COMPRESSION SPECIFICATION FOR EFFICIENT USE OF HIGH RESOLUTION SATELLITE DATA

Emmanuel Christophe, Carole Thiebaut and Christophe Latry

CNES DCT/SI/AP Bpi 1219
18 av E. Belin, 31401 Toulouse Cedex 09
{emmanuel.christophe, carole.thiebaut, christophe.latry}@cnes.fr

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ABSTRACT:

For an efficient usage and distribution of high resolution satellite images, several problems need to be solved. The issue comes with the increasing size of these data. Constraints are different than those of the on-board compression, thus different solutions can be selected. For on-board compression, the main constraints are the computational complexity and the rate attainable with qualified space equipments. For on-the-ground compression, computational constraints are not so strong, but particular care is needed to make sure that the chosen format is widely spread and that users will be able to exploit these data easily.

1 INTRODUCTION

For an efficient usage and distribution of high resolution satellite images, several problems need to be solved. The issue comes with the increasing size of these data. A standard scene from the Pleiades satellite, the coming optical high resolution satellite from CNES, will typically represent 14 GB of data (more 40000×40000 pixels in 4 spectral bands on 16 bits). The difficulties with such data do not occur only in the distribution process, but also in the processing steps, data selections, quality assessment.

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2 SATELLITE DATA SPECIFICITIES

Most of popular compression formats cannot be used for satellite data which often reach their limits. The first problem is the size of the data: already often reaching 30000 pixels per dimension, it is easy to foresee products exceeding 2^{16} pixels. The second problem is the dynamic range of the values: instead of the more common 8 bits, these data are often coded on 12 bits to be able to cover the wide dynamic range of observed scenes. Finally, these data often comprise at least four spectral bands while most compression formats target the typical color images with three components (Fig. 1).

The JPEG 2000 standard was designed to answer these limitations (Taubman and Marcellin, 2002). The facts that this is a well accepted standard and that it is starting to be widely available through numerous and well performing implementations make it a good candidate for satellite data distribution. However, this standard comprises many options and not all are adapted for high resolution satellite images. Thus, it is necessary to explore these possibilities to find the right combination ensuring an efficient access for the end-user with a limited complexity.

3 END-USERS REQUIREMENTS

End-users need the access to derived products from the satellite image. For a question of cost or efficiency, the high resolution is often not required on the full scene. One of the most valuable product is the high resolution on a specific area (city, disaster area,...) and a lower resolution around to give a precise idea of the context of the scene. Ideally, this higher resolution information should be available on-demand according to the user's decision on the lower resolution level.

Fast and multiresolution data access is also necessary. When visualized at full resolution, one scene represents more that 700 computer screens. In these conditions, finding the valuable information is like looking for a needle in a haystack.

This multiresolution feature is also very valuable for the steps of data quality assessment. For example, the full resolution is not necessary when establishing the cloud coverage notation.

Another strong requirement is the possibility to include complex metadata directly on the compressed streams. Apart from the essential localization information, additional data corresponding to some data extraction results (classification, road extraction, clouds mask...) or coming from vectorized map should be available in the images.

In some situations, fast access to the data is critical. For example, when the image is to be used in the context of a crisis (hurricane, tsunami, flooding, earthquake) to help to organize the rescue, it is inconceivable to waste precious hours in inefficient data transfer.

New data distribution schemes can also arise from advanced data structures. For example, the full product could be delivered on a DVD with part of it encrypted. Unlocking the full product would consist in buying the key from the data provider which results in a near instantaneous transaction. The main advantage is that the low resolution data can be delivered for a very reasonable price and the full resolution with a very short delay according to the image processing requirements.

(a) Singapore (8192 × 8192) (b) Switzerland (1000 × 1000)

Figure 1: Quickbird data used for simulations, original Pan and Xs images are orthorectified and fusioned

4 JPEG 2000 OPTIONS AND SIMULATIONS

4.1 Intercomponent transform

One of the most critical options for efficient use of the JPEG 2000 standard on high resolution satellite image resides in the multicomponent transform. The part 1 of the standard only makes provision for the three bands color transform. In part 2, it becomes possible to specify an ad-hoc transform. Using a specific transform with fixed coefficients computed on a set of images (Thiebaut et al., 2007).

Spectral bands of high resolution satellite images present a strong correlation. This is particularly the case after the PAN-sharpening step. Thus, it is important to decorrelate these images before compressing them. After the intercomponent transform, images B'_0, B'_1, B'_2 and B'_3 are compressed with JPEG 2000 and the rate allocation is common to all the transformed bands. Three different situations of reasonable complexity are studied:

- No intercomponent transform to keep the compatibility with part I of JPEG 2000 standard.

$$\begin{pmatrix} B_0 \\ B_1 \\ B_2 \\ B_3 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} B'_0 \\ B'_1 \\ B'_2 \\ B'_3 \end{pmatrix} \quad (1)$$

- A YCbCr transform on the first three band and no transform for the fourth one.

$$\begin{pmatrix} B_0 \\ B_1 \\ B_2 \\ B_3 \end{pmatrix} = \begin{pmatrix} 1 & 1.772 & 0 & 0 \\ 1 & -0.344136 & -0.714136 & 0 \\ 1 & 0 & 1.402 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} Y \\ C_b \\ C_r \\ B_3 \end{pmatrix} \quad (2)$$

- A transformation by an average Karhunen-Loeve (KLT) obtain on a big image data set with similar spectral characteristics (sensor dependant) (Thiebaut et al., 2007):

$$\begin{pmatrix} B_0 \\ B_1 \\ B_2 \\ B_3 \end{pmatrix} = \begin{pmatrix} 0.32418259 & -0.3069099 \\ 0.58451217 & -0.38087386 \\ 0.52300888 & -0.23381439 \\ 0.52887922 & 0.84028111 \end{pmatrix} \quad (3)$$

$$\begin{pmatrix} -0.59952748 & 0.66428901 \\ -0.2377866 & -0.67582405 \\ 0.75526749 & 0.31837578 \\ -0.11659861 & 0.02488911 \end{pmatrix} \begin{pmatrix} B'_0 \\ B'_1 \\ B'_2 \\ B'_3 \end{pmatrix} \quad (4)$$

Fig. 2(a) and 2(b) show that using the part 2 extension enables a gain of 5 to 8 dB PSNR.

4.2 Vector data

Using the Geographic Markup Language (GML) standard (GML in JPEG 2000 for Geographic Imagery (GMLJP2) Encoding Specification, 2006), JPEG 2000 is able to handle complex metadata directly in the compressed stream. This is an advantage as complex product can be presented in a simple way.

The GML standard defined by the Open Geospatial Consortium (OGC) can modelize, carry and save geographical data in the XML format. This standard can describe:

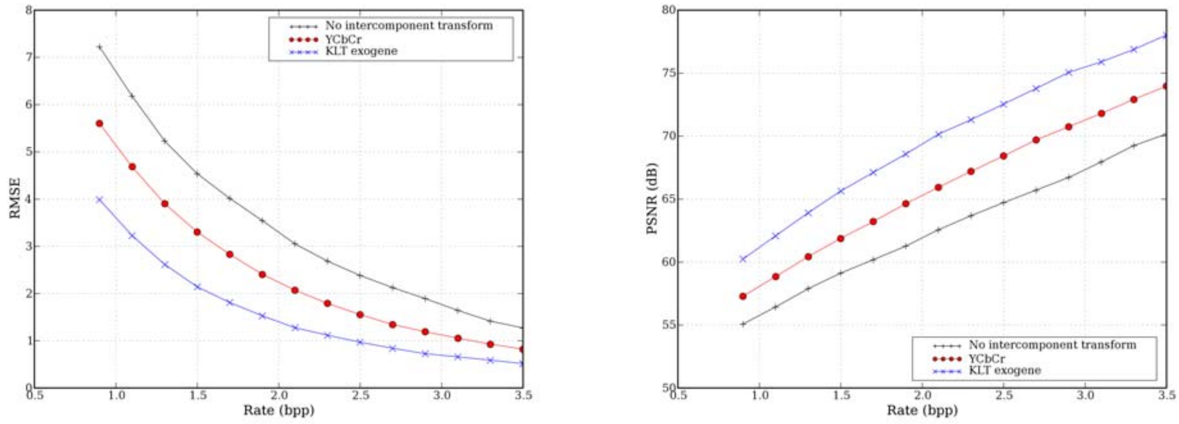
- geographical objects
- projection systems
- geometry
- topology
- time
- measurement units
- attributes of geographical objects.

Thus, the GML standard is well adapted to carry auxiliary data with a satellite image. Information can be: clouds mask, road extraction result, segmentation result (eventually obtained by the data provider with external information), region of interest descriptions…

4.3 Data organization

In JPEG 2000, several possibilities are available to structure the data organization. Several progression orders are available with JPEG 2000. They are denoted with the letters LRCP: L being the quality Layer, R the Resolution, C the Component and P the Partition of the image. Order of the letter indicates the organization of the different property progression. The default order LRCP is illustrated on Fig. 3.

The five available progression orders are:



(a) (b)

Figure 2: Performances comparisons according to the intercomponent transform. Using a precomputed KLT on huge set of similar data enables a bitrate gain of a factor of 1.75 to 2.

- LRCP: progressive quality on the whole image;
- RLCP: progressive resolution on the whole image;
- RPCL: progressive resolution with a more localized access;
- PCRL: fast random acces on the image;
- CPRL: fast random access by component.

The five progression order are compared in term of speed access and quicklook generation. On Fig. 4, the quicklook generation time is detailled for different progression order. Differences between progression remains small as the access was on hard drive which are quite efficient for random access. Differences are expected to be much bigger when data are accessed through a network.

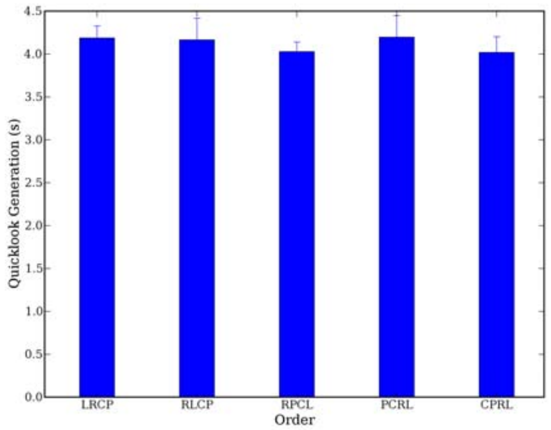


Figure 4: Quicklook generation time for a compressed Quickbird image of size 27504×26636. The quicklook correspond to a reduction in pixel number by 32 in each direction.

4.4 Visualization session

The interest of using compressed data is also studied in the situation of normal data visualization. A typical visualization session with ENVI is simulated and it appears that using directly compressed data enables a gain of 20 in time. Results are presented in Fig. 5. The increase in computational complexity for the decompression is more than balanced by the reduced data transfer required from the disk. This advantage of compressed data would be even stronger in the case of distant usage of data through a network.

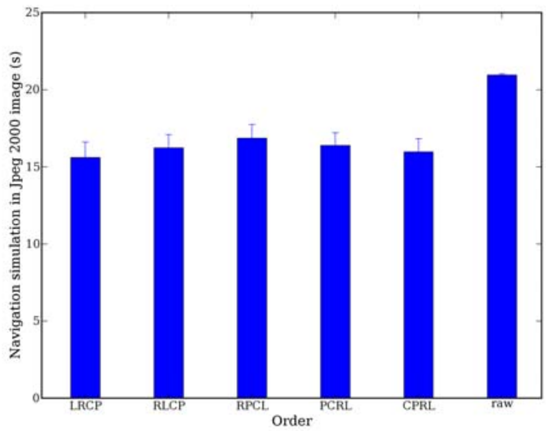


Figure 5: Simulation of navigation session in a JPEG 2000 image with random access. Despite the computational cost of the decompression, it is still faster to work directly with compressed data (disk access is reduced).

4.5 Tiling impact

Tiling is an important concept to ease memory constraints at the compression and decompression steps. For such images, where holding the whole image into memory is out of question, tiling is mandatory. The impact of tiling on visual quality is explored for the common rates. Three different tile sizes are compared on Fig. 6(a) and 6(b): 8192×8192, 4096×4096 and 1024×1024. Using smaller tiles enables a reduction in memory requirements without a loss in image quality. A block effect could arise for low bitrate but above 0.5 bpp these are not visible.

5 A NEW COMPRESSION PARADIGM

With these end-users requirements in mind, this study leads to perceive the compression in a new way. The main purpose is not to use less space or to reduce transfer delays any more, but to organize the valuable information differently. The multiresolution structure on the new compression standards enables the fast an efficient generation of low resolution products for a limited complexity. This new vision of compression advantages should lead to an increase use of compression directly within image processing algorithms.

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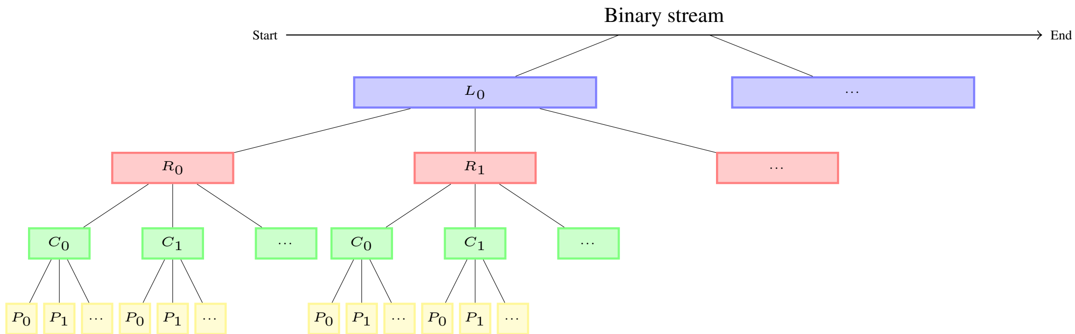
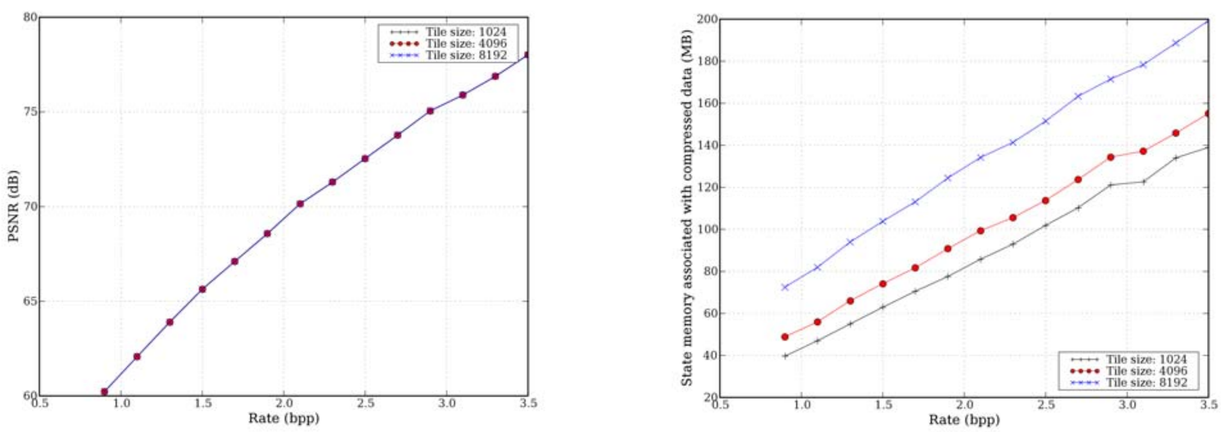


Figure 3: Example of bitstream organization for the LRCP order. To obtain the first quality layer, one just has to read the beginning of the bitstream. However, to decode only one resolution level (R_0 for example), or just a specific area of the image (P_1 for example), the decoder have to retrieve information in different part of the bitstream.



(a) Quality

(b) Memory

Figure 6: Impact of tile sizes on quality is neglectable (for realistic values). On the oposite, using tiles can greatly reduce the required memory for processing.