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Image Denoising Using Dual Tree Complex Wavelet Transform

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ABSTRACT

We have implemented the image denoising using dual tree complex discrete wavelet transform (DT-CWT) which has significant advantages over real wavelet transform for certain signal processing problems. In this technique, two wavelet trees are used; one is generating the real part of the complex wavelet coefficients real tree and other generating the imaginary part of the complex wavelet coefficients imaginary tree. The DT-CWT based image denoising method is analyzed and the experimental results demonstrate that the Dual-Tree Complex Wavelet Transform overcome the problem of the separable DWT and outperforms for applications like image denoising and enhancement.

KEYWORDS: Complex Wavelet Transform (CWT), Dual-Tree Complex Wavelet Transform, Filter Bank, Shift Invariance.

I. INTRODUCTION

Wavelet techniques are successfully applied to various problems in signal and image processing. Data compression, motion estimation, texture synthesis, segmentation, classification and denoising are only some examples. Denoising of images is an important task in image processing and analysis, and it plays a significant role in modern applications in different fields, including medical imaging and preprocessing for computer vision. Denoising goal is to remove that noise. The Discrete Wavelet Transform (DWT) of image signals produces a non-redundant image representation, which provides better spatial and spectral localization of image formation. But, it has lack of shift invariance, lack of symmetry of the mother wavelet and poor directional selectivity. However, a major problem of the common decimated discrete wavelet transform is its lack of shift invariance. This means that on shifts of the input signal, the wavelet coefficients vary substantially. The shift dependence is illustrated in Figure. 1. The DWT suffers from the following two problems: -

- Lack of shift invariance: - this results from the down sampling operation at each level. When the input signal is shifted slightly, the amplitude of the wavelet coefficients varies so much.
- Lack of directional selectivity: - as the DWT filters are real and separable the DWT cannot distinguish between the opposing diagonal directions.

These disadvantages can be diminished using a complex wavelet transform. Complex wavelets have not been used widely in image processing due to the difficulty in designing complex filters which satisfy a perfect reconstruction property. To overcome this, Kingsbury proposed a dual-tree implementation of the CWT (DT-CWT), which uses two trees of real filters to generate the real and imaginary parts of the wavelet coefficients separately. In this paper DT-CWT, which is an alternative to the basic DWT the outputs of each tree are down sampled by summing the outputs of the two trees during reconstruction and the aliased components of the signal are suppressed and approximate shift invariance is achieved. The DT-CWT has improved shift-invariance and directional selectivity than the separable DWT.

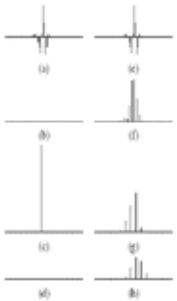

Figure 1: shift sensitivity of the discrete wavelet transform: (a) original signal, (b)-(d) magnitude of wavelet sub-band coeffcients, (e) signal (a) shifted by one sample, (f)-(h) magnitude of new wavelet subband coeffcients

II. DUAL-TREE COMPLEX WAVELET TRANSFORM

The Dual - Tree Complex Wavelet Transform (DT-CWT) has been developed to incorporate the good properties of the Fourier transform in the wavelet transform. As the name implies, two wavelet trees are used, one generating the real part of the complex wavelet coefficients real tree and the other generating the imaginary part of the complex wavelet coefficients imaginary tree.

The Dual-Tree Complex Wavelet Transform (DT-CWT) provides the following properties:-

1. Shift Invariance: -

DT-DWT has approximate shift-invariance, or in other words, improved time-shift sensitivity in comparison with standard DWT. The reconstructed

details at various levels and approximation at the last level have almost uniform shifts for the time-shifted unit step functions. The property of shift invariance makes the DT-DWT well suited for applications such as Motion estimation and Image fusion at various resolution levels.

2. Good Selectivity and Directionality: -

DT-DWT gives better directional selectivity in 2-D with Gabour like filters (also true for higher dimensionality m-D). Standard DWT offers the feature selectivity in only 3 directions with poor selectivity for diagonal features, where as DT-DWT has 12 directional wavelets (6 for each of real and imaginary trees) oriented at angles of in 2-D. The improved directionality with more orientations suggests the advantage of DT-DWT in a vide rage of directional image processing applications, e.g. texture analysis.

3. Phase Information: -

Local phase extraction is possible through analytic interpretation of two parallel trees of DT-DWT. The phase of any given subband at a given level can be computed with its corresponding real and imaginary coefficients.

4. Perfect Reconstruction (PR): -

The DT-DWT structure follows PR conditions; hence, the original signal can be reconstructed from the transform domain complex wavelet coefficients.

5. Limited Redundancy: -

DT-DWT has redundancy of 2:1 (2m:1) for 1-D (m-D) independent of scales (levels) of iteration. Though DT-DWT structure is expensive than

standard DWT, it is significantly less expensive than WP, or non-decimated DWT (SWT) for the same advantage of reduced shift-sensitivity. Moreover, DT- DWT has other advantages such as improved directionality and phase information to compensate for its limited redundancy over standard DWT.

The filter bank structure of Dual-Tree CWT that it resembles the filter bank structure of standard DWT with twice the complexity. It can be seen as two standard DWT trees operating in parallel. One tree is called as a real tree and other is called as an imaginary tree. Sometimes the real tree will be referred to as tree-a and the imaginary tree as tree-b.

The design of the filters is particularly important for the transform to occur correctly and the necessary characteristics are: -

- The low-pass filters in the two trees must differ by half a sample period.
- Reconstruction filters are the reverse of analysis.
- All filters are from the same orthonormal set.
- Tree (a) filters are the reverse of tree (b) filters.
- Both trees have the same frequency response.

The orthogonal two-channel filter banks with analysis low-pass filter given by the z-transform H0(z), analysis high-pass filter H1(z) and with synthesis filters G0(z) and G1(z) is shown in Figure.2

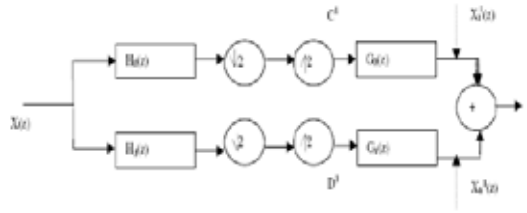

Figure2: DWT Filter Bank

For an input signal X(z), the analysis part of the filter bank followed by upsampling produces the low-pass

and the high-pass coefficients respectively, and decomposes the input signal into a low frequency part Xl1(z) and a high frequency part Xh1(z), the output signal is the sum of these two components.

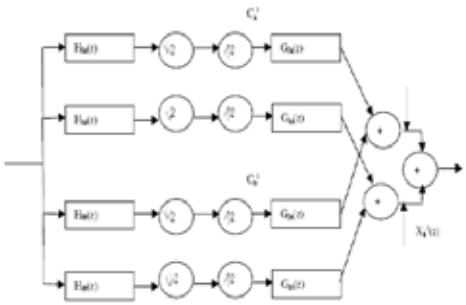

Figure 3: One level complex dual tree.

One possibility to obtain a shift invariant decomposition can be achieved by the addition of a filter bank with shifted analysis filters and synthesis filters and subsequently taking the average of the low-pass and the high-pass branches of both filter banks as shown in Figure 3.

DT-DWT is developed to overcome two main drawbacks of DWT: shift variance and poor directional selectivity. With carefully designed filter banks, DT-DWT mainly has following advantages: approximate shift invariance, directional selectivity, limited redundancy, and similar computation efficiency as DWT. Either the real part or the imaginary part of DT-DWT yields perfect reconstruction and thus can be employed as a stand-alone transform. We use magnitude of sub-bands to calculate feature vector. The implementation of DT-DWT is very straight forward. An input image is decomposed by two sets of filter banks, (H0a, H1a) and (H0b, H1b) separately, filtering the image horizontally and then vertically just as conventional 2D DWT does. Then eight sub bands are obtained: LLa, HLa, LHa, HHa , LLb , HLb , LHb and HHb . Each high-pass sub-band from one filter bank is combined with the corresponding sub-band from the other filter bank by simple linear operations: averaging or differencing. The size of each sub-band is the same as that of 2D DWT at the same level. But

there are six high pass sub-bands instead of three high pass sub-bands at each level. The two low pass sub-bands, LLb and LLa , are iteratively decomposed up to a desired level within each branch. The basic functions of 2D DDWT and 2D DWT are shown in Fig. 4a and Fig. 4b respectively. Each DDWT basis function is oriented at a certain direction, including ±75º, ± 15º, and ±45º. However, the basis function of HH sub-band of 2D DWT mixes directions of ±45º together.

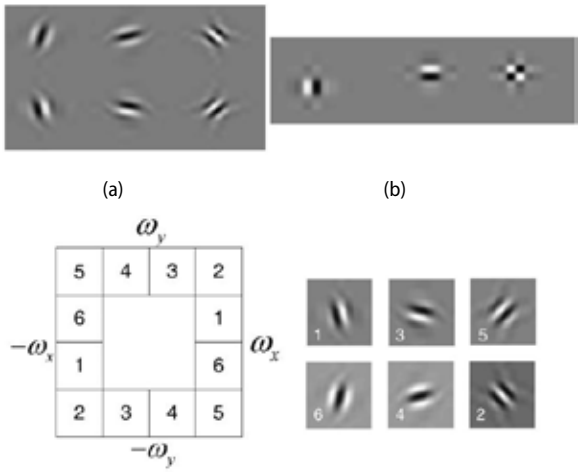

Fig 4: (a) Six basis functions of 2D DT-DWT (real part) at level 3 and (b) three basis functions of 2D separable DWT at the same level.(c) frequency tiling of 2-D DT-DWT and six wavelets of 2-D DT-DWT.

The Dual-Tree CWT uses two trees of real filters to generate the real and imaginary parts of the wavelet coefficients separately. The outputs of each tree are down sampled by summing the outputs of the two trees during reconstruction, the aliased components of the signal can be suppressed and approximate shift invariance can be achieved.

Moreover, the Dual-Tree Complex DWT can be used to implement 2D wavelet transforms where each wavelet is oriented, which is especially useful for image processing. (For the separable 2D DWT, recall that one of the three wavelets does not have a dominant orientation.) The Dual-Tree Complex DWT outperforms the critically-sampled DWT for applications like image denoising and enhancement.

IV. CONCLUSIONS

The Dual-Tree Complex Discrete Wavelet Transform has been developed to incorporate the good properties of the Fourier transform in the wavelet transform. As the name implies, two wavelet trees are used, one generating the real part of the complex wavelet coefficients tree and the other generating the imaginary part tree.

The shift invariance and directionality of the CWT may be applied in many areas of image processing like denoising, feature extraction, object segmentation and image classification. Here we considered the denoising application. The Dual-Tree Complex Wavelet Transform is used for denoising as an important signal/image processing application. DT-CWT technique is a powerful tool in removing signal/image noise. We proposed the DT-CWT as a useful front-end for many multi-dimensional signal analysis and reconstruction tasks, and demonstrate this with simple examples of edge enhancement and denoising. Simulation and experimental results demonstrated that the Dual Tree Complex Wavelet Transform (DT-CWT) outperforms a number of other existing wavelet transform techniques and it is particularly effective for the very highly corrupted images.

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