PROGRESSIVE CODING OF SATELLITE IMAGES WITH REGIONS OF INTEREST

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ABSTRACT

This paper proposes a selective compression scheme to enhance the quality of regions of interest and by saving coding resources on irrelevant parts of satellite images. It is based on region of interest (ROI) coding methods and on the Consultative Committee for Space Data System (CSSDS) recommendation for image data compression (IDC). Two ROI coding methods have been integrated to the CCSDS-IDC algorithm: the maxshift and the scaling methods. This paper motivates the choice of these methods and explains the modifications required to adapt the CCSDS-IDC algorithm. Finally results are given for the compression of Earth observation images on which clouds are considered irrelevant.

INTRODUCTION

Although 80% of SPOT 5 images contain clouds, the information about clouds is irrelevant in these images since, like many other optical Earth observation satellite, the main mission of SPOT 5 satellite is the Earth ground observation. However in current on-board compression algorithms pixels of clouds are processed as any other pixels of the image and are transmitted with the same quality and bit rate. This results in a waste of data rate which could have been used either to enhance the quality of the relevant part of the transmitted image (thanks to progressive coding) or to transmit more images. The goal of selective image coding is to avoid this waste by on-board cloud detection [1] and ROI coding techniques. This paper focuses on this second point: the implementation of ROI coding techniques in an algorithm derived of the CCSDS 122 recommendation [2].

Two ROI methods have been implemented : the maxshift and the scaling methods. First, we shall motivate the choice of these ROI methods and detail both methods. As the implemented algorithm does not comply with the CCSDS 122 recommendation, the modifications required to add ROI coding features to the algorithm will be developed in the next section. Finally, the proposed coding scheme will be evaluated by comparing rate-distortion curves obtained by the compression of several Quickbird satellite images with the ROI methods and the original CCSDS-IDC coder.

SELECTION OF THE ROI CODING METHODS

Several methods have been described in the literature in order to encode images with ROI. The general principle is to transmit more information on the ROI than on the background. These methods can be classified into for groups: region based coding methods, implicit ROI coding methods, scaling methods and bit-plane ordering methods.

Three characteristics were defined for the selection of the ROI coding methods: 1) the possibility to define regions with a fine delineation, 2) the compliance of the ROI method with a progressive coding of the image; 3) the possibility to adapt the CCSDS-IDC algorithm to the ROI coding method without huge modifications.

Region based coding methods are used to encode only the ROI in the image. These methods are generally used for object oriented video coding or for medical image coding. They employ of a modified version of the wavelet transform called the SA-DWT (Shape Adaptive Discrete Wavelet Transform) [5]. These methods are not studied here because they

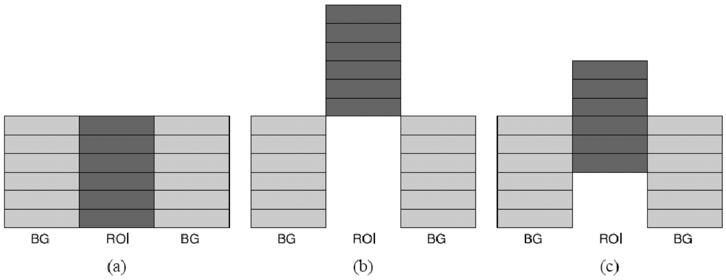

Fig. 1. Representation of bit-planes in the ROI and in the background (BG).
(a) Original wavelet transform, (b) Maxshift method, (c) Scaling method

would require a new implementation of the wavelet transform in the CCSDS-IDC and do not allow to transmit any information about the background region of the image.

Implicit ROI coding methods are implicit in the sense that the information on the ROI is not explicitly sent to the decoder. These methods are specific of JPEG2000. They consist in organizing the bit stream so that the encoded data packets which correspond to code-blocks in the ROI are sent and decoded before the other packets of the bit stream [6]. The advantages of this method over those described in the following are that the dynamic of the encoded wavelet coefficients is not changed. Moreover, when the image is fully transmitted, the implicit ROI coding method do not affect the global performance of the compression since no bit-plane is added to the wavelet transform [7]. However, the spatial precision of the ROI is limited to the size of the code-blocks modulo the resolution of the subband to which they belong. Implicit ROI coding methods cannot be applied to the CCSDS-IDC algorithm since the notions of packets and quality layers are not defined in this algorithm.

The scaling method by multiplication can be applied to any progressive bit-plane coder. It consists in multiplying the values of the wavelet coefficients belonging to the ROI by a scaling factor greater than 1. The scaling factor can be adjusted to give more or less importance to the ROI. Once the values of the wavelet coefficients belonging to the ROI have been multiplied by the scaling factor, the bit-plane encoding is performed. ROI coefficients are thus found significant in bit-planes higher than those of the background coefficients. As the progressive transmission is performed from the most significant bit-plane toward the least significant bit-planes, more information is sent about the ROI coefficients than about the background at the beginning of the transmission. One drawback of the scaling method is that the ROI mask must be explicitly transmitted to the decoder before it can reconstruct the image. At the decoder side, when the ROI mask has been received, ROI wavelet coefficient values are divided by the scaling factor. Then the inverse wavelet transform is computed to reconstruct the image. If the bit stream is not fully transmitted, ROI are reconstructed with greater quality than the background.

As the scaling methods, the bit-plane ordering methods can be applied to any progressive bit-plane coder. The most popular of these methods are the maxshift method and the scaling method by bit shifts. They are both included in JPEG2000 Part 2 [9]. In this standard, if the scaling method is used, ROI shapes are limited to be rectangular or elliptic so that the ROI mask transmission is resumed to the transmission of the parameters of these shapes. After the wavelet transform, the maxshift method operates by up-shifting all the ROI bit-planes above the most significant bit-plane of the background region as illustrated by Fig. 1. The scaling method operates by up-shifting the ROI bit-planes by an arbitrary number of shifts not necessarily greater than the most significant bit-plane. As the coding process stops before it reaches the least significant bit-plane, up-shifted ROI wavelet coefficients are coded with greater accuracy than the background coefficients. As a result, ROI are transmitted with better quality than the background region. Other more sophisticated bit-plane ordering methods, such as the bit-plane by bit-plane shift [10], are derived of the maxshift and scaling methods. However, in this study we chose to focus on the most standard ROI methods for a preliminary performance assessment on Earth observation images with clouds.

The maxshift method and the scaling methods by bit shifts and by multiplication respect the constraint of progressive coding and fine regions delineation and the CCSDS-IDC algorithm can be adapted to these methods. They have thus been chosen to be implemented in a modified version of the CCSDS-IDC algorithm.

ROI CODING WITH THE CCSDS-IDC ALGORITHM

In this section, we explain how to locate the wavelet coefficients needed to reconstruct the ROI. This is achieve through the generation of a wavelet ROI mask from the image ROI mask. These wavelet coefficients are modified by the ROI

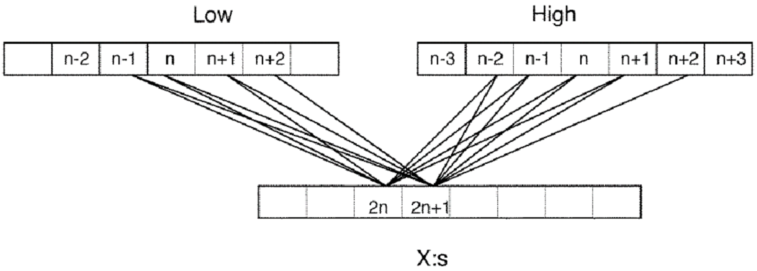

Fig. 2. Wavelet coefficients needed to reconstruct of the coefficients X(2n) and X(2n+1) with the 9/7 synthesis filters

Fig. 3. Example of ROI mask.
53.3% of the pixels are in the ROI

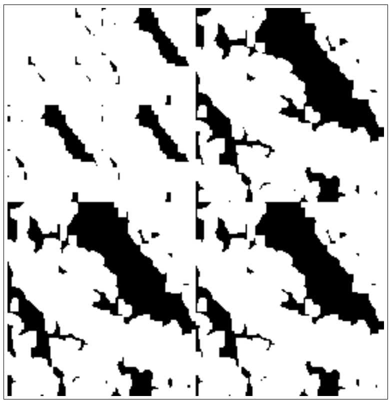

Fig. 4. The corresponding ROI wavelet mask.
76.5% of the wavelet coefficients are in the ROI

methods (multiplied by the scaling factor or bit shifted). Then, we mention the modifications made to the CCSDS-IDC algorithm that were needed to encode these modified wavelet coefficients. Finally, we describe how the decoder is able to determine the region to which a wavelet coefficient belong when the maxshift method is employed the since the ROI mask is not sent to the decoder.

ROI wavelet mask generation

The same method as the one defined in JPEG2000 Part1 [8] is applied to generate the ROI wavelet mask. The ROI wavelet mask is computed like the wavelet transform row by row, column by column and scale by scale. The ROI wavelet mask generation process follows the steps of the inverse wavelet transform in the inverse order. At each steps, it indicates the wavelet coefficients needed to create the wavelet coefficients of the next step. The scheme represented on Fig. 2 shows that the coefficients needed to reconstruct the coefficients X(2n) et X(2n+1) are the coefficients L(n-1) to L(n+2) and H(n-2) to H(n+2). This scheme is the same for the 9/7 synthesis wavelet filters of the CCSDS-IDC and JPEG2000. Fig. 3 and Fig. 4 illustrate one ROI mask and the corresponding ROI wavelet mask. On such scattered ROI shapes, it can be noted that the proportion of wavelet coefficients in the ROI is greater than the proportion of pixels in the ROI.

In our implementation within a modified version of the CCSDS-IDC algorithm, we set all the wavelet coefficients of the LL_3 subband in the ROI. Indeed, many experiments have shown that this allows to keep a better quality on the background without reducing the compression performance on the ROI.

Bit plane Encoder Modifications

In the CCSDS-IDC, after the wavelet transform, the Bit Plane Encoder (BPE) encodes the wavelet coefficients from the most significant bit-plane to the least significant bit-plane and produces an embedded bit stream [3]. The BPE has been modified to support ROI coding with the maxshift, the scaling method by bit shifts and the scaling method by multiplication.

First, a dynamic excess management is required. Indeed, the ROI methods increase the dynamic of wavelet coefficients. As the BPE can only encode wavelet coefficients up to a dynamic of 31 bits, dynamic excesses often appear. This problem has been solved by discarding the least significant bit-planes of the wavelet coefficients when a dynamic excess occurs. Then, the drawback is that the background can not be decoded without loss.

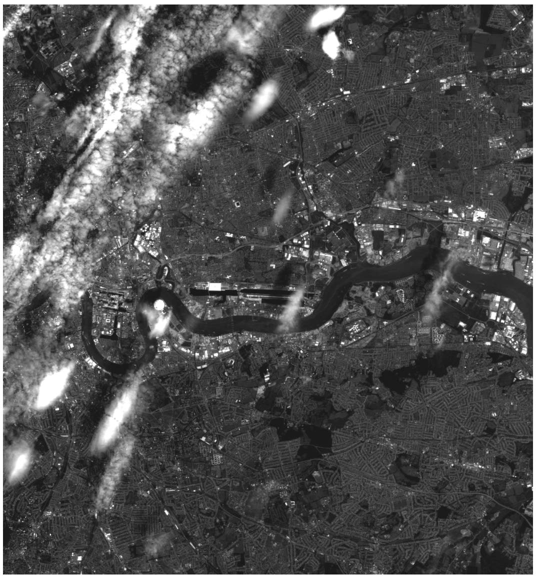

Fig. 5: Blue component of a Quickbird image of London of size 860x927

Fig. 6. Cloud mask for the image of London. Clouds represent 14 % of the image. The ROI is the white region

A header has also been added to each segment of the wavelet transform encoded by the BPE so as to transmit the ROI parameters. These parameters are the presence of ROI in the segment, the ROI method applied, the number of bit shifts or the scaling factor.

Other technical modifications have been made to the BPE. The goal of these modifications is to avoid encoding bits added by the shifts below the wavelet coefficients belonging to the ROI. Moreover, modifications have also been made so as to avoid encoding the bits added above the wavelet coefficients which belong to the background when the scaling method by bit shift is employed. This is possible since the decoder knows the ROI mask.

How the Decoder Determines the Region to Which a Wavelet Coefficient Belongs

After transmission of the compressed bit stream, the decoder needs to determine the region to which belongs each wavelet coefficient. This is required so as to apply the correct inverse ROI method to the decoded wavelet coefficients: down shifts in the cases of the maxshift method and the scaling method by bit shift, and division by the scaling factor in the case of the scaling method by multiplication.

This determination is not a problem in the cases of the scaling methods since the ROI mask is explicitly transmitted to the decoder. This is not the case with the maxshift method. The decoder has to recover the ROI mask by the information sent within the wavelet coefficients.

The decoder proceed this way. For each wavelet coefficient, while no bit value 1 as been decoded (the coefficient is in the not significant state), it is not possible to determine the region to which it belongs. By default, it belongs to the background region. As this coefficient value is 0, bit shifts have no impact on its value. As soon as the first bit 1 is decoded for this coefficient (it enter in the significant state), the decoder can determine the region to which it belongs: if this bit 1 has been decoded in bit-planes greater than the bit shifts applied at the compression side, the coefficient belongs to the ROI. Otherwise it belongs to the background. The ROI mask is thus implicitly transmitted with the wavelet coefficients when the maxshift method is used.

PERFORMANCE EVALUATION

A performance evaluation is performed on the blue component of the image of London presented on Fig. 5. This is a Quickbird image with a dynamic of 11 bits. The cloud mask associated to this image is presented on Fig. 6. In the following performance evaluation, clouds represent the background while the remaining of the image represents the ROI.

Tab. 1. Quality comparison for the compression of the image of London at 2.2 bpp with the CCSDS-IDC and with the maxshift method and the modified BPE

		PSNR (dB)		
Method	**Bit rate (bpp)**	**Background**	**ROI**	**Entire image**
CCSDS-IDC	2.2	50.18	49.55	49.63
Maxshift	2.2	39.74	50.21	46.34

Tab. 2. Bit rates comparison to obtain a PSNR of 50 dB on the ROI with the CCSDS-IDC, the maxshift method and the scaling method

		PSNR (dB)		
Method	**Bit rate (bpp)**	**Background**	**ROI**	**Entire image**
CCSDS-IDC	2.29	50.8	50.0	50.1
Maxshift	2.16	39.7	50.0	46.3
Scaling of 4 bits	2.16	41.1	50.0	47.1

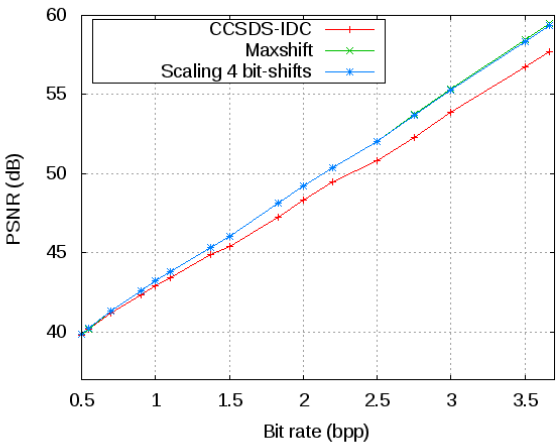

Fig. 7. PSNR on the ROI as a function of the bit rate for the different coding schemes

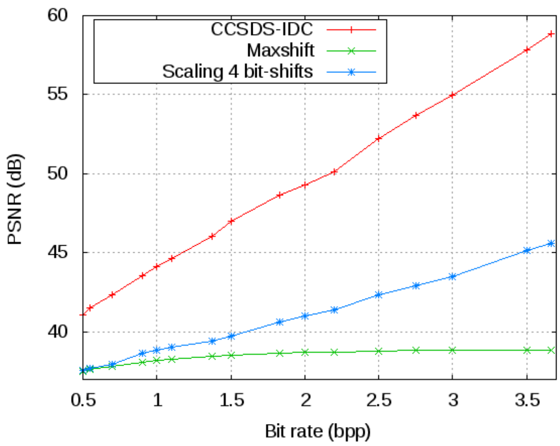

Fig. 8. PSNR on the background as a function of the bit rate for the different coding schemes

Compression Results comparison

The image of London is compressed at 2.2 bpp. This correspond to a compression ratio of 5. Reference performances reported in the first line of Tab. 1 have been obtained with the CCSDS-IDC algorithm. The quality on the clouds (the backgound) is greater than the quality on the rest of the image. Performance obtained with the maxshift method and the modified BPE are reported in reported in the second line of Tab. 1. The quality on clouds is reduced. However, although the ROI forms 86% of the image, the PSNR on the ROI is increased of 0,6512 dB.

Tab. 2 presents the compression results with the CCSDS-IDC, the maxshift method and the scaling method with 4 bit shifts to obtain a PSNR of 50 dB on the ROI of the image of London. In each case, the bit rate is adjusted by dichotomy. Without ROI coding in the CCSDS-IDC algorithm, a bit rate of 2.29 bpp is needed to obtain a quality of 50 dB on the ROI region. With the maxshift and the scaling methods, a PSNR of 50 dB is obtained on the ROI at a bit rate of 2.16 bpp. Thus, the ROI methods and the modified BPE allow to save 0.13 bpp. This correspond to 5.8% of the total bit rate. Note that the background (the clouds) represent only 14% of the image compressed here and only 9.1% percent of the wavelet coefficients in the ROI wavelet mask.

The scaling method allows to obtain the same quality on the ROI as the maxshift method at the same bit rate. Moreover,

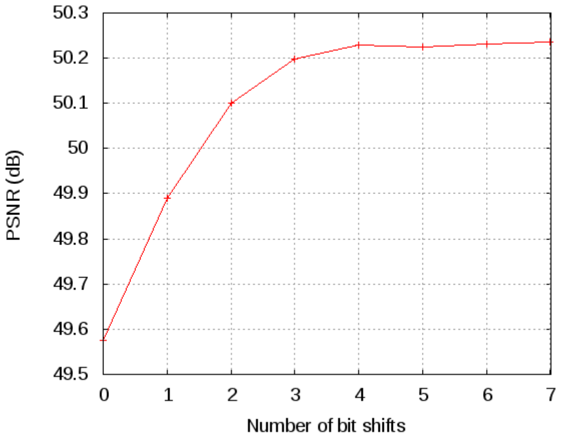

Fig. 10. Impact of the number of bit shifts with the scaling method at a fix bit rate of 2.2 bpp

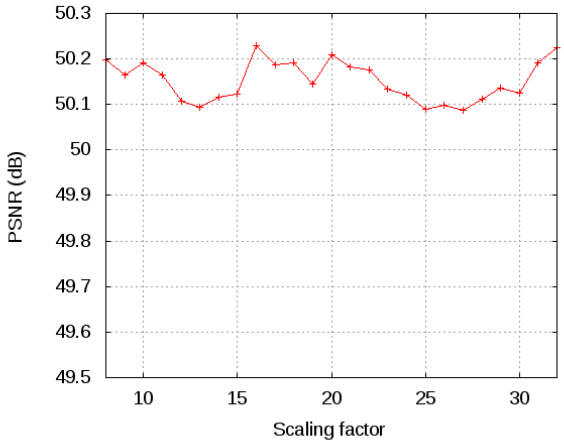

Fig. 9. Impact of the scaling factor on the performance at a bit rate of 2.2 bpp

the scaling method allows to have a better quality of the background. However, the bit rate needed to transmit the ROI mask to the decoder is not taken into account in the presented results. A test with a simple RLE shows that the transmission of the ROI mask requires 0.13 bpp. The benefit of the scaling method would thus be lost in this case.

Fig. 7 and Fig. 8 present the PSNR obtained with the different methods respectively on the ROI and on the background. These PSNR have been computed for the compression of the image of London to bit rates between 0.55 bpp and 3.67 bpp. They correspond to compression ratio between 20 and 3. The additional bit rate needed with the scaling method for the transmission of the ROI mask is not taking into account in the presented results. The maxshift and the scaling methods perform equivalently on the ROI at all bit rates. However, in the case of the scaling method, the quality of the background slowly increases with the bit rate. In the case of the maxshift method, the quality of the background stay below 40 db. Indeed, with the scaling method, bit planes of wavelet coefficients of the background can only be transmitted when all the bit planes of the wavelet coefficients of the ROI has been transmitted. This is not the case for a bit rate below 3.67 bpp.

The ROI methods have been applied to other Earth observation images. On an image with 46.6% of scatter clouds, only 23.5% of the wavelet coefficients are in the background after the computation of the ROI wavelet mask (see the mask in Fig. 3 and Fig. 4). The maxshift method applied for the compression of the ROI in this image allow to save 12.9% of the bit rate at 2 bpp. Other experiments have been conducted with a compact ROI representing 36.2% of the pixels an a background representing 63.8% of the pixels of an image. They have shown that the proportion of the wavelet coefficients in the background is 61.8%. For a quality of 50 dB on the ROI, the bit rate has been reduced of 58% with the maxshift method and of 44% with the scaling method.

Impact of the Scaling Factor on the Scaling Methods Performance

PSNR results with the scaling method and different numbers of bit shifts are plotted on Fig. 10. These results have been obtained on the ROI of the image of London compressed at 2.2 bpp. Four bit shifts are sufficient to obtain results close to the best achievable on the ROI. That is why scaling of 4 bits have been used in the results presented in the previous section.

PSNR results obtained with the scaling method by multiplication are presented on Fig. 9. Results have been plotted for scaling factors varying from 8 to 32. Difference up to 0.15 dB in PSNR can be obtained by changing the scaling factor but it can be observed that the best results are obtained for scaling factor value equal to powers of two. In these case, the scaling method is performed by bit shifts. It is thus recommended to use scaling method by bit shifts rather than the scaling method by multiplication.

Complexity Comparisons

The compression time of the ROI methods have been evaluated from 1.4 times (at 3.5 bpp) to 1.6 times (at 0.5 bpp) the compression time of the CCSDS-IDC. This difference is mainly due to the computation of the ROI wavelet mask (about 55% of the additional time). Other contributors are the bit shifts computation (analysis of the dynamic excess) and application (about 15% of the additional time) and the modifications made to the BPE (about 30%).

CONCLUSIONS

Maxshift and scaling ROI methods have been integrated to a modified version of the CCSDS-IDC. They allow to enhance the compression performance on predefined region of interest in the image. It has been shown that the scaling method by bit shifts should be preferred to the scaling method by multiplication. At a fix bit rate, these methods enhance the quality on the ROI. At a given quality on the ROI, they can save bit rate. Applied on satellite Earth observation images with clouds, it has been shown that the maxshift method saves 5.8% of the total bit rate for the compression of an image with only 14% of cloud pixels or 12.9% of the total bit rate for the compression of an image with 46.6% of scatter clouds pixels. Better performances can be obtained on image with compact ROI.

Although is allows to control the quality between the ROI and the background, the scaling method requires the explicit transmission of the ROI mask to the decoder. The additional bit rate generated can cancel the benefit of this ROI method. Solutions to this problem could be the use of efficients specialized coders such as the one proposed in [11]. An other solution is to down-sample the ROI mask. But then, the ROI could suffer from loss of quality on the borders. A third solution is to use another ROI method such as the bit-plane by bit-plane shift method proposed in [10] which do not require the ROI mask transmission.

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