IMPROVING COMPRESSION RATIO FOR SATELLITE TRANSMISSION BY USE OF CLOUD EXTRACTION

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ABSTRACT

This paper presents an alternative approach to JPEG 2000 based ROI coding, for use on-board satellite image compression. The proposed method works in the wavelet domain and modifies the wavelet coefficients in a way to allocate fewer bits for cloud-covered areas. This approach improves compression ratio and/or improves the quality of un-cloud-covered areas. The algorithm is implemented with pixel based and codeblock based schemes. Pixel based scheme can be embedded into any wavelet transform based codec. Both schemes allow packing of the coefficients into a fully JPEG2000 decoder compatible bitstream as soon as a codeblock is formed. The performance of the proposed schemes are demonstrated by tests on real satellite images acquired by BILSAT I[1].

1. INTRODUCTION

Downlink capacity, transmission speed, and available on-board power are three of the limiting factors that restrict the efficiency and extend of on-board applications for low orbit satellites. Fast and memory efficient algorithms are needed in order to process, compress, and transmit the acquired images. JPEG 2000 [1] is known to provide a good tradeoff between quality and compression rate, and has been successfully implemented on-board many satellites. Yet, there is effort to further improve the tradeoff, by use of on-board preprocessing techniques. Region based compression is among those efforts, that aims to encode a region of interest with higher quality than the rest [2-6]. In [2], urban and forested regions, which appear highly textured, are considered as of no interest, and their boundaries are coded with high quality while textured regions are smoothed. Many others consider cloud and/or water as of no interest and emphasize on cloud and water extraction [3-6]. [4-5] exploit smoothing of cloud boundaries, and is based on old JPEG standard. Some of the recent algorithms exploit ROI (region of interest) coding recommended by JPEG 2000 [6]. However, JPEG 2000 ROI uses MAXSHIFT method [1,7]. This method shifts ROI coefficients up in the bitplane, so that minimum ROI coefficient will be placed higher than the maximum non-ROI coefficient at the bitplane, hence will be encoded first. The rest can be encoded if the transmission time or bandwidth permits. This requires scanning of full wavelet bands in order to determine MAXSHIFT factor. This is not desirable for our application, where wavelet coefficients are coded and transmitted as soon as they are computed. PCRDopt [1] based applications [3] are also not considered for our application, because rate-distortion optimisation requires a number of iterations over all of the wavelet coefficients. We prefer to modify the wavelet coefficients that belong to the region of no-interest by one pass algorithm, while packing them into a bitstream.

2. EXTRACTING THE REGION OF NO-INTEREST

Content-based compression mostly focuses on regions of interest, for applications with limited transmission capacity. In some cases, it is more feasible to see the problem from the other side, i.e. to extract the regions of no-interest. For example, for natural images, textured regions may not be of interest, since human eye is not sensitive to the loss in texture. In satellite imagery, some of the pictures are occluded with dense clouds. Even when the cloud is not dense, it decreases the visibility to great extent, and results in transmission of data that is of no use to a majority of the receivers. Clouds are easily extracted from multichannel images using blue color component and/or IR band. Clouds are highly reflective; hence appear as high magnitude pixels in Blue band. The simplest way to extract clouds is thresholding in the B channel as in [3]. Region growing can also be applied as in [4-5]. The result will be a binary mask where region of no-interest (RONI) is denoted by 1 and the rest by 0. The pixels belonging to the region labelled as 1 will be modified in the transform domain, hence, discrete wavelet transform (DWT) coefficients corresponding to those regions are needed to be located. We propose two different ways to locate RONI coefficients. Those methods are explained in the next section.

3. MODIFICATION OF THE COEFFICIENTS

3.1 Pixel based modification

In pixel-based modification, each high frequency coefficient is suppressed or left as is, depending on its

[1] BILSAT 1 is the earth observing low earth orbit satellite launched by Tubitak Bilten in 2003.

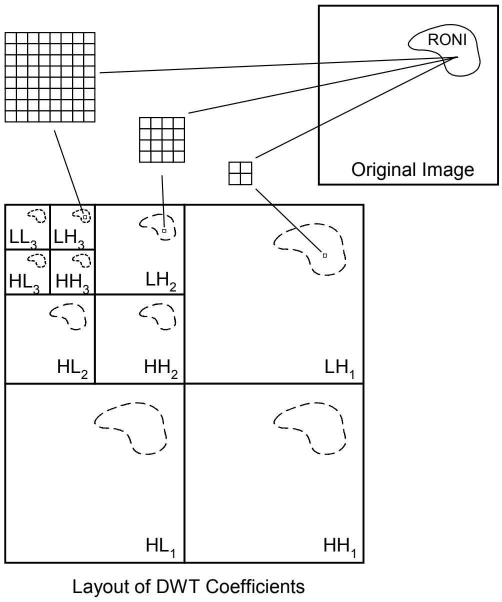


Figure 1. Layout of DWT coefficients and parent-ancestor link.

descendent nodes in the RONI map. The ancestor-descendent relationship is presented in Figure 1. Suppose that we need to decide whether or not to suppress pixel (i,j) in LH_3 band, i.e. $LH^{i,j}_3$. This pixel is the ancestor of 8×8 children from $RONI^{8i,8j}$ to $RONI^{8i+7,8j+7}$ in the RONI map. $LH^{i,j}_3$ is suppressed if more than a preselected number of 8×8 children are labelled as 1. For pixel $LH^{i,j}_2$, more than a preselected number of 4×4 children from $RONI^{4i,4j}$ to $RONI^{4i+3,4j+3}$ should be labelled as 1. For $LH^{i,j}_1$, more than a preselected number of 2×2 children from $RONI^{2i,2j}$ to $RONI^{2i+1,2j+1}$ should be labelled as 1. HL and HH bands are treated equivalently. The LL_3 band is left as is in order to send a very coarse representation of RONI.

3.2 Codeblock based modification

In codeblock based modification, the decision to suppress or not to suppress the coefficients is given once for each codeblock. The following algorithm is proposed for D level of DWT:

For $d = 1$ to D,

- Divide the input image into $(N/(2^d \cdot sz))^2$ square blocks, $B^{i,j}$, where N and sz refer to tile and codeblock size, respectively. Let $P_d^{i,j}$ be the percentage of cloud covered region in $B^{i,j}$.
- if $30 < P_d^{i,j} < 60$, suppress (i,j)th codeblock of HH_d, leave HL_d, LH_d as is
- else if $P_d^{i,j} > 60$, suppress (i,j)th codeblock of HH_d, HL_d, LH_d.

Block based processing treats non-cloud covered regions in a codeblock as cloud, if most of that codeblock is covered with cloud. Suppressing the whole codeblock increases the time efficiency of the coding at the expense of more loss around the boundaries of clouds. Note that, any pixel modification in the transform domain will not only affect its descendent pixels in the original image, but also the neighbouring pixels to the descendents. However, because of the short support of the wavelet filters, this effect will only propagate to the immediate neighbours, hence it is considered negligible.

As for hardware implementation constraints, pixel based modification algorithm requires a memory for the storage of RONI map, of which size depends on the computation method of wavelet coefficients. For block based implementation, each transformation level is computed after the preceding level, and required memory size is $N \times N$. For row based implementation, computation of coefficients from a level starts immediately after sufficient number of coefficients from the preceding level are available, and required memory size is $O(N)$. In the latter case, the bits corresponding to $RONI^{2^D i, 2^D j}$ to $RONI^{2^D i+2^D-1, 2^D j+2^D-1}$ are no longer needed, and can be dismisse from the memory. A reduction in memory by 4 in the first case or by 2 in the latter case can be achieved by using a modified $RONI_1$, where $RONI_1^{i,j}$ equals 1 if more than a preselected number of pixels from $RONI^{2i,2j}$ to $RONI^{2i+1,2j+1}$ is 1.

4. EXPERIMENTAL RESULTS

We tested our algorithms over 28 1024×1024 RGB images. The images are acquired by BILSAT I satellite and include 0-76% cloud covered regions, when cloud threshold is set to 180. The parameters of JPEG 2000 is set as: tile size = 256, codeblock size = 32, number of resolution level = 3. Multicomponent (color) transform is not exploited. Experiments showed that multicomponent transform did not effect bitrate/PSNR improvement. The following experimental settings are used:

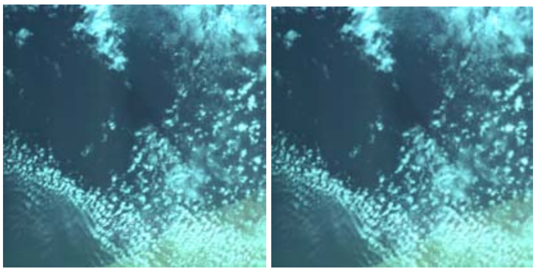
1. Pixel based modification (Section 3.1) is performed and the rest is coded without loss. In the modification phase:
   - 2.a. LL band is not modified.
   - 2.b. LL band is quantized with step size 4.
   - 2.c. LL band is quantized with step size 16.
   - 2.d. LL band is completely suppressed.
2. Pixel based modification is performed and the rest is coded at CR=0.25 using PCRDopt. In the modification phase:
   - 2.a. LL band is not modified.
   - 2.b. LL band is quantized with step size 16.
   - 2.c. LL band is completely suppressed.
3. Codeblock based modification (Section 3.2) is performed, and the rest is coded lossless.

The results of the experimental setting 1 are presented in Table 1. CR refers to (raw image data size)/(compressed image data size) in bytes, bitrate impr refers to percentage of change in CR, and PSNR impr refers to difference between $PSNR_{mod}$ and $PSNR_{unmod}$, where unmod and mod refers to unmodified and modified, respectively.

It is seen that, at lossless compression, suppressing the high frequency components of cloud-covered regions reduces the bitrate in proportion with the percentage of the cloud. When LL components of the cloud are quantized, significant improvement is seen only when quantization step size is over 16. Table 2 presents the results of Experimental Setting 2. In

Table 1. Quantitative results of experimental setting 1.

img no.	cloud %	CR	bitrate improvement Exp a	Exp b	Exp c	Exp d
1	76	0.36	65.27	65.96	69.30	74.04
2	59	0.38	49.98	50.55	53.02	57.58
3	50	0.34	45.32	45.70	47.69	51.08
4	43	0.37	36.36	36.71	38.25	42.24
5	43	0.36	32.89	33.10	34.67	38.28
6	24	0.33	22.25	22.45	23.20	24.84
7	20	0.43	12.16	12.25	13.05	16.45
8	19	0.43	11.56	11.61	12.33	15.20
9	19	0.36	16.23	16.37	17.15	19.41
10	15	0.37	11.82	11.88	12.49	14.48
11	15	0.37	11.80	12.53	13.80	17.41
12	13	0.38	12.16	12.31	13.06	14.56
13	10	0.40	7.20	7.23	7.57	8.93
14	10	0.39	7.52	7.56	7.93	9.52
15	8	0.38	6.45	6.49	6.71	7.38
16	8	0.37	6.63	6.70	6.93	7.46
17	8	0.36	7.05	7.09	7.44	8.52
18	6	0.33	5.75	5.99	6.26	7.23
19	6	0.39	5.75	5.80	6.00	6.88
20	6	0.36	5.37	5.39	5.49	5.88
21	6	0.38	5.55	5.61	5.84	6.62
22	4	0.34	3.46	3.49	3.60	3.99
23	4	0.38	3.28	3.31	3.40	3.74



a b

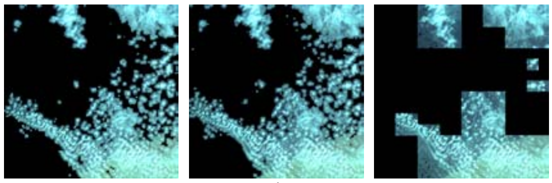
Figure 2. Original image and pixel based modification result.

this setting, CR is set to 0.25, hence bitrate improvement is expected only when the modified image can be losslessly encoded at below CR=0.25. PSNR results in Table 2 are computed over non-cloud-covered regions. The results show that pixel based modification reduces bitrate significantly also at lossy (near lossless) compression, when at least 40% of the image is covered with clouds. Furthermore, it increases PSNR for cloudless regions, as expected. The results of experimental setting 3 are not tabulated, because, no significant difference from experimental setting 1 is observed.

In Figure 2a-b, test image 9 and its modified version (setting 1.a) are displayed. Detected RONI when cloud threshold is set to 180 and 160 are displayed in Figures 3.a and 3.b, respectively. Modified pixel locations with cloud based modification are presented in Figure 3.c. The right bottom parts of Figure 1.a-b are zoomed in Figure 4a-b, and codeblock based modification result of Figure 1.a is zoomed in Figure 4.c. As also seen in Figure 3.a-c, pixel based

Table 2. Quantitative results of experimental setting 2.

img no.	cloud %	bitrate impr a	b	c	PSNR original	PSNR impr (dB) a	b	c
1	76	54.2	58.9	65.7	54.77	6.27	4.96	4.73
2	59	33.2	36.5	42.3	54.36	4.82	4.54	4.74
3	50	26.7	35.5	39.6	56.53	4.48	4.11	4.07
4	43	18.6	20.3	24.7	56.53	2.2	2.17	2.3
5	43	19.2	21.2	26.0	54.27	2.56	2.31	2.35
6	24	7.9	8.6	10	56.59	3.25	3.21	3.4
7	20	0	0	0	51.88	1.73	1.81	2.16
8	19	0	0	0	52.4	1.21	1.28	1.55
9	19	5.7	6.1	7.4	55.17	1.46	1.52	1.66
10	15	0	0.8	1.3	54.67	1.45	1.49	1.62
11	15	2.7	3.6	6.0	53.61	1.75	1.76	1.94
12	13	0	1.0	2.9	54.68	0.41	0.41	0.41
13	10	0	0	0	53.29	1.06	1.1	1.24
14	10	0	0	0	53.75	1.1	1.14	1.26
15	8	2.6	2.9	3.8	54.03	0.31	0.25	0.24
16	8	0	0	0	54.33	0.48	0.48	0.51
17	8	0	0	0	55.3	0.85	0.89	0.99
18	6	0	0.4	1.1	56.28	0.57	0.58	0.59
19	6	0	0	54.7	53.99	0.59	0.6	0.71
20	6	1	0.9	1.1	54.92	0.46	0.47	0.46
21	6	0	0.0	0	54.17	0.51	0.53	0.59
22	4	0	0.5	0.5	55.7	0.47	0.48	0.52
23	4	0	0	0	54.25	0.33	0.34	0.37

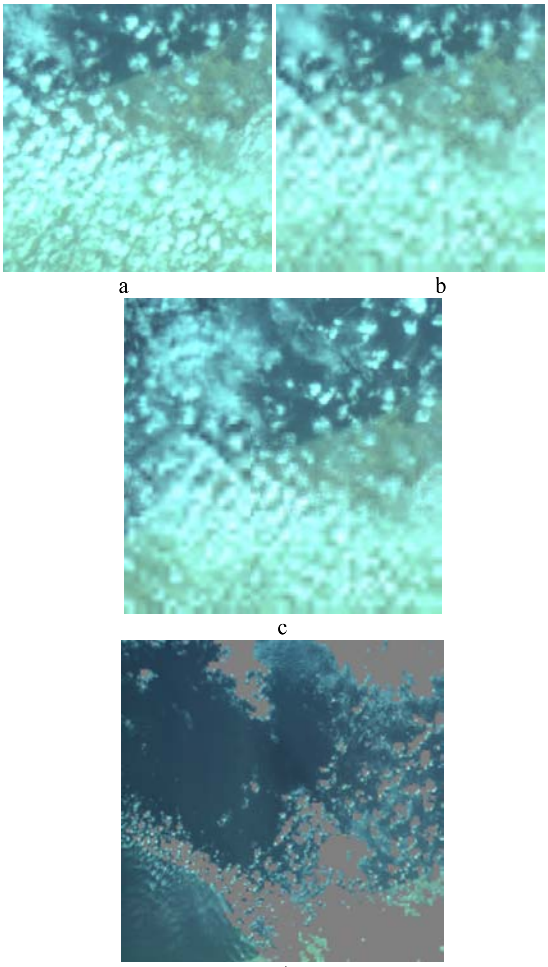


a b c

Figure 3. RONI for the image in Figure 2.a.

modification smoothes cloud pixels together with immediate neighbors only, whereas codeblock based modification smoothes larger neighborhood of cloud pixels. Figure 4 is the result of pixel based modification where DWT coefficients corresponding to cloud pixels are completely suppressed (setting 1.d). This is equivalent to setting RGB values at those locations to 128 (due to DC shift in JPEG 2000). Although setting 1.d offers higher bitrate improvement than setting 1.a, the visual quality may disturb the end-users. The quantitative results presented in Table 1-2 and the visual results presented in Figure 2-4 demonstrate the bitrate improvement performance of pixel based modification.

In literature, few quantitative results of content based satellite image compression exist, and comparison is difficult due to use of different settings [3-4]. In [3], although successful results with water (16.7% bitrate improvement when 34.5% of the image is covered with water) and urban area identification are achieved, no significant bitrate improvement with cloud extraction is reported. The reason is explained as fragmented RONI map due to haze. Our pixel based modification performs well even for such cases. In Figure 5.a, a BILSAT I image covered with 60% water is



a b c d

Figure 4. Pixels included in cloud-covered regions are modified with different settings.

displayed. Our pixel based modification provides 48% bitrate improvement for that image which is consistent with the results reported in [3]. The modified image is presented in Figure 5.b. In [4], lossy compression by old JPEG standard is applied and blocks including at least 20 cloud pixels are assigned to average grey level of the image (comparable to Exp d). Some of their results are tabulated in Table 3. Note that the bitrate improvements tabulated in [4] are higher due to combination of other improvement methods. The improvement reported in Table 3 are only the portion due to content-based compression. Those results may seem slightly better than ours, but that method achieves good results by old JPEG standard (block based compression), which achieves significantly less compression than JPEG 2000.

5. CONCLUSIONS

In this work, onboard content based compression of satellite images is addressed. Cloud covered regions are considered as of no interest to the user for this application. Two algorithms are proposed for allocating fewer bits to encode RONI. The algorithms are embedded in JPEG 2000, and transform

Figure 5. Original image and pixel based modification result.

Table 3. Quantitative results deduced from [4].

cloud %	CR	bitrate impr.	cloud %	CR	bitrate impr.
49	0.20	32.8	21	0.21	22.9
40	0.30	44.8	16	0.15	27.5
38	0.22	54.1	13	0.23	16.5
33	0.21	19.8	10	0.29	13.7
29	0.29	35.8	5	0.18	11.8

coefficients corresponding to RONI are modified by pixel based and codeblock based suppression. The two methods satisfy two important criteria for onboard compression: iterative rate-distortion optimisation is not required, and transform coefficients are packed into the bitstream as soon as a codeblock is formed. Quantitative results on real satellite images including cloud covered regions show that both methods result in significant bitrate improvement. However, pixel based modification yields a finer classification of cloud and non-cloud regions, hence yields better visual results, especially when RONI map is fragmented due to fragmented clouds or haze.

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