

EFFECT OF LOSSY DATA COMPRESSION TECHNIQUES ON GEOMETRY AND INFORMATION CONTENT OF SATELLITE IMAGERY

Jochen Schiewe

University of Vechta, Institute for Environmental Sciences
PO Box 1553, 49364 Vechta, Germany
e-mail: jochen.schiewe@uni-vechta.de

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ABSTRACT:

The recording and transfer rates of digital imaging systems can not keep abreast of the actual captured amount of data. Because the compression rates of standard loss-less techniques are still too low, lossy techniques like the well-known JPEG or a new method based upon wavelets have to be taken into account. In order to study the decrease in image quality the effect of these methods will be examined with respect to the geometrical accuracy and the information content – both using manual as well automatic processing methods.

1 INTRODUCTION

The examination of the influence of data compression techniques on the quality of satellite imagery is an important research and development topic nowadays. On one hand, the technical status can not be equal to the desired transfer and recording rates. As an example, during the German MOMS-02 mission in 1993 only 35 percent of the potential data could be recorded. On the other hand, it is desirable to distribute data at lower spatial resolutions with as less quality loss as possible. Due to the fact that future high-resolution systems will offer significantly larger swath widths there is a need for advanced compression methods with rates clearly above a factor of 10 (aplin et.al., 1997; Fritz, 1998).

It can be shown that standard loss-less methods like the Run-Length-Encoding (RLE) or the Differential Pulse Code Modulation (DPCM) can not fulfill these demands due to the in-homogeneity of the satellite image data. Therefore, lossy transformation procedures have to be taken into account. In the following this will be tested by means of the standardized JPEG-method and an algorithm based on a wavelet transformation which will be shortly described in chapter 2.

In contrast to most examinations the effects of these methods will be discussed both on the geometry (chapter 3) as well as on the information content (chapter 4). In both cases it has to be differentiated between visual and automatic processing methods.

Test are performed on basis of data from the above mentioned space-borne sensor MOMS-02 (Modular Optoelectronic Multi-Spectral Stereo-Scanner in its second version) which was employed during the D2-Spacelab mission in 1993 for experimental purposes and since 1996 onboard the Russian MIR space station for a pre-operational use. The camera system offers pixel sizes down to 4.5 m and stereo imagery obtained through the along-track principle. For more details on MOMS-02 see Schiewe (1997).

2 TRANSFORMATION ENCODING

2.1 Overview

In general two data compression approaches are followed. Using *quantization encoding* the number of pixels of the original pixels stays constant but the numbers of bit per pixel shall be reduced. A typical method for this strategy is the Differential Pulse Code Modulation (DPCM). In the case of MOMS-02 a compression of the so-called "high-resolution" channel for the on-board storage using the latter method resulted into a reduction from 8 to 6 bit. It is obvious that the resulting *compression rate* (K) of 1.33 does not satisfy the demands as pointed out in chapter 1.

Lossy compression techniques are normally belonging to *transformation encoding* procedures. These methods are employing the following algorithmic steps:

- *Transformation* into the frequency domain.
- Compression, in general through rounding the obtained values to integer values (*quantization*).
- Loss-less *binarization* of the resulted coefficients.

In the following two members of the transformation encoding approach will be discussed: Firstly, the well known JPEG-method, secondly a rather new algorithm based upon a wavelet transformation.

2.2 JPEG-method

The *Joint Photographic Experts Group* (JPEG) developed a transformation encoding procedure for image data which originally was meant for videotext applications. But in the meantime it could be transferred to other digital imagery and was established as an ISO-standard (International Organization for Standardization).

Because JPEG supports not all necessary information for decompression of data, in 1991 some hardware and software vendors created an addendum called *JPEG File Interchange Format* (JFIF).

Typically for this algorithm is the first step with a division of the input image into blocks of 8•8 pixels. On each block a so-called Discrete Cosine Transformation (DCT) is applied for the transformation into the frequency domain. This results into 64 coefficients for each block which are sorted according to their value (resp. their frequency) and then quantized and entropy coded.

Practically, the user chooses very often has to determine the so-called quality factor Q as input parameter whereby the compression rate decreases exponentially with Q.

2.3 Wavelet compression

Wavelets are mathematical functions with particular features that can not be discussed in detail in the scope of this paper. The basic idea is to transform the two-dimensional signal of the original image into the frequency domain applying different spatial resolutions. Hence, wavelets can be interpreted as filter operators for given image matrices. In contrast to the Fourier-transformation wavelets allow the partition of the input signal not only with respect to their spectral but also to their spatial properties.

Wavelets have already been applied for photogrammetric tasks like extraction of roads, texture description, image matching or surface reconstruction. Operational compression techniques based on wavelets are rarely available at present. In the following we will use the software package *LuRaWave*, which has been developed by the German company LuRaTech for the remote sensing imagery (Thierschmann et.al., 1997; LuRaTech, 1998). Another software package on the market using wavelet transformations is MrSID (Multi-Resolution Seamless Image Database) by the GAF Company.

From an algorithmic point of view the LuRaWave procedure performs a hierarchical transformation of the color or grey values. Starting with the image T_i four matrices each consisting exactly half of the dimension of T_i are generated (see figure 1):

- One subimage T_{i+1} is a representation of the low frequency parts of the starting image (in the easiest case obtained through the application of a low-pass filter) and
- The remaining three subimages H_x , H_y and H_{xy} are representing the high frequency parts (in the easiest case obtained through difference filters in a horizontal, vertical and diagonal direction).

In practise, more complex filters are used. With an increasingly growing partition level respectively from T_j to T_k ($k > j$) the high frequency parts are getting smaller and can be neglected under consideration of some losses. On the other hand, stopping at a lower partition level (which means less amount of data) would lead to a worse image quality.

The quantization as the next algorithmic step is a threshold function that transforms the floating wavelet coefficients into integer values and causes further losses. Finally, an entropy coding as the loss-less binarization step takes place.

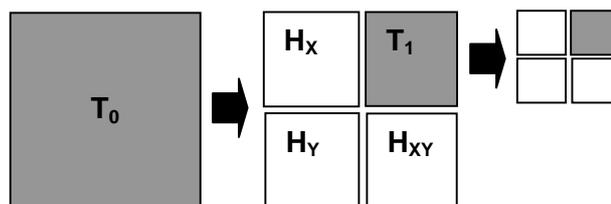


Figure 1: Partitioning image using wavelet filters

3 EFFECTS ON GEOMETRY

3.1 Manual measurements

In the following the effect of JPEG- and wavelet compression operations on the geometrical accuracy based on a manual, monoscopic on-screen digitization will be examined. As test imagery serves a pan-chromatic, "high-resolution" scene (pixel size: 4.5 m) of the MOMS-02 scanner from Dubai-City (United Arab Emirates).

Sixty identical points have been measured in the original and the compressed imagery (with compression rates ranging from $K = 5$ to $K = 70$). From multiple measurements within the original the repeating accuracy was determined to $s_0 = 0.41$ Pixel. This rather poor value can be led back to the fact that also such control points have been integrated in the process on purpose that do not show an optimal identification within the satellite image (like corners of buildings).

The exterior accuracy is determined through the positional residuals between points within the original and the compressed image. From the resulting standard deviations s statistical methods are applied in order to decide whether a significant difference to the original measure s_0 is present or not. This decision is based upon the FISHER-distribution with an error probability of 5% according to the following scheme:

Zero-hypothesis:	$H_0: \sigma = \sigma_0$ (\Rightarrow no difference)
Alternative hypothesis:	$H_A: \sigma > \sigma_0$ (\Rightarrow difference)
Quantil (FISHER):	$F_{11,12,95\%} = 1.53$ ($f_1=f_2=60$ points)
Test value:	$Z_F = s^2 / s_0^2$
Test decision:	$H_0: Z_F < F$ / $H_A: Z_F \geq F$

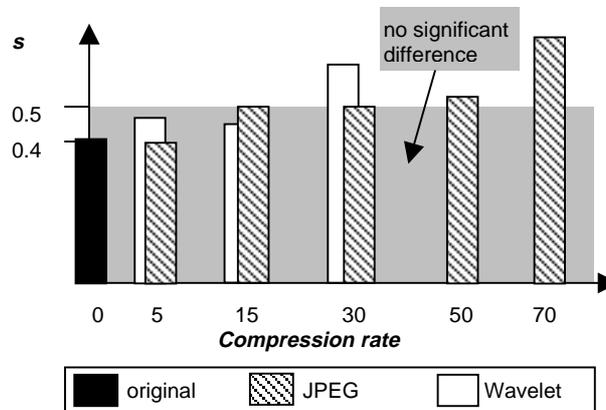


Figure 2: Geometrical accuracies depending on compression technique (manual measurements)

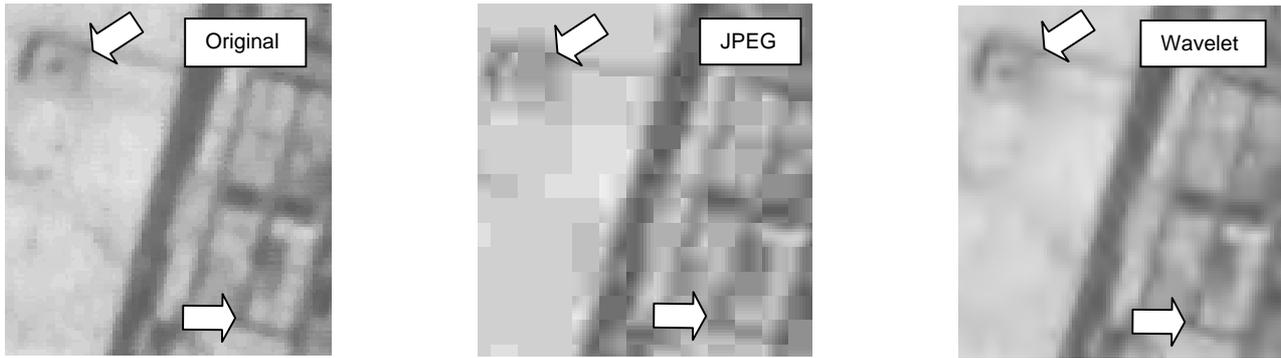


Figure 3: Comparison between original and compressed imagery (K=50) - indicated zones showing pointing problems for manual measurements

Vice versa, in this particular case standard deviations of s greater than 0.5 pixel are indicating a significant accuracy decrease.

Figure 2 summarizes the results for both compression techniques. In general, a significant decrease of the positional accuracies in comparison to the original can be detected for a $K = 15$ to 30 for JPEG resp. $K = 30$ to 50 for wavelet transformations.

Considering the JPEG compression it is not possible to clearly identify the control points in images with a compression rate larger than 50. Here the typical $8 \cdot 8$ pixel blocks disturb the interpretation of corners and crossings. On the other hand, the wavelet compression using the same rate show a smoothed impression which still allows a sufficient interpretation of targets (figure 3).

3.2 Automatic measurements

The automatic measurement is performed by means of the image matching algorithm of the program MEPAS-IC (Wang, 1994). As test imagery serves a stereoscopic "low-resolution" scene (pixel size: 13.5 m) of the MOMS-02 scanner from Pasajes (Bolivia).

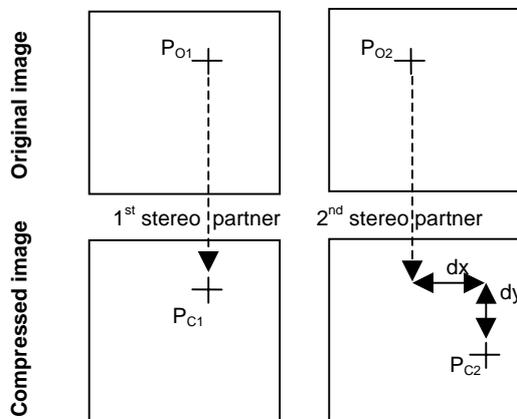


Figure 4: Accuracy measure for the evaluation of automatic measurements

For the accuracy evaluation only such points are considered that are identically in the first stereo channel in the original and the compressed image. Then the resulting deviations dx and dy of the matched points within the second stereo channel serve as accuracy measure (figure 4).

As figure 5 – that builds the standard deviation s from dx and dy - shows, that both techniques yield significant deviations from the expected value of 0.0 even for very small compression rates. The reason for this are the elimination (JPEG) resp. smoothing effects (wavelet) that destroy high-frequency structures. On the other hand those are essential for automatic measurements. Depending on the application this significant decrease has to be taken into account.

Having rates larger than 30 the wavelet method is superior against JPEG. Furthermore, using wavelets one finds approximately twice as much identical points in the first stereo channel which gives a much better overall reliability. Nevertheless, for both techniques the number of identical points for compression rates larger than 50 are too small in order to derive reliable measures.

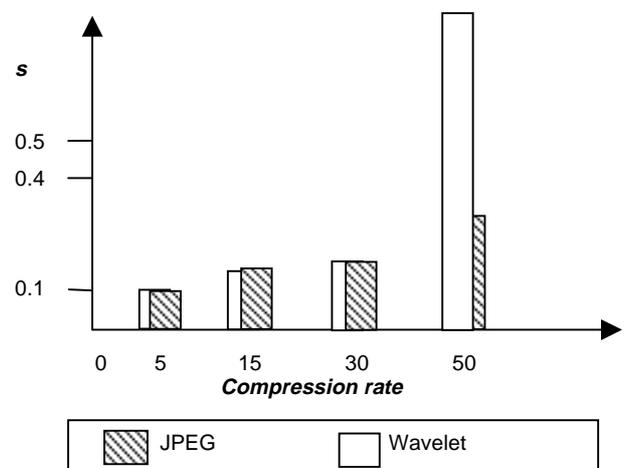


Figure 5: Geometrical accuracies depending on compression method (automatic measurements)

4 EFFECTS ON INFORMATION CONTENT

4.1 Visual interpretation

Applying a compression rate of 15 - either with JPEG or with wavelets - it is hardly possible to detect visually any changes between the original and the compressed image.

In contrast to the wavelet image the by factor 30 compressed JPEG image shows distinct changes in the shape of objects. This is due to the isolated transformed 8•8 pixel blocks that produce artefacts of the same size which finally make an interpretation impossible (see figure 3). With increasing rates the semantical quality of the compressed imagery of both techniques is clearly reduced. Hereby the problem with wavelets is the progressively increasing smoothing effect.

In order to obtain quantitative measures an analysis of the grey value histograms has to be performed which can lead to the *Peak-Signal-to-Noise-Ratio (PSNR)* which describes the relation between the maximal grey value within the original image (peak) and the noise that is caused through the compression:

$$PSNR = 10 \cdot \log\left(\frac{peak^2}{noise}\right)$$

$$with: \quad noise = \frac{1}{n \cdot m} \sum_{i=0}^{n-1} \sum_{j=0}^{m-1} (g_{ij} - g'_{ij})^2$$

Here g_{ij} is the grey value within the original and g'_{ij} the corresponding value within the compressed image (both images of dimension $n \cdot m$). It is desirable to obtain as less noise as possible and with that a large PSNR value. Figure 6 demonstrates the superiority of the wavelet method against JPEG with increasing compression rates and validates the mentioned results of the visual inspection.

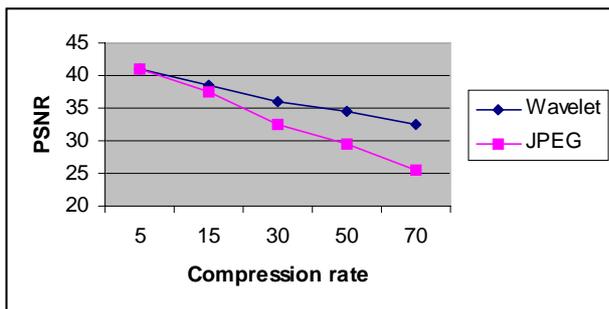


Figure 6: Relationship between compression rate and PSNR depending on compression technique

4.2 Automatic interpretation

In order to study the effects on an automatic interpretation a standard edge detection algorithm (Wang, 1994) is applied. The visual inspection of the resulting edge images (figure 7) shows that for both techniques using low compression rates ($K < 15$) short edges get lost and some

new edges are created. This results into the loss of some very small objects but the general impression can be kept.

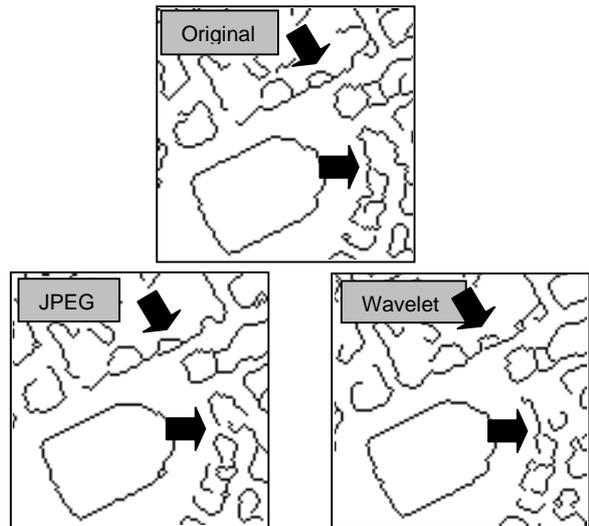


Figure 7: Comparison of automatically detected edges within original and compressed imagery ($K=10$). Losses and changes of structures are indicated.

For the JPEG compressed imagery the influence of the 8•8 pixel artefacts can be clearly seen. A high number of false edges with a straight horizontal or vertical direction arise so that the original object shapes get lost.

In the case of wavelet compressed images the structures can be obtained to a higher compression rate, but through the progressively increasing smoothing effect the number of edges are reduced.

In order to obtain a quantitative measure figure 8 shows

- the number of original edges which have not been found in the compressed image again (error of 1st type) and
- the number of edges detected within the compressed image which are actually not present within the original (error of 2nd type).

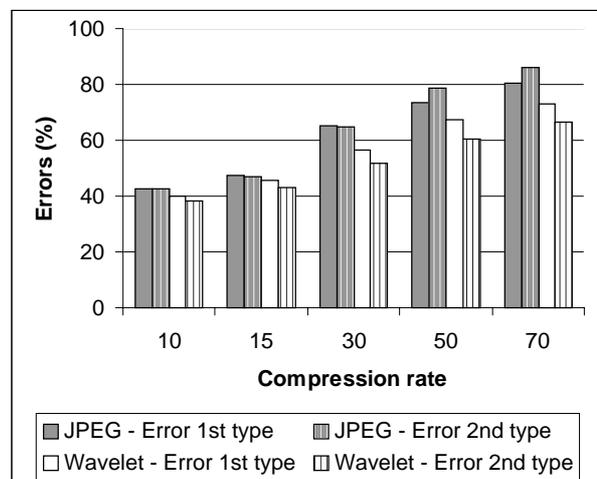


Figure 8: Edge detection errors depending on compression techniques

The corresponding values are considering the exact geometrical location of edges so that for example edges that have been displaced parallel to the original are also counting as errors. Nevertheless, for semantical interpretation purposes these absolute positions are not necessary. The relative comparison demonstrates again the superiority of the wavelet method.

5 SUMMARY AND CONCLUSIONS

Compression techniques in the context of transferring data from satellite sensors to ground stations as well as for the further processing are a major development topic nowadays due to the dilemma between the captured huge amount of data and the technical restrictions. For example, the MOMS-02/D2 mission could only record about 35% of the theoretically available data.

For future systems with expected better spatial resolutions and larger swath widths compression rates larger than 10 should be aspired. Hence, lossy techniques like the well-known JPEG or a new method based upon wavelets have to be taken into account.

Examinations regarding effects on the geometrical accuracies and the information content have revealed that up to a compression rate of 15 both compression techniques are sufficient for most applications – at least when manual processing methods are used. With less restrictive demands even higher rates are acceptable.

It could be demonstrated that for the measurement as well as for the interpretation the human eye is not so much affected by the loss of high-frequency structures like automatic procedures that rely very much on these parts. Hence, automatic procedures are more negatively influenced by lossy compression operations.

Furthermore, the employed method based on wavelets was clearly superior against the JPEG method - especially for very high compression rates ($K > 50$).

Summarizing these results one can state that transformation encoding procedures and in particular the wavelet method are generally suited for applications within photogrammetry and remote sensing. They enable not only a higher amount of data to be transferred but also a more flexible, multi-resolution offer to the end-user.

Finally it has to be mentioned that in order to become operational these methods have to be developed further concerning the necessary computing times.

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