An Adaptation of shape adaptive wavelet transform for image coding

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Abstract: *We propose a method for coding of segmented images based on shape adaptive wavelet transform approach. Wavelet transform is computed directly on particular image segments without extension outside the boundaries. We adapted the transform method from [1], where it was used for compression of image segments but less effective zero tree coding was involved. Though used approach does not yet outperform the non-segmented methods in the sense of MSE, the visual quality of image segments is comparable. We propose also an alternative adaptation with comparative results, which can be used with classical DWT implementations.*

Keywords: *wavelet, object, segment, adaptive transform, SPIHT, zero tree*

1. Introduction

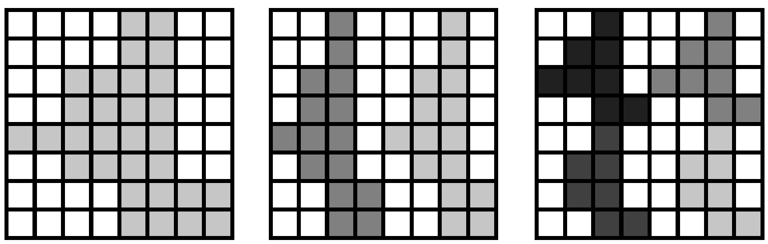
In recent years the area of interest is moving from the compression of images to the compression of objects and regions of interest in the images. Many methods can be used to identify the objects in the image and retrieve image segments. In the text below are the words object and segment used interchangeable.

Most of the methods compute the transforms on rectangular areas circumscribing the object, optionally using data extrapolation [2][3] outside the object. However this approach introduces redundancy of the spectrum, which should be properly (maybe iteratively [2][4]) optimized. Optional approach can be the same as in SADCT (rows and then columns are shifted to the left upper corner of bounding box and transformed), but the lack of these methods is that shifting of pixels causes the loss of the spatial correlation between them, which has negative effect on the quality of the reconstructed object. We refer to this method as “SADCT like”.

Rather than using extrapolation or shifting of image pixels we use a wavelet transform which is computed directly on rows and columns of the object, thus no extrapolation is needed and in transform process only the object’s pixels are affected. One implementation of this type of DWT was presented as Shape Adaptive Wavelet Transform (SADWT) in [1]. In this article we couple the SADWT approach with effective SPIHT coder. Additionally we present another SADWT approach performing comparable to [1], but using classical DWT kernel.

2. SADWT

The SADWT works strictly on the object and is never computed outside its boundaries. The object is during transformation viewed as a set of rows and columns, whose relative positions must be preserved in each decomposition level. The proper row/column positioning is the crucial part of SADWT algorithm. This handling allows the transform to make the best of the spatial correlations between adjacent pixels in the object. Finally, spatial correlations between different sub-bands can be utilized by the well known SPIHT [5] algorithm and an embedded stream can be produced. Fig. 1. shows an example of object representation during calculation in detail.



a) b) c)

Fig. 1. Object representation during one level SADWT calculation: a) Original b) Low pass (L) and High pass (H) part after SADWT calculation on rows of (a). c) Low pass (LL, LH) and High pass (HL, HH) parts after SADWT calculation on columns of (b).

In each stage of decomposition are first processed all rows of the object with the well known 1D DWT. The sub sampled low pass (LP) and high pass parts (HP) are combined into one spectrum using positioning method. After, a similar technique is used on all columns. The process can be iteratively repeated. The object's boundaries must be known exactly to make the positioning possible. There are some known possible "effectivity" problems that could be caused, by "thin" parts of objects in the image. In those parts, the maximum decomposition level is reached first. We don't stop the decomposition here, but let the following decomposition steps to "copy" the energy to lower sub bands only.

The transforming of rows and columns directly is accompanied with the problem of the positioning of their decomposed and sub sampled parts. With even start offset of the row/column this isn't a problem, since their transformed offsets (LP and HP part) can be calculated as start offset (e.g. beginning of the row/column) divided by two (Fig. 1. is such a case). With odd start offsets gets the situation a bit more complicated, since the resulting transformed offsets have to be integer numbers. The positioning of the coefficients can be generally handled in several ways as shown in the Table I.

3. Positioning of spectral coefficients

Method (A) does not make special handling when calculating transformed offsets and the calculation does not regards the possibility of an even start offset. This leads to the shifting of the rows/columns with odd start offset (distortion of the outer shape of the object) and to the lost of spatial correlation of the pixels within the object (distortion of the inner shapes). This effect is cumulative in the levels of object's wavelet decomposition and is an important quality factor of the reconstructed object. Even though, that it is possible to suppress the outer distortion of the object (C), the inner distortion cannot be eliminated when rows/columns have an odd start offset.

To suppress all these effects we can use an additional coefficient on the left/upper side of the row/column to make it start with an even offset (D), then a SADWT approach with classical kernel can be used. Other possibility is to use a SADWT approach with an adapted kernel.

Table I - Positioning methods

	Transformed offset (LP,HP) calculation using start offset N* $\left(\left\lfloor \frac{N+i}{2} \right\rfloor, \left\lfloor \frac{N+j}{2} \right\rfloor\right) \quad i,j = \{0,1\}$	**Outer shape**	**Inner shapes**	**Spectrum properties**
(A)	i=0 and j=0	May be distorted	May be distorted	Non redundant
(B)	i=1 or j=1	No sense: undesired overlaps or gaps		
(C)	i, j depending on the start offset (N) and length of the segment in the current row/column (L)	Undistorted	May be distorted	Non redundant
(D)	i=0 and j=0 (Rows/columns padded to have even start offset, fixed sub sampling is used)	Undistorted	Undistorted	Non redundant solution possible
(E)	i,j depending on the start offset (N) and length of the segment in the current row/column (L) with adaptive sub sampling [1]	Undistorted	Undistorted	Non redundant solution

*) The transformed HP part is shifted into HP sub band.

4. SADWT with adaptive sub sampling (SADWT-AS)

This method as described in [1] uses adaptive sub sampling scheme to avoid loss of spatial correlation between pixels. In cases with an even start offset a so called even sub sampling is used, that means the row/column is transformed using classical kernel (rows/columns are transformed using even sub sampling for DP and odd sub sampling for HP coefficients). The cases with odd start offset are handled with odd sub sampling scheme. That means DP samples are obtained from odd spectral coefficients and HP samples are obtained using even coefficients. This has the same effect as a phase shift i.e. moving the odd start row/column to an even index and the total number of coefficients in the spectrum is the same as there is the number of pixels in the image. This permits to preserve the spatial correlation between object's rows/columns with odd/even start offsets.

5. SADWT with fixed sub sampling (SADWT-FS)

To compensate the odd start offset, a coefficient can be padded to have an even offset start. This introduces a low redundancy into the spectrum. Since the object's boundaries are known before calculation, the redundant pixels can be uniquely identified on the each level of the reconstruction and can be removed in the reconstruction process. More over, the knowledge of the boundaries offers a possibility to completely remove the redundancy (by exploiting the dependency of padded values from known boundary pixel values). Our tests showed that complete redundancy removal is inefficient - increases the complexity without notable improvement of compression efficiency. The process is shown on Fig. 2.

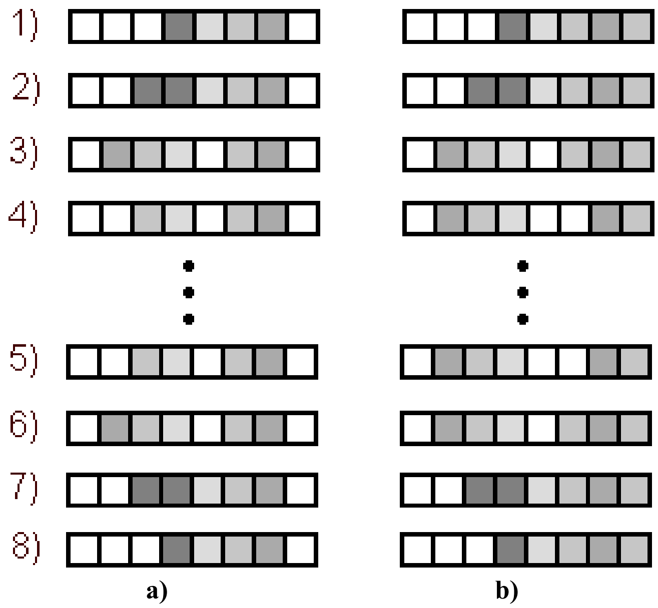
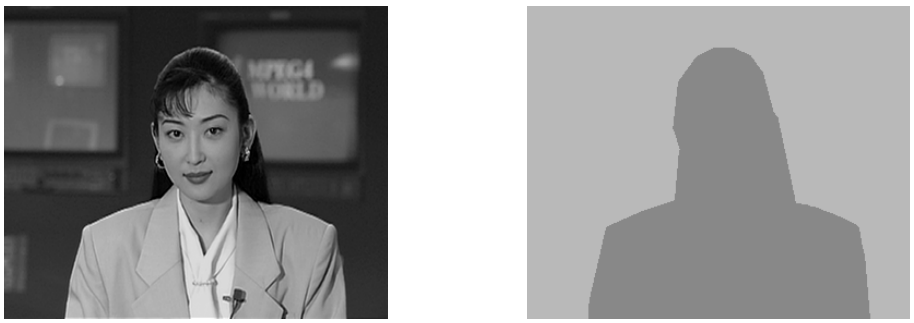


Fig. 2. Padding a signal with odd length a): The signal has odd start offset N=3 (1), it is padded (2) for example with the left most value and transformed to corresponding LP and HP part (3), the "redundant" LP coefficient is removed (4) e.g. set to zero. The reconstruction continues later at (5), and the missing coefficient is padded in that way (6), that after reconstruction the two most left coefficients will be the same (7), finally the padded coefficient is removed in the reconstructed signal (8). Padding of signal with even length shows b). In that case a redundant HP coefficient is removed.

6. Results

We tested the both SADWT methods by comparing them to "SADCT like" object wavelet transform approach and classical non segmented SPIHT approach. The boundary information is not included in the bitrate. The SADWT was coupled together with effective SPHIT binary coder adapted for coding of segments. The segments (background and foreground) transformed by SADWT (set of FBI9/7 filters was used to obtain non expansive wavelet representation) were separately encoded by a modified SPIHT algorithm which encodes only the spectral coefficients that belong to the object and ignores the rest [6]. The Akiyo image with two segments, as shown on the Fig. 3. was used. Segments were obtained with an unsupervised segmentation method [7].

We present the image compression results in the sense of achieved PSNR at various bitrates. One can clearly see that the SADWT methods are superior to the “SADCT like” wavelet transform approach because of the preservation of spatial correlation of the object’s pixels. The performance of the non segmented approach is better at the first look. However the visual quality at object boundaries is significantly improved. Additionally, effective bitrate control possibility for the each object is obvious. Result summary is in the Table II, sample of compressed images can be seen on the Fig. 4.



a) **b)**

Fig. 3. Akiyo image a) and segment mask b) used for compression

Table II – Compression results [PSNR]

Method \ Bitrate [bpp]	SPIHT	“SADCT-like” approach	SADWT-FS	SADWT-AS
1	45,0114	38,3654	41,2437	41,5265
0.5	40,2228	33,7938	36,0554	36,2772
0.25	35,3241	30,6925	32,1846	32,3703
0.125	31,3202	28,3309	29,2184	29,5423

a) **b)**

Fig. 4. Compressed Akiyo image at 0,25 bpp. a) SPIHT b) SADWT-AS

7. Conclusion

We have presented an Adaptive wavelet transform suitable for compression of image objects. The approach enables to code single objects in the image independent from the other without using extrapolation techniques. The modified SPIHT encoder outperforms the same method using zero tree encoding approach in [1]. The alternative approach with fixed sub sampling (SADWT-FS) produces comparable results and can be used with common existing hardware realization of DWT. The main advantage of SADWT is that it preserves spatial correlation of the pixels in the object and the method as described above is an efficient way how to deal with segmented image.

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