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VLSI Architecture Design for Bi-orthogonal Wavelet Filters using Algebraic Integer Encoding

P.Vijayalakshmi[1], M.Vidya[2]

(Department of Electronics and Communication Engineering, Final year ME (Applied Electronics), Sri Venkateswara College of Engineering, Sriperumbudur) [1]

(Department of Electronics and Communication Engineering, Assistant Professor, Sri Venkateswara College of Engineering, Sriperumbudur) [2]

Abstract--As the world advances with technology and research, images are widely used in many fields such as biometrics, remote sensing, reconstruction etc. This growth in image processing applications, demands majorly for low power consumption, low cost and small chip area. Thus the advances in the VLSI system provides powerful tool for complicated imaging systems. A flexible architecture presents for algebraic integer based encoding of bi-orthogonal wavelet filters. A single final reconstruction step of algebraic integer encoding provides filtered and down sampled image outputs resulting in low levels of quantisation noise. Filter coefficients of the bi-orthogonal wavelet filters are quantized before implementation. In this architecture, all multiplications are performed using less shifts and additions. MSE and PSNR values of algebraic integer encoding provides improvement when compared to the fixed point representation. This architecture also provides better performance in terms of reducing chip area when compared to the Fixed point Technique.

Keywords: Biorthogonal wavelet Transform, Fixed Point Approximation, Algebraic Integer Encoding

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I. Introduction

Recent advances in medical imaging and telecommunication systems require high speed, resolution and real-time memory optimization with maximum hardware utilization. The 2D Discrete Wavelet Transform (DWT) is widely used method for these medical imaging systems because of its reconstruction property. Discrete Wavelet Transform can decompose the signals into different sub bands with both time and frequency information and facilitate to arrive at maximum compression ratio. Wavelet architecture, in general, reduces the area requirements and enhances the speed of communication by breaking up the image into the blocks.

VLSI has been around for a long time, there is nothing new about it, but as a side effect of advances in the world of computers, there has been a dramatic proliferation of tools that can be used to design VLSI circuits. A wavelet is a mathematical function used to divide a given function or continuous-time signal into different scale components. Usually one can assign a frequency range to each scale component. Each scale component can be studied with a resolution that matches its scale.

A wavelet transform is the representation of a function by wavelets. The wavelets are generally scaled and translated copies are known as daughter wavelets of fast-decaying oscillating waveform known as the mother wavelet. Wavelet transforms have advantages when compared to current Fourier transforms for representing functions that have breaks and sharp peaks, and for accurately analysing and recreating finite, non-periodic and non-stationary signals. Generally, an estimate to Discrete Wavelet Transform is used for data compression and the CWT is used for signal analysis. Thus, DWT is commonly used in engineering and computer science, and CWT in scientific research. Wavelet transforms are now being applicable for many number of applications, often replaced the current Fourier Transform.

Many areas of physics have seen this paradigm swing, including molecular dynamics, ab initio designs, astrophysics, density-matrix localisation, seismology, optics, commotion and quantum mechanics. This change has also happened in image processing, blood-pressure, heart-rate, brain rhythms, DNA analysis, protein analysis, climatology, general processing of signal, speech recognition, computer graphics and multifractal analysis. In computer vision and image processing, the idea of scale-space representation and Gaussian derivative operators is regarded as a canonical multi-scale representation.

II. Related Work

Many architectures have been proposed to perform DWT, but few address the precision of the coefficients necessary to ensure perfect reconstruction. The goal of this work is to determine the precision of the filter coefficients (for an orthogonal wavelet) needed to compute the 2-D DWT without introducing round-off error via the filter. It needs at least 14 bits for 1 octave of decomposition if both forward and inverse DWT are fixed-point operation, while 13 bits are enough to correlate with the same result if only the transform DWT is fixed-point[2]. The implementation of 2D DWT using fixed point representation are shown and the results shown that this can be performed without any loss [3]. "VLSI Architectures for the 4-Tap and 6-Tap 2-D Daubechies Wavelet Filters Using Algebraic Integers," offered an algebraic integer (AI) based multi-encoding of Daubechies-4 and -6 2-D wavelet filters having error-free integer-based computation. It also guarantees a noise-free computation throughput the multi-level multi-rate 2-D filtering operation. Comparisons are provided between Daubechies-4 and -6 in terms of several parameters [1].

III. PROPOSED WORK

Fig.1 shows the block diagram of the proposed system. Initially the image is given to the bi-orthogonal wavelet filter, where the image is decomposed based on sub band coding. The coefficients which we got from the bi-orthogonal wavelet filter are quantized using fixed point approximation. Finally the image is reconstructed.

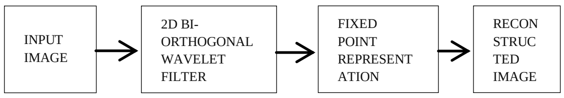

Fig.1 Block diagram of proposed system

SUB-BAND CODING

Generally image is decomposed based on sub-band coding. This sub-band coding is the general form of bi-orthogonal wavelet transform. If the scaling and wavelet functions are separable, the summation can be decomposed into two stages. First step is along the x-axis and then along the y-axis. For each axis, we can apply wavelet transform to increase the speed. The two dimensional signal (usually image) is divided into four bands: LL (left-top), HL (right-top), LH (left bottom) and HH (right-bottom). The HL band indicated the variation along the x-axis while the LH band shows the y-axis variation. The power is more compact in the LL band. Fig.2 shows the single level decomposition

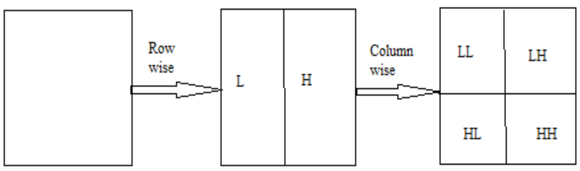

Fig.2 First level of decomposition

IV. BI-ORTHOGONAL WAVELET TRANSFORM

Already known bases that span a space do not have to be orthogonal. In order to gain greater tractability in the construction of wavelet bases, the orthogonality condition is unperturbed allowing semi-orthogonal, bi-orthogonal or non-orthogonal wavelet bases. Bi-orthogonal Wavelets are families of compactly supported symmetric wavelets. The regularity of the filter coefficients is often desirable since it results in linear phase of the transfer function. In the bi-orthogonal case, rather than having one scaling and wavelet function, there are two scaling functions $\varphi, \tilde{\varphi}$ that may generate different multiresolution study, and accordingly two different wavelet functions Ψ, $\tilde{\Psi}$ is used in the analysis and is used in the synthesis. In addition, the scaling functions φ, $\tilde{\varphi}$ and the wavelet functions Ψ, $\tilde{\Psi}$ are related by duality in the following equations (1) and (2)

$$\int \psi_{j,k}(x)\tilde{\psi}_{j',k'}(x)dx = 0 \qquad (1)$$

as soon as $j \neq j'$ or $k \neq k'$ and even.

$$\int \varphi_{o,k}(x)\varphi_{0,k'}(x)dx = 0 \qquad (2)$$

as soon as $k = k'$

There are two sequences, g_n and h_n to act as decomposition sequences and two sequences to act as reconstruction sequences. If c_n^1 is a data set, it should be decomposed as which is shown in the equation (3) and (4)

$$c_n^0 = \sum_k h_{2n-k} c_k^1 \qquad (3)$$

$$d_n^0 = \sum_k g_{2n-k} c_k^1 \qquad (4)$$

For reconstruction it is shown as

$$c_l^1 = \sum_n \tilde{h}_{2n-l} c_n^0 + \tilde{g}_{2n-l} d_n^0 \qquad (5)$$

If we want perfect reconstruction, so decomposing and then reconstructing shouldn't change anything. This imposes some conditions shown in equation (6) & (7)

$$g_n = (-1)^{n+1} \tilde{h}_{-n} \qquad (6)$$

$$\tilde{g}_n = (-1)^{n+1} h_{-n} l \qquad (7)$$

The separation of analysis and synthesis is such that the useful properties for analysis (e.g., oscillations, zero moments) can be concentrated on the $\tilde{\psi}$ function. The interesting property for synthesis (regularity) which is assigned to the Ψ function has proven to be very useful.

The dual scaling and wavelet functions have the following properties:

- They are zero outside of a segment.
- The calculation algorithms are maintained, and thus very simple.

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- The associated filters are symmetrical.
- The functions used in the calculations are easier to build numerically than those used in the Daubechies wavelets.

FIXED POINT APPROXIMATION

The designs of a wavelet transform processor, to treat the data and filter coefficient values in fixed-point values. Fixed point has the advantages of being easier to implement, requires less silicon area, and makes multiplications faster to perform. Floating point allows a greater range of numbers, though floating point numbers require 32 or 64 bits. Fixed-point numbers can be 8 to 32 bits (or more), possibly saving space in the multiplier.

V. ALGEBRAIC INTEGER INTERPRETATION

The motivation for algebraic integers to represent bi-orthogonal filter coefficients comes from a recently introduced algebraic integer based encoding scheme that allows low complexity error free computation. Algebraic integers are defined by real numbers that are root of monic polynomials with integer coefficients such as $\sqrt{2}$, $\sqrt[3]{7}$ etc. Many research works have been performed using single-dimensional and multi-dimensional algebraic integer encoding of the transform matrix. This technique increases the sparseness of the encoding matrix, as well as, by making an appropriate choice of the variables we can reduce the dynamic range of the transformation coefficients substantially, which leads to more efficient hardware implementation.

The whole point of algebraic integer quantization is not just the reduction of the number of arithmetic operations, but the lowering of the dynamic range of the computations which is much more important. This AI encoding is used which has the advantage of mapping the required irrational coefficients into arrays of integers. By manipulating these polynomial representations of the coefficients, instead of approximate representations of the coefficients themselves, we have eliminated any errors in the calculations until the final reconstruction step. Both forward and inverse mapping can be performed using the same polynomial expansion. In this reconstruction step appears only once without any intermediate reconstruction steps.

ADVANTAGES

- No floating point calculations,
- Absolutely error-free computations (Infinite precision until final reconstruction step),
- Parallel architecture for multiplication which is very suitable for VLSI implementation,
- Less arithmetic calculation which results simplicity in hardware implementation and finally
- The hardware requirements are less in case of AI compared to classical binary approach.

FINAL RECONSTRUCTION STEP

For the computation of a 2-D DWT or IDWT, we need to recover the integer part of the result and the most significant bit of the fractional part, to allow correct rounding. To produce output results in a conventional number system, we make a final substitution of the representation of z in the polynomial representation of the output data. Since z is irrational, we will not find an error-free finite representation within a conventional weighted system (e.g. binary); therefore, we have to use an approximation, and the error relating to that approximation dictates the quality of the output result.

VI. ARCHITECTURE DESIGN

In this paper it is proposed the improved architecture in performance by the way of using Algebraic integer Encoding.

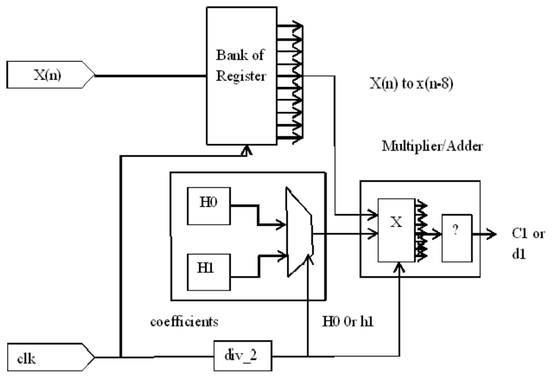

Fig.3 Architecture design of 2D- Discrete Wavelet Transform

The Fig.3 shows that the architecture of 2D Discrete Wavelet Transform. Where the input x(n) is given as image pixels which is stored in the Registers. The image coefficients are given as input to the low pass and high pass filters. Then applying Wavelet Transform by passing the coefficients into the low pass and high pass filter. Then convolving these coefficients by using multiplier and adder.

The output DWT data c1 is given as input for applying encoding process. The Fig 4 shows the encoding process. This architecture design is done by using Xilinx 14.2 software. The encoded data is again applied for IDWT and then decoding is done.

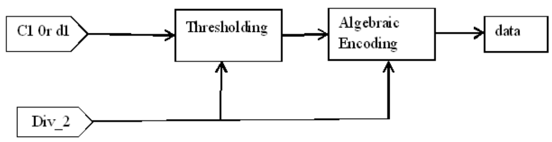

Fig.4 Algebraic Integer Encoding Process

VII. RESULTS

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The comparison between the fixed point and algebraic integer was done by using MATLAB software. Input image is applied for bi-orthogonal wavelet transform and then algebraic integer coding is applied. The image is reconstructed and PSNR, MSE values are noted for various images. The values shown that there is increase in performance using algebraic integer encoding.

Architecture is designed using Xilinx 14.2. Initially image is given as a input and from that input image red, blue and green components are separated. Each component is saved as a text. Then these components are given to the input of the bi-orthogonal wavelet filter. After doing filtering and encoding operation the output values are decoded and the image is reconstructed.

Fig.5 Input Image

Fig. 6 Reconstructed Image

The Fig.5 and 6 shows that the input image is taken for decomposition and reconstruction using fixed point approximation. Then PSNR and MSE values are found. The Fig.7 and 8 shows that input image taken for Algebraic Integer Encoding.

Fig.7 Input Image

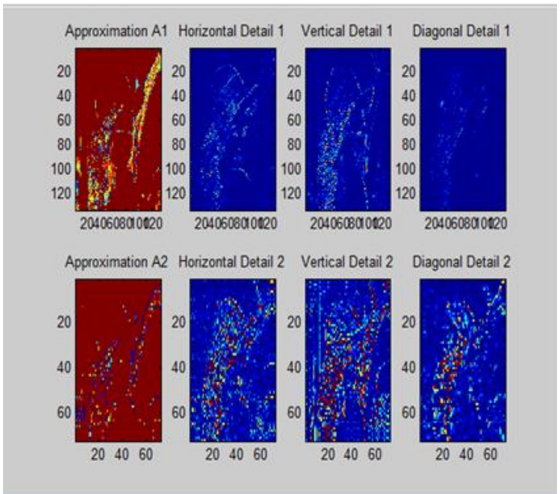

Fig.8 Approximation Details

The Table.1 shows that the comparison between fixed point approximation and Algebraic Integer encoding.

	FIXED POINT		ALGEBRAIC INTEGER	
	Db4	**Bior 7/3**	**Db4**	**Bior 7/3**
PSNR	15.552 dB	310.47 dB	248.51dB	311 dB
MSE	1.82e+003	4.66e027	9.23e-021	5.16e-027

Table.1 Fixed Point Vs Algebraic Integer

The results shown that Algebraic integer provides better performance when compared to the Fixed Point approximation. The Third stage of this project is to design an Architecture using Xilinx.

The main focus to design an architecture for many image processing applications are the major demands for power consumption and no of components usage. This architecture provides better results when compared to the fixed point approximation.

ARCHITECTURE DESIGN

Designers of digital systems are inevitably faced with the task of testing their designs. To verify that a design operates correctly generally simulation is needed, which is the process of testing design by applying inputs to a circuit and observing its behaviour. The output of a simulation is a set of waveforms that show how a circuit behaves based on a given sequence of inputs.

Initially input image is taken and pixel points are extracted and saved as a text. Then apply DWT process by writing VHDL program. Then encoding the 8 bit data by using Algebraic Integer Encoding. Then apply inverse DWT, decode and finally resize the image. Then the

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reconstructed image is compared with the original image and PSNR, MSE values are calculated.

The Fig.9 is the input image taken for image compression. Then from the image Red, Green, Blue components are extracted. Then these components are saved as a text file.

Fig.9 Input Image

Then VHDL code is simulated, the text file is given as a input and the code is simulated using Xilinx Isim Simulator. The output is stored in the output folder. The RTL schematic is shown in Fig.10. The simulated timing diagram for this architecture is shown in Fig.11. After simulating by entering any key in the matlab command window, the image is reconstructed and the image is shown in Fig.12. The RGB components also reconstructed and several parameters such as compression ratio, PSNR and MSE values are calculated.

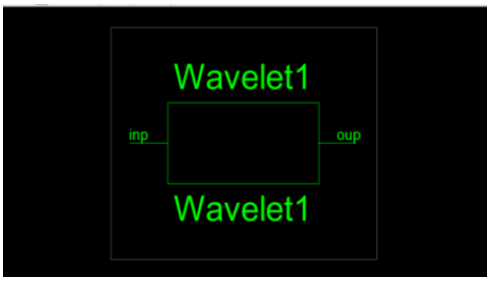

Fig.10 RTL Schematic

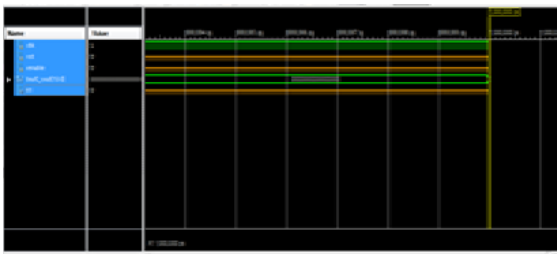

Fig.11Timing diagram

	No. of FFs	Area in (um2)
EXISTING	295	3.54 um2
PROPOSED	76	0.912 um2

Table.2 Comparison of Fixed Point Vs Algebraic Integer Architecture

The Table.2 shows that decrease in the no of components used when compared to the proposed system. This in terms we can say that area is reduced.

Fig.12 Reconstructed Image

VIII. CONCLUSION

A VLSI architecture for computing the AI based forward and inverse 2-D Discrete Wavelet Transform has been presented in this paper. The introduced design employs AI based arithmetic which is error free and free of multiplications. In order to assess the effectiveness of the proposed scheme, the design is simulated using Xilinx and MATLAB. The architecture has been captured by means of the VHDL language and simulated on data taken from random images. This architecture is better than the existing architecture in terms of multipliers and adders which results in small chip area. Based on the view of high image quality on reconstructed image, this proposed architecture outperforms the existing technique. Experimental results expose the performance of our proposed Algebraic Integer Encoding technique that accomplishes high PSNR value and reduced no of components used as compared to the existing fixed point technique. The same scheme can be extended to 3-D DWT.

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