Chapter 2
CNES Studies for On-Board Compression of High-Resolution Satellite Images

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Abstract Future high resolution instruments planned by CNES for space remote sensing missions will lead to higher bit rates because of the increase in resolution and dynamic range. For example, the ground resolution improvement induces a data rate multiplied by 8 from SPOT4 to SPOT5 and by 28 to PLEIADES-HR. Lossy data compression with low complexity algorithms is then needed while compression ratio must considerably rise. New image compression algorithms have been used to increase their compression performance while complying with image quality requirements from the community of users and experts. Thus, DPCM algorithm used on-board SPOT4 was replaced by a DCT-based compressor on-board SPOT5. Recent compression algorithms such as PLEIADES-HR one use wavelet-transforms and bit-plane encoders. But future compressors will have to be more powerful to reach higher compression ratios. New transforms have been studied by CNES to exceed the DWT but other techniques as selective compression are required in order to obtain a significant performance gap. This chapter gives an overview of CNES past, present and future studies of on-board compression algorithms for high-resolution images.

1 Introduction

The French Space Agency (Centre National d'Etudes Spatiales – CNES) is in charge of the conception, development and operation of satellites. For more than 20 years, optical Earth observation missions have been one of its specialities. Indeed, since 1986, CNES has launched several Earth observation satellites with gradual improvement of the spatial resolution. The SPOT family is a good example of this progress: SPOT1/2/3/4 launched from 1986 to 1998 had a spatial resolution of 10 m and

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Fig. 2.1 SPOT5 (*left hand side*) and PLEIADES-HR (*right hand side*) images of a famous place in Toulouse. SPOT5 image resolution is 2.5 m and PLEIADES-HR one is 0.7 m

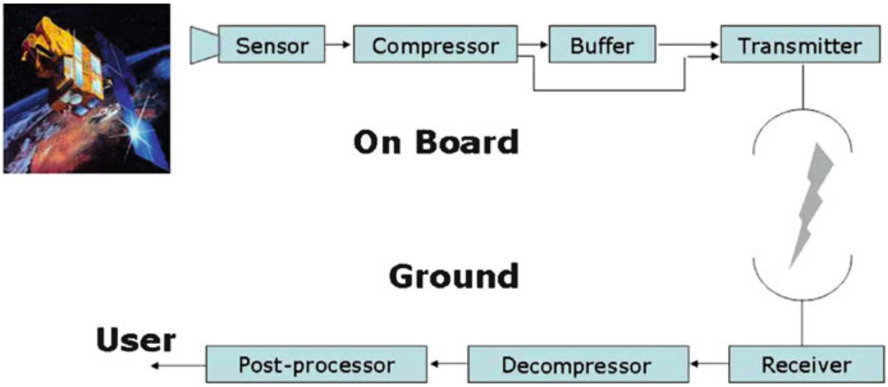

Fig. 2.2 On-board to ground image channel

SPOT5 launched in 2002 had a resolution of 5 m for the panchromatic band (HRG instrument) with an unchanged swath of 60 km [1]. Moreover, the THR mode of SPOT5 could produce images of 2.5 m thanks to a quincunx sampling. With the very agile satellite PLEIADES-HR, CNES is going further with a panchromatic band at 70 cm and a swath reduced to 20 km [2]. This spatial resolution improvement from 10 m to 0.7 m (see Fig. 2.1) induces a natural increase of data rate. Simultaneously, transmission bit rate of telemetry has not increased in the same order of magnitude. For example, for SPOT1-4, only one channel of 50 Mbits/s was used. Two such channels are used for SPOT5.

For PLEIADES-HR, each one of the three telemetry channels will have a capacity of 155 Mbits/s. This limitation combined with the growth of instrument data rate leads to an increasing need in compression. As shown on the on-board to ground image channel depicted in Fig. 2.2, on-board compression is useful to reduce the amount of data stored in the mass-memory and transmitted to the ground. On-board compression algorithms studied and implemented by CNES have been adapted to the user's constraints in terms of image quality while using performing tools available in the image processing domain. High-resolution Earth observation images have very strong constraints in terms of image quality as described in [3]. Requirements such as perfect image quality are asked whatever the landscape viewed by satellite. Furthermore, the on-board implementation issue is also a big challenge to deal with. Fortunately, highly integrated circuits (ASIC technology) make possible the implementation of high bit-rate functions such as image compression. Indeed, high-resolution missions have very high instrument bit-rate (128 Mbits/s for SPOT5, 4.3 Gbits/s for PLEIADES–HR) which makes impossible the implementation of software compression units. The hardware circuits available for space applications have lower performances than ground-based ones which prevent the chosen algorithms to have comparable performances. This chapter gives an overview of CNES studies in terms of development of image compression algorithms for high-resolution satellites. Section 2.2 gives a brief overview of implemented compressors since 1980s up to current developments. Section 2.3 illustrates present and future of on-board compression domain. New spatial decorrelators are also described and the principle of selective compression is introduced. Authors explain why and how this type of techniques could lead to higher compression ratios. Section 2.4 is a conclusion of this overview.

2 On-Board Compression Algorithms: History and Current Status

2.1 *First Compressors*

In 1986, a 1D-DPCM (Differential Pulse Code Modulation) with fixed length coding was implemented on-board SPOT1. The same algorithm was used up to SPOT4. As shown in Fig. 2.3, it provided a low compression ratio equal to 1.33. Every three pixels, one complete pixel was transmitted (on 8-bits) and the two following values were predicted as the mean value of the previously coded and

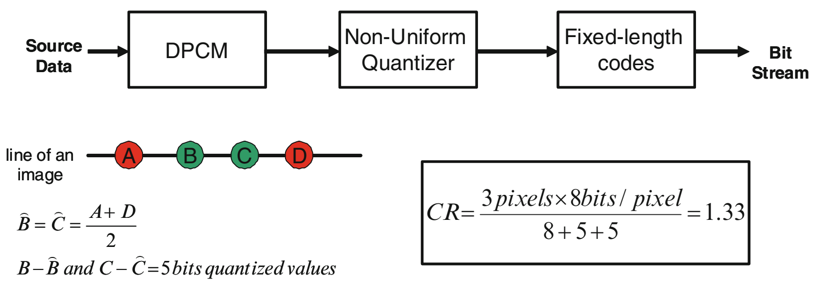

Fig. 2.3 SPOT1-4 compression scheme and its resulting compression ratio

Fig. 2.4 SPOT5 satellite and its compression unit

the next one. Errors between prediction and real values for those pixels were non-uniformly quantized and coded on 5 bits. This simple algorithm had a complexity of three operations per pixel which was compatible to the very poor space qualified electronics of that time.

Shortly after, studies on the Discrete Cosine Transform (DCT) started, first with a fixed length coding (used on Phobos missions) and an off-line software implementation. Then, in 1990, with the development of a compression module using a DCT and a variable length encoder with space qualified components [4]. The throughput of this module was 4 Mpixels/s and the compression ratio was adjustable between 4 and 16. This module – called MCI for Module de Compression d'Image (Image Compression Module) – was used for several exploration missions (CLEMENTINE Lunar Mission, Mars 94/96 Probes, Cassini Probe . . .). Since this module did not specifically target Earth observation missions, another algorithm was developed for SPOT5 satellite images.

2.2 DCT-Based Compressor

SPOT5 algorithm introduced a DCT with a uniform scalar quantizer and a variable length coding (JPEG-like coding stage). Moreover, an external rate allocation procedure was implemented because fixed-rate bit-streams were required. The rate regulation loop was adapted to push-broom scanned data. It computed the complexity criteria over a line of blocks (8 lines high by 12,000 pixels) which gave an optimal quantization factor for each line of blocks using rate-prediction parameters [3]. After iteration with the user's community, a compression ratio was decided. This ratio is equal to 2.81 and is associated with a very good image quality both around block boundaries and in the homogeneous regions. The compression unit and SPOT5 satellite are shown in Fig. 2.4.

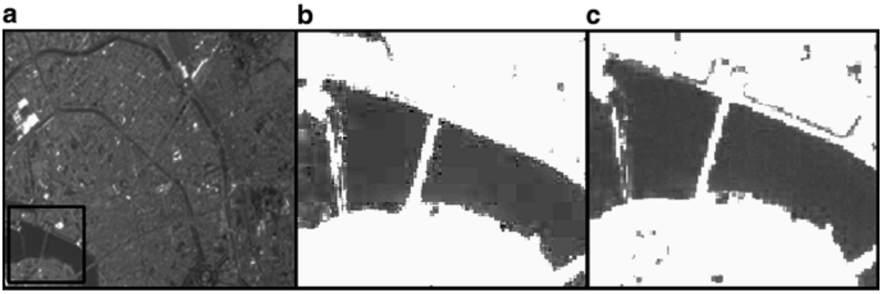

Fig. 2.5 (**a**) SPOT5 image of Toulouse (5 m). (**b**) Zoom before exceptional processing. (**c**) Zoom after exceptional processing

Nevertheless, a so-called "exceptional processing" was performed for some blocks presenting poor image quality compared to the whole line of blocks. These blocks are low-energy areas which are too much quantized compared to the mean complexity of the line of blocks. According to the number of DCT-transformed AC coefficients, the quantization step could be divided by 2 or 4 for those blocks [3]. Due to the very local characteristic of the modification (3.4% of exceptional blocks in average), the algorithm's behavior is not perturbed and the rate regulation remains stable. The proposed modification leads to a slight increase of the quantization factor and a negligible rise in average RMSE (Root Mean Square Error). However, as seen in Fig. 2.5, the obtained image quality is more uniform. In fact, the [signal]/[compression noise] ratio between image blocks is more homogeneous and the image quality of the final product is significantly enhanced.

This algorithm and its exceptional processing were validated on simulated and real SPOT4 images before SPOT5 launch date and then during its commissioning period.

Even with the exceptional processing described above, it was observed that beyond a compression ratio of 3, block artefacts due to the DCT appeared. It is a well-known drawback of this decorrelator at high compression ratios [5]. Accordingly, this algorithm is limited to compression ratios lower than 3, meaning a bit rate larger than 3 bits/pixel for 8-bits images. This was the reason why CNES looked for a new transform for PLEIADES-HR satellite images. Furthermore PLEIADES images are encoded on 12 bits with a targeted compression ratio close to 6.

2.3 *Wavelet-Based Compressor*

A wavelet-based algorithm was developed for PLEIADES-HR images [5]. This algorithm uses a 9/7 biorthogonal filter and a bit-plane encoder to encode the wavelet coefficients. The PLEIADES-HR panchromatic images are compressed with a bit rate equal to 2.5 bits/pixel and the multispectral bands are compressed at 2.8 bits/pixel. As for SPOT5, user's community, including French army, tuned this

Fig. 2.6 PLEIADES-HR satellite and its compression unit

data rate for preserving the image quality of final products. The in-flight commissioning period will confirm this choice. A module with ASICs including both Mass-Memory and compression module was designed for this mission.

This unit integrates a generic compression module called WICOM (Wavelet Image Compression Module). This high-performance image compression module implements a wavelet image compression algorithm close to JPEG2000 standard. ASIC optimized internal architecture allows efficient lossless and lossy image compression at high data rate up to 25 Mpixels/s. The compression is done at a fixed bit-rate and enforced on each strip or on full images. No compression parameter needs to be adjusted except the compression data rate. Input image dynamic range up to 13-bits can be handled by the module which has a radiation-tolerant design. The compression unit and the satellite are presented in Fig. 2.6.

2.4 A Standard for Space Applications: CCSDS Recommendation

CNES chose a non-standard algorithm for PLEIADES-HR compression because JPEG2000 standard [6] was considered too complex for a rad-tolerant hardware implementation. In the same time, CNES was involved in the Image Data Compression (IDC) Working Group of the CCSDS (Consultative Committee for Space Data System). In 2006, the new recommendation CCSDS-IDC was published [7]. In this algorithm, a wavelet transform and a bit-plane encoding of wavelet coefficients organized in trees (8×8 coefficients) are performed. Even if it was too late to be used for PLEIADES-HR, this recommendation was adapted to Earth observation missions' throughput. An ASIC implementation is currently available, it has been developed at the University of Idaho's Center for Advanced Microelectronics and Biomolecular Research (CAMBR) facility where the Radiation-Hardness-By-Design (RHBD) technique is being applied to produce high-speed space-qualified circuits. The projected throughput is over 20 Mpixels/s.

This implementation separates the DWT and the Bit Plane Encoder into two ASICs. CNES has performed several comparative studies on several reference data sets (PLEIADES simulated images, very-high resolution images from airborne sensors, CCSDS reference data set). Both PLEIADES and CCSDS have very similar performances in terms of quantitative criteria (Mean Error, Maximum Error and Root Mean Squared Error).

2.5 Image Quality Assessment

As explained in [3], image quality is a very strong requirement for the choice of a compression algorithm. Criteria that are usually taken into account in this trade-off are statistical, such as the Root Mean Squared Error, though it has been proved that these quantitative criteria are not enough to specify a compression algorithm. Expert users' analyses are useful to evaluate different algorithms and several compression ratios. These experimentations belong to an iterative process between algorithm refinement and image quality requirement assessment. Lately, better statistical criteria, more related to the experimental results, are being considered. The signal variance to noise variance ratio is a candidate. In fact, a set of criteria should be used to validate and finalize a compression algorithm but users' feedback remains necessary. In addition, high-resolution imagers need a restoration phase including deconvolution and denoising. These steps are performed on-ground after decompression. These techniques are necessary to produce a good-quality image without blurring effect due to the MTF (Modulation Transfer Function) and instrumental noise. Until now, statistical criteria used to evaluate the compression efficiency were computed between original and decompressed images, meaning that restoration functions were not taken into account. In 2009, CNES started a study to optimize both compression and restoration steps. The complete image chain from instrument through on-board compression to ground restoration will be considered.

3 On-Board Compression Algorithms: Present and Future

3.1 Multispectral Compression

Future high resolution instruments planned by CNES will have higher number of spectral channels than current instruments. In the case of so-called multi-spectral or super-spectral missions about ten bands are acquired simultaneously with a narrow swath and a spatial resolution from 10 m to 1 km. In the case of very high resolution instruments, a smaller number of bands are acquired, typically four bands: blue, red, green and near infra-red, sometimes completed with the short-wave infrared or a

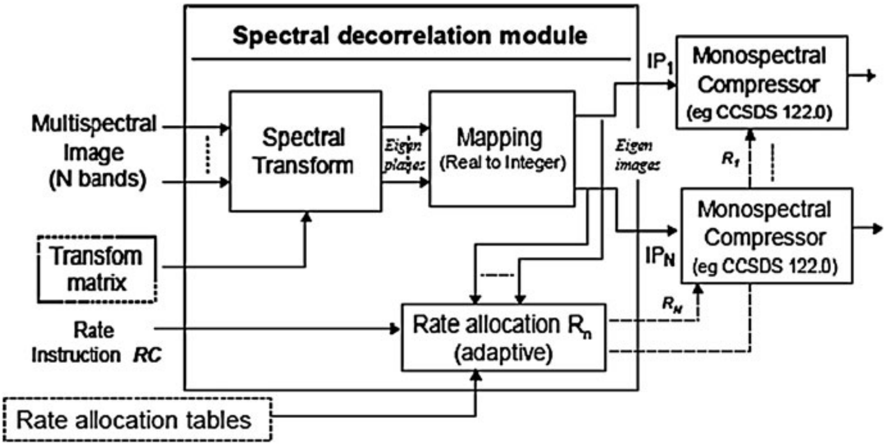

Fig. 2.7 Spectral decorrelation module based on an exogenous KLT

panchromatic band with a better spatial resolution. This is the case for PLEIADES images which have a panchromatic band and four multispectral bands. Up to now, data compression is done independently on each channel, which means on the panchromatic one and on each multispectral channel. In this case, the so-called "monospectral" compressor only exploits the spatial redundancies of the image, ignoring the redundancy between the different images of the same scene taken in different spectral bands. For optimum compression performance of such data, algorithms must take advantage of both spectral and spatial correlation. In the case of multispectral images, CNES studies (in cooperation with Thales Alenia Space) studies have led to an algorithm using a fixed transform to decorrelate the spectral bands, where the CCSDS codec compresses each decorrelated band using a suitable multispectral rate allocation procedure [8].

As shown in Fig. 2.7 this low-complexity decorrelator is adapted to hardware implementation on-board satellite. It is suited to high-resolution instruments for a small number of spectral bands. For higher number of bands (superspectral and hyperspectral images), CNES has also led several studies based on a spectral decorrelator followed by an entropy encoder (CCSDS, SPIHT3D, JEPG2000) [9]. In the framework of the new CCSDS Multispectral and Hyperspectral Data Compression Working Group, CNES is currently studying a hyperspectral compression algorithm suitable for space applications and based on a spectral decorrelator and the CCSDS Image Data Compression recommendation [10].

3.2 *Wavelet Limitations*

Using the PLEIADES-HR compressor or the CCSDS recommendation, it can be seen that artefacts appear for high compression ratios. These artefacts can be well-known blurring effects, high quantization of low-complexity regions (due to

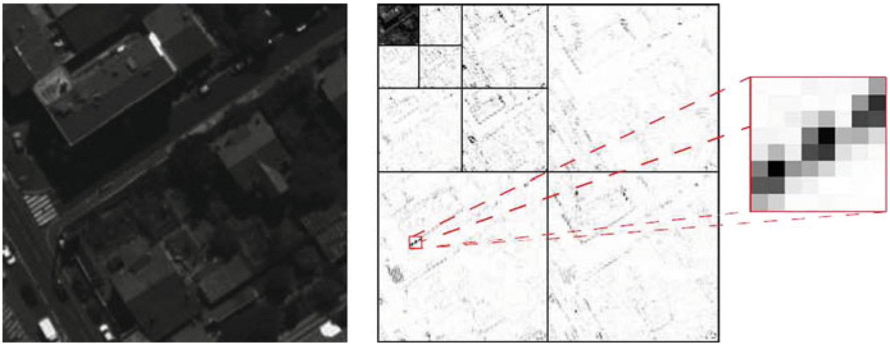

Fig. 2.8 High-resolution image from airborne sensor (*left*) and its wavelet transform (*right*) with a zoom on some coefficients

the rate-allocation procedure over large swath of pixels) but also bad definition of image edges. This last artefact is due to the wavelet transform which has residual directional correlation between wavelet coefficients in a small neighborhood (see Fig. 2.8). In [11], Delaunay has shown that EBCOT is very efficient in capturing these residual values. This context coding makes JPEG2000 among the best existing compressors but its implementation complexity issue has been previously explained in this chapter.

3.3 A New Transform for On-Board Compression

Since 2004, CNES has investigated new spatial decorrelators while considering the on-board satellite implementation constraints. Several promising transforms such as contourlets, curvelets, ridgelets and bandelets have been studied. Finally a post-transform optimization based on wavelet coefficients and very close to the basic idea of the bandelet transform has been achieved [12]. Transform bases are designed based on directional groupings and on Principal Component Analysis (hereafter PCA) on blocks of wavelet coefficients. A Lagrangian rate-distortion optimization process is used to select the best transform for each 4×4 wavelet coefficients block. An internal study showed that this size was optimal in terms of performances versus complexity trade-off. In [13], it is proved that bases resulting from PCA on various sets of blocks are better than directional bases. These performances are compared to CCSDS and JPEG2000 compressors on a set of very high resolution images (Fig. 2.9). We observe a gain from 0.5 to 1 dB in the range [0.6, 2.6 bpp] over the CCSDS. Nevertheless, the JPEG2000 performances are never reached and whatever the post-transform, results are around 0.6 dB lower than JPEG2000.

In terms of implementation complexity, the post-transform studied in this case does not mean complex operations. Wavelet coefficients are projected on 12 bases

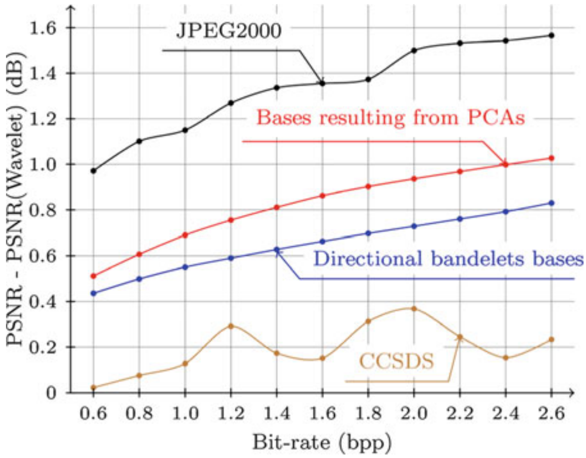

Fig. 2.9 Post-transforms performances in peak signal to noise ratio compared to CCSDS and JPEG2000 standards

of 16 $\times$ 16 coefficients. Then, a Lagrangian cost is computed and post-transformed coefficients are encoded.

The arithmetic coder is used for experimental testing but a last study of best basis selection was performed to do a complete analysis of optimal quantization steps, Lagrangian multiplier and transform bases. We plan to replace the arithmetic coding stage, which is known to have difficult implementation issues, by a bit-plane encoder allowing bit accurate and progressive encoding. This encoder has to be adapted to the post-transform wavelet coefficients. An efficient bit-plane encoding procedure should provide as good results as the arithmetic coder. The final bit-stream should be fully embedded like the CCSDS recommendation or the PLEIADES-HR compressor allowing progressive transmission.

3.4 COTS for On-Board Compression

CNES, as a member of the JPEG2000 standard committee plan to use this algorithm on-board satellites. Consequently it performed in 2000, an implementation study of the JPEG2000 standard with radiation hardened components. The results were quite disappointing because this algorithm was considered too complex to be implemented on this kind of hardware, principally because of the arithmetic coder and the rate allocation procedure (handling of optimal truncation points). This was the same conclusion of the CCSDS Image Data Compression Working Group when it started to look for a candidate for the CCSDS-IDC recommendation. The published recommendation is finally half complex than the JPEG2000 standard with performances 2 dB lower in a scan-based mode (memory limited). In 2008, CNES started a complete study of the commercial component from Analog Device compliant to the JPEG2000 standard (ADV212). The ADV212 integrated circuit is a System-On-Chip designed to be a JPEG2000 codec and targeted for video and high bandwidth image

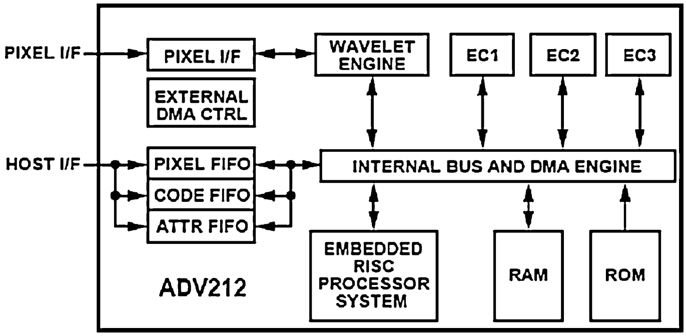

Fig. 2.10 ADV212 internal architecture

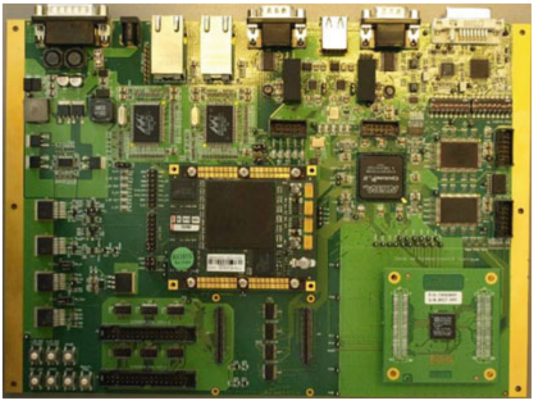

Fig. 2.11 ADV212 evaluation board (ADV212 integrated circuit is at the bottom right)

compression applications. The Integrated circuit includes multiple hardware functions such as wavelet engine, RiSC processor, DMA, memories and dedicated interfaces. Figure 2.10 presents the ADV212 architecture. The software executed within the circuit allows the chip to perform compression or decompression. The evaluation board is shown in Fig. 2.11. This study was both a performance analysis and a spatial environment tolerance study (radiation sensitivity). The algorithmic performances were compared to Kakadu software and CNES took a special care about tile partitioning limitations, compression performances and fixed bitrate ability. The radiation campaign was led in Louvain-La-Neuve cyclotron during first quarter of 2010. This circuit was tested against latch-up and SEFI events. Results were not satisfying for latch-up as the Integrated Circuit revealed a high sensitivity (from 2 latch-ups per second under high energy Xenon beam with 100 particle/s, to a bare 1 latch-up per minute under low energy Azote beam with 1,000 particle/s). The last beam setup allowed to perform functional tests that led to timeout error, configuration error... Not a single image was compressed successfully (within the ten tests done) under heavy ions beam.

According to these results, the use of this COTS (Commercial of the Shelf) for space applications seems really inappropriate despite its efficiency for JPEG2000 compression.

3.5 Exceptional Processing for DWT Algorithms

In Sect. 2.2.2, the DCT-based SPOT5 compressor has been presented and the associated exceptional processing briefly explained. In that particular case the occurrence of the defects or artefacts was linked to the choice of a locally unsuitable quantization factor in the rate regulation loop, as this factor was the same for the whole line of blocks. The exceptional processing developed and validated for SPOT5 locally corrected the quantization factor by a factor of 2 or 4, depending on the number of AC coefficients in the block. For both DWT-based PLEIADES compressor described in 2.3 and CCSDS standard described in 2.4, no rate regulation loop is needed, because bit plane encoders hierarchically organize the output bit-stream so that targeted fixed bit rate can be obtained by truncating this bit-stream. However, because of on-board memory limitations, the DWT, bit-plane encoding and truncation are performed over a fixed-size image area. For PLEIADES compressor, this image area is 16 lines (width equal to image width). For CCSDS compressor, this image area is called a segment and its size is defined by the user. In both cases, the quantization induced by truncation of the bit planes description is the same for the studied image area and some defects already observed in SPOT5 compressed images still appear with these DWT-based compressors. In order to locally correct the defected blocks, CNES has studied exceptional processing. The criteria used to decide whether exceptional processing is needed for a block is the [signal variance]/[compression noise variance ratio]. As defined in [7], a block of wavelet coefficients consists of a single coefficient from the LL3 subband, referred to as the DC coefficient, and 63 AC coefficients. Depending on this ratio value, the wavelet coefficients of the block are multiplied by a positive factor before bit-plane encoding. These multiplied coefficients will be treated earlier than in the nominal case (without exceptional processing) by the encoder. This wavelet coefficients processing is similar to what is done in JPEG2000 standard for Region of Interest handling [6]. The image quality improvement brought by the exceptional processing has been confirmed by image analysis. However, its utilization is not needed for PLEIADES images because the targeted bit rate is high enough to prevent such defects.

3.6 Selective Compression

Algorithms presented above are associated with low performance gain while preserving a good image quality whatever the scene and wherever in the scene. However, this gain is not enough compared to the increase of data rate. Unfortunately, any transform has been able to obtain a significant gain on compression ratio

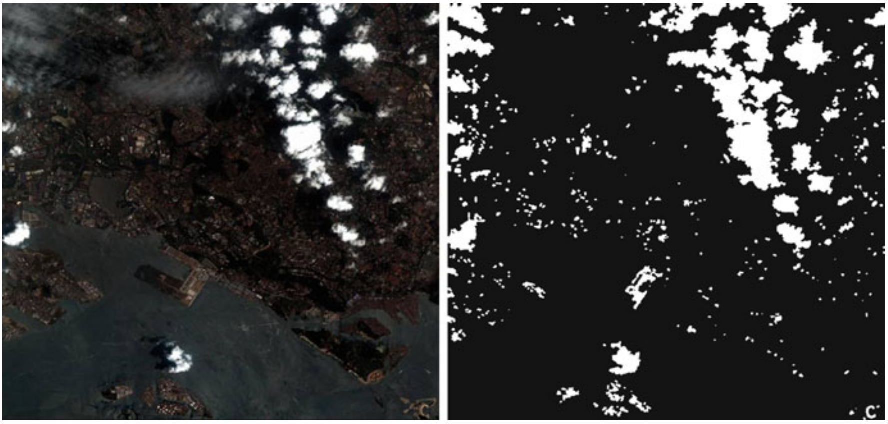

Fig. 2.12 Cloudy SPOT5 image and its associated cloud mask

for the same image degradation. To reach such bigger compression ratios, it is necessary to perform "smart" compression, meaning different compression ratios inside a scene. Thus, on-board detection of useful or non-useful data is required, the non-useful data being more compressed to ensure a compression gain. This kind of compression is called "selective compression" and consists of detecting and then compressing a so-called region-of-interest (ROI) or non-interest. Nevertheless, on-board detection for Earth observation missions must be performed at high data rate and detection algorithms are often too complex. Moreover, selective compression is not so famous because it is hard to describe useful or non-useful data. Fortunately, one type of data can be considered, for almost all CNES High-Resolution applications, as non-useful data: the clouds. In fact, despite the use of weather forecast in satellite scheduling, most of optical satellite images are cloudy; this is the case of SPOT5 for which up to 80% of the images are classified as cloudy by the SPOT-image neural network classifier.

Figure 2.12 gives an example of a cloudy image and its associated binary mask indicating a cloud-pixel when pixel is white (output of a classifier) and a non-cloud-pixel when pixel is black. Considerable mass-memory and transmission gains could be reached by detecting and suppressing or significantly compressing the clouds. Compression algorithms should use this kind of mask during the encoding stage to differently compress both regions of the scene.

3.6.1 On-Board Cloud-Detection Feasibility

During the last years, CNES has studied the implementation of a cloud detection module on-board satellite [14]. The idea was to simplify and optimize for on-board implementation an already existing cloud-detection module used on-ground for PLEIADES-HR album images [15]. This algorithm uses a Support Vector Machine

Table 2.1 Comparative global results between the reference model and fixed-point/VHDL model

Cloud mask coverage	Cloud mask surface in pixels (ref. model)	Cloud mask surface in pixels (fixed-point model)	Common coverage (ref. vs. fixed point) (%)	Different coverage (ref. vs. fixed point) (%)
Acapulco_1	298,570	299,871	100.0	0.4
Bayonne_1	243,113	244,345	100.0	0.5
Dakar_2	475,644	481,180	100.0	1.1
La_Paz_1	167,772	168,542	100.0	0.4
La_Paz_2	749,313	753,932	100.0	0.6
London_1	418,660	416,966	99.5	0.4
Los_Angeles_2	120,225	120,428	100.0	0.1
Marseille_1	153,887	155,251	100.0	0.8
Papeete_1	361,610	362,916	100.0	0.3
Quito_1	724,569	726,453	100.0	0.2
Quito_2	544,185	545,662	100.0	0.2
Seattle	275,310	276,590	100.0	0.4
Toulouse	123,691	123,872	100.0	0.1

classifier on images at low resolution (wavelet transform 3rd decomposition level). The main stages of this algorithm consist in computing top of atmosphere radiance of the image using the absolute calibration factor, computing classification criteria and finally classifying these criteria with the trained SVM configuration.

The on-board implementation study firstly analyzed independently all the phases of this process to propose an on-board simplified model of cloud cover detection algorithm based on SVM technique. The proposed restrictions computed together, via a floating-point software model, showed that equivalent performances could be obtained by the on-board simplified model ($<1\%$ of error).

In order to prepare the VHDL description other restrictions were taken into account as the ranges and targeted accuracies of each computing parameter for fixed-point operations.

Finally, an HLS tool was used to obtain fixed-point and VHDL descriptions and to verify the performances if compared with the reference model. Table 2.1 shows some main results for 13 different sites: maximum error complies with the initial specifications with about 1% of error in cloud detection coverage and mask generation. Furthermore, as worst-case errors correspond to cloud pixels considered as ground pixels (common coverage ~100%), almost any additional loss will be introduced in the region of interest by this cloud compression stage.

3.6.2 ROI Coding

The last step of selective compression is the “smart” encoding of the Region Of Interest. In the case of on-board cloud-detection, the background is the cloud-mask and the foreground (ROI) is the rest of the image. ROI coding methods already exist and the principle of the general ROI scaling-based method is to scale (or shift) wavelet coefficients so that the bits associated with the ROI are placed in higher

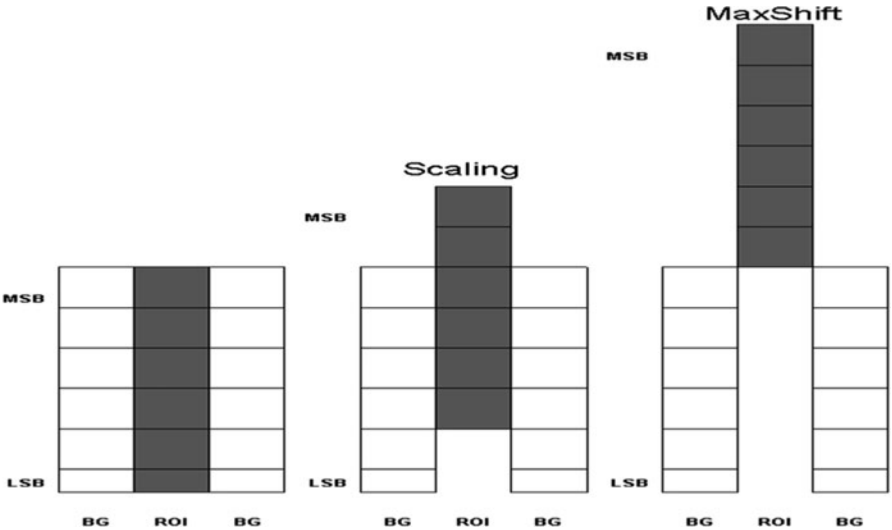

Fig. 2.13 Standard vs. shifted bit plane coding with “Scaling” and “MaxShift” methods

bit-planes than those of the background (see Fig. 2.13). Then, during the embedded coding process, the most significant ROI bit-planes are placed in the bit-stream before background bit-planes of the image.

Two different ROI coding capabilities, Maxshift and Scaling, have been already added by CNES to existing compressors (CCSDS IDC…) in order to perform selective compression over all kind of image including cloudy ones.

Of course, both methods have particular advantages and drawbacks considering the application: thus, Maxshift is a better candidate for cloud detection applications as it preserves the best reachable image quality over the ROI and the decompressor can automatically decode the cloud covering mask. Its main drawback is that users cannot control the image quality over the background region (e.g. clouds), or between regions with different degree of interest. The Scaling method will be preferable for this kind of applications but extra over-head must be expected for ROI mask transmission. Other techniques, as Bitplane-By-Bitplane Shift, may also be studied with the aim of allying the advantages of these two methods.

On-going CNES studies will provide rate allocation compatibility for these ROI compression techniques.

3.7 Fixed Quality: Variable Data Rate Compression

Actual on-board compressors assign “almost” the same data rate to every image segment on the scene in order to globally simplify the system data handling by providing highly-predictable volumes and data rates. This is not, however, the best way of achieving the optimum image quality for a scene or a group of scenes for a given amount of data (i.e.: on-board mass memory capacity).

Even if selective compression can offer a significant improvement if compared to classical fixed data rate compression, it is still hard to describe the different regions of interest and even more to handle them in order to obtain efficient compression schemes.

Thus, Fixed Quality-Variable data rate compression algorithms seem to be a better option to optimally compress images with the lowest amount of data: depending on the image complexity (computed by block or segment inside a scene), the compressor will assign the appropriate compression ratio to comply with the selected quality requirements. Nevertheless, as image complexity will vary, variable data rates will be obtained after compression. Satellite data system must be then overvalued to be able to handle the highest volumes/data rates associated with very complex images (i.e. urban areas). Accordingly, CNES will study during the next years the application and the impact of such techniques for High-Resolution satellite systems. The main idea is that compressors will be able to prior compute the image complexity in order to assign the optimum description level (bitplane) for a chosen quality limit. A global limit in terms of data amount should be also imposed for on-board handling and storage issues. Some good approaches, as quality-limit parameters BitPlaneStop and StageStop of CCSDS IDC algorithm, will certainly play an important role in these future compression methods.

4 Conclusions

In this chapter, we have firstly given an overview of past compression algorithms that have been implemented on-board CNES satellites devoted to Earth observation missions. The development of compression algorithms has to deal with several constraints: telemetry budget limiting the data rate after compression, image quality constraints from expert image users and space qualified electronics devices also limiting the implementation and its performances. By using performing techniques such as DCT and then DWT, CNES has developed several modules for Earth observation missions that have been described here. As shown in Fig. 2.14, the used techniques allow a gain in compression ratio while preserving a very good image quality. This gain is more and more necessary to face up to the growing data rate of very high resolution missions. But for coming missions, new compression techniques have to be found. New transforms with better decorrelation power, on-board detection techniques for selective compression or algorithms performing fixed quality compression represent the CNES main fields of study to prepare the future.

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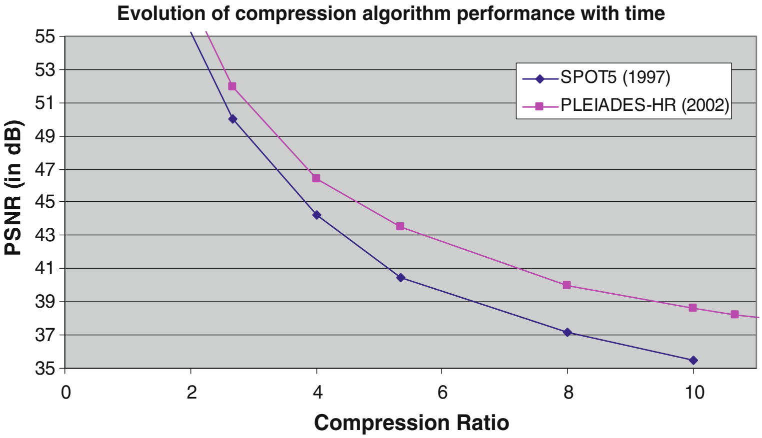

Fig. 2.14 Evolution of compression algorithm performance with time: from SPOT5 to PLEIADES-HR

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