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A Survey on FPGA implementation of 3D DWT using Lifting based Algorithm

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Abstract: In this paper we review the recent developments in the algorithms for the efficient implementation of lifting based discrete wavelet Transform (DWT). The lifting based DWT architecture has the advantage of low power computational complexities transforming the signals with extension and regular data flow. We provide a survey on these architectures for both 1-D and 2-D DWT. 3-D DWT uses a cascade combination of three 1-D wavelet transform along with a set of in chip memory buffers between the stages.

Keyword: DWT, CWT, FPGA, Video compression

I. Introduction

Wavelet transforms is one of the most modern areas of mathematics. In the last few decades, there has been an enormous increase in the applications of wavelets, in which it is used as an analytical tool in various areas of technical research such as electronics, computers and telecommunication systems that require efficient speed, resolution & real time memory and optimization with maximum hardware utilization. A wavelet, as the name suggests, is a little piece of a wave. They are used in representing data and other functions that satisfy certain mathematical requirements. The fundamental idea behind wavelets is to analyze according to scale. Wavelet algorithms process data at different scales or resolution. Wavelet transforms offer a wide variety of useful features in contrast to other transforms such as Fourier or cosine transform. Fourier transform is a powerful tool for analyzing the components of stationary signal, but it failed for analyzing non-stationary signal, whereas wavelet transforms allows the components of a non-stationary signal to be analyzed by using a set of damped oscillatory functions known as wavelet basis. Wavelet transforms in its continuous form is represented as CWT. A discrete and fast implementation of CWT is known as standard DWT. It decomposes the signal into different sub-bands with both time and frequency and facilitates to arrive at high compression ratio.

DWT architecture reduces the memory requirements and speed of communication by breaking up the image into blocks. FPGA is used in these systems due to the low cost and high computing speed with reprogrammable property. FPGA offers a very attractive solution that balance high flexibility, time-to-market, cost and performance. Following this trend, the researches community has focused in evaluating DSP functions on FPGAs to take advantage of the high level of parallelism. Recent advances in implementation of image coding and progressive image transmission through DWT demand both a large number of computations and large storage features that are not desirable for either high speed or low power applications. A methodology for implementation of the above complex applications have been proposed known as lifting based DWT that often has far fewer computations than DWT. In lifting scheme, the signal is divided like a zipper and a series of convolution-accumulate operations across the divided signals is applied, since this technique applies to each of this individual divided signals. Finally, brief summaries are given in below sections to conclude the paper.

II. Wavelets

A. Wavelet Definition: A 'wavelet' is a small wave which has its energy concentrated in time. It has an oscillating wavelike characteristic but also has the ability to allow simultaneous time and frequency analysis and it is a suitable tool for transient, non-stationary or time-varying phenomena.

B. Wavelet Characteristics: The difference between wave (sinusoids) and wavelet is shown in figure 2. Waves are smooth, predictable and everlasting, whereas wavelets are of limited duration, irregular and may be asymmetric. Waves are used as deterministic basis functions in Fourier analysis for the expansion of functions (signals), which are time-invariant, or stationary. The important characteristic of wavelets is that they can serve as deterministic or non-deterministic basis for generation and analysis of the most natural signals to provide better time-frequency representation, which is not possible with waves using conventional Fourier analysis

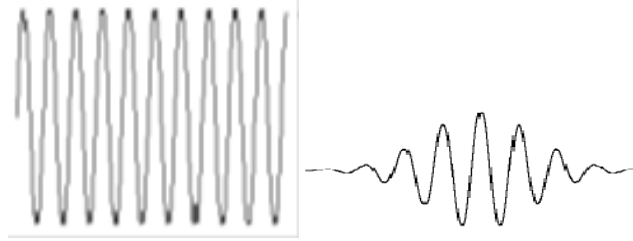


Fig. 2. Representation of a wave and wavelet

C. Wavelet Analysis: The wavelet analysis procedure is to adopt a wavelet prototype function, called an ‘analyzing wavelet’ or ‘mother wavelet’. Temporal analysis is performed with a contracted, high frequency version of the prototype wavelet, while frequency analysis is performed with a dilated, low frequency version of the same wavelet. Mathematical formulation of signal expansion using wavelets gives Wavelet Transform (WT) pair, which is analogous to the Fourier Transform (FT) pair. Discrete-time and discrete-parameter version of WT is termed as Discrete Wavelet Transform (DWT).

D. Advantages of Wavelets:

(a).Wavelet analysis is an exciting new method for solving difficult problems in mathematics, physics, and engineering, with modern applications as diverse as wave propagation, data compression, signal processing, image processing, pattern recognition, computer graphics, the detection of aircraft and submarines and other medical image technology.

(b).Wavelets allow complex information such as music, speech, images and patterns to be decomposed into elementary forms at different positions and scales and subsequently reconstructed with high precision.

(c).Wavelets are a powerful statistical tool which can be used for a wide range of applications, namely:Signal processing, Data compression, Fingerprint verification, Blood-pressure, heart-rate and ECG analyses, DNA analysis, and protein analysis.

III. Discrete Wavelet Transform

A. Wavelet Transforms: Wavelet transform has gained widespread acceptance in speech, image and video processing, and in signal processing in general because of its attractive characteristics to represent non-stationary signals in both frequency and time domains. The wavelet transform is computed separately for different segments of the time-domain signal at different frequencies. *Multi-resolution analysis:* analyzes the signal at different frequencies giving different resolutions. Multi-resolution analysis is designed to give good time resolution and poor frequency resolution at high frequencies and good frequency resolution and poor time resolution at low frequencies. Good for signal having high frequency components for short durations and low frequency components for long duration, e.g. Images and video frames.

B. Discrete Wavelet Transforms: It is a wavelet transform for which the wavelets are discretely sampled. DWT of a signal $x(n)$ is calculated by passing it through a series of filters. First the samples are passed through a low-pass filters with impulse response $g(n)$ resulting in a convolution of the two.

$$Y[n] = (x * g)[n] = \sum_{k=-\infty}^{\infty} x[k]g[n-k] \quad (1)$$

The signal is also decomposed simultaneously using a high-pass filter $h(n)$. The outputs giving the detail coefficients (from the high pass filter) and approximate coefficients (from low pass filter) as shown in fig.3. These 2 filters are related to each other and they are known as a quadrature mirror filters. The frequency of the signal have now been removed, half the samples can be discarded according to Nyquist’s rule. The filter output’s are then sub sampled by 2 (g-high pass and h-low pass).

$$Y_{low}[n] = \sum_{k=-\infty}^{\infty} x[k]g[2n-k] \quad (2)$$

$$Y_{high}[n] = \sum_{k=-\infty}^{\infty} x[k]h[2n-k] \quad (3)$$

This decomposition has halved the time resolution since only half of each filter output characterizes the signal. Each output has the frequency band of the input so the frequency resolution has been doubled.

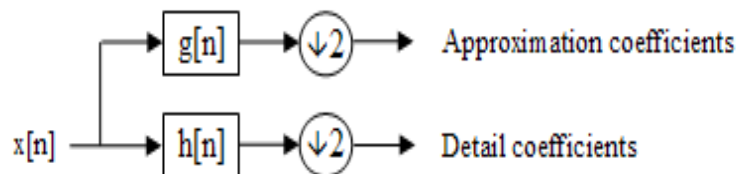


Fig. 3. One-Dimensional DWT

IV. Two Dimensional DWT

One-Dimensional DWT can be easily extended to two dimensions which can be used for the transformation of two dimensional images. A two dimensional digital image which can be represented by a 2-D array $x[n1,n2]$ with $n1$ rows and $n2$ columns, where $n1$ and $n2$ are positive integers. First, a one-dimensional DWT is performed on rows to get low frequency 'L' and high frequency 'H' components of the image. The fundamental block diagram of a 2-D DWT is as shown in fig 4a.

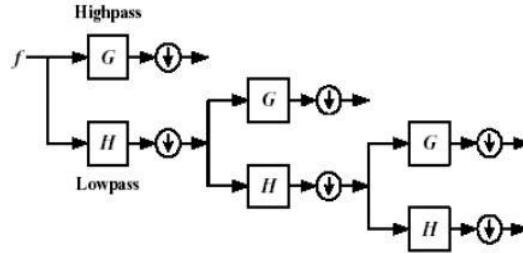


Fig. 4a Two-Dimensional DWT

At each scale, an image $f(x,y)$ is decomposed into an approximation image a_j of a low-pass band, and three detail images d_j^x, d_j^y, d_j^{xy} corresponding to a horizontal high-pass band d_j^x , a vertical high-pass band d_j^y , and a diagonal high-pass band d_j^{xy} as given below:

$$\begin{aligned} a_j(x, y) &= \langle f(x, y), \phi_j(x)\phi_j(y) \rangle \\ d_j^x(x, y) &= \langle f(x, y), \psi_j(x)\phi_j(y) \rangle \\ d_j^y(x, y) &= \langle f(x, y), \phi_j(x)\psi_j(y) \rangle \\ d_j^{xy}(x, y) &= \langle f(x, y), \psi_j(x)\psi_j(y) \rangle \end{aligned} \quad (4)$$

$$\text{Compare with single dimension case } Wf(b, s) = \int f(t) \frac{1}{\sqrt{s}} \psi\left(\frac{t-b}{s}\right) dt = f * \bar{\psi}_s(b) \quad (5)$$

$$= \langle f(t), \psi(t) \rangle \quad (6)$$

Due to down-sampling of the coefficients, the size of the image at lower level is half of that of the higher level. In two-dimensional image analysis, the three wavelets are given by:

$$\begin{aligned} \psi^1(x, y) &= \phi(x)\psi(y), \\ \psi^2(x, y) &= \psi(x)\phi(y) \\ \psi^3(x, y) &= \psi(x)\psi(y) \end{aligned} \quad (7)$$

Extract image details at different scales and orientations. At each scale, we end up with three "detail" images: (a) Low-pass filtered in the x-direction and high-pass filtered in the y direction, $\psi^1(x, y) = \phi(x)\psi(y)$, yielding detail D^x . (b) Low-pass filtered in the y direction and high-pass filtered in the x direction, $\psi^2(x, y) = \psi(x)\phi(y)$ yielding detail D^y , and, (c) finally, high-pass filtered in both x and y directions yielding detail D^{xy}

I_2	D_2^x	D_1^x
D_2^y	D_2^{xy}	
D_1^y		D_1^{xy}

Fig.4b. Components of decomposed image, three details and one approximation at each scale.

So, we have three orientations for details: Horizontal, Vertical and Diagonal. To cover the entire image using one dimensional wavelets, we consider image composed of rows or columns which are one dimensional in rows

or columns. We apply wavelet transform for each row (i.e. keeping x constant but changing y) starting from the top row. Then apply wavelet transform on the results of row operations but now move column-wise starting from the left column where we use wavelet or scaling function depending on whether we want LL, LH, HL or HH signal components. Since we are using one dimensional wavelet transform at each scan of x or y direction, we have only two filters low pass 'L' and high pass 'H' where we use them in sequence in x and y directions. To obtain low frequency band in x and y direction, we need to use low pass filters as shown in Fig.4c. Similarly we use LH, HL and HH for other frequency bands.

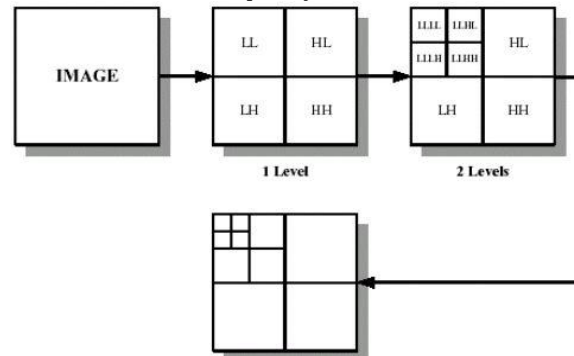


Fig.4c. Different levels of decomposition of an image

V. Three Dimensional DWT

The 3D DWT can be considered as a combination of three 1D DWT in the x, y and z directions as shown in the fig. 5. The preliminary work in the DWT processor design is to build 1D DWT modules, which are composed of high-pass and low-pass filters that perform a convolution of filter coefficients and input pixels. After a one-level of 3D discrete wavelet transform, the volume of image is decomposed into HHH, HHL, HLH, LHL, LHH, LLH and LLL signals as shown in fig.5. The process results in 8-data stream. The approximate signal resulting in scalar operations only goes to the next octave of the 3D transform. It has roughly 90 percent of the total energy. Meanwhile, the seven other streams contain the detail signals. Note that though conceptual drawing of the 3D DWT for one octave has 7 filter phases, this doesn't mean that the process needs 7 physical pairs. For example, a folded architecture maps multiple filters onto one filter pair.

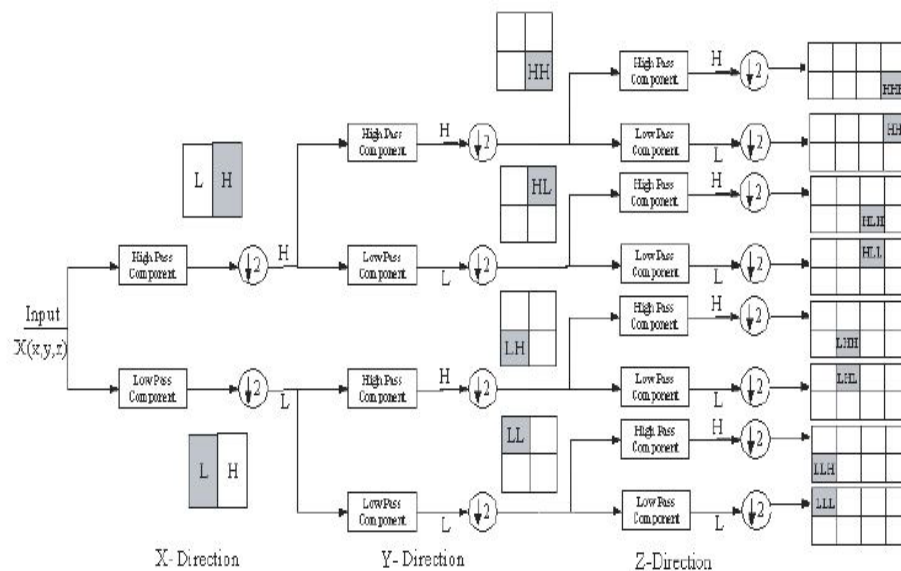


Fig.5. 3-Dimensional DWT

VI. Lifting based DWT

The development of the lifting scheme was proposed for the construction of bi-orthogonal wavelets. The main feature of the lifting scheme is that all constructions are derived in the spatial domain. It does not require complex mathematical calculations that are required in traditional methods. Lifting scheme is simplest and efficient algorithm to calculate wavelet transforms. It does not depend on Fourier transforms. Lifting scheme is used to generate second - generation wavelets, which are not necessarily translation and dilation of one particular function. Constructing wavelets using lifting scheme consists of three steps: (a) Split step: where the data is split-

up into odd and even sets. (b)Predict step: in which odd set is predicted from even set. Predict phase ensures polynomial cancellation in high pass. (c)Update phase: that will update even set using wavelet coefficient to calculate scaling function. Update stage ensures preservation of moments in low pass. Block diagram of forward Lifting scheme is as shown in Fig.6a.

6.1. Working of lifting scheme:

The basic idea behind lifting scheme is that, it tries to use the correlation in the data to remove redundancy. First split the data into 2 sets (split phase) i.e., odd sample and even sample. Because of the assumed smoothness of the data, we predict that odd samples have a value that is closely related to their neighboring even samples. We use N even samples to predict the value of a neighboring odd value (predict phase). With a good prediction method, the chance is high that the original odd sample is in the same range as its prediction. We calculate the difference between the odd sample and its prediction and replace the odd sample with this difference.

6.2. For Image Compression: In each lifting stage, the predicting or updating operations are carried out in the direction of image edges and textures in a local window, and are not necessarily horizontal or vertical. This adaptation can significantly reduce the signal energy of high-pass sub-bands. High angular resolution in prediction is achieved by the use of fractional pixels in prediction and update operations. The fractional pixels can be calculated by any existing interpolation method. In order to guarantee perfect reconstruction, the predicted and updated samples are always in integer pixel positions.

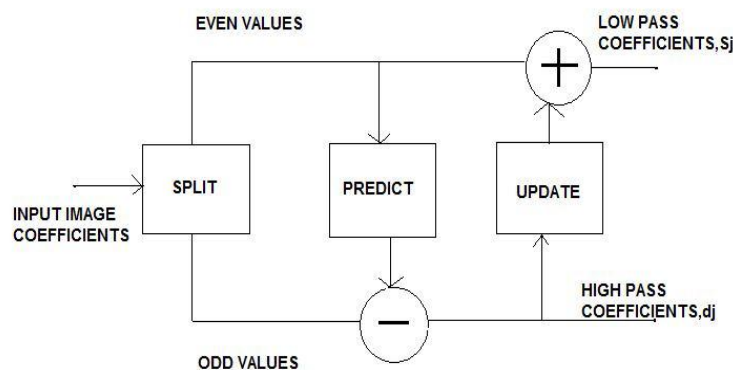


Fig.6a. Block diagram of forward Lifting scheme

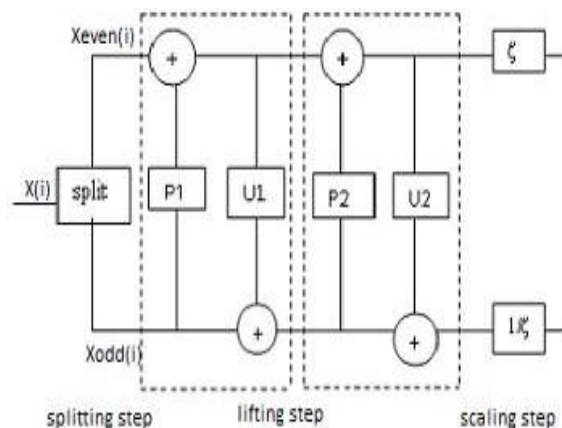


Fig.6b. Architecture of DWT based on lifting scheme

6.3.Reasons the choice of Lifting scheme

We have used lifting scheme of wavelet transform for the digital speech compression, because lifting scheme is having following advantages over conventional wavelet transform technique. (1)It allows a faster implementation of the wavelet transform. It requires half number of computations as compare to traditional convolution based discrete wavelet transform. This is very attractive for real time low power applications. (2)The lifting scheme allows a fully in-place calculation of the wavelet transform. In other words, no auxiliary memory is needed and the original signal can be replaced with its wavelet transform. (3)Lifting scheme allows us to implement reversible integer wavelet transforms. In conventional scheme it involves floating point

operations, which introduces rounding errors due to floating point arithmetic. While in case of lifting scheme perfect reconstruction is possible for loss-less compression.

VII Conclusion

In this paper, we presented a survey of the existing lifting based implementations of 1-dimensional and 2-dimensional Discrete Wavelet Transform. We briefly described the principles behind the lifting scheme in order to better understand the different implementation styles and structures. We have presented several architectures of different flavors ranging from highly parallel ones to highly folded ones to programmable ones. We provided a systematic derivation of each architecture and evaluated them with respect to their hardware and timing requirements.

VIII References

- [1] Senthilkumar.M ,Uma .S ” High speed 3d DWT VLSI architecture for image processing using lifting based wavelet transform”.International journal of communication and computer technologies. Vol 01-no.36.
- [2] Niladri Ghosh and K. Pradeep Vinaik “A Lifting based wavelet transform VLSI Architecturefor Image Processing”.IMACST: vol 3.
- [3] Kishore Andra, Chaitali Chakrabarti, member IEEE, and Tinku Acharya, sentor member IEEE” A VLSIfor lifting based forward and inverse wavelet transform“.IEEE transactions on signal processing. Vol 50,no. 4.
- [4] Malay Ranjan Tripathy, Kapil Sachdeva and Rachid Talhi “3D Discrete wavelet transform VLSI architecture for Image processing” progress in Electromagnetics research symposium proceedings Moscow, Russia.
- [5] Patrick Longa “ An Optimized architecture for 2D discrete wavelet transform on FPGA’s usingdistributed arithmetics 2006.
- [6] O. Rioul and M. Vetterli, “Wavelets and Signal Processing,” IEEE Signal Processing, vol. 8, issue: 4,pp. 14-38, Oct. 1991.
- [7] ISO/IEC. International Standard, 15444-1: 2000(E), JPEG2000 Image Coding System – Part I Core coding system.
- [8] C. Chakrabarti, M. Vishwanath, and R. M. Owens, “Architectures for wavelet transforms: A survey,” J. VLSI Signal Process., vol. 14, pp.171–192, 1996.
- [9] W. Sweldens, “The lifting scheme: A construction of second-generation wavelets,” SIAM J. Mathematical Analysis, vol. 29, no.2, pp. 511–46, 1997.
- [10] P. Chen, “VLSI implementation for one-dimensional multilevel lifting-based wavelet transform,” IEEE Trans. on Computers, vol.53, no.4, pp.386-398, April 2004.
- [11] Niladri Ghosh and K. Pradeep Vinaik “A Lifting based wavelet transform VLSI Architecture for Image Processing”.IMACST: vol 3.
- [12] N.D. Zervas, G.P. Anagnostopoulos, V. Spiliotopoulos,Y. Andreopoulos, and C.E. Goutis, “Evaluation of Design Alternatives for the 2-D Discrete Wavelet Transform,” IEEE Trans. Circuits and Syst. Video Tech., Vol. 11, No. 12, pp. 1246-1262, December 2001.
- [13] C. Chrysafis and A. Ortega, “Line-Based, Reduced Memory, Wavelet Image Compression,” IEEE Trans.Circuits and Syst. Video Tech., Vol. 9, No. 3, pp.378-389, March 2000.