A Novel Lossy and Lossless Image Compression System with Multilevel Scalability

F. A. Perez, P. M. Iriondo, D. Orive, I. Calvo

***Abstract*—** his article presents an image compression system with multilevel scalability capacity based on the Reversible Wavelet Transform (RWT). Two types of scaling methods are discussed: Spatial scaling and Fine Grain Scalability (FGS). The presented approach uses the same algorithm (based on a finite arithmetic reversible transform) for both lossy and lossless compression. The codification method, based on a methodology presented in previous works (CETRO), generates an embedded binary stream highly scalable which may be adapted to a specific size by using truncation. Also a component rearrangement mechanism which introduces a substantial improvement over the truncation mechanism is used. This mechanism allows consistent scaling from both analytical and perceptual points of view. Finally, the scaling mechanism allows a FGS compression without using a decoder in the encoding stage.

***Keywords*—** Image compression, reversible wavelet transform, scalability, FGS, VBLm, CETRO.

I. Introduction

THE transmission of images and video requires mechanisms to scale the transmitted information adapting it to a variety of available resources, such as the transmission bandwidth. The availability of these resources varies due to technological and channel congestion reasons.

Typically, scalable systems use a multilevel structure, which may be of two types: *self-contained levels*, where every level contains a complete description of the original information being independent of the other levels; and *base plus enhancement levels* (Fig. 1), where an elementary level exist (*base level*) from which the decoder is able to reconstruct a first approximation of the original information, and several additional levels improve its quality.

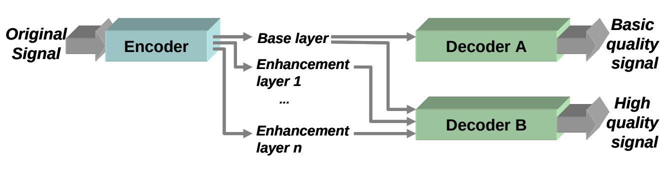

Fig. 1- Multilevel scalability

Manuscript received March 20, 2007. Revised manuscript received June 13, 2007. This work has been supported in part by MCYT&FEDER under project DPI 2002-2399. And in other part by ETORTEK, AmIGUNE.

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Even though the discrete cosine transform (DCT) has proven efficient enough for compression systems, it is not suitable for a scalable codification. Hence, other methods should be used.

Since 1993, when Shapiro [3] proposed the general structure of EZW and later, in 1996, SPITH [4] was introduced, the discrete wavelet transform (DWT) has been applied to the image and video compression field by means of the decomposition method of Mallat [5], leading to standards such as JPEG2000 [9]. In order to produce reversible compression algorithms, some DWT encoders [10, 11] use non-lineal integer to integer transforms [7, 8], such as the Reversible Wavelet Transform (RWT) used with the lifting schema proposed by Sweldens [6].

The use of the DWT in a pyramidal decomposition in subbands allows the distribution of the transformed coefficients into a final bistream. This subband based distribution permits a direct scaling in resolution. However, most traditional encoders based on DWT use hierarchical set partitioning which do not provide an efficient scaling method.

Taubman [1] discusses the scalability characteristics of EBCOT (predecessor of JPEG2000), both in resolution as in quality.

The properties of a scalable codification for JPEG2000 are analyzed by Bilgin and Marcellin [2] extending the perspectives of reversible transforms.

This article follows with a brief overview of the *CETRO* compression methodology, previously presented in [13, 14]. Next, the scaling approach, which is based on a component rearrangement method, is introduced. Latter, spatial scalability and FGS scaling methods are discussed. Also in the article, some tests are proposed to analyze the performance of the proposed algorithm showing the obtained results. The article concludes with some conclusions.

II. General Description of the Compression System

This section presents a brief introduction to the whole *CETRO* compression system. The basics of the system are covered in [13, 14] in greater detail.

The *CETRO* system carries out the compression of the images in several stages (see Fig. 2). The first stage of the CETRO system consists of the application of an integer-to-integer reversible wavelet transformation (RWT) to the input image. The coefficients obtained from this transformation may be quantified, depending on whether the loss of information is acceptable. Next, the coefficients obtained from previous stages are encoded by means of a codification method known as *"Codification in Function of the Partitioning in Subcomponents"* (CFDS) [13]. This type of codification is a modification of the bit significance codification (used in some compression standards, such as JPEG2000 [9]) that allows the coding of integer values dividing the whole resolution into different fields (subcomponents). In the following stages, the components obtained from the CFDS codification are linealized and reorganized by means of an alignment algorithm consisting of the arrangement of the components based on their resolution. This process is highly configurable being possible to adapt to different levels of quality (known as *importance levels*). Finally, the components of every importance level are encoded by means of an entropic code system of variable length (*VBLm*) that allows the generation of an embedded bitstream that encodes a static compressed image.

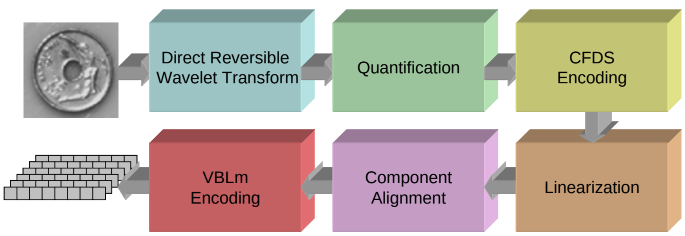

Fig. 2 - General description of the compression system.

III. Multilevel Scalability

The bitstream generated by the CETRO compression system after the alignment algorithm has an embedded nature as long as the distribution of the coefficients enforce the concentration of the highest levels of the energy of the signal in the initial part of the bitstream, always depending on the used alignment mechanism. The generated bitstream is structured in several importance levels that are encoded by means of the VBLm algorithm.

A. Adaptation of the Bitstream to Multilevel Scalability

The length of the encoded importance levels obtained from the multilevel scalability algorithm is variable depending on several factors such as the size of the image, the dispersion of energy of the image, the number of levels of the wavelet decomposition or the used alignment algorithm.

This algorithm generates an embedded bitstream that may be truncated in almost any point without impeding the complete reconstruction of the image, although with bigger or smaller degradation in function of the quantity of energy that remains in the truncated bistream. Typically, the first generated package corresponds to the basic scaling level, whereas the successive packages enhance the quality of the image. These packages, known as components, contain one, part or several importance levels that use the same VBLm structure.

In fact, this algorithm permits the concrete localization of the information in the bitstream obtained from the VBLm encoder. Thus, it is possible to restore completely or in part the wavelet coefficients. Also, keeping in mind the highly spatial component of the transformation wavelet, it is possible to recompose the original image without having all the coefficients. It may be assumed that every generated package is an elementary and consistent unit of the image that, by itself, is able to reconstruct the complete image with better or worse quality in function of the number and precision of the components used.

The multilevel scalability algorithm may use two possible mechanisms to create the embedded bitstream:

1) *Truncation and definition of the truncated length*: The embedded bitstream contains the basic level whereas the successive ones, which are truncated at certain point, contain the enhancement levels.
2) *Segments rearrange*: This mechanism is based on the application of the structure of the VBLm frame shown in Fig. 3. Every package begins with the definition of the VBLm frame and the length of the VBLm frame is adapted from the size of the package. In this case there is no truncation of the VBLm frame but a division of contents to form two VBLm frames from the original one.

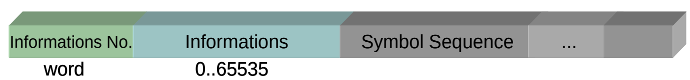

Fig. 3 - VBLM frame structure.

The first mechanism, so-called *CETRO-D* (*CETRO-Direct*), will be used in the simplest cases whereas the mechanism of segments rearrange, so-called *CETRO-FGS* will be used for finer scaling. It is convenient to remark that from the point of view of implementation the mechanism of truncation is always available since the lost symbols are supposed as zeros.

B. Segments Rearrange Method

The segments rearrange method [14] is really a packing process. From the VBLm bitstream corresponding to the successive importance levels, this method selects the VBLm information necessary to complete the size of the bitstream of the package.

In the packing process remains the order of the importance levels, so that if an importance level is not included in a package, it will be included, if possible, in the following package.

The selection of the VBLm information is carried out depending on its resolution, higher resolution means more energy and, therefore, bigger image information. The information is sequentially selected starting from its position in the treated importance level.

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The underrated information is converted into null resolution segments (*dummy segments*) so that, although it does not imply load of symbols in the final bitstream, it remains load of information in the VBLm frame structure.

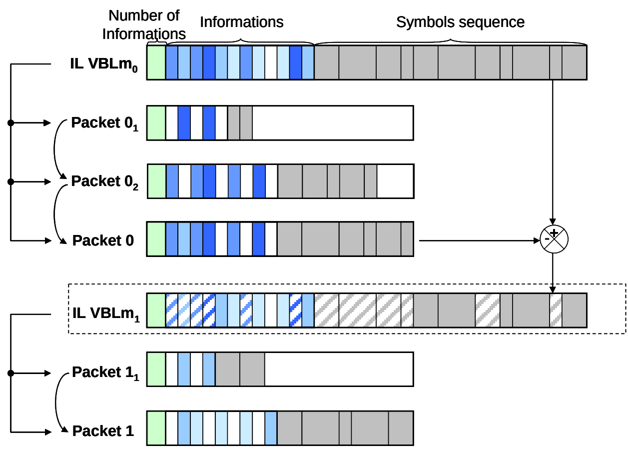

Fig. 4 - Packing with segments rearrange.

C. *Basic Images and Enhancement Images*

The packets generated in the packing process can be treated as images. This is part of the characteristic of *consistency* of the system. Since the components are structured as VBLm frames, the localization of the subcomponents in the wavelet decomposition matrix is immediate and, therefore, it is possible to apply the inverse wavelet transform in any moment independently of the quantity of available information (*analytic consistency*). This method also allows the reconstruction of the original image with real information starting from any packet (*perceptual consistency*).

Two types of reconstruction images can be distinguished:

1) *Basic Images*: They contain, at least, the basic level of scaling package with a zero scaling level.
2) *Enhancement Images*: They only contain enhancement packets with a scaling level superior to zero.

An image is structured in several hierarchical levels so the final bitstream, both for basic and scaled images, is also structured in several layers (Fig. 5).

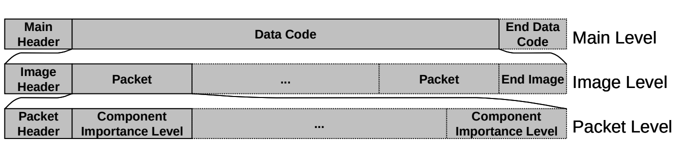

Fig. 5 - Multilayer image structure.

IV. Spatial Scalability

Systems based on wavelet transforms are suitable for using spatial scalability with octave-based resolution increments due to their multiresolution nature. Precisely, Mallat presented in [5] a fast transform method to decompose an image into a pyramidal structure with an inherent spatial scalability.

However, most compression systems that use the wavelet transform, mainly those that use it in hierarchical set partitioning with entropic coding on bit planes, do not provide spatial scalability inherently.

This paper presents a compression system that even though it is not specially designed to support spatial scalability, allows spatial scalability when several conditions are satisfied:

a) *Use of levels of spatial scalability in powers of two*: This condition is related to the multiresolution nature of the fast wavelet transform when the Mallat decomposition is applied.
b) *Selection of a suitable system of components alignment*: The main obstacle for using spatial scalability is the alignment mechanism in subcomponents planes. Depending on the type of alignment mechanism used, the energy of the transformed coefficients mixes among the different subbands derived from the wavelet transform

It is possible to choose from different mechanisms of subcomponents alignment, some of them adapt perfectly to the scalable spatial nature, others could work with spatial scalability whereas others directly are not suitable.

V. FGS Scalability

The FGS scalability is a scalable method in quality where the enhancement level can be adjusted dynamically to the channel requirements.

In the FGS system every scaling level is associated to a different package. For the construction of the packages, the FGS system uses the segments rearrange method, as it permits the adaptation of the bitstreams obtained by the VBLm code of the importance levels to sizes of certain packages.

The FGS scalability maintains the same structure in packages, packing process and representation of basic and enhanced images that was presented in the multilevel scalability section.

A. *Architecture of the FGS System*

In traditional implementations of FGS encoders (Fig. 6), the coefficients of the enhance layer are obtained from the subtraction between the coefficients of the original signal and the coefficients obtained after reconstructing the basic level signal information. The main reason for this is that the coding mechanisms used for encoding the basic level are not designed for the realization of a FGS encoder.

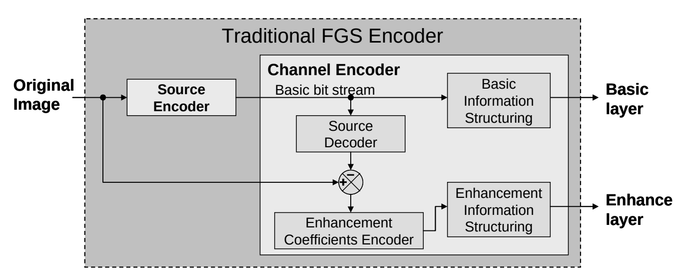

Fig. 6 - FGS Traditional Encoder.

The system proposed in this work allows obtaining the enhanced layer coefficients directly from the FGS system without previous reconstruction of the basic level signal information (see Fig. 7). Thus, the coefficients used in the subsequent levels of improvement are not residuals but elements coming directly from the general encoder. The FGS system understands each other then like a direct extension of the code system and not like an additional element.

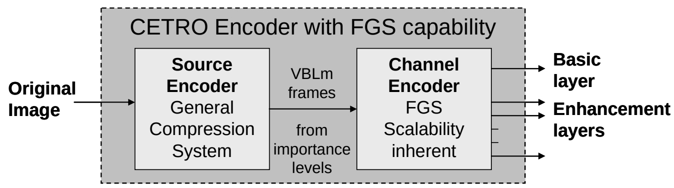

Fig. 7 - CETRO-FGS Encoder.

B. *Characteristic of the FGS System*

Usually, FGS systems use two channels: one for basic information and another for enhanced information. However, the proposed FGS system allows different combinations between basic and enhancement levels.

Also, this FGS scalability system presents the following characteristics:

a) The basic package is limited to a selected size.
b) The enhancement package may be limited to a concrete size.
c) Determination of an enhancement package of undetermined size (in case there is only one enhancement package).
d) Possibility of several enhancement levels.

C. *FGS Compression with and without Losses*

The FGS scalable system developed allows lossy and lossless coding (Fig. 8). When both types of compression are required, the basic compression algorithm generates a bitstream, in which quantification, entry points in alignment [14] or truncated of the bitstream are avoided.

The proposed FGS system is reversible and therefore it does not lose any information.

The use of a basic package of indefinite length belongs together with a direct compression without losses in which enhancement levels are not used, that is to say it gets lost the scaling capacity.

The use of a basic finite package and one indefinite enhancement package for the FGS is the traditional approach. This approach requires two channels to send the information: One is used to send the basic package with concrete size fixing the quality of elementary reconstruction whereas the other is used to send refinement packages. If the enhancement package has indefinite length, it could be truncated to be adapted to the capacities of the channel, but introducing information losses.

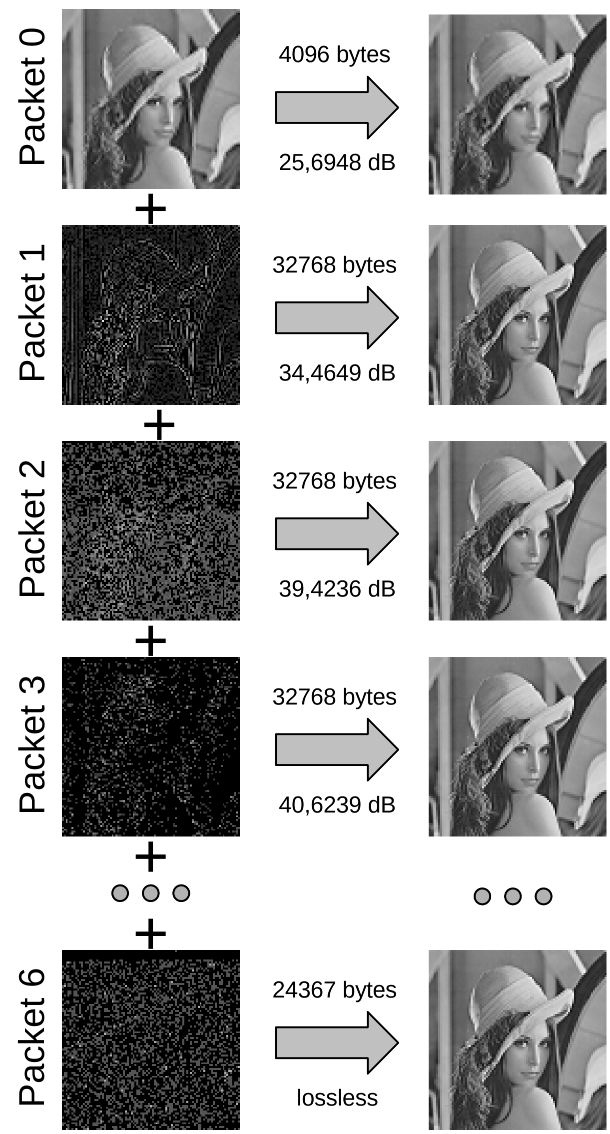

Fig. 8 - FGS Scalability for Lena encoding.

VI. TEST AND RESULTS

This section compares the performance when different compression algorithms are used with several images in PNM format. Two of these algorithms were presented in previous sections, namely, *CETRO-D* (*CETRO-Direct*) is the compression algorithm without scalable behaviour (described in section 3) whereas *CETRO-FGS* is the compression algorithm with Fine Grain Scalability (also described in section 5).

The main characteristics of the compression system are: It is used the RWT SP transformation with 5 levels of decomposition without pre-processing [14]. Quantification of components is not used. A code relationship CFDS of 4:4 is used [13]. The alignment mechanism is in stairway without entry points [14].

A. *Adaptation of the Capacity of the Compression System*

This test evaluates the performance of a lossy compression system when segment rearrangement is carried out. The obtained results are compared with the performance obtained in traditional systems.

In CETRO-D the bitstream is truncated in order to obtain a wished compression factor whereas the CETRO-FGS algorithm obtains the wished compression factor by definition of the length of the basic level package.

The figure (Fig. 9) represents the general results of the media compression with losses for each one of the compression systems.

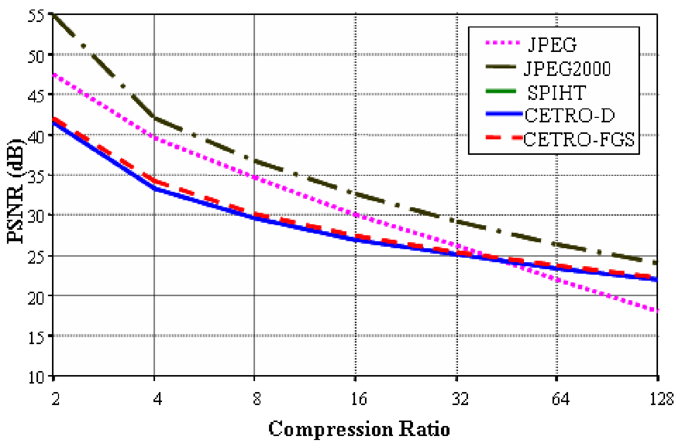

Fig. 9 - General results for lossy compression.

B. *Increment of the Reconstruction Quality with FGS*

This test discusses the results obtained when the FGS algorithm is applied to a group of images.

The size of the packages has been fixed as follows: the basic level package has a size of 1/128 of the original image size; the enhancement level packages have a size of 1/16 of the original image size; the number of enhancement levels is unknown until a lossless compression is achieved.

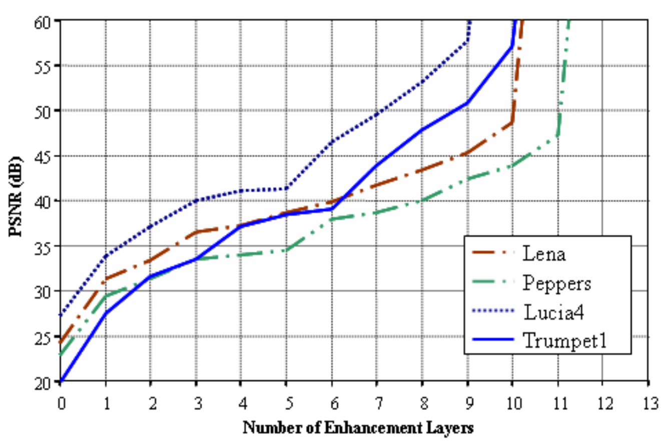

Fig. 10 - Increase of the reconstruction quality with FGS.

In Fig. 10 it is possible to observe that with the configuration parameters specified above, with less than 13 packages the image can be reconstructed in all cases without any loss. Each enhancement package improves the image reconstruction.

VII. Conclusions

This paper presents an image codification system with scalable capacity that allows both lossy and lossless codification by using the same structure.

The proposed approach is based on the segments rearrange achieving a substantial improvement in the efficiency of the encoder.

The presented FGS system allows a multilevel encoder which is simpler than traditional multilevel encoders.

One of the main advantages of this codification system is that allows both lossy and lossless image coding, providing at the same time a scalable codification system in which perfect reconstruction may be achieved.

The present coding system does not offer large results in rate compression for conventional multimedia systems. However, its high scalable capacity makes it valid to be used in applications of transmission with very small or very variable bandwidth.

This approach may be used in applications where images must coexist at the same time with different degrees from quality. Also, this compression system may be used in index image systems.

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