An improved compression scheme dedicated to multispectral images telebrowsing

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Abstract

The topic of this paper deals with coding methods dedicated to progressive telebrowsing of multispectral images. In previous works, we have proposed a general subband decomposition scheme with perfect reconstruction which has the merit of exploiting simultaneously the spatial and the spectral redundancies of multispectral images. In this paper, we provide a specific decomposition able to code four-component images. Furthermore, we discuss the opportunity of a preprocessing stage. Finally, we evaluate the performances of the proposed coders on SPOT images.

Key words

Lossless coding, spectral and spatial decorrelation, progressive reconstruction.

1 Introduction

Multispectral images are valuable sources of information for several applications such as target imaging, geology, ... The continuous improvement of remote sensing systems yield to the production of increasing amounts of images. Thus, managing such a huge volume of data becomes a real challenge. Therefore, efficient image compression techniques have to be applied. Generally, for storing purposes, a perfect reproducibility of the data (in other words, lossless coding) is required. Besides, progressive reconstruction is a desirable feature for telebrowsing through images databases. Nonlinear subband decompositions [10, 4, 6, 8] provide a compact pyramidal exact representation of the input image. The decomposition called $c_{2,2}$ has been retained in the lossless mode of the standard JPEG 2000 [7]. But, in the case of multispectral images, after a preprocessing, the spectral compo-

nents are decomposed separately. Obviously, a better compression ability could be achieved if the spectral correlations are exploited. In a recent work [2], we have proposed a nonlinear hybrid subband decomposition scheme with exact reconstruction. Its main merit is the decomposition scheme itself incorporates hybrid (spatial and spectral) predictors. The contributions of this paper is two-fold. First, another hybrid subband decomposition is investigated. Secondly, the interest of adding a monoresolution preprocessing is discussed. The remainder of this paper is organized as follows. In Section 2, we present the hybrid hierarchical and reversible decomposition tool we are using. In Section 3, the problem of spectral decorrelation as a preprocessing step is addressed. In Section 4, experimental results are given and some conclusions are drawn.

2 Proposed interband decomposition

2.1 Multiresolution intraband decompositions

First of all, let us describe the nonlinear intraband decomposition tools which are at the origin of our work. Figure 1 shows a class of nonlinear M-band decomposition schemes proposed in [6]. Exact reconstruction holds for any operators $\mathcal{B}_i$, $\mathcal{C}_i$ and injective operators $\mathcal{A}_i$ for $i \in \{1, \dots, M\}$ [6]. Such subband decomposition with perfect reconstruction is a very appealing tool for generating multiresolution decompositions. The $\mathcal{B}_i$'s decorrelate the input signals and the $\mathcal{C}_i$'s smooth the associated input. Extension to 2D signal is handled in a separable manner. With this decomposition structure, it is possible to describe the most important lossless coders based on nonlin-

ear multiresolution analyses [1]. Indeed, the concept of lifting developed by Sweldens *et al.* [4] corresponds to a structure which is included in this scheme with $M = 2$. Several examples of such operators have been already tabulated in [4]. In the following, $c_{N,\tilde{N}}$ denotes the wavelet transforms with N (resp. $\tilde{N}$) vanishing moments of the analyzing (resp. synthesizing) high-pass filters. The S+P transform is another compelling transform proposed by Said and Pearlman [10].

2.2 The interband extension

Now, let $\{s(n)^{(b)}\}_{b=1,\dots,B}$ be a multicomponent signal. In a recent work [2], we proposed to take the even and odd samples of its *several* approximation bands at resolution level j as the $M = 2B$ inputs of the decomposition scheme:

$$\forall b \in \{1,\dots,B\}\ x_b(n) = s_j^{(b)}(2n),\ x_{b+B}(n) = s_j^{(b)}(2n+1).$$
(1)

The outputs are classified into prediction errors $d_{j+1}^{(b)}$ and the approximation coefficients $s_{j+1}^{(b)}$:

$$\forall b \in \{1,\dots,B\}\ y_b(n) = s_{j+1}^{(b)}(n),\ y_{b+C}(n) = d_{j+1}^{(b)}(n).$$
(2)

For 2D signals (multispectral images), a separable decomposition is performed. Although the dependences existing between the bands could be extracted by a wide class of nonlinear operators, linear filters followed by rounding operations (denoted by $\lfloor \cdot \rfloor$) are more tractable. As was pointed out in [2], some conditions must be satisfied concerning the supports of the considered filters in order to guarantee an exact reconstruction.

2.3 A new interband decomposition

We have already proposed efficient decompositions for three-component images such as the one decomposition described in [3] (denoted by DEC3). Here, we develop another decomposition (denoted by DEC4) for the case of four-band images ($B = 4$) like those provided by SPOT4. The first band b_0 is predicted in a purely spatial mode with the $c_{2,2}$ transform [4]. The remaining bands are predicted according to:

$$d_{j+1}^{(b_i)}(n) = s_j^{(b_i)}(2n) - \lfloor \mathbf{p}_i^T \mathbf{s}_j^{(b_i)}(n) \rfloor,$$
(3)

where

$$\mathbf{s}_j^{(b_1)}(n) \triangleq \begin{pmatrix} s_j^{(b_0)}(2n) \\ s_j^{(b_1)}(2n-1) \\ s_j^{(b_1)}(2n+1) \end{pmatrix}, \qquad \mathbf{p}_1 \in \mathbb{R}^3$$
(4)

$$\mathbf{s}_j^{(b_2)}(n) \triangleq \begin{pmatrix} s_j^{(b_0)}(2n) \\ s_j^{(b_1)}(2n) \\ s_j^{(b_2)}(2n-1) \\ s_j^{(b_2)}(2n+1) \end{pmatrix}, \qquad \mathbf{p}_2 \in \mathbb{R}^4$$
(5)

$$\mathbf{s}_j^{(b_2)}(n) \triangleq \begin{pmatrix} s_j^{(b_0)}(2n) \\ s_j^{(b_1)}(2n) \\ s_j^{(b_2)}(2n) \\ s_j^{(b_3)}(2n-1) \\ s_j^{(b_3)}(2n+1) \end{pmatrix}, \qquad \mathbf{p}_3 \in \mathbb{R}^5.$$
(6)

For all the bands b_i, the update operations are expressed as follows:

$$s_{j+1}^{(b_i)}(n) = s_j^{(b_i)}(2n-1) + \lfloor u_i(d_{j+1}^{(b_i)}(n-1) + d_{j+1}^{(b_i)}(n)) \rceil.$$
(7)

where $u_i \in \mathbb{R}$. The reversibility of DEC4 can be easily shown.

3 Opportunity of a pre- or post-processing

Generally, a spectral decorrelation is performed *before* or *after* the spatial decomposition. For example, a multiresolution intraband scheme of depth J can be first applied separately on each band. Then, the spectral correlations existing between the $3J + 1$ resulting subbands can be exploited by a purely Spectral Predictor (SP) described in [8]. A SP is applied on each B-uplets of subbands which have the same resolution level and the same orientation. Alternatively, it is possible to add preprocessing operators before the DEC3 or DEC4 decompositions. Color transforms associated with the RGB model can be used. Indeed, SPOT images are obtained in the green, red and near red-infrared wavelengths. So, each image plane may keep some physical meaning if a RGB model is considered. However, some caution should be taken in the choice of such operator in order to ensure a perfect reconstruction. Indeed, it is well known that the Karhunen-Loève Transform (KLT) is the optimal linear transform that decorrelates the components of a random vector. Unfortunately, KLT is a lossy transform when a finite precision is used for arithmetic operations. In [12], a lossless transform approximating the KLT was presented. Very often, it is preferred to apply fixed (image-independent) integer to integer decorrelating transforms as the T transform [9] or the Original Reversible Color Transform (ORCT) [5]. The ORCT is an integer to integer approximation of the traditional conversion RGB-YCrCB. Its advantages are two-fold: ORCT reduces successfully the psychovisual redundancy in a color image and it is very easy to implement with a low computational complexity. These are the reasons why ORCT has been adopted in the JPEG-2000 standard [7] as a preprocessing stage. Here, we propose to extend the ORCT

transform to the B-band case as follows:

$$\begin{cases} t^{(1)} & \triangleq & \left\lfloor \dfrac{(B-1)s^{(b_0)} + s_{b_1} + \cdots + s^{(b_{B-1})}}{2(B-1)} \right\rceil \\ t^{(2)} & \triangleq & s^{(b_1)} - s^{(b_0)} \\ & \vdots & \\ t^{(B)} & \triangleq & s^{(b_{B-1})} - s^{(b_0)}. \end{cases}$$

(8)

where $(s^{(b_i)})_{i=0,\ldots,B-1}$ is the original multiband image and $(t^{(i)})_{i=1,\ldots,B}$ is the resulting multicomponent image. In the sequel, we will denote the Generalized-ORCT by the acronym G-ORCT.

4 Experimental results

Experiments are carried out on two sets of SPOT3 ($B = 3$) and SPOT4 ($B = 4$) images. They are formed by B components XS1, XS2, XS3 (and possibly XS4) of size 512×512, coded at 8 bpp (see Fig.2). When DEC3 (resp. DEC4) are applied to SPOT3 (resp. DEC4) images, band ordering is a great issue in the decorrelation procedure. Since XS1 and XS2 are highly correlated, it is recommended to order the bands either by taking $(b_0, b_1) = (1, 2)$ or $(b_0, b_1) = (2, 1)$. In each case, the image is decoded and the losslessness of the scheme is systematically controlled. For the pyramidal schemes, it is recommended to limit the number of stages of the decomposition in the context of progressive transmission because the receiver is not able to recognize rapidly and reliably images of small size at a coarse resolution. Thus, on each image, we performed only four-stages decomposition. The compactness of the resulting representations is firstly measured by the sum H of the entropies of each spectral component as indicated in Tab. 1 and 2. The first lines of these tables highlight the self ability of the preprocessing to (spectrally) decorrelate the images. The initial value of the entropy has decreased dramatically after an ORCT (or a G-ORCT) or a T transform. The relative poor performances of the KLT could be explained by the nonstationarity of the underlying images. It could be expected an improvement with a block-based transform. As expected, the interband decompositions DEC3 and DEC4 outperform clearly the intraband decompositions (S+P and $c_{N,\bar{N}}$) since the latter do not exploit any spectral correlation. The outperformance of the new interband decomposition DEC3 and DEC4 holds in both cases: with or without a preprocessing stage. It is worth noting that preprocessing stage based on the ORCT is more favourable to $c_{2,2}$ than to DEC3. The main reason is that DEC3 is able to capture efficiently and simultaneously the spectral and the spatial redundacies. Finally, for real compression schemes, entropy coders must be applied to the resulting hierarchical representations in order to exploit the residual redundancies. Therefore, it is possible to compute the

average bit rate r (in bpp) of the resulting bitstream. The Embedded Zerotree Wavelet (EZW) designed by Shapiro [11] generates an embedded bitstream which allows a gradual reconstruction of the original image. Figure 3 shows the sequence of the resulting average bit rates at each step of the encoding algorithm for DEC4 and $c_{2,2}$. Again, it is noted that DEC4 allows a valuable savings in term of bit rate. The final bit rate are 3.9888 bpp for $c_{2,2}$ and 3.3647 bpp for DEC4 (without any preprocessing).

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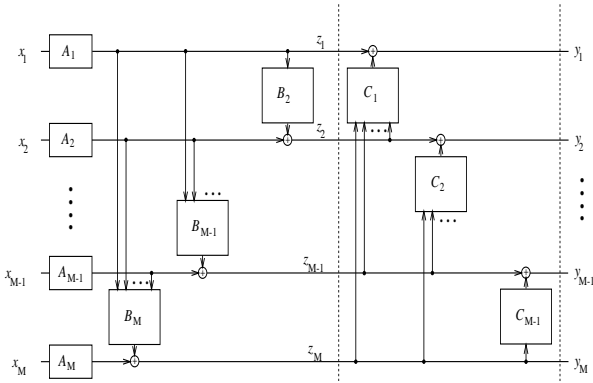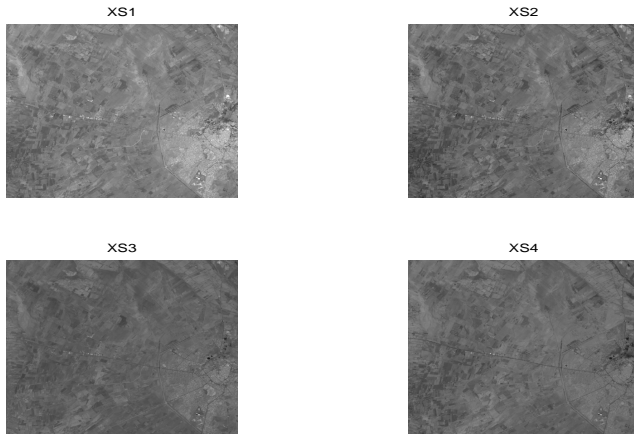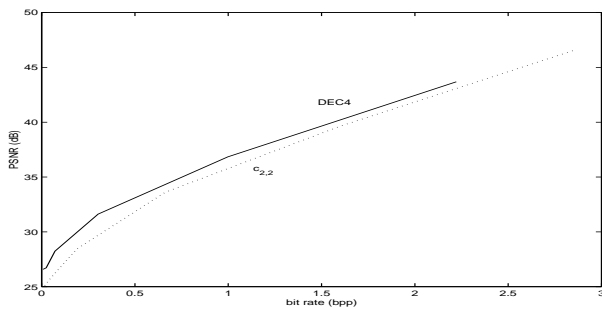
Figure 1: Nonlinear M-band decomposition structure.

Table 1: SPOT4 image: resulting entropies. ORCT then $c_{2,2}$ means that the ORCT is applied only to the three first components and XS4 is not preprocessed.

Decomposition	H
Original	23.3259
G-ORCT	20.7152
SP	19.1667
S+P	15.8924
$c_{2,4}$	16.1935
$c_{4,2}$	15.9205
$c_{4,4}$	15.9373
$c_{6,2}$	15.9708
$c_{2+2,2}$	15.9538
$c_{2,2}$	16.0848
ORCT then $c_{2,2}$	14.7855
DEC4	**15.0113**
G-ORCT then DEC4	**14.6821**

Figure 2: Original spectral bands of "Kairouan". (a): band 0, (b): band 1, (c): band 2, (d): band 3.

Figure 3: Rate-distortion function.

Table 2: SPOT3 image: resulting entropies of lossless coders.

Decomposition	H
Original	21.2296
ORCT	19.0414
T transform	19.0090
Lossless TKL	19.5349
S+P	14.7972
$c_{2,4}$	14.9744
$c_{4,2}$	14.8328
$c_{4,4}$	14.8440
$c_{6,2}$	14.8599
$c_{2+2,2}$	14.8332
$c_{2,2}$	14.9787
$c_{2,2}$ then SP	13.8461
ORCT then $c_{2,2}$	13.4880
DEC3	**12.9663**
ORCT then DEC3	**12.9590**