Military Technical College
Kobry El-Kobba,
Cairo, Egypt

11-th International Conference
on Aerospace Sciences &
Aviation Technology

Investigation of On-Board Compression techniques for Remote Sensing Satellite Imagery

Fawzy ELtothamy Hassan*,Ph.D.Gouda Ismail Salama*,Ph.D.
Mohammed Sharawy Ibrahim, prof. Dr. Ramy Mohammed Bahy*,B.Sc.

Abstract:

The transmission of image data acquired by remote sensing missions, based on space borne platforms is a major bottleneck, as a result of the limitation of on-board power, the huge volume of transmitted data, and the number of accessible ground receiving stations. In particular these arguments hold true for small satellites that faces additional design constraints in terms of size, mass and cost .To overcome downlink restriction, image compression has to be applied, although the provided data transmission rates are constantly growing, they can't keep up with the exponentially increasing data flood provided by the scanners, the reasons are twofold: **First** the acquisition rate exceeds the transmission rate. **Second** the satellite is not in constant visibility of ground receiving station, which effectively limits the downlinkable data volume per orbit. This paper introduces implementation of some of the compression techniques for both lossy and lossless which are used for the On-Board satellite missions, taking into consideration that the introduced compression method should support and enable the real time imaging and transmission. Also, a comparison study between both techniques is introduced based on measures like Compression Ratio (CR), Root Mean Square Error (RMSE) and Peak Signal-to-Noise Ratio (PSNR).The experimental results showed that: Huffman code is the most suitable code for lossless compression technique for satellite images, since it gives a considerable high compression ratio with respect to the other lossless algorithms (Run-Length Encode, Lempel-Ziv-Welch code and Arithmetic code). Huffman code does not require much storage capacity such as LZW or more computational requirements such as arithmetic code. Also, the most suitable lossy compression techniques for satellite images is applying Discrete Wavelet Transform (DWT) on the four Most Significant Bit Planes (MSPB) of the image then applying the arithmetic code over the resultant DWT coefficients. This technique achieves higher average compression ratio (**8.28:1**) than the two other techniques and at the same time the image quality is accepted.

Keyword: Lossy image compression, Lossless image compression, Satellite imagery, Remote Sensing.

---

* Egyptian Armed Forces

1- Introduction:

Image compression techniques are divided into two main categories [2], Lossless and Lossy compression techniques. The compression technique is called Lossless when the original image can be exactly reconstructed from the compressed version without any loss in the image information while the compression technique is called Lossy when an approximated image is reconstructed from the decompressed image file [2].

Lossless compression is also called error free compression [1-2] it is desirable in some applications such as medical and military applications, where lossy compression usually is prohibited, also in satellite images processing where both the use and cost of collecting the data makes any loss undesirable, in lossless compression of R.S satellite imagery the compression ratios vary (form 2:1 to 5:1) [6], unfortunately, most Lossless compression techniques seldom achieve higher compression ratio except in some state of the art Lossless compression techniques such as JPEG-LS where the ratio reaches 14:1 [4-5]

Lossy image compression methods, in contrast, can achieve much higher compression ratio but at the cost of introducing artifacts and distortions. The challenge in image compression research is to develop some compression methods that combine the three desirable qualities:

1- Deep Compression ratio.
2- Low image distortion (high image quality).
3- High computational speeds.

In order to meet this challenge, it is required to decide what amount of information to discard and how, so that the human perceptual system still thinks that the decompressed image almost looks like the original image.

In Remote Sensing (R.S) satellite for civilian applications, the first priority is to obtain a higher compression ratio. In order to achieve high compression ratio with a considerable image quality, the lossy image compression algorithms can be applied.

The paper is organized as follows: *Section 2* presents the considerations of comparative study for both lossy and lossless compression techniques. *Section 3* introduces a study analysis on some of lossless compression techniques and a comparison among these different techniques.

Section 4 introduces a study analysis on some of lossy compression techniques and a comparison among these different techniques. *Section 5* summaries and concludes the work results. Finally, references are given in section *6*.

2. Comparative Study considerations

1- The analysis is performed on ten different satellite sub-images namely *imgsat 1, imgsat 2,…….imgsat 10* respectively.

2- The images are acquired by the commercial Remote Sensing satellites SPOT 5 *(imgsat 1, imgsat 3, imgsat 5, imgsat 7, imgsat 9*) and LANDSAT 7 *(imgsat 2, imgsat 4, imgsat 6, imgsat 8, imgsat 10*).

3- Images are gray scale images of 8-bit (G.L 0 → 255).

4- The images size is 256X256 pixels.

5- The images format is TIF.

6- The analysis programs are performed using MATLAB 6.5 with a PC whose configuration is (Pentium III, Intel 1200 MHZ processor, 256 Mbyte cash memory, 128 Mbyte RAM).

7- The scalar quantization value in case of lossy image compression will be 0.05.

3. Lossless Compression techniques

This section introduces an overview for the different lossless compression techniques and then presents some experimental results to show the difference among them.

3.1 Overview

The lossless compression techniques include:

(1) Run-Length Encode (RLE): is considered an effective compression algorithm only when the image includes run of the same pixels values [1,2].

(2) Lempel Ziv- Welch (LZW) coding: belongs to yet another category of lossless compression techniques known as dictionary coders, In which the coding techniques rely upon the observation that there are correlations between the gray levels. The basic idea is to replace those repetitions by (shorter) references to a "dictionary" containing the original [7]

(3) Arithmetic code: based on defining an arbitrary range of values, for convenience this range will be defined as [0,1).Next, the working range (or sometimes called the current interval) is subdivided into **n** subintervals, where **n** is the total number of image gray levels. The compressed image is represented by a single fractional number instead of a series of discrete symbols or codes [8]

(4) Huffman code: The average number of bits per pixel can be reduced by assigning binary codes of different bit length to various image intensities. Hence, short codeword are assigned to the gray levels of high probability of occurrence and longer codeword to less frequent gray levels [1, 2].

3.2 Experimental Results of Lossless image compression techniques

Analysis is performed on Run-Length encode (RLE), Lempel Ziv- Welch (LZW) code, Huffman code and Arithmetic code as the most popular lossless compression methods on a sample of satellite imagery or precisely on a sub-images of size 256X256 pixels. To compare among different lossless compression techniques in order to determine which of them more efficient, the compression ratio will be the comparison metric, as SNR will be equal to infinity and RMSE will be equal to zero, since reconstructed imagery is exactly the same replica from the original.

Table1 indicates a comparison among Huffman, Arithmetic, LZW and RLE codes. This comparison is based on the compression ratio (CR). It could be observed that Huffman code is considered the most suitable technique for satellite imagery, since it gives a considerable high average compression ratio (**2.36:1**) with respect to other lossless techniques. Also, Huffman code is preferred in lossless compression due to the following reasons:

(a) The dictionary coding types, such as LZW are not preferred due to their storage requirements and computational complexity of search operation. Also, the LZW requires establishing a dictionary which certainly requires more storage capacity [7].

(b) The RLE has a poor compression ratio (**1.08:1**) since it is mainly depends on a successive data repetition, which may not continuously occurs, but it is suitable as a pre-processor as in case of standard JPEG, where RLE increases the compression efficiency of the JPEG algorithm if it is applied on the transformed quantized coefficients and before using Huffman code.

(c) The arithmetic code achieves considerable compression ratio and has low memory requirements but its disadvantages is its high time consuming, this is because of its complex computations [8].

Fig.1 depicts the average CR for a ten satellite images using various lossless compression techniques (RLE, LZW, Huffman, and Arithmetic).

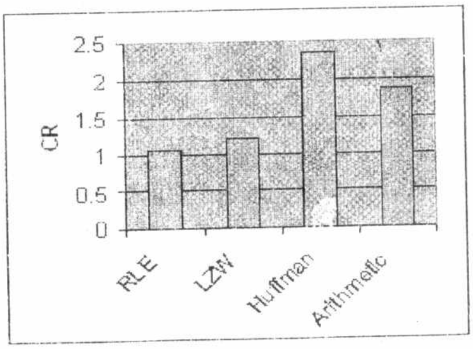


Fig.1. The average compression ratio of a ten satellite images using various lossless codes (RLE. LZW, Huffman, and Arithmetic).

Table (1) comparison ratio for various lossless codes (RLE. LZW, Huffman, and Arithmetic) using ten satellite images

Sat. Images	RLE	LZW	Huffman	Arithmetic
imgsat 1	1	1.02	2.1	1.88
imgsat 2	1.05	1.63	2.33	1.86
imgsat 3	1.02	1.13	2.34	1.8
imgsat 4	1.48	1.29	2.78	2.1
imgsat 5	1.03	1.05	2.32	1.68
imgsat 6	1.01	1.1	3.1	2.26
imgsat 7	1.04	1.003	1.88	1.69
imgsat 8	1	1.53	2.8	2
imgsat 9	1.14	1.28	2	1.79
imgsat10	1.03	1.07	1.93	1.69
Average CR	**1.08**	**1.21**	**2.36**	**1.87**

4. Lossy Compression techniques

This section introduces an overview for the different lossy compression techniques and then presents some experimental results to show the difference among them.

4.1 Overview

Analysis is performed on some of the lossy compression techniques which are recommended by Consultative Committee for Space Data Systems (CCSDS) and already used in the On-Board satellite image compression [9-10]. The lossy Compression techniques include DCT+Huffman code, DWT+Arithmetic code and MSBP+DWT+Arirhmetic code.

Fig.2 depicts the functional block diagram of the first lossy compression technique which based on Discrete Cosine Transform as a one of an effective image transformation since it is used in the standard JPEG technique [1-3].

The presence of quantization step is an important since it reduces the value of the transformation coefficients resulting from DCT and making these coefficients suitable for the next coding step by Huffman code which assigns shorter codeword to the gray levels of high probability of occurrence and longer codeword to less frequent gray levels [1-2].

The results after applying this technique on the selected images are given in Table 2. Fig.6. shows a set of example satellite images before and after applying this technique. Fig.3 shows the functional block diagram of the second lossy compression technique which based on Discrete Wavelet Transform as a one of an effective image transformation since it is used in the standard JPEG2000 technique[1-3], also DWT has proved to be the most suitable image transformation especially for satellite images [10,11]. In this technique the 9-7 Daubechies filters will be used as a DWT filters where, the comparison of wavelet filters on some representative images have

shown that 9-7 Daubechies [8] filters are the best ones for image compression [12]. The use of Arithmetic code is more suitable to code the wavelet coefficients as in the standard JPEG2000 [1].
Table 3 gives the results after applying this technique and Fig.7 depicts the difference between the original image and its corresponding reconstructed image.

Fig.4 illustrates the functional block diagram of the third lossy compression technique which depends on the acquisition of the four Most Significant Bit Planes (MSPB) of the input original image as in bit-plane coding technique [1] and discarding the four least Significant Bit Planes (LSBP), the discarding of LSBP will increase the compression efficiency. At the same time the image quality will not be severely affected since most of image information is concentrated in the first $MSPB_S$ [1], then every bit plane will be treated separately by applying DWT and quantization step then the arithmetic code, the coded planes are arranged as shown in Fig.5 and then we obtain the output coded bit planes. Table 4 gives the results after applying this technique and Fig.8 depicts the difference between the original image and its corresponding reconstructed image.

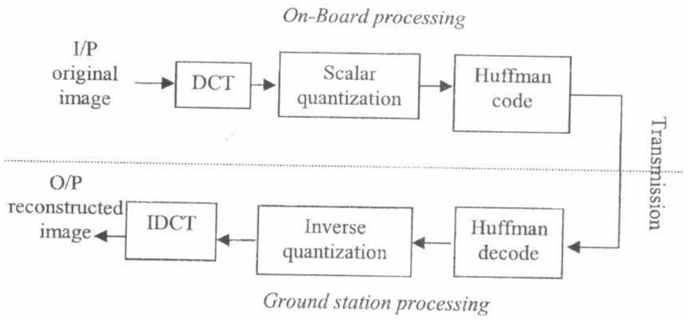


Fig..2. Functional Block Diagram of the lossy compression technique which based on DCT+Huffman code

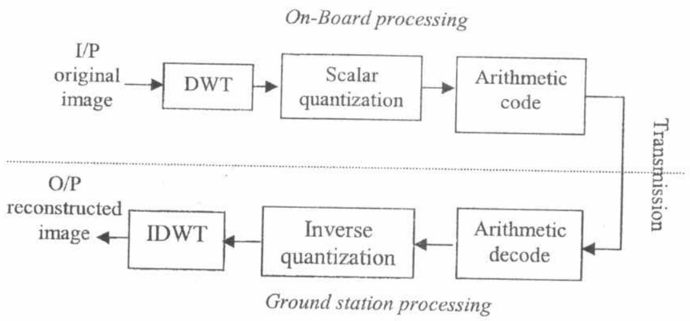


Fig.3. Functional Block Diagram of the lossy compression technique which based on DWT+Arithmetic code

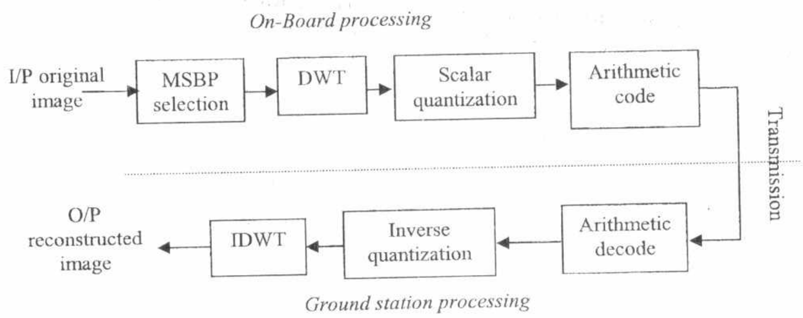


Fig. (4) Functional Block Diagram of the lossy compression technique which based on MSBP+DWT+Arithmetic code

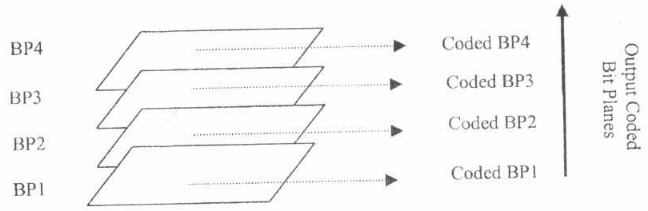


Fig.5. Flow of Coded Data from Bit Planes (BP_s)

4.1 Experimental Results of Lossy compression techniques

The evaluation of the compression efficiency in case of lossy compression doesn't depend only on CR as in lossless compression, but we will take into consideration another two metrics, peak signal to noise ratio (PSNR) and root mean square error (RMSE), since the reconstructed image (after compression and decompression operations) differs from the original one, according to experimental results shown in Tables (2,3 and 4). It could be noticed that DCT+Huffman code is a preferable technique if we are interested in obtaining a higher image quality than obtaining a higher compression ratio. From table (2), it could be observed that the average PSNR of the ten selected satellite images is **41.38** which is greater than the PSNR of the other two techniques. Also, the average RMSE is **2.26** which is smaller than the RMSE of the other two techniques. On the other hand, if we are interested in obtaining a higher compression ratio than obtaining a higher image quality, the use of DWT+Arithmetic code is a preferable technique Also, the use of DWT instead of DCT is more powerful in increasing the compression ratio where DWT enables using more than one decomposition level [1][3]. From table (3) the average compression ratio of the ten satellite images is **7.6:1** which is greater than the first technique. The third technique (MSBP+DWT+Arithmetic code) is considered a modified version of the second technique hence; discarding the LSBP increases the compression ratio. The third technique is considered the most suitable lossy compression techniques for satellite images where, it gives a higher average compression ratio (**8.28:1**) than the other two techniques with considerable image quality where there is no great differences in the reconstructed image quality in the three selected techniques, these can be obviously seen in Fig.6, Fig.7 and Fig.8. Also, the relation between CR, PSNR and RMSE of the three selected techniques is shown in Fig.9, where as the CR increases the PSNR decreases and the RMSE is also increases and vice versa.

Table (2) Results of the conducted experiments (ten satellite images) using the metric measures (CR, PSNR, and RMSE) for the lossy compression technique which is based on DCT+Huffman code

Sat. Images	CR	PSNR	RMSE
imgsat 1	4.81	40.27	2.47
imgsat 2	3.07	36.93	3.63
imgsat 3	8.1	43	1.8
imgsat 4	7.51	44	1.6
imgsat 5	7.7	43.34	1.7
imgsat 6	3.5	37.26	3.5
imgsat 7	3.83	40.77	2.33
imgsat 8	10.88	44	1.6
imgsat 9	4.55	41.43	2.16
imgsat 10	4.8	42.8	1.85
Average	**5.86**	**41.38**	**2.26**

Table (3) Results of the conducted experiments (ten satellite images) using the metric measures (CR, PSNR, and RMSE) for the lossy compression technique which is based on DWT+Arithmetic code

Sat. Images	CR	PSNR	RMSE
imgsat 1	6.58	34.69	4.7
imgsat 2	3.64	33.8	5.2
imgsat 3	10.65	37.64	3.34
imgsat 4	6.87	37	3.6
imgsat 5	9	37	3.57
imgsat 6	10.89	38.75	3.62
imgsat 7	3.6	33.85	5.2
imgsat 8	15.48	39	2.86
imgsat 9	5.2	34.47	4.82
imgsat 10	4.2	34.59	4.76
Average	**7.6**	**36**	**4.2**

Table (4) Results of the conducted experiments (ten satellite images) using the metric measures (CR, PSNR, and RMSE) for the lossy compression technique which is based on MSBP+DWT+Arithmetic code

Sat. Images	CR	PSNR	RMSE
imgsat 1	7.23	28.58	9.5
imgsat 2	8.8	28.63	9.44
imgsat 3	7.7	28.72	9.35
imgsat 4	11	26.8	11.62
imgsat 5	8.44	29	9.2
imgsat 6	7	28.73	9.34
imgsat 7	7.26	28.8	9.25
imgsat 8	10.34	27.75	10.45
imgsat 9	7.57	28.8	9.25
imgsat 10	7.5	28.7	9.34
Average	**8.28**	**28.45**	**9.67**

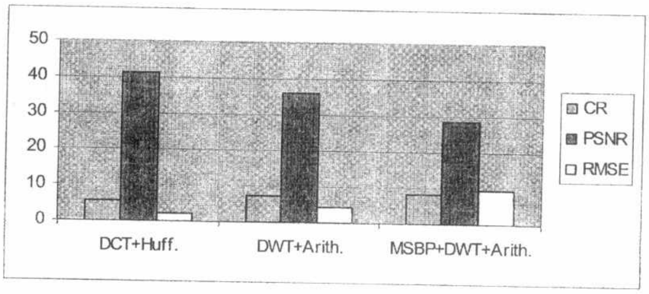
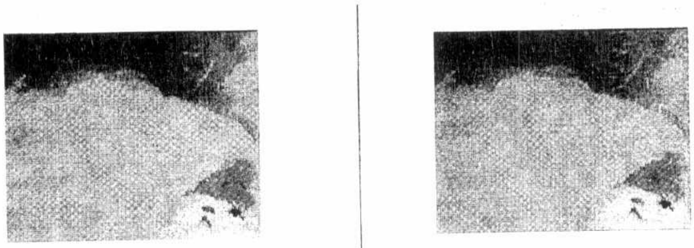


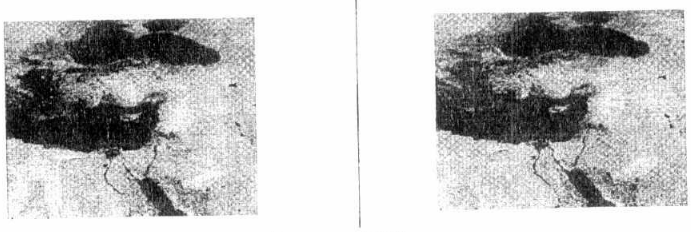
Fig.9. relation between CR, PSNR and RMSE of the three selected compression techniques

5- Conclusion and future work:

The experimental results showed that the Huffman code is considered the most suitable technique for *lossless compression of satellite imagery*; since it gives a considerable high compression ratio with respect to the other examined lossless algorithms and also does not require much storage capacity such as LZW or more computational requirements such as arithmetic code. Also, the most suitable *lossy compression* techniques for satellite images is applying DWT with the four MSPB of the image then applying the arithmetic code over the resultant DWT coefficients. This technique achieves higher average compression ratio (8.28) than the two other techniques and at the same time the image quality is accepted.



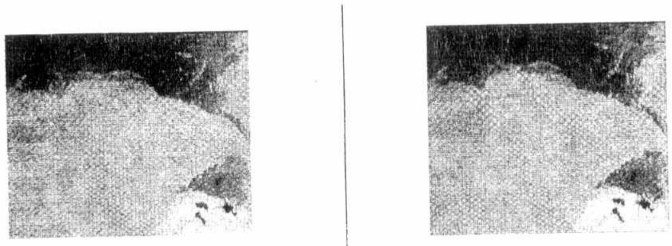
imagsat 5



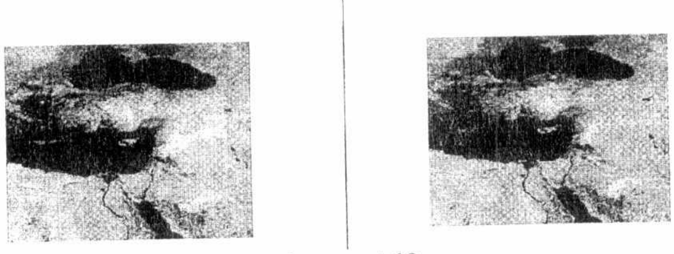
imagsat 10

(a) (b)

Fig.6. Original and Reconstructed images after applying DCT+Huffman code. (a) Original image, (b) Reconstructed image



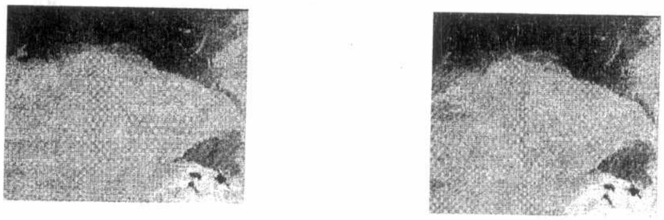
imagsat 5



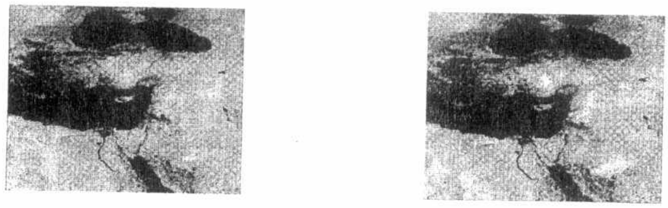
imagsat 10

(a) (b)

Fig.7. Original and Reconstructed images after applying DWT+Arithmetic code. (a) Original image, (b) Reconstructed image



imagsat 5



imagsat 10

(a) (b)

Fig.8. Original and Reconstructed images after applying MSBP+DWT+Arithmetic code. (a) Original image, (b) Reconstructed image

6- References:

[1]	Rafel C.Gonzalez , Richard E.Woods, "Digital image processing", Second edition, university of Tennesse, MedData Interactive,2002
[2]	Guy E.Blelloch ,"Introduction to Data compression ",Guy E.Blelloch, computer science department, Carnegie Mellon University, October 16, 2001.
[3]	Rashid Ansari, university of Illinios at Chicago,Vasir Memon, Polytechnic University "Hand book of image and video processing" ,2000
[4]	R M Susilo, T R Bretschneider, "On Real time Satellite Image Compression of X-sat", School of computer engineering, Nanyang Technological University, 2003
[5]	Shantanu D.Rane, Guillermo Spario, "Evaluation of JPEG-LS, the new lossless and Controlled-Lossy still image compression standard, for compression of high-resolution elevation data",IEEE, Vol. 0196-2892, 2001.
[6]	Arto Kaarna, Jussi Parkkinen, "Comparison of Compression methods for multispectral images", Lappeenranta University of Technology, Department of Information Technology, University of Joensuu, Department of Computer Science,2000
[7]	Christina Zeeh, "The Lempel Ziv Algorithm", Seminar "Famous Algorithms", January 16, 2003
[8]	Tom Kaminski "A Hardware Implementation of Arithmetic Compression", Final Report for 24.433 Thesis Project for the faculty of Computer Engineering at the University of Manitoba",March 2001

[9]	Philippe Kajfasz, Didier Nicholson, Philippe Bonnot, "Satellite On-Board image Coding using PIRANHA systematic-DSP"THALES communication, ATMEL IPITEC, France, 2002.
[10]	Tobias Trenschel, TimoBretschneider, Graham LeedhamUsing "Using JPEG2000 On-Board Mini-Satellites for image driven compression" School of computer Engineering, Nanyang Technological University,2002.
[11]	Lambert-Nebout, Christophe Latry , Gilles Moury, Christophe Parisot, Marc Antonini , Michel Barlaud, "On-Board optical image compression for future high resolution remote sensing systems", CNES, 13S Laboratory, IEEE vol. 4115-39,San Diego, USA, August 2000.
[12]	Antonini, M. Barlaud, C. Lambert-Nebout, C.Latry, G.Moury," On-Board strip-based wavelet image coding for future space remote sensing missions", C.Parisot, M.,Center National d'Etudes Spatiales -CNES.