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Implementation of Dual Tree and Double Density Dual Tree Complex Wavelet Transform In Verilog HDL

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ABSTRACT: Complex Wavelet Transform is additionally a substitute, complex valued extension to standard DWT. The underlying inspiration behind the implementation of Wavelet transform is to avail both magnitude and phase information. This paper presents an outline of implementation of Dual tree complex wavelet transform (DTCWT) and Double density Dual tree complex wavelet transform (DDDTCWT) executed in VLSI architecture also we are applying these transform techniques on image to exploit merits and demerits of these techniques so as to determine proper applications of both. The proposed architecture has been implemented using Lifting Scheme. This wavelet decomposition is implemented in Xilinx 13.2 version software using verilog HDL
Keywords:- DDDTCWT, DTCWT, DWT, FPGA, HDL

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I. INTRODUCTION

In various signal processing applications a unified framework has been given by verified wavelet hypothesis. For instance sub-band coding, speech and video processing, wavelet series expressions created for applied mathematics. The theory of Wavelet covers a significant expansive zone, it works with both continuous and discrete time cases. Wavelet transform is utilized for analysis of non-stationary signals as an alternative of short time fourier transform.

In Digital Signal Processing (DSP) applications, the frequency content of signal is incredibly vital. The fourier transform is handiest appropriate transform used to get frequency spectrum of a signal. However the fourier transform is simply suitable for stationary signals i.e signals whose frequency content does not change with time. The Fourier transform, tells what proportion of every frequency exists within the signal but it does not tell at which time frequency elements occur.

Signal resembling image and speech have completely different characteristics at different time or space i.e. they are non-stationary. Most of the biological signals too, such as electromyogram, electroencephalogram, electrocardiogram etc. square measure are non-stationary. To analyze these signals both time and frequency signals are required at same time i.e., a time- frequency representation of signal is required.

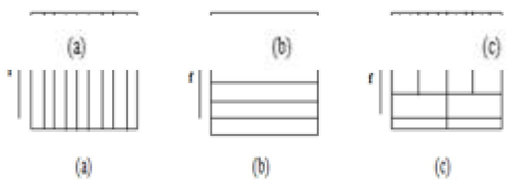

Fig.1 Time- Frequency tiling for (a) Time Domain (b) Frequency Domain (c) DWT

Fig 1(a) shows time frequency tiling in time domain plane and it does not give any frequency information, Fig 1(b) shows frequency domain plane and it does not give time information, Fig 1(c) shows tiling in wavelet transform and it gives both time and frequency information.

CWT utilize complex valued analytic filter that breaks down the complex signals into real and imaginary parts in transform domain. The real and imaginary coefficients are utilized to compute amplitude and phase information, simply the sort of data required to precisely depict the energy localization of oscillating functions. Another way to deal with implementation of an expansive CWT first applies a Hilbert transform to the data. The real wavelet transform is then applied to both original data and Hilbert transformed data and the coefficients of every wavelet transform are joined to get a CWT[4],[8].

Making the wavelet responses analytic is a good way to halve their bandwidth and thus minimising aliasing. Yet, we can't utilize complex filters in to obtain analyticity and perfect reconstruction together, as a result of conflicting prerequisites. Analytic filters must smoothen negative frequencies, while consummate reconstruction requires a flat overall frequency response.

So we utilize Dual tree complex wavelet transform:-

- To create real and imaginary parts of analytic wavelets independently, utilising 2 trees of simply real filters;
- To proficiently orchestrate a multiscale shift invariant filter bank, with culminate reconstruction and just 2:1 redundancy(and computation);
- To deliver complex coefficients whose amplitude differs gradually and whose phase shift depends roughly linearly on displacement[3],[5].

II. FORMULATION OF DUAL TREE AND DOUBLE DENSITY COMPLEX WAVELET TRANSFORM

2.1 Dual Tree Complex Wavelet Transform

For many applications, it is essential that transform be consummately invertible. A few authors, including Lawton have experimented with complex factorization of the standard Daubechies polynomials and got perfect reconstruction complex filters, yet these don't give filters with good frequency selectivity properties[3],[8],[9]. DTCWT accompanies an alternate approach with a specific end goal to conquer this drawback.

In 1998, Nick Kingsbury first presented the DTCWT, that depends on the perception that approximate shift invariance can be accomplished with real DWT by doubling the sampling rate at each level of the tree. For this to work, samples must be evenly spaced. The sampling rates can be doubled by eliminating by down-sampling by 2 after each level.[4],[6],[7]

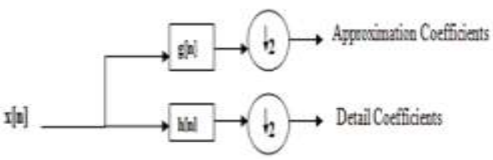

Fig.2 Block Diagram of Filter Analysis

Fig2 shows block diagram of filter analysis. The output giving detail coefficients (from high pass filter) and approximate coefficients (from low pass filter) where g[n] is low pass channel and h[n] is high pass channel[10].

As on account of filter design for wavelet transform there are different ways to deal with filter designs for DTCWT [2]. In the accompanying, we depict strategies to design filters fulfilling the following desired properties:-

- Appropriate half sample delay properties
- Perfect Reconstruction
- Finite support(FIR filters)
- Linear Phase filters

Besides, only complex filter responses need to be linear phase; this can be achieved by taking:

$$go = ho(N - 1 - n) \qquad \text{------- (1)}$$

where,

N=Total no. of samples

n= Sample at any instant

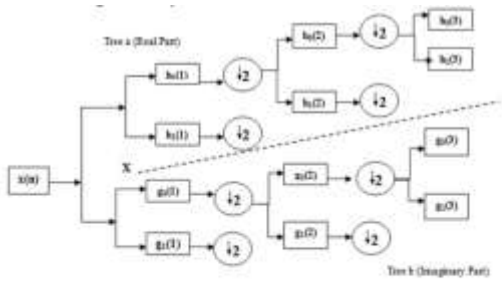

Fig.3 Block Diagram of DTCWT

In dual tree complex wavelet transform input image is disintegrated into 16 sub-bands by two detachable 2D- DWT from which 12 are of high sub-bands and 4 of low sub-bands. As a result, sub bands of 2D DT-CWT at each level are acquired as:

$$\left.\begin{array}{l}(LHa + LHb)/\sqrt{2}, (LHa - LHb)/\sqrt{2} \\ (HLa + HLb)/\sqrt{2}, (HLa - HLb)/\sqrt{2} \\ (HHa + HHb)/\sqrt{2}, (HHa - HHb)/\sqrt{2}\end{array}\right\} \quad \text{----- (2)}$$

2.2 Double Density Dual Tree Complex Wavelet Transform

DDDTCWT is formed by combining the characteristics of DDDTCWT and DTCWT so it is the extension of Dual tree complex Wavelet Transform. The DDDTDWT is based on two scaling function and four different wavelets, each of which is designed such that the two wavelets of first pair are offset from one other by half and other form approximate Hilbert Pair transform. It is 4-times expansive.

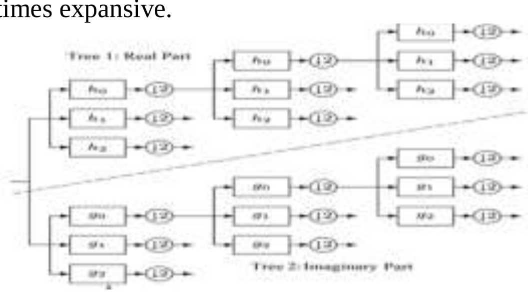

Fig.4 Block Diagram of Double Density Dual Tree Complex Wavelet Transform filter bank

Fig 4 shows block diagram of double density dual tree complex wavelet transform filter bank in which one of the wavelets can be interpreted as real and other as imaginary part. The Double density dual tree complex wavelet transform is an overcomplete CWT designed to simultaneously possess the properties of DDDTCWT and DTCWT.

2.3 Lifting Scheme

A mathematical formulation for wavelet transform has been proposed by Wim Sweldens in 1994 based on spatial construction of wavelets and an extremely flexible plan for its factorization[7]. This approach is called Lifting based wavelet transform or simply lifting. The main feature of lifting based scheme is that all constructions are derived in spatial domain. It does not require complex numerical estimations that are required in conventional techniques. Lifting scheme is simplest and efficient algorithm to calculate wavelet transform and it has significantly less number of arithmetic computations and memory utilisation as compared with convolution based DWT. It does not depend on fourier transform. It is used to generate second generation wavelets, which are not necessarily interpretation and expansion of one particular function. Constructing wavelets, using lifting scheme comprises of three steps:

1) Split phase- This step spilts data into odd and even sets. One frame consists of even index samples, Other frame consists of odd samples.
2) Predict step- In this step, Odd set is predicted from even set. Predict Phase ensures polynomial cancellation in high pass coefficients.
3) Update phase- It will update even set using wavelet coefficient to ascertain scaling function. Update stage ensures preservation of moments in low pass.

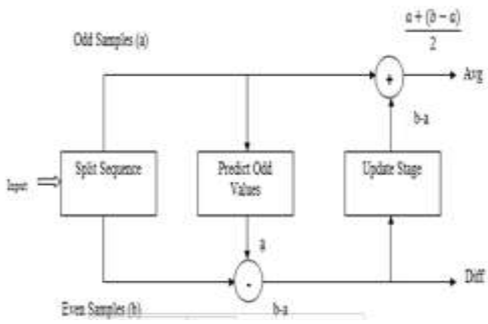

Fig.5 Lifting Steps for forward wavelet transform

Above fig 5 shows lifting steps. Input signal is splitted into even (b) and odd (a) samples. After prediction stage high band signal ‘diff’ is obtained and after update stage low band signal ‘Avg’ is obtained. The lifting based scheme conspire separate Low pass and high pass wavelet filters into a sequence of smaller filters. These decomposed filters are then converted into sequence of upper and lower triangular matrices. .[10],[11],[13],[14]

$$\left.\begin{aligned} s &= \frac{(a+b)}{2} \\ d &= (b-a) \end{aligned}\right\} \quad \text{----------(3)}$$

$$\left.\begin{aligned} &a \leftarrow s \qquad b \leftarrow (b-a) \\ &b \leftarrow d \qquad a \leftarrow (a+b)/2 \end{aligned}\right\} \quad \text{---------(4)}$$

The high and low pass filters can be expressed as:

$$g[n] = \sum_{i=0}^{n} gi[n] \qquad \text{--------- (5)}$$

$$h[n] = \sum_{i=0}^{n} hi[n] \qquad \text{--------- (6)}$$

where n is the filter length. To factor the wavelet transform filters into lifting steps, the high pass and low pass filters are first separated into even and odd parts:

$$g[n] = g_e[n^2] + z^{-1} g_0[n^2] \qquad \text{--------- (7)}$$

$$h[n] = h_e[n^2] + z^{-1} h_0[n^2] \qquad \text{--------- (8)}$$

They can also be expressed as polyphase matrix as follows:

$$P(n) = \begin{bmatrix} he[n] & ge[n] \\ ho[n] & go[n] \end{bmatrix} \qquad \text{--------- (9)}$$

III. DESIGN METHODOLOGY

In this section we develop a scheme for computation DTCWT and DDDTCWT architecture with characteristic features appropriate to the quality of image. In order to achieve the operation of DTCWT we need to focus on following strategies: (i) The proposed architectural system should emphasis to implement suitable hardware architecture for 2D DTCWT (ii) The proposed architecture should have good precision and must be reliable for JPEG standard images.

Regardless our point we begin our work with a 20*20 matrix as shown in fig 6 for computation 2D DWT. The data is stored in internal memory, and undergone upto 2level decomposition. The 20bit data is given as input in verilog module. This data is read from RAM1 and given as input to demultiplexer from were data is further computed in DWT module where lifting scheme is used for transform. The computed data is further written to RAM2 through multiplexer. The first iterated data was 1D output and further computation is for achieving 2D output[1].

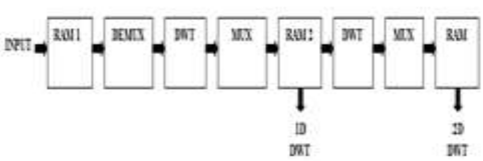

Fig.6 Block Diagram for 2-D computation of DWT

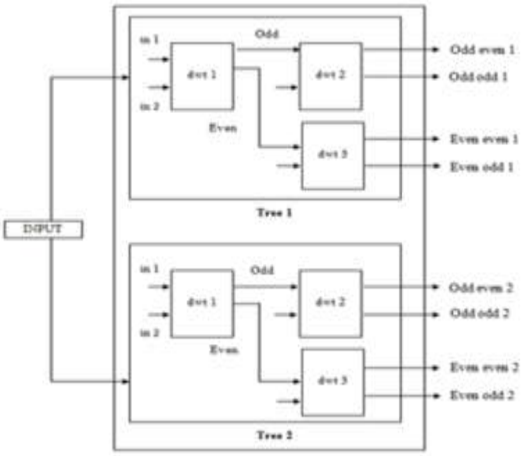

Fig.7 Block diagram for computation of 2D DTCWT

Fig 7 shows Block diagram of proposed methodology. The input value is passed through dwt1 from which 2 components are obtained even and odd, odd part is given input to dwt2 and even part to dwt3 getting 4 lower frequency components even even1,even odd1, odd even1, odd odd1 for tree 1 similarly 4 lower frequency components are obtained for tree 2. Even component is obtained by finding out average of inputs in1 and in2 each of 20bits and odd part is obtained by differencing both the inputs.

IV. SYNTHESIS AND PERFORMANCE RESULTS

We implemented and simulated the design flow of fig.8 in Xilinx synthesis tool to generate a RTL schematic. For implementation IC XC6SLX9 is used which is available on Spartan 6.

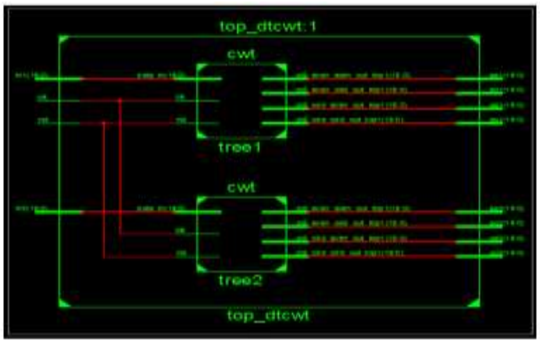

Fig.1.6 RTL Schematic of 2D DTCWT

Fig1.6 shows the RTL schematic of DTCWT showing two trees tree1 as real part and tree 2 as imaginary part decomposed upto 2 level giving 8 low frequency components oo1,oe1,ee1,eo1,oo2,oe2,ee2,eo2 four of each tree.

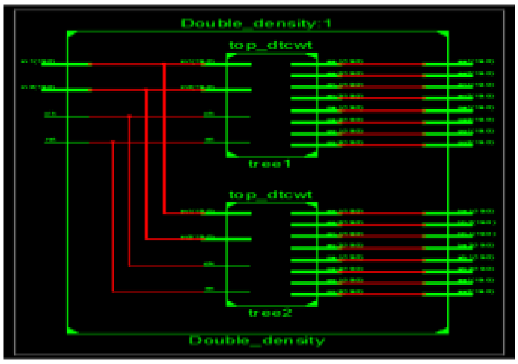

Fig.1.7 RTL schematic of DDDTCWT module

Fig.1.7 shows RTL schematic of DDDTCWT module name Double_density module showing two trees tree1 as real part and tree 2 as imaginary part decomposed upto 2 level giving eight lowfrequencycomponentsoo1,oe1,ee1,eo1,oo2,oe2, ee2,eo2 of tree1 and another eight low frequency components aa1ab1,ba1,bb1,aa2,ab2,ba2,bb2 of tree2.

Table1. Hardware Utilisation Summary of DTCWT in Spartan 6

Parameters	Total Used in Spartan 6	Total Available in Spartan 6	Percentage used in Spartan 6
No. of Slice registers	490	11440	4%
No. of Slice LUTs	371	5720	6%
No. of Bonded IOBs	102	102	100%
No. of Block RAMs	96	1440	6 %

Table1 shows hardware utilisation of DTCWT with respect to given parameters when implemented in Xilinx Synthesis tool on XC6SLX9 chip.

Table2. Hardware Utilisation Summary of DDDTCWT in Spartan 6

Parameters	Total used in Spartan 6	Total Available in Spartan 6	Percentage used in Spartan 6
No. of Slice registers	765	11440	6%
No. of Slice Flip-Flop	977	5720	17%
No. of block RAM	192	1140	13%
No. of bonded IOBs	102	102	100%

Table2 shows hardware utilisation summary of DDDTCWT when implemented in Xilinx synthesis tool on XC6SLX9.

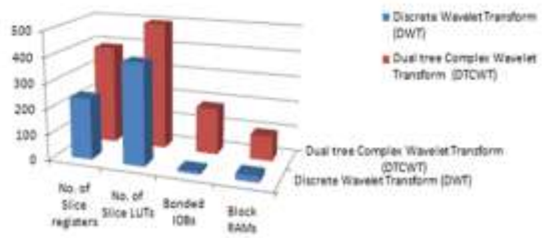

Fig 1.8 Graphical representation of Hardware Utilisation of DWT and DTCWT

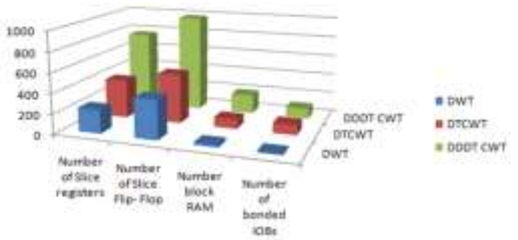

Fig 1.9 Graphical representation of Hardware Utilisation of DWT, DTCWT and DDDTCWT

Fig1.8 shows hardware utilisation between DWT and DTCWT whereas Fig 1.9 shows hardware utilisation between DWT, DTCWT and DDDTCWT.

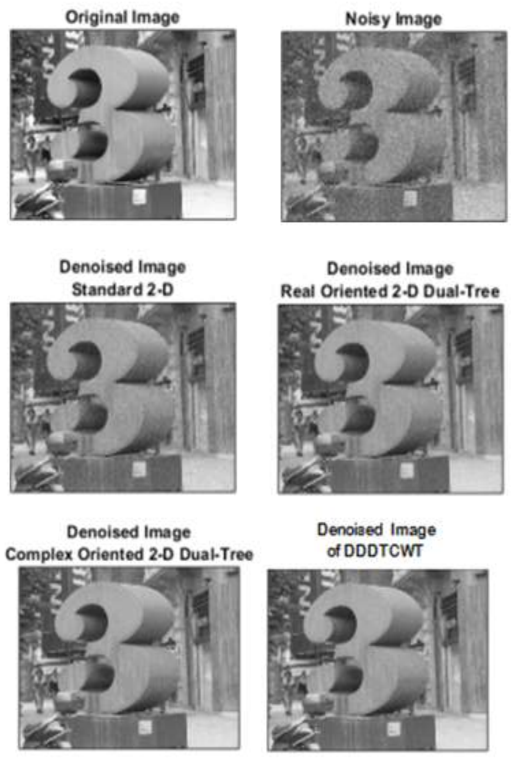

Fig.1.10 An Example of Image Denoising

Fig 1.10 shows an example of image denoising when undergone through DWT, DTCWT, DDDTCWT. It can be seen that DTCWT and DDDTCWT has features such as Shift–invariance, Directional selectivity i.e., if used for signal, image and video processing can give better results as compared to DWT.However, while comparing the implementation cost DDDTCWT can be quite expensive. Also DDDTCWT have more design freedom in wavelets allowing for better cutoff frequency.

V. CONCLUSION

In this paper we have designed 2D-DTCWT and DDDTCWT architecture implemented in Xilinx 13.2 using Verilog HDL on XC6SLX9 chip available in Spartan 6 FPGA. The objective of this work is hardware development because these functions are already defined in MATLAB tool. Simple DWT provides limited results having poor transform properties as compared to DTCWT however it uses more hardware components. The result has portrayed us that the proposed architecture provides good performance with respect to execution time of 6.41secs for DTCWT and 10.70secs for DDDTCWT having clock frequency of 128.217 MHz. In future we endeavor to execute proposed design calculation utilizing even less hardware resources, utilizing distinctive mother wavelet and compare results at different hardware platform for accomplishing desired performance.

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