Advanced On-board Image Compression in Conjunction with Cloud Detection for Micro-satellite Optical Imaging

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Abstract

In this paper we propose two improvements to standard JPEG (Joint Picture Expert Group) coding that can improve the compression ratio achieved for compressing remote sensing images obtained by sensors on-board micro-satellites by more than 39-60%. The first improvement consists in using a quantisation table that has been shown experimentally to be more appropriate for remote sensing images. The second and more significant improvement comes from the use of a novel region growing algorithm that can identify the outer border of a cloud region. The blocks that correspond to cloud regions are subsequently smoothed, as they represent unwanted information for the applications we are interested in, and encoded. The results are demonstrated with the help of several real images obtained by the Surrey University satellites.

1. Introduction

Micro-satellites are becoming more and more popular for Earth observation. Their major advantage is their cost effectiveness [1] . They can obtain images of the surface of the Earth with resolution down to 50m or less. As they orbit the Earth in approximately 1 hour, they have the capacity to capture many images, and they can hold in memory approximately 200. However, they remain for only a few minutes in contact with a single tracking station, and down-loading such images is the bottleneck of the whole process. The obvious solution is the coding of the images on board. In some preliminary experiments, we divided an image containing clouds into non-overlapping 8 by 8 blocks. Then analysis based on the JPEG coding scheme was applied. The number of bits used by the non-zero quantized Discrete Cosine Transform (DCT) coefficients for each block were recorded and the mean square-error between the original and the reconstruction of each block was calculated. The 1000 blocks which incur the largest reconstruction error are delineated in Fig.1-a, and the 1000 blocks which occupy the largest number of non-zero bits are indicated in Fig.1-b. A strong correlation between these two distributions of blocks can be observed. This example demonstrates a general observation: most of the blocks in an image which require the most bits for JPEG encoding and which are least reliably reconstructed are blocks that contain rims of clouds where rapid transitions from the very bright cloud region to the dark Earth surface or the sea take place. These "transition" blocks do not really represent useful information about the surface of the Earth, and so it appears that significant gains in coding can be obtained if these blocks are isolated and treated separately. In cases where the images are not needed for Meteorological observations, clouds, which are very common in optical Earth observation, represent effectively unwanted "noise". We call this "application noise". In a meteorological application on the other hand, the application noise may be that part of the image which depicts the surface of the Earth, rather than the clouds. In this paper we assume that the application noise are the clouds, and blocks that contain only clouds will be specially treated by the coding process. Further, we shall pay particular attention to the rims of clouds and make sure that the blocks that contain cloud rims are treated as cloud regions, so that no bits are wasted in coding those blocks accurately.

In this paper we shall present the application of an algorithm, that was proposed recently for identifying the outer fuzzy rims of microcalcifications in mammograms [3], in order to identify the cloud rim. The algorithm is used as an extension of a conventional cloud detection method [2] exactly because of its capacity to identify the outer rim of a fuzzy bright region. Blocks that are inside the detected boundary, or include part of it are labelled as cloud blocks and they are given a flat grey value of 255. Before we proceed in presenting the details of the approach, we shall give in section 2 a brief overview of the classical JPEG-like algorithm and some improvement we can obtain by using a different lookup quantization table than the conventional one. In section 3 we shall outline the region growing algorithm for cloud detection. In section 4 we shall present some experimental results, and we shall conclude in section 5.

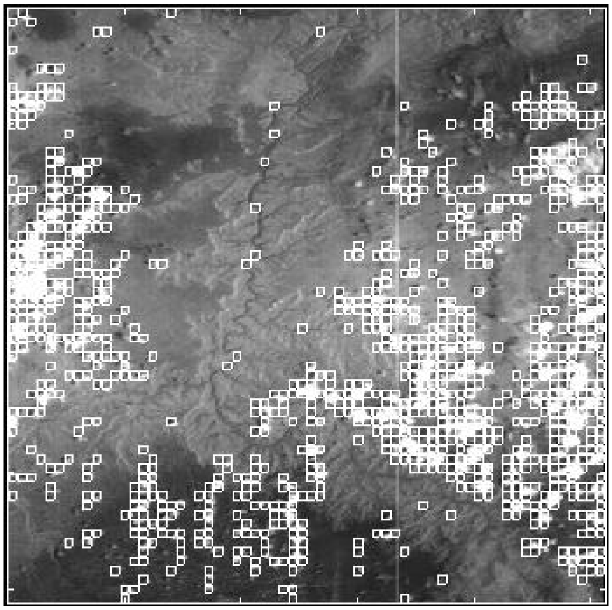


Fig.1-a. Blocks incurring the largest distortion after reconstruction

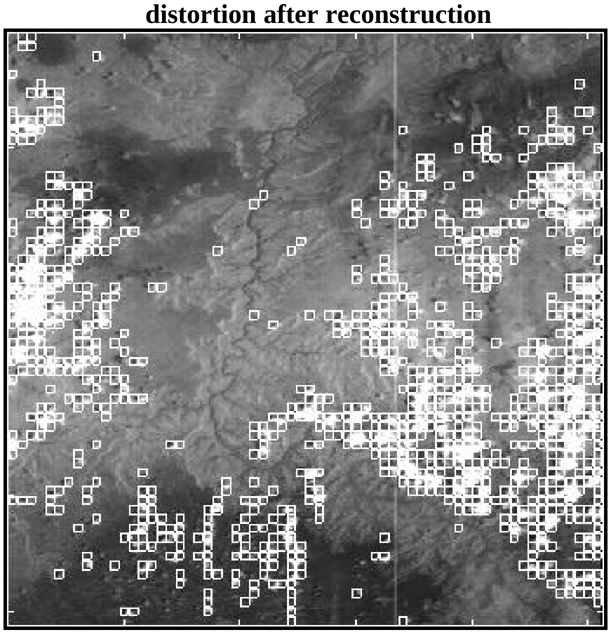


Fig.1-b Blocks occupying the largest number of bits.

2. JPEG coding for remote sensing

JPEG compression algorithm has been proposed to compress general continuous tone images for several years. Now its variants are still widely used in many applications including on-board remote sensing coding [4]. For lossy compression of this method, DCT coefficients' quantization is the key for the trade-off between compression ratio (C.R.) and reconstruction quality (measured by the Root Mean Square Error (RMSE)). For JPEG-like compression system, this quantization is implemented with the help of a predefined divisors look-up table —quantization table. It is easy to know that such a table couldn't provide optimal results for different applications or image context. Most of JPEG-like routines provide Q-factor to adjust the predefined table linearly, however this is mainly used in modifying resulted compression ratio or reconstruction error. Theoretically, different image block context would require different quantization table to provide optimal result, but the adoption of multiple quantization tables and on-line selection will increase computational complexity and also coding overheads. From our experiment, we found through some arithmetical operations and thresholding to the CCITT & ISO recommended one (Table-1(left)), the new table, e.g. Table-1(right), is more suitable for microsatellite images. The operations regarding the new table presented here include dividing the old table by 2 and if any resulted component is larger than 17, modify it to 17. We use both tables to do tests with four raw images, which are shown in Fig.2-a through Fig.2-d, and results can be seen in Table -2. These four images are captured by CCD cameras of PoSat-1 of Surrey Satellite Technology Limited, the sensor provides coverage of 150 km x 100 km, at a resolution of 200 metres per pixel, and senses in the red part of the spectrum (610-690 nm). For the convenience of display, each image is cropped to the dimension of 512 by 512.

From above Table-2, it can be noticed that at the same level of reconstruction error, compression ratio based on modified quantization table can be improved by 14% to 24%. These results are achieved by Q-factor of 85 for CCITT & ISO table and Q-factor of 45 for modified table. Similar improvement using other Q-factor pairs or applying to other test images can be also observed.

3. Overview of the region growing algorithm

The region growing method by pixel aggregation is used for the cloud detection purposes. The method, like other region growing techniques, starts with a point that meets a detection criterion and grows the point in all directions to extend the region. A unique feature of the proposed approach is that in each step at most only one candidate pixel exhibits the required properties to join the region. This makes the direction of the growing process more predictable.

In the approach, a boundary pixel is joined to the current region provided it has the highest grey level among the neighbours of the region. If the process starts from a local maximum, pixels with monotonically lower and lower grey levels will sequentially join the region. In this approach, we also define two region measurements, *average contrast* and *peripheral contrast.* In order to do this, the following terminology is introduced: "Current boundary" (CB) is the set of pixels adjacent to the current region. "Internal boundary" (IB) is defined as the boundary produced by the set of connected outermost pixels of the current region. The current region and the two boundaries, CB and IB, are dynamically changing during the growing process. Using this terminology the *average contrast* is defined as the difference between the average grey level of the whole region and the average of its CB pixels. The *peripheral contrast* is defined as the difference between the grey level average of its IB and CB. The mappings of the two measurements exhibit multiple peaks which can be used to segment out a distinct region which will meaningfully correspond to the information conveyed by the internal part of the region. In order to produce unique boundary for a region, the last local maximum of the *peripheral contrast* occurring before the maximum of the *average contrast* measure is used to determine the final boundary of region.

Table-1: Two different quantization table

16	11	10	16	24	40	51	61
12	12	14	19	26	58	60	55
14	13	16	24	40	57	69	56
14	17	22	29	51	87	80	62
18	22	37	56	68	109	103	77
24	35	55	64	81	104	113	92
49	64	78	87	103	121	120	101
72	92	95	98	112	100	103	99

CCITT & ISO table

8	6	5	8	12	17	17	17
6	6	7	10	13	17	17	17
7	7	8	12	17	17	17	17
7	9	11	15	17	17	17	17
9	11	17	17	17	17	17	17
12	17	17	17	17	17	17	17
17	17	17	17	17	17	17	17
17	17	17	17	17	17	17	17

Modified table

Table-2: Result compare using two kinds of quantization table for JPEG-like compression

	Recommended table		Modified table		C.R.
	C.R.	RMSE	C.R.	RMSE	improvement
Fig2-a	5.52	3.26	6.54	3.35	18%
Fig2-b	5.36	3.41	6.28	3.16	17%
Fig2-c	6.86	2.84	8.64	2.84	26%
Fig2-d	3.95	3.77	4.51	3.78	14%

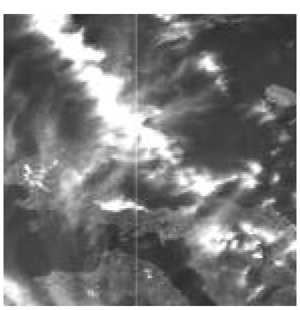


Fig.2-a

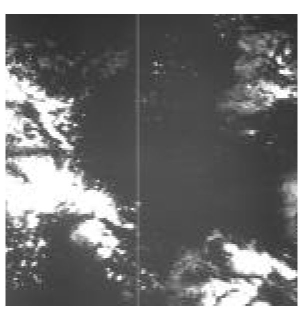


Fig.2-b

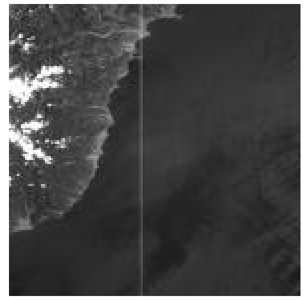


Fig.2-c

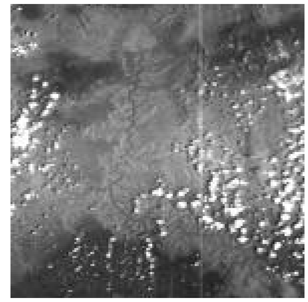


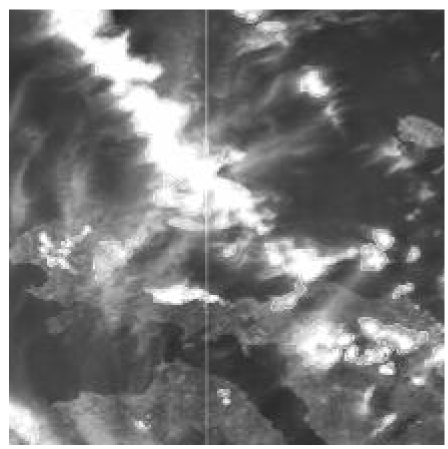
Fig.2-d

Fig2: Test images (raw data)

4. Experimental results

For raw images shown in Fig.2, the above region growing method is applied. We use the combination of edge detection and histogram thresholding to slice out the central clouds regions in images and then growing procedure is employed based on these *internal* regions to get the outer rims of the clouds. Part of the results are shown in Fig.3. The outer boundaries of clouds are indicated using solid lines.

After the clouds are detected, we use 8 by 8 blocks to approximate the indicated cloud regions. These blocks are



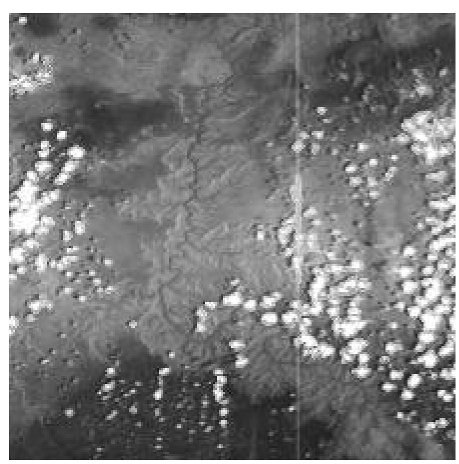


Fig.3: clouds detection results

arranged using the same way as image splitting in JPEG. Each block should contain at least 20 cloud pixels labelled by the region growing algorithm. If impose the resulted blocked clouds shape on the real shape of clouds, we obtain the outcome shown in Fig.4. These blocks which are inside the detected boundary, or include part of it are labelled as cloud blocks and all of them are given a flat grey value of 255. We use the JPEG algorithm with two kinds of quantization tables described previously to compress the four partially smoothed images and the results are shown in Table-3. The final reconstructed images using modified quantization table can be seen in Fig.5.

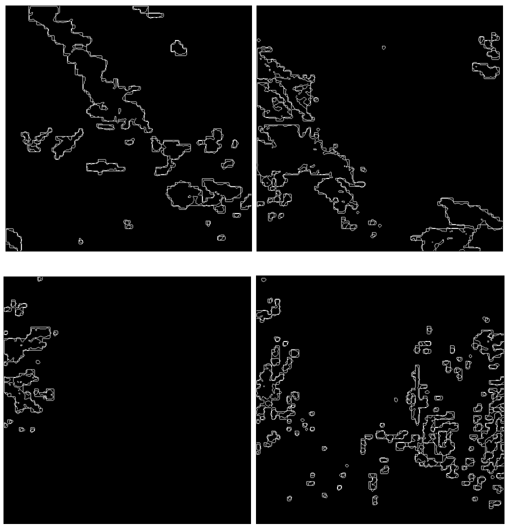


Fig.4: Approximation of clouds boundary using blocks

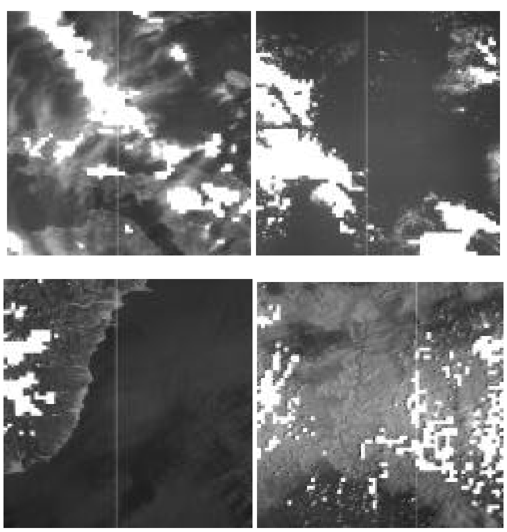


Fig.5: Reconstructed images

In Table-2, Fig.2-a-s through Fig.2-d-s refer to the smoothed test images. The calculation of RMSE take account only of the scenes left after block-cloud labelling. C.R.$^+$ means compression ratio improvement compared to respective compression result without clouds smoothing in advance. The overall C.R.$^+$ refers to compression ratio improvement from modified quantization table plus clouds smoothing to recommended table without clouds smoothing. Compared with Table-2, we can see RMSE in Table-3 are lower than those of Table-2 respectively. Actually cloud regions in the original raw images will lead to more reconstruction error, if they are also coded in the same way as the other regions. This is because rapid transitions within some cloud blocks containing cloud rims were present from the very bright cloud region to the dark Earth surface or the sea.

Table-3: Result of compression with clouds smoothing in advance

	Recommended Table			Modified Table			Overall
	C.R.	RMSE	C.R.$^+$	C.R.	RMSE	C.R.$^+$	C.R.$^+$
Fig.2-a-s	6.54	3.23	19%	7.83	3.34	20%	42%
Fig.2-b-s	7.13	3.27	33%	8.56	3.11	36%	60%
Fig.2-c-s	7.62	2.72	11%	9.79	2.78	13%	43%
Fig.2-d-s	4.76	3.61	21%	5.47	3.72	22%	39%

5. Conclusions

In this paper, we present a new method for improving JPEG algorithm for the application of remote sensing. It consists of a different quantization table from the recommended one and the incorporation of cloud detection and smoothing. The results from four test images presented show up to 60% compression ratio improvement, depending on the amount of cloud presented in the image and the image context, at the same level of reconstruction quality as that obtained by the traditional JPEG scheme .

6. References

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