Adaptive Compression of Cartographic Images based on Haar's Wavelets

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Abstract
In most applications of image processing, the user is interested generally only in certain regions of the image. In these cases, it is reasonable to consider adaptive processing of different regions in the image.
In this work, we propose an adaptive image compression technique for still images using irreversible methods. After the selection of regions of interest, the approach consists in applying Haar's wavelets compression to these regions and classical losses JPEG compression to the context of the image. Testing this approach on cartographic images with regions of interest produced good results. Preliminary results revealed the superiority of adaptive compression in terms of compression ratio for comparable visual image quality. Moreover, when the context is compressed using losses JPEG, the Haar's wavelets method on regions of interest always outperforms the reversible LZ77 method in terms of compression ratio and visual image quality.

Keywords: Image processing, adaptive compression, regions of interest, Haar's wavelets, JPEG, LZ77.

1. Introduction
The image is the tool of choice in several fields such as medicine, multi-media and cartography. Its digitalization makes its transmission and storage reliable. Still, it is required that both transmission and storage devices have respectively high capacities and broad bandwidth [12]. The user is often only interested in a specific piece of information conveyed through the image, and it is this particular information which will be qualified as pertinent [4]. Moreover, an interesting compression approach consists of not degrading certain regions of interest while degrading other regions in the context in a controlled way. This suggests the use of an adaptive compression approach.
The adaptive approach is based on coding the scene by degree of importance with the help of various methods. The zones of interest can be detected manually or in a semi-automatic or automatic way. During the last decade, the adaptive compression has been used by many studies. In this context, Guisto and al. in 1990 [9] suggested a "smart" compression based on the use of a system which first locates the zones of interest. The compression phase consists of applying some techniques such as the vectorial quantification or polynomial approximation on these zones without worrying about losses. Nguyen [13] introduced an original method of selective compression of sequences of images classified by zones for transmission with very low flow. This method is based on the idea of level of interest affected at each zone of the scene in which the coder, which is of a hybrid structure, uses a global sub-band representation. The author gives a great emphasis on coding while the method does not allow control of the resolution of the filtered context. To overcome this problem, Benharrosh used an adaptive approach based on traditional reversible compression techniques associated with multi-resolution analysis. The objective is to transmit in an optimal way through a network of limited flow an image containing items preserved to full resolution in a low resolution context, while making it possible to avoid any potential loss of the zones of interest [3]. More recently, Albanesi used a model of human visual system that takes advantage of the space and the properties of frequency-localization of decomposition by wavelets to permit a quantification stage for each wavelet coefficient. In order to maintain the visual quality of the target image, his approach allows to the user to define arbitrarily formed zones of interest and allocate for each one a different quality factor [2]. The results obtained in these various works have incited us to test the performance of an adaptive method on the basis of irreversible compression techniques applied on the different zones of the image.
In this work, we are mainly concerned with the image quality in the zones of interest, the reconstructed image as a whole, and the...
compression ratio. Identification of the zones of interest will be done manually. Considering great success of wavelets in compression, we suggest applying a method based on Haar’s wavelets to the zones of interest. We applied the losses JPEG method on the context. We tested this approach on different images with one or many zones of interest. We compared the performance in terms of visual quality and compression ratio with those obtained by applying LZ77 method on the zones of interest. Further, we compared the results with those obtained with carrying out compression by Haar’s wavelets then by losses JPEG method on the whole image.

2. Methods

2.1. Adaptive compression concept

The proposed adaptive compression is directly concerned with the process of data exchange. This process consists of:

- A preliminary analysis of the data by the transmitter, who determines the qualified regions of interest;
- A manual or semi-automatic selection of the zones of interest;
- An adaptive compression of data to be transmitted or stored in such a way that the zones of interest are not degraded significantly.

After transmission or storage, synthesis or data reconstruction and analysis are performed. The first consists of reconstructing the transmitted data, which corresponds to data decompression stage [16]. The analysis consists of examining the transmitted data (zones of interest in a degraded context).

In an image with zones of interest, the image context must allow the user to comprehend the scene as a whole. Therefore, it is not necessary for the image to be represented with full resolution [18]. Moreover, it is possible for the user to choose to compress it strongly according to his/her own interest. The JPEG method with losses allows the user to have high compression ratios after carrying out smoothing and decimation [20].

2.2. Compression of the zones of interest

2.2.1. Extraction of the zones of interest

The objective is to introduce a method that can generate a low resolution image while keeping the user’s zone of interest intact. To achieve this, the preliminary stage consists of detecting then extracting it. Algorithms for extraction are not yet very reliable and need to be implemented and tested. On the other hand, the zones of interest in an image can differ greatly, requiring a study and implementation of various algorithms for extraction [6].

In this study, we chose to manually extract the zones of interest based on surface selection. This consists of selecting some squares, which are represented by three parameters for each zone: the first two locate it in the initial image (coordinates of the center \((x_i, y_i)\) and the side \(a_i\)), the third parameter corresponds to its intrinsic value in the image. That is to say, the radiometry of the pixels constitute the zone of interest (Fig. 1).

For the manual extraction of the zones of interest we chose the software LView Pro.
2.3.2. Compression by Haar’s wavelets method

The following figure shows the principle of compression by wavelets method:

![Fig.2. Principle of the image compression by wavelets](image)

**Algorithm**

One carries out a decomposition of the frequential and space image, by successive projections (in a recursive way in fact) on two orthogonal subspaces, one giving the general pace of the image (it acts of the image of half resolution) and the other the details. The subspaces are defined by an orthonormal base of vector, of which I explain construction further. Projection is done very simply, since one has an orthonormal base. It is not absolutely necessary to calculate scalar products.

To apply the Haar’s method, one could regard the matrix as a sampling, by putting his lines end to end. However one loses the bond with the columns. It is thus more effective to apply the Haar’s algorithm to the lines of the matrix then to its columns. This algorithm of differentiation and summation results in the matric multiplication using a matrix containing much of 0 [7].

Let us take the example of a matrix 4×4:

\[
\begin{bmatrix}
\frac{1}{2} & 0 & \frac{1}{2} & 0 \\
\frac{1}{2} & 0 & -\frac{1}{2} & 0 \\
0 & \frac{1}{2} & 0 & \frac{1}{2} \\
0 & \frac{1}{2} & 0 & -\frac{1}{2}
\end{bmatrix}
\]

It is called matrix A. Indeed it is noticed that if a matrix M is taken, let us suppose (a, b, c, d) its first line. Then the product of M by A gives us the following line.

\[
\begin{bmatrix}
a + b \\
c + d \\
a - b \\
c - d
\end{bmatrix}
\]

In the case of a matrix 8×8 the hollow matrix will take the following form.

\[
\begin{bmatrix}
\frac{1}{2} & 0 & 0 & 0 & \frac{1}{2} & 0 & 0 & 0 \\
\frac{1}{2} & 0 & 0 & -\frac{1}{2} & 0 & 0 & 0 & 0 \\
0 & \frac{1}{2} & 0 & 0 & \frac{1}{2} & 0 & 0 & 0 \\
0 & \frac{1}{2} & 0 & 0 & -\frac{1}{2} & 0 & 0 & 0 \\
0 & 0 & \frac{1}{2} & 0 & 0 & \frac{1}{2} & 0 & 0 \\
0 & 0 & \frac{1}{2} & 0 & 0 & -\frac{1}{2} & 0 & 0 \\
0 & 0 & 0 & \frac{1}{2} & 0 & 0 & 0 & \frac{1}{2} \\
0 & 0 & 0 & \frac{1}{2} & 0 & 0 & 0 & -\frac{1}{2}
\end{bmatrix}
\]

That is to say \( A = \frac{1}{\sqrt{2}} \)

And so on, does it of it is the principle already exposed in the compression of signal, i.e. that first half of the columns of the matrix represents the master sample and the second the details. Some is the row of the matrix, one can define his coefficients in the following way:

Either \( n \) the number of column of the matrix, \( n \) is even, \( i \) and \( j \) a positive entiities.

\[
\begin{align*}
A_{ij} &= \frac{1}{2} \text{ if } j \leq n/2 \text{ and } i=2j-1 \text{ or } 2j \\
A_{ij} &= \frac{1}{2} \text{ if } j > n/2 \text{ and } i=2(j-n/2) \\
A_{ij} &= -\frac{1}{2} \text{ if } j > n/2 \text{ and } i=2(j-n/2)-1 \\
\text{Else } A_{ij} &= 0
\end{align*}
\]

Thus some is the row of the matrix representing the image, one can easily define an algorithm, and thus build a program allowing to obtain the hollow matrix of compression.

To carry out the operation on the columns, it is enough to multiply on the left by transposed of A. We thus obtain a matrix \( N = (A^t)M^t \). Then a precision \( e \) is chosen, and one removes the coefficients of absolute value lower than \( e \) of matrix N. One thus obtains a new matrix \( N' \). One recovers the matrix M by posing:

\[
M' = (A^{-1})N^tA^{-1}
\]

One can reduce calculations while making the Matrix orthogonal. Thus the reverse of matrix A will be calculated easily. The vectors of A are already orthogonal compared to the Euclidean scalar product. It is thus enough to normalized.

Here it is thus enough to replace \( \frac{1}{2} \) by \( \frac{1}{\sqrt{2}} \) [7].

One can thus write matrix A like the product of orthogonal matrices while taking:

- Storage or transmission
- Reversible coding
- Quantification
- Wavelet Transform
- The source image
There are thus $A=A_1 \times A_2 \times A_3$, of this fact one can say that $A^{-1} = A_1^{-1} \times A_2^{-1} \times A_3^{-1}$.

The transformed image corresponds to multi-resolution analysis of the image, used in several layers. In each one, the geometrical dimensions are reduced at a rate of 2 per whole of the orthogonal filters (where the characteristics are determined by the wavelet family used). Thus, the result consists of 4 small images. One of them represents the source image (henceforth “smooth” image) while the 3 others contain information of high frequencies lost during the reduction stage (henceforth “detail” image). The passage from one layer to another is done through the reduced image (smooth), there are then, 4 times fewer points to treat: see Fig.3 [5].

The treatment is done by successive filterings on each image axis followed by a decimation (keeping one point out of two) Fig.4 [8].
The objective of the treatment resides in "detail" image characteristics which allow us to make use of efficient algorithm quantification. The analysis of these images reveals that they consist of many points of low value, which once forced to zero in quantification, will permit a strong compression ratio. However, the "smooth" image does not change (there is no quantification). Therefore, it is necessary to limit its size to reduce the data volume; a 5 layer treatment produces a "smooth" image that is 1024 times smaller than the original image [7].

2.3. General description of the method

Our adaptive compression method consists in applying the Haar's Wavelets who is an irreversible method but which gives good quality on the qualified zones of interest. To compress the context we applied losses JPEG method. Our goal is to have a good quality on the zones of interest and on the totality of the image, with a lower compression ratio, in order to solve the problems known on the storage mediums and the telephone infrastructures of transmission [21]. We used the language C to program our adaptive compression algorithm which is based on the Haar's Wavelets. In order to carry out our source codes developed in language C, we used the software "Dev-C++". Thus, for the calculation of qualities and the memory sizes occupied by the rebuilt images, we used the software "Compression Studio" and the software "XnView". The principle of the adaptive compression method based on the reversible method LZ77 which gives good quality on the zones of interest but with a compression ratio higher than that obtained after application of the Haar's Wavelets.

Figure 5 describes the methodology suggested. The compression ratio using this methodology will depend, first, on the size of the zones of interest as compared to the image size and second, on the reduction factor applied on the support. The suggested method stipulates treating each datum in an optimal way compared to its type.

2.3.1. Diagram of the introduced method
3. Results

We tested the adaptive method on a variety of cartographic images from the internet with manually selected zones of interest.

3.1. Compression of the zones of interest (branch1, Fig.5)

In all the images, we chose to consider the zones of interest as a binary mask allowing us to locate the centers and sides of the square in the image and an image file containing pixels radiometries constituting these squares.

The mask is compressed by means of Run Length Encoding [10] (the compression ratio is on average of order 10). The associated radiometries file is also determined by the Haar’s wavelets method (compression ratio higher than 20). We could also consider the zone of interest as a textual file containing the coordinates and radiometries of each element. However, this method is not valid unless the number of elements belonging to the zone of interest is very small as compared to the initial image size (lower than 1%). We notice that when the selection of the zones of interest is manual, it would be preferable to consider the binary mask as a vectorial file rather than an image in order to construct the mask [14].
3.2. Compression of the context (branch2, Fig.5)

Smoothing is carried out simply to make the algorithms more effective considering the increase in correlation between close pixels [17]. It is followed by context decimation, which leads to a large increase in the compression ratio on the context. However, it is necessary before decimation, to carry out diffusion in such a way to limit the effects due to spectrum folding up. It should be noted that the degradation level applied to the image during the diffusion is a function of the selected decimation factor [11].

Under-sampling as much as JPEG allows to compress the context in an important way. However, while considering the quality of the reconstructed image, it is better not to under-sample and apply a JPEG very strongly [15], [19]. The applied JPEG compression after decimation produces block effects. Nevertheless our method allows us to apply the JPEG method with losses on the context, and consequently obtain a much smoother image and additionally offer, a better compression ratio and a better quality.

In order to evaluate the decimation performances in term of compression in a theoretical way, we have used the theoretical curves in figure 8, which show the evolution of the compression ratio according to the under-sampling factor applied on the context and on the size percentage of the zone of interest compared to the whole image. In case the user chooses to compress only the zones of interest without transmitting, for instance the degraded context, he obtains the “limit” curve, according to the importance of the zone of interest as compared to the image [1]. In our case, we found that for an image with 5% of the points belonging to the zone of interest, an under-sampling factor equal to 4 yields a compression ratio on the order of 10.

3.3. Comparison of our approach with the JPEG method with losses, the Haar’s wavelets method and the adaptive method based on LZ77

3.3.1. A case of one zone of interest

![Fig.8. Theoritical compression ratios obtained according to the under-sampling factor](image-url)
Image compressed by Harr's Wavelets
Format: JPG-JFIF
Size of file: 7915 bytes
Quality: 0.80
Definition: 229(H) x 199(V) pixels
Bits by Pixels: 24
Resolution: 96(H) x 96(V) dpi

Image compressed by losses JPEG
Format: JPG-JFIF
Size of file: 6642 bytes
Quality: 0.80
Definition: 229(H) x 199(V) pixels
Bits by Pixels: 24
Resolution: 96(H) x 96(V) dpi

Image compressed by the adaptive method based on the LZ77
Format: JPG-JFIF
Size of file: 6582 bytes
Quality: 0.80
Definition: 229(H) x 199(V) pixels
Bits by Pixels: 24
Resolution: 96(H) x 96(V) dpi

Image compressed by introduced method
Format: JPG-JFIF
Size of file: 6496 bytes
Quality: 0.80
Definition: 229(H) x 199(V) pixels
Bits by Pixels: 24
Resolution: 96(H) x 96(V) dpi

Z.I. compressed by LZ77
Format: JPG-JFIF
Size of file: 479 bytes
Quality: 0.80
Definition: 23(H) x 23(V) pixels
Bits by Pixels: 24
Resolution: 96(H) x 96(V) dpi

Z.I. compressed by Haar's wavelets
Format: JPG-JFIF
Size of file: 407 bytes
Quality: 0.80
Definition: 23(H) x 23(V) pixels
Bits by Pixels: 24
Resolution: 96(H) x 96(V) dpi
3.3.2. A Case of two Zones of interest

Image compressed by Haar's wavelets
Format: JPG-JFIF
Size of file: 7593 bytes
Quality: 0.80
Definition: 229(H)x199(V) pixels
Bits by Pixel: 24
Resolution: 96(H)x96(V) dpi

Image compressed by losses JPEG
Format: JPG-JFIF
Size of file: 7926 bytes
Quality: 0.80
Definition: 229(H)x199(V) pixels
Bits by Pixels: 24
Resolution: 96(H)x96(V) dpi

Image compressed by the adaptative method based on LZ77
Format: JPG-JFIF
Size of file: 7401 bytes
Quality: 0.80
Definition: 229(H)x199(V) pixels
Bits by Pixels: 24
Resolution: 96(H)x96(V) dpi

Image compressed by introduced method
Format: JPG-JFIF
Size of file: 7318 bytes
Quality: 0.80
Definition: 229(H)x199(V) pixels
Bits by Pixels: 24
Resolution: 96(H)x96(V) dpi
3.3.3. A Case of three Zones of interest

Image compressed by Haar's wavelets
Format: JPG-JFIF
Size of file: 9319 bytes
Quality: 0.83
Definition: 229(H)x199(V) pixels
Bits by Pixels: 24
Resolution: 96(H)x96(V) dpi

Image compressed by losses JPEG
Format: JPG-JFIF
Size of file: 9729 bytes
Quality: 0.83
Definition: 229(H)x199(V) pixels
Bits by Pixels: 24
Resolution: 96(H)x96(V) dpi
We notice that the application of our adaptive method and that using LZ77 give good quality, but concerning compression ratio our approach is superior to that of each one of these methods.
Table 1: A comparison of the introduced method, given by the Quality and the Size of the compressed image, with the adaptive method using LZ77, losses JPEG method and method based on the Haar’s wavelets.

<table>
<thead>
<tr>
<th>Image/Method</th>
<th>Original Size in bytes</th>
<th>Traditional methods</th>
<th>adaptive Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>losses JPEG</td>
<td>Haar's Wavelets</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quality of file</td>
<td>Quality of file</td>
</tr>
<tr>
<td>Cartographic image1 (JPG-JFIF)</td>
<td>7953</td>
<td>0.80</td>
<td>6642</td>
</tr>
<tr>
<td>Cartographic image2 (JPG-JFIF)</td>
<td>9091</td>
<td>0.80</td>
<td>7926</td>
</tr>
<tr>
<td>Cartographic image3 (JPG-JFIF)</td>
<td>11161</td>
<td>0.83</td>
<td>9729</td>
</tr>
</tbody>
</table>

Table 2: A comparison between the Haar’s wavelets and LZ77 compression of the zones of interest on the various images tested.

<table>
<thead>
<tr>
<th>Zone of interest</th>
<th>Original Size in bytes</th>
<th>Compression method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LZ77</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quality of file</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quality of file</td>
</tr>
<tr>
<td>Cartographic image1 (JPG-JFIF)</td>
<td>Zone1</td>
<td>494</td>
</tr>
<tr>
<td>Cartographic image2 (JPG-JFIF)</td>
<td>Higher Zone</td>
<td>564</td>
</tr>
<tr>
<td></td>
<td>Lower Zone</td>
<td>526</td>
</tr>
<tr>
<td>Cartographic image3 (JPG-JFIF)</td>
<td>Left Zone</td>
<td>521</td>
</tr>
<tr>
<td></td>
<td>Intermediate Zone</td>
<td>520</td>
</tr>
<tr>
<td></td>
<td>Right Zone</td>
<td>512</td>
</tr>
</tbody>
</table>

4. Conclusion

We have suggested the adaptive method concept. It resides on the fact that the user is generally interested only in some parts of the image.

We have come to the conclusion that an interesting approach resides on a degradation of certain zones of interest, which is imperceptible to the naked eye, and a controlled degradation of the context. The selection of the zones of interest can be done either in a supervised way or not. The suggested method of compression can integrate some multi-resolution analysis techniques in a very sophisticated way together with some existing compression techniques (with or without loss). It enables the user to consider each datum in an optimal way according to its type. Consequently, the user obtains relatively high compression ratios and a higher quality image. As we have pointed out, using our method, we obtain
a good quality with a compression ratio higher than that of the adaptive method using LZ77, losses JPEG and the Haar's wavelets method.

The automated methods for extracting the zones of interest have the advantage of controlling the resolution of the filtered image. However, their application opens is very heavy (management of a great number of images, “detail” images and resolution images degraded in the same size as the initial image as it is the case of the Wavelet Transform by Holes W.T.H). However, these methods do not allow synthesis to whatever scale.

We are considering extending this research work by applying the wavelets package and the combining fractals and wavelets on the zones of interest.

REFERENCES