence in the time domain is shown in Fig. 5.

11	10	10	10	10	10		10
9	9	8	9	9	9	9	8
9	8	9	8	8	8	8	8
8	9	8	8	8	7	9	8
8	7	7	7	7	7	8	8
7	8	7	7	8	8	8	8
8	7	7	8	8	8	7	7
7	8	8	7	7	8	8	7

Fig. 2: An example of bit assignment map

1011	1010	1010	1010	1010	1010	1010	1010
1001	1001	1000	1001	1001	1001	1001	1000
1001	1000	1001	1000	1000	1000	1000	1000
1000	1001	1000	1000	1000	0111	1001	1000
1000	0111	0111	0111	0111	0111	1000	1000
0111	1000	0111	0111	1000	1000	1000	1000
1000	0111	0111	1000	1000	1000	0111	0111
0111	1000	1000	0111	0111	1000	1000	0111

Fig. 3: Binary encoded bit assignment map

1	2	5	5	8	9	10	10
3	4	6	8	9	10	10	10
4	6	8	9	10	10	10	10
7	7	9	10	10	10	10	10
7	9	10	10	10	10	10	10
10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10

Fig. 4: Coefficient associated transmission stages

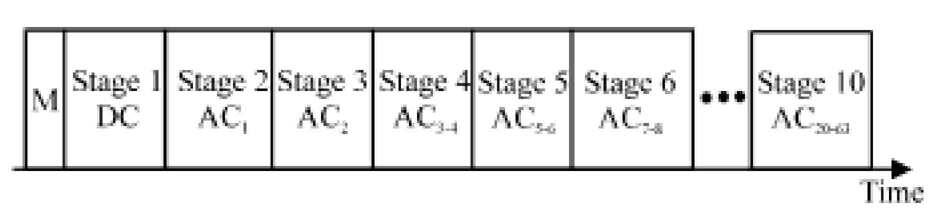

Fig. 5: Transmission sequence in the time domain

Decoding and reconstruction: This phase is the inverse operation of the encoding and transmission phase. Note that the M must be recovered initially. Then the successive received content can be decoded according to the M.

If the first stage content received, perform inverse 8×8 IntDCT on the DC coefficients and thus a coarse image can be obtained. If the second stage content received, also perform inverse 8×8 IntDCT on the DC and AC1 coefficients, the reconstructed image quality is enhanced. Other stages are processed like this. As soon as all stages are received, the reconstructed image is exactly the same as the original image.

RESULTS

Two test satellite images are shown in Fig. 6a and b. The image 1# contains much fine detail information and content of the image 2# is relatively smooth. Note both of them and all the other resultant images shown in this paper have been scaled down to the same size with real size indicated. We adopt bit per pixel (bpp) and the reconstructed image quality as performance evaluation metrics. Here bpp consists of the transmission bit rate of each stage and the accumulated bit rate of received stages. It is defined as:

$$\text{bpp} = \frac{B}{P} \tag{2}$$

where, P and B are the total number of pixels in an image and transmitted bits for this image, respectively. Peak Signal-to-Noise Ratio (PSNR) is used to evaluate the quality of the reconstructed image that defined as:

$$\text{PSNR} = 10\log_{10}\frac{255^2}{\text{MSE}}\text{dB} \tag{3}$$

where, MSE is the mean-square error computed as:

$$\text{MSE} = \frac{1}{N^2}\sum_{x=1}^{N}\sum_{y=1}^{N}(S(x,y)-R(x,y))^2 \tag{4}$$

where, S(x, y) and R(x, y) denote the gray levels of the pixel in the position of (x, y) of the original NHN satellite image and the reconstructed image. Lower bpp and higher PSNR values indicate better performance.

The reconstructed images PSNRs at different stages are shown in the Fig. 7 and more details are given in Table 1. We find that out method is effective to reconstruct the image with good quality at an early stage and meanwhile bpp is very low. Figure 8a-i show the

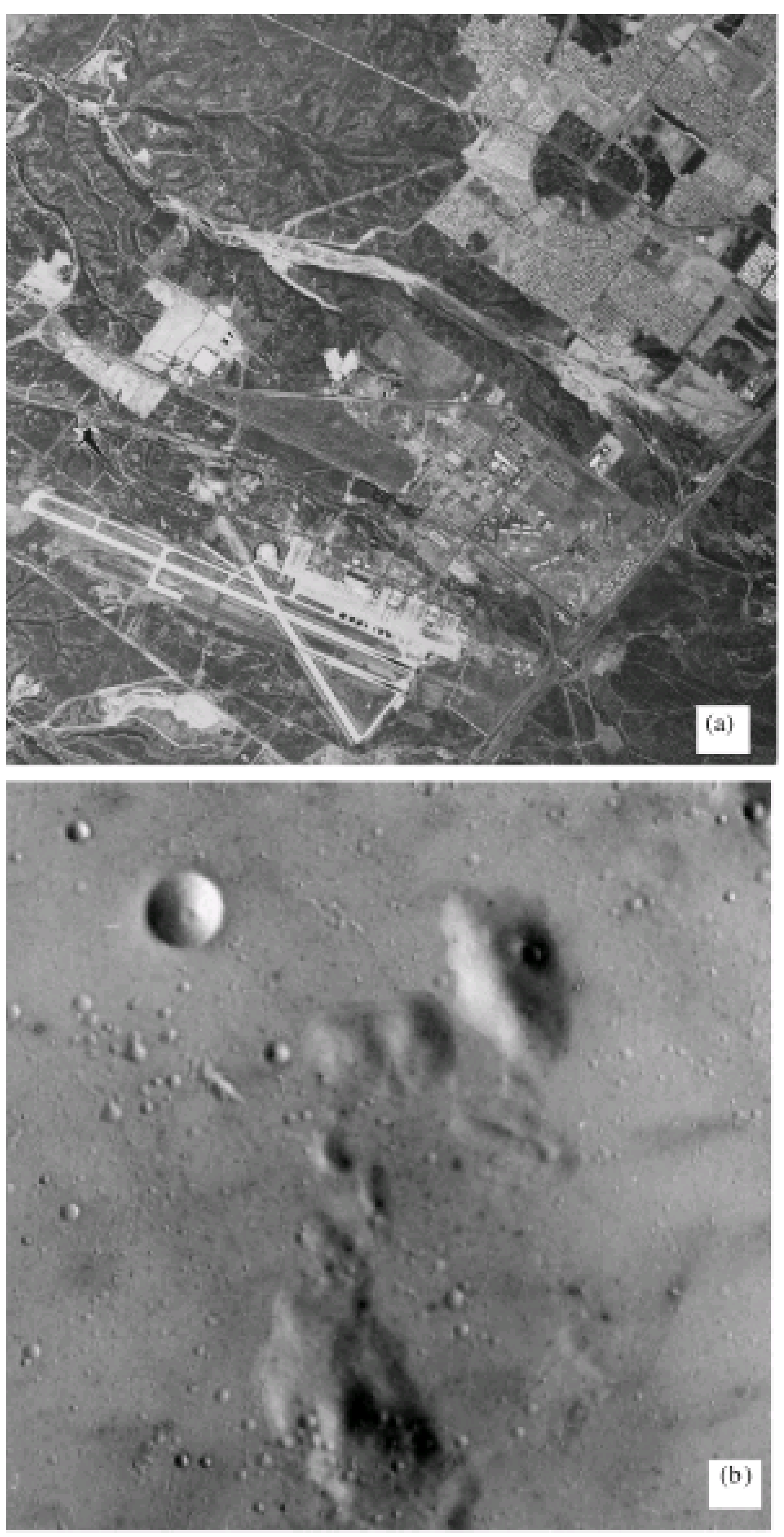

Fig. 6: Test satellite images, (a) image 1# (512H512) and (b) image 2# (256H256)

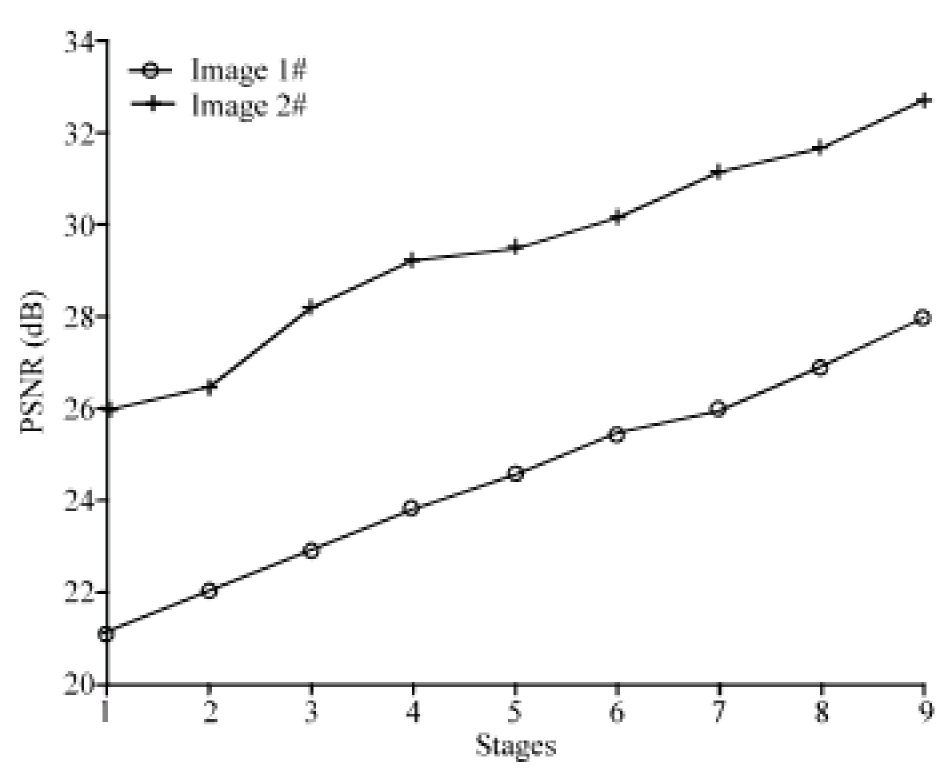

Fig. 7: The reconstructed images PSNR values at different stages

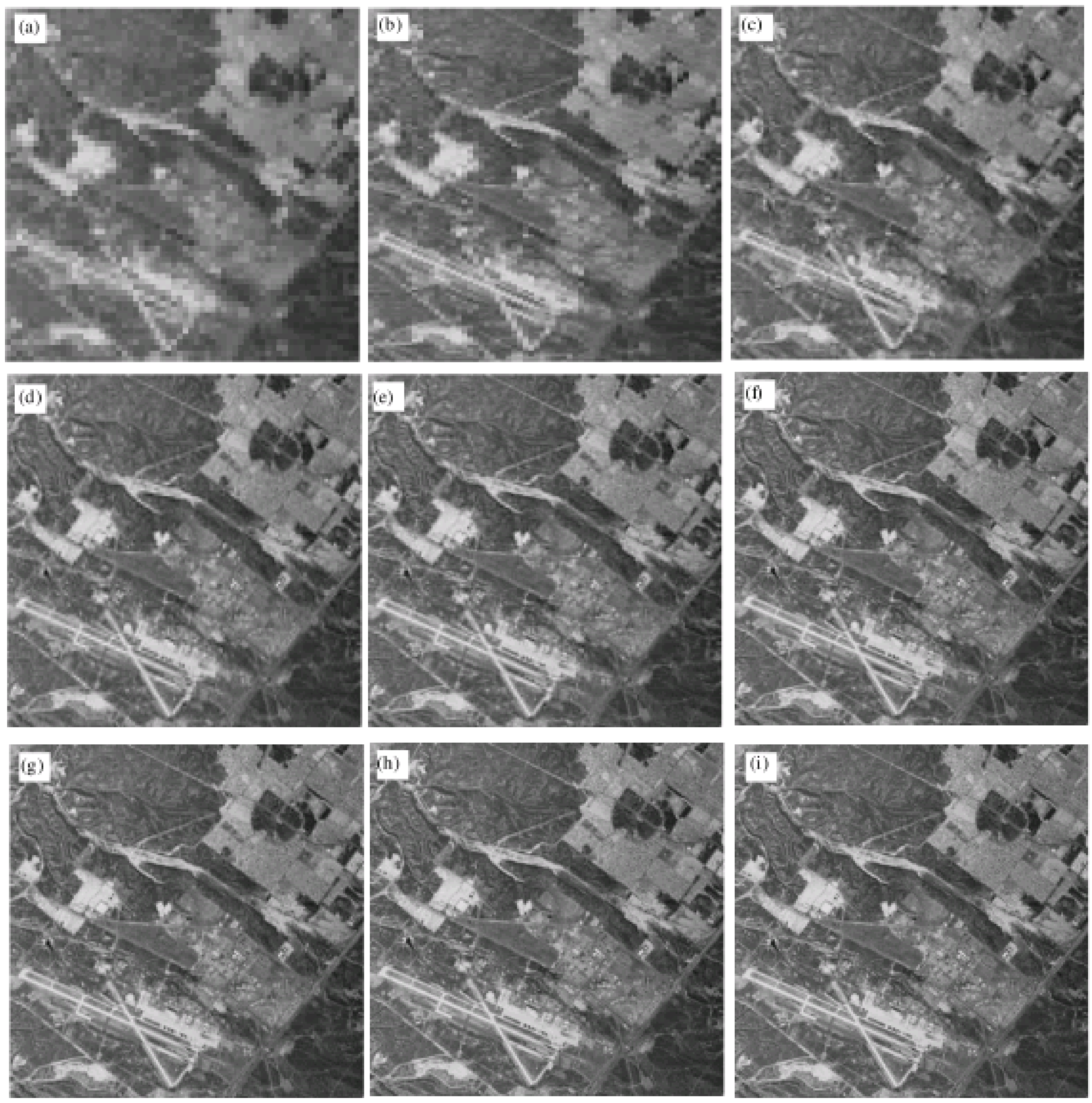

Fig. 8: The reconstructed images at different stages, (a) Stage 1 (PSNR = 21.08 dB), (b) Stage 2 (PSNR = 22.05 dB) (c) Stage 3 (PSNR = 22.88 dB), (d) Stage 4 (PSNR = 23.81 dB), (e) Stage 5 (PSNR = 24.56 dB), (f) Stage 6 (PSNR = 25.42 dB), (g) Stage 7 (PSNR = 25.96 dB), (h) Stage 8 (PSNR = 26.85 dB) and (i) Stage9 (PSNR = 27.98 dB)

Table 1: The reconstructed images PSNR values at different stages

	Transmission bit rates (bpp)		Accumulated bit rates rates (bpp)		PSNR (dB)	
Stages	Image 1#	Image 2#	Image 1#	Image 2#	Image 1#	Image 2#
1	0.17	0.17	0.17	0.17	21.08	25.93
2	0.16	0.16	0.33	0.33	22.05	26.47
3	0.14	0.14	0.47	0.47	22.88	28.15
4	0.28	0.23	0.75	0.70	23.81	29.18
5	0.31	0.30	1.06	1.00	24.56	29.49
6	0.25	0.25	1.31	1.25	25.42	30.13
7	0.39	0.33	1.70	1.58	25.96	31.10
8	0.44	0.39	2.14	1.97	26.85	31.66
9	0.66	0.58	2.80	2.55	27.98	32.66
10	5.34	4.45	8.14	7.00	lossless	lossless

reconstructed images at different images. The last stage reconstruction is exactly the same as the original image. It also demonstrates effectiveness of our method.

A classical low-complexity PIT method is the Bit-Plane Method (BPM) based on spatial domain. Its basic idea is to transmit the image from the most significant bit-plane to the least significant bit-plane one by one. Similar as our method, BPM is simple and requires less computation. However, its bpp is very high for each stage corresponds to 1.00 bpp. Moreover, accumulated 5 bpp in BPM is usually needed to achieve the better reconstruction image quality. From the experimental results shown in Table 1, BPM = s disadvantage of high transmission load is improved in our method.

DISCUSSION

According to a large quantity of experimental results on diverse satellite images such as remote sensing images and aerial images, we find that the reconstructed images visual quality at stage 4 is acceptable and the associated bit rate is approximately 0.2. In addition, when all stages transmission completed, the reconstructed image is accurately recovered. This is quite important for satellite images applications for they are obtained with a high cost.

Compared with those PIT methods based on spatial domain pixels operations and transform domain methods such as those based on wavelet, our scheme preserve the following two properties. One is the low computational complexity for only the integer DCT is involved for each 8H8 blocks. The implement of 8×8 block integer DCT is very fast and thus our scheme can be used in satellite image real-time transmission and processing. The other advantage lies in the intermediate image quality at the early stage decoded is acceptable. Consequently, if the satellite data is wrong transmitted or not required, the receiver can cut off the transmission task in time so that the subsequent useless transmission can be avoided.

To further improve the performance of our scheme, we need to take the advantages of the available methods (Chung and Tseng, 2001; Hu and Jiang, 2005; Chang *et al.*, 2008; Villanueva-Oller *et al.*, 2007) into account. In particular, the integer DCT can be combined with the principle of quadtree or wavelet transform. In this way, the intermediate decoded image quality can be further improved. Besides, our scheme may be redeveloped for some specific domain satellite images applications. That is the content of these satellite images is also considered.

CONCLUSION

A progressive transmission method for satellite image is proposed. It requires low computational complexity for block IntDCT computation is simple and can be parallelly processed. Furthermore, reconstruction of the transmitted satellite image is lossless because of the reversibility of IntDCT. In the future, our research focus on reducing the bpp with better image quality maintained. This improvement will start with IntDCT coefficients lossless compression.

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