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Color Image Processing Using Complex Wavelet Transform

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Abstract – Discrete wavelet transform became a powerful method for signal processing in the last decades. One of the most important applications of this tool is compression, for the bi-dimensional signals, JPEG 2000 being an example. Complex wavelet transform offers improved directionality compared with classical discrete wavelet transform but it is redundant. The paper presents an experimental study that refers to R, G, B images compressed with complex or classical wavelet transform. This study wants to emphasize the tradeoffs between redundancy and improved directionality of complex wavelet transform in compression field. For this study we used for compression Embedded Zero-Tree Wavelet (EZW) algorithm proposed by Shapiro. The experimental results discussed at the end of the paper have been realized for lower and higher bit rates for both transforms. The whole work is intended to find reliable methods for applying Dual-Tree Complex Wavelet Transform (DTCWT) in JPEG 2000 standard.
Keywords: complex wavelets, compression, JPEG 2000

I. INTRODUCTION

The discrete wavelet transform (DWT) [1], [2], [14], have been developed in the last decades and became an important method for signal processing.

It was applied successfully in compression applications, including image compression, in this sense a new standard JPEG2000 [3], [4], [5] being developed by the researchers community.

The heart of the JPEG2000 standard is DWT, which is the most important stage in image compressing chain. JPEG 2000 standard specify for DWT the 9/7 taps filters for lossy compression or 5/3 taps filters for lossless compression. It is known that images present features or details along many directions. Related to this property, DWT emphasizes the details only after three directions. This fact makes DWT to have poor directionality. To eliminate this, the researchers started to develop new transforms with

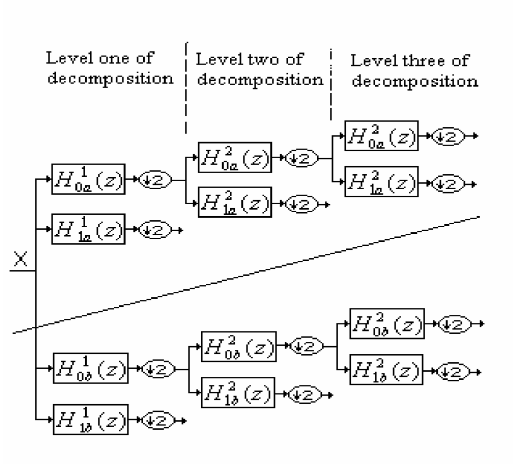

Figure 1. DTCWT for one-dimensional case

more directions that will hopefully perform better in the compression field. After a tremendous work Kingsbury [6], [7], [8] propose a new transform with improved directionality.

He called it Dual Tree Complex Wavelet Transform (DTCWT), because uses two DWT in parallel trees. Two branches decompose the signal independently as it can be seen in figure 1. Finally, the subbands from both trees are combined in a proper manner attaining six subbands with complex coefficients oriented at $\pm 15^0$, $\pm 45^0$ and $\pm 75^0$. Figure 1 presents the block scheme for the one-dimensional DTCWT case, where $H(z)$ represents the Z-domain of the filters used in decomposing the signal. More details about how the filters can be choused can be read in [9], [10].

II. COMPRESSION SYSTEM

The new transform, DTCWT, detects the details over more than three directions comparing with DWT,

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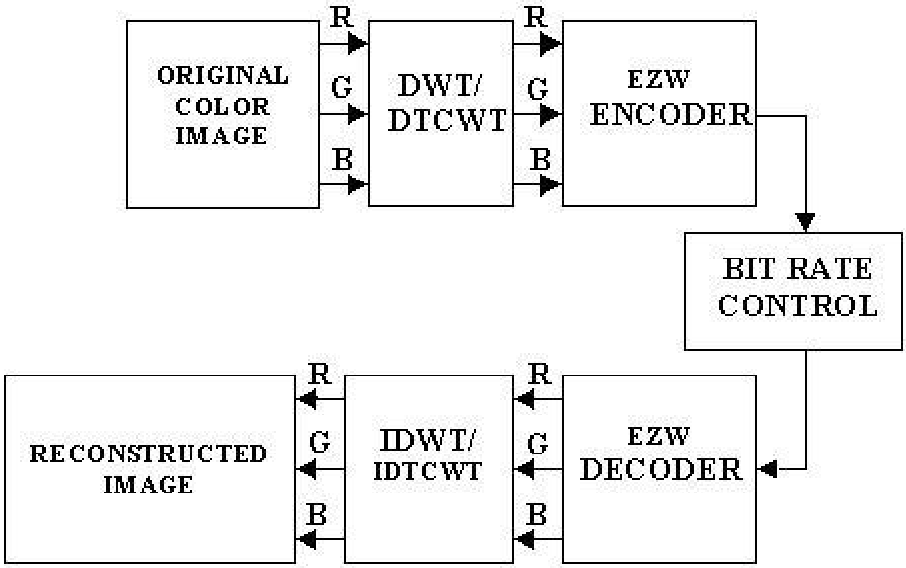

Figure 2. Bloc scheme of compression system

which is an important advantage for compression applications.

The process of coding and decoding an image is showed in the figure 2. For the beginning images suffer a decomposition process into R, G, B plans. Then, DWT or DTCWT are applied to every color plane while for coding we used (EZW) algorithm, proposed by Shapiro [12] specifically to code the wavelet coefficients. It is well known the fact that after the discrete wavelet decomposition is performed, for bi-dimensional signals, four subbands are resulting (LL, LH, HL, HH) at every level of decomposition.

For every coefficient from a low subband corresponds a set of four coefficients in the next higher subband, all those characterizing the same area of the image but at a different scale. These coefficients can form a zero-tree [12] if the root and all its descendants are insignificant related to a threshold. A zero-tree is labelled on only two bits in EZW algorithm thus a large number of coefficients being coded for high values of the threshold. After the image is decomposed in subbands, it is necessary to scan the coefficients in a predetermined way to reduce the information needed to the decoder. There are two methods for doing this: raster and Morton scan, presented in figure 3. Although the quality of final reconstructed image depends on the way that coefficients are scanned, in our study we used only the Morton scanning method. Some problems appeared when we tried to apply EZW algorithm to subbands resulted from the DTCWT decomposition. This is because we have no order relationship between complex coefficients and real numbers that are the thresholds.

Real subbands can be made from complex coefficients of DTCWT. This is based on the way that complex subbands are obtained [6], [7].

In [13] a detailed 2D decomposition scheme is described. Thus from complex subbands oriented at $\pm 15^0$ a real subband can arise combining these coefficients. The algorithm is presented in figure 4.

"*Complex subband 1*" refers to the $+15^0$ while "*Complex suuband 2*" to the -15^0. The same is with the other subbands oriented at $\pm 45^0$ or $\pm 75^0$. The process is repeated at every level of decomposition and ensures that three real subbands arise from the six complex subbands. After the transformation from complex to equivalent real subbands is complete, we can apply EZW algorithm similar with the case of DWT. Combining complex subbands in this way, the property of ascendant and descendent coefficients is preserved. Next operation is to control the budget of bits used to code the wavelet coefficients, an increased number of bits meaning that almost or all the coefficients have been coded while less bits used lead to sending only a part of them. Having the received coefficients, IDWT or IDTCWT is applied depending on the transform used in the coding part. In this way we get the reconstructed image.

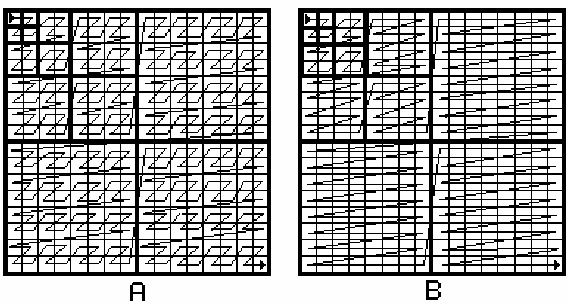

Figure 3: Scanning methods: A) Morton; B) raster

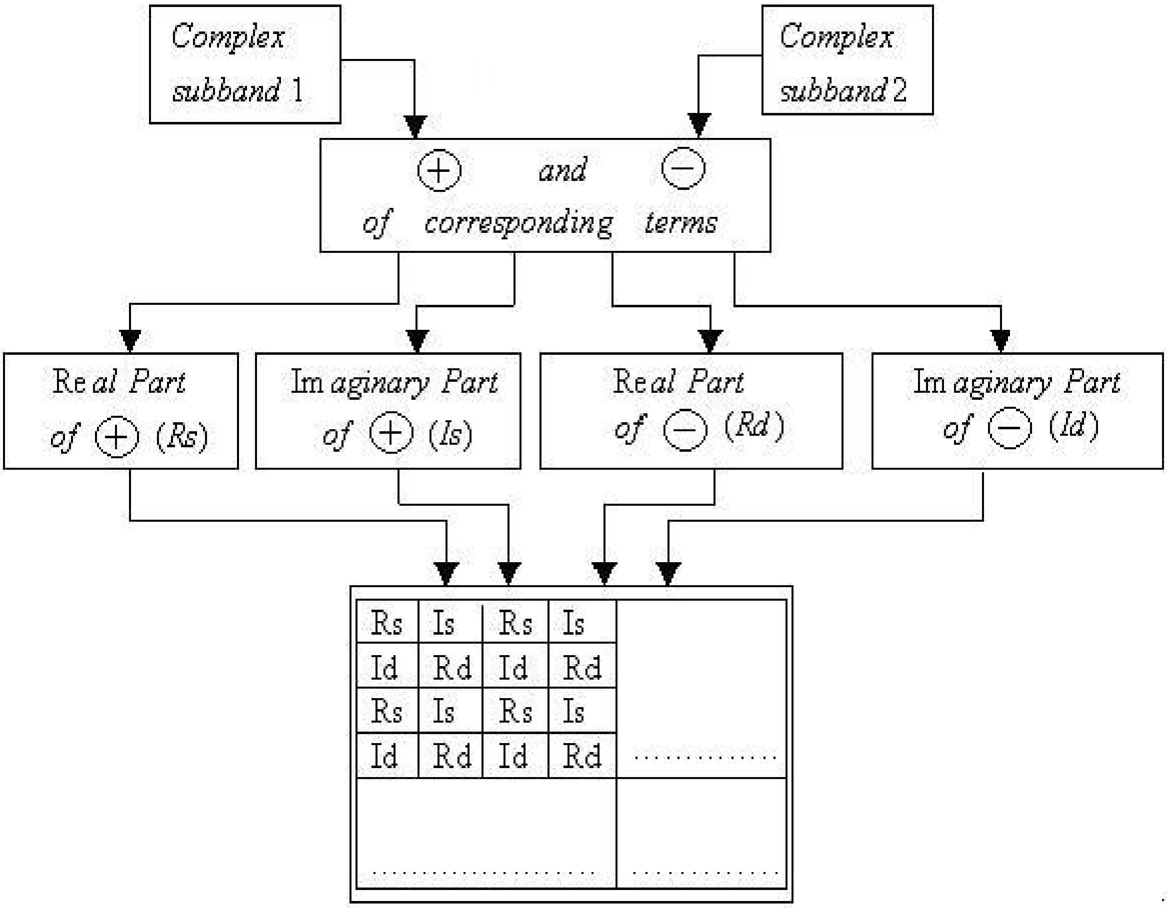

Figure 4. Illustration of the method in order to obtain a real subband

Note that the quality of reconstructed image will be affected by the bit budget scheduled in our experiments. As this budget is increased, more coefficients will arrive at the decoder and reconstructed image will approximate better the original.

III. EXPERIMENTAL RESULTS

Some of our experimental results regarding compression of colored images with complex wavelet transform are presented next.

In our previous paper [11] was shown that using complex wavelet transform in compression applications could lead to satisfactory results for some bit rates.

DTCWT transform is a redundant transform [6], which is an undesired property for compression applications where redundancy is not wanted and at a first look most researchers dropped out their studies of using redundant transforms in compression field. Indeed, redundancy is a disadvantage against classical transform DWT.

On the other hand a redundant transform provides more coefficients non-zero compared with a non-redundant transform (DWT). Also, in compression applications, it is desired to have a lot of coefficients that are non-zero instead of having zero coefficients. This fact can be viewed as an important and undoubtedly advantage of DTCWT over the DWT in compression.

Another important reason that leads to our studies and make us trying DTCWT in compression is that this transform retains the details over the six directions. Compared with the three directionality of DWT, the new transform offers more important information.

Knowing that in an image the details are oriented at different degrees we think that preserving details over the six directions leads to an improved image.

Now that the motivations for applying a redundant transform in compression applications were presented lets see the results obtained in our study.

We have done many tests and simulations of our compression system presented in figure 2. We thought that before replacing DWT with DTCWT in JPEG 2000, it is better to simulate this easier system, having in this way an idea of what is being to happen.

The system was tested for a large variety of standard test images in two situations: with DWT or with DTCWT in order to compare these two processings. Our principal goal was to see how the system works at different bit rates. Second goal was to see if the different filters used in both DWT and DTCWT influence the quality of processed image. We started our experiments with low bit rates

As it can be seen in figures 5 and 6, first two images in each figure, at bit rates sized between 0.5bpp and 1bpp, DWT perform better than DTCWT.

Here the differences and the qualities of reconstructed images are not good comparing with the original, no matter how transform is used, but especially when we used DTCWT.

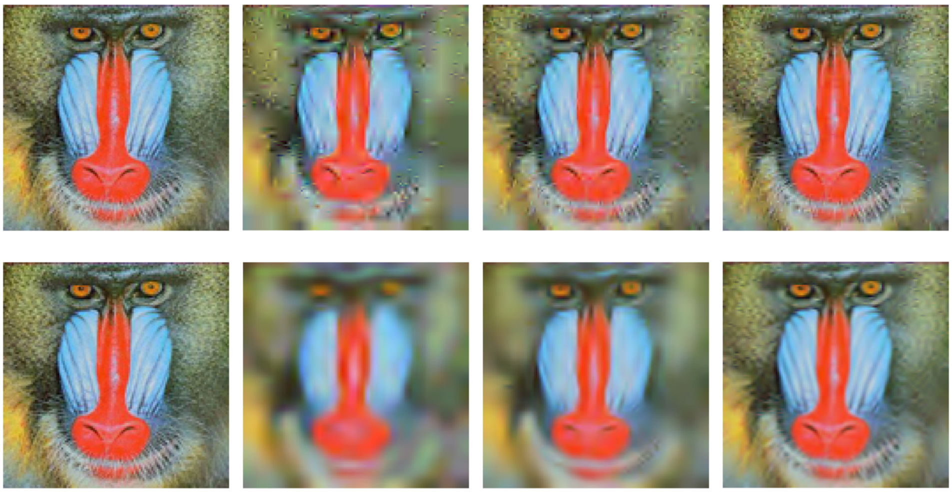

Figure 5. Baboon: from left to right: first row: original image; image compressed using DWT, at: 0.5bpp; 1bpp; 1.5bpp second row: original image; image compressed using DTCWT, at: 0.5bpp; 1bpp; 1.5bpp

Figure 6. Peppers: from left to right: first row: original image; image compressed using DWT, at: 0.5bpp; 1bpp; 1.5bpp second row: original image; image compressed using DTCWT, at: 0.5bpp; 1bpp; 1.5bpp

This is an expected result and it is explained by the redundancy of DTCWT. This situation is encountered around of a 1.3 - 1.5bpp values of bit rate.

Starting with 1.5bpp value of the bit rate, the images processed with DWT or DTCWT are visually very closed. For the “baboon” image in figure 5 the differences are almost invisible. In case of “peppers” the final result with DTCWT is more blurred than image compressed with DWT.

The study showed us that around this value colored images decomposed with DTCWT are visually slightly worst than those decomposed with DWT but at higher bit rates indicates no significant differences when it is used DWT or DTCWT decomposition. It is worth to mention that we haven’t take into consideration bit allocation procedure. As future works we will focus on improving even these results by considering this procedure. Figures 7 and 8 presents for the same “baboon” and “peppers” images the R, G, B color planes of compressed images at this bit rate.

As we have written before, the second goal was to verify if different pair of filters influences the final results.

In this direction we tested 5/3 and 9/7 pairs of linear phase filters for the DWT, while for the DTCWT we used in the first level the same 5/3 and 9/7 and for the following levels “q-shift” filters designed by Kingsbury [8].

We found that the differences are not significant, for every option finding the same critical bit rate, or slightly around, where DTCWT start to perform better than DWT.

Unfortunately, although DTCWT delivers details along six directions, at lower bit rates the redundancy property affects the performances of the compressed images.

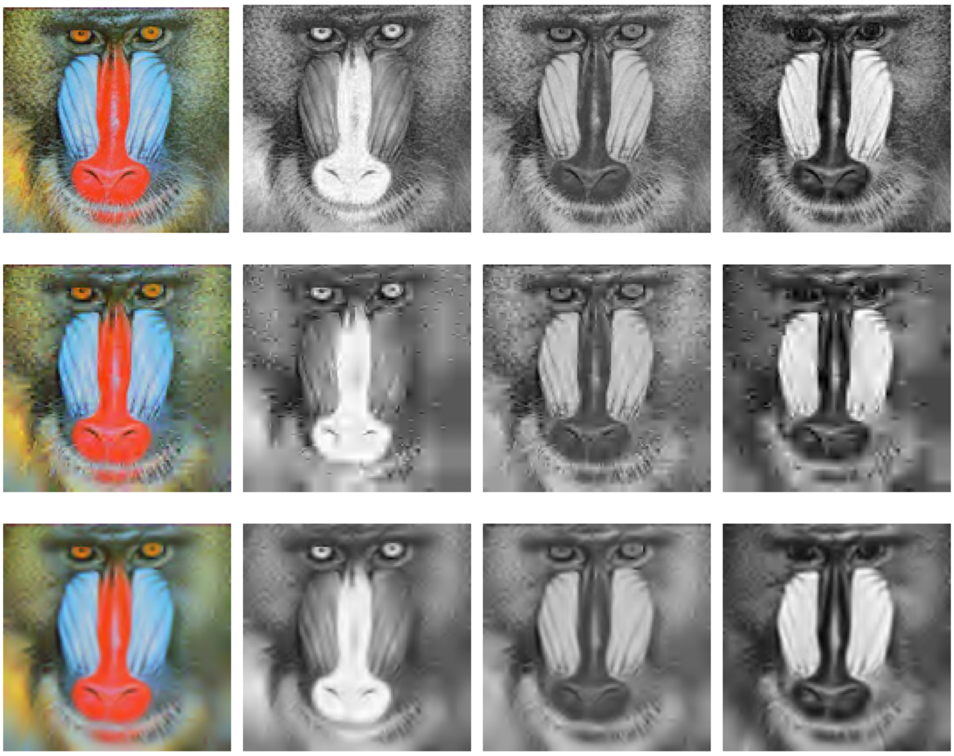

Figure 7. Baboon: from left to right: first row: original image and original R, G, B color planes. Second row: compressed image and compressed R, G, B color planes at 1.5bpp using DWT; Third row: compressed image and compressed R, G, B color planes at 1.5bpp using DTCWT

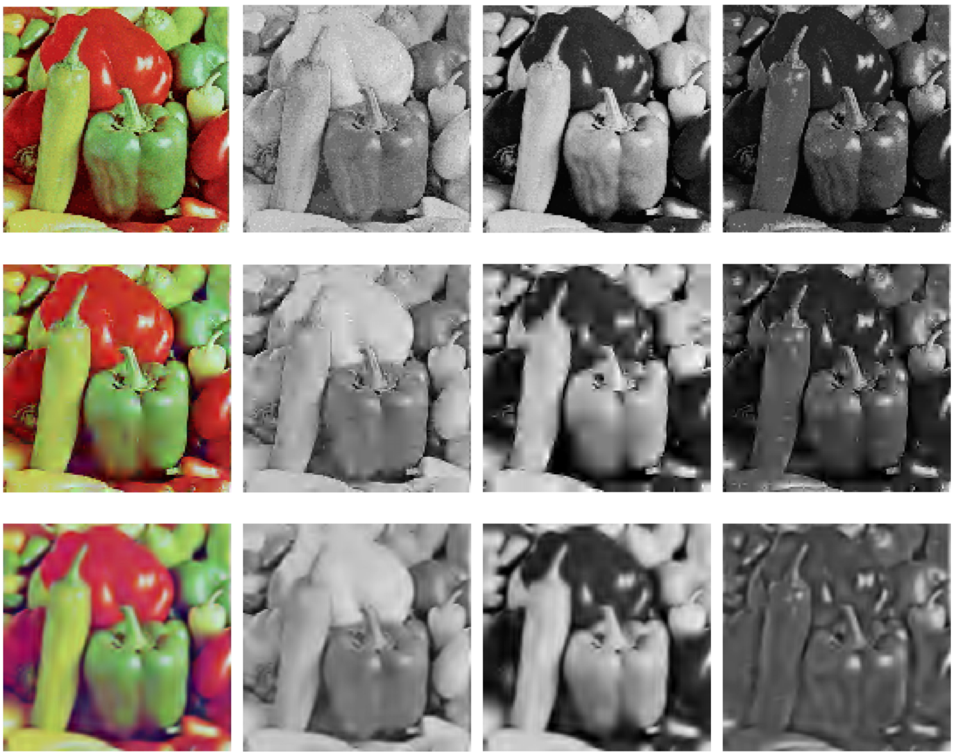

Figure 8. Peppers: from left to right: first row: original image and original R, G, B color planes; second row: compressed image and compressed R, G, B color planes at 1.5bpp using DWT; third row: compressed image and compressed R, G, B color planes at 1.5bpp using DTCWT

IV. CONCLUSIONS

The paper presents a study of applying complex wavelet transform in compression applications. For this, was simulated a compression system that used EZW algorithm to compress wavelet coefficients. In case of complex wavelet transform that supply complex coefficients there is a need of a pre-processing stage where coefficients are mixed for getting real numbers. Combining complex coefficients in the way showed in figure 4, the property of ascendant and descendent coefficients is preserved.

Our study focused on finding the point when we can use DTCWT instead of DWT in decomposition stage, in image compression application. For this we found out that there is an interval around 1.5bpp where the quality of reconstructed images is very bosom no matter what transform is used in decomposition step. Below this value we cannot apply DTCWT successfully because of redundancy, which seems to restrict the useful of it only at higher bit rates. We can say that the redundancy covers the advantage offered by DTCWT of those six oriented subbands.

Also, these partially satisfactory results are obtained without taking into account bit allocation procedure that could improve the quality of compressed image.

Another point in our study was to see if different pairs of filters that decompose the signal modify the final results. In our tests we tried 5/3 and 9/7 taps linear phase filters for DWT, while for DTCWT we used the same linear filters for level one of decomposition and "q-shift" filters for higher levels. We found that the differences are not significant, for every option finding the same critical bit rate, or slightly around.

V. FUTURE WORK

Future work will be focused on finding reliable methods for applying DTCWT in JPEG 2000 standard.

We think that complex wavelet transforms with improved directionality can perform better than classical discrete wavelet transform in compression field.

Of course, redundancy is not good for compression but we hope to find a link between the, in coefficients of both trees of DTCWT this case coding only a part of the coefficients being an acceptable solution. In this way the redundancy can be removed and we would exploit only the advantage of improved directionality.

VI. ACKNOWLEDGEMENT

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