MEMORY EFFICIENT THREE LEVEL 2-D DWT ARCHITECTURE

A PROJECT REPORT

Submitted by

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BONAFIDE CERTIFICATE

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INTERNAL EXAMINER **EXTERNAL EXAMINER**

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ABSTRACT

The aim of this project is to reduce the size of image efficiently by image compression. Image data require huge amounts of disk space and large bandwidths for transmission. Hence, image compression is necessary to reduce the amount of data required to represent a digital image. Therefore efficient technique for image compression is highly pushed to demand. Although, lots of compression techniques are available,but the technique which is faster, memory efficient and simple surely hits the user requirements. In this paper, the image compression, need of compression, its principles, how image data can be compressed, and the image compression techniques are reviewed and discussed. Also, wavelet-based image compression algorithm using three level 2D Discrete Wavelet Transform (DWT) based on convolution technique is discussed in detail.

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LIST OF ABBREVATION

DWT	Discrete Wavelet Transform
DAUB	Daubechies Filter
JPEG	Join Photographic Experts Group
FPGA	Field Programmable Gate Array
DPCM	Differential Pulse Code Modulation
2-D	Two Dimension
DCT	Discrete Cosine Transform
DFT	Discrete Fourier Transform
DSP	Digital Signal Processor
VLSI	Very Large Scale Integration
ASIC	Appliction Specific Integrated Circuits
CDF	Cohen-Daubechies-Feauveau
PU	Processing Unit
PE	Processing Element
DU	Delay Unit
MU	Multiplier Unit
CLK	Clock
MUX	Multiplexer
DMUX	Demultiplexer

HUE	Hardware Utilization Efficiency
ADP	Array Delay Product
DRAM	Dynamic Random Access Memory
ARC	Arithmetic Core
EPI	Energy Per Image
FE	Functional Element

LIST OF FIGURES

1.INTRODUCTION

Image compression is minimizing the size in bytes of a graphics file without degrading the quality of the image to an unacceptable level. The reduction in file size allows more images to be stored in a given amount of disk or memory space. It also reduces the time required for images to be sent over the Internet or downloaded from Web pages.

The underlying basis of the reduction process is the removal of redundant data. The transformation is applied prior to storage or transmission of the image. At some later time, the compressed image is decompressed to reconstruct the original image or an approximation to it.

The high algorithmic performance of the 2D DWT in image compression justifies its use as the kernel of both the JPEG2000 still image compression standard and the MPEG-4 texture coding standard . It is widely recognized that the LeGall (5, 3) and the Daubechies (9, 7) filters are among the best filters for DWT-based image compression. In fact, the JPEG2000 image coding standard employs the (5, 3) and the (9, 7) filters as the default wavelet filters for respectively loss and lossy compression.

With this compression ratio, the reconstructed image provides good visual quality. Several VLSI architectures have been proposed for computing the 2D-DWT. They are mainly based on convolution scheme and lifting scheme

Andra et al. proposed a 2-D DWT architecture which composes of simple processing units and computes one stage of DWT at a time.This paper propose a energy efficient, high performance; low power and convolution based architecture design for the 2D-DWT.

1.1 NEED FOR COMPRESSION:

The image associated with visual information is so large that its storage requirement is enormous, although the capacity of several storage media are substantial. Their access speeds are usually inversely proportional to their capacity. Typical television images that generate higher data rates. Storage and transmission of data require large capacity and/or bandwidth which could be very expensive.

Image data compression techniques are concerned with reduction of number of bits required to transmit images without any appreciable loss of information. Image transmission applications are: Broadcast television, Remote sensing via Satellite, Aircraft, Radar, Sonar, Teleconferencing, Computer communications and facsimile Transmission. Image storage is required widely for educational and business documents. Medical image used in patient monitoring system. Because of their wide applications data compression is of great importance in digital image processing.

1.2 PRINCIPLES BEHIND COMPRESSION:

A common characteristics of images is that the neighboring pixels are correlated and therefore contain redundant information. The foremost task then is to find less correlated representation of the image. The Fundamental component of compression are redundancy and irrelevancy reduction.

SPATIAL REDUNDANCY:

Spatial redundancy is defined as correlation between neighboring pixels values.

SPECTRAL REDUNDANCY:

Spectral redundancy is defined as correlation between different color planes are spectral bands.

TEMPORAL REDUNDANCY:

Temporal redundancy is defined as correlation between frames in a sequence of images.

Image compression research aims at reducing the number of bit needed to represent an image by removing the spatial and spectral redundancies as much as possible.

1.3 COMPRESSION TECHNIQUES:

Two ways of classifying compression techniques are mentioned here

1.3.1 LOSSLESS AND LOSSY COMPRESSION:

In lossless compression schemes, the reconstructed image, after compression, is numerically identical to the original. However lossless compression can only achieved a modest amount of compression. An image reconstructed following lossy compression contains degradation relative to the original Often this is because the compression scheme completely discards redundant information. However, the lossy schemes are capable of achieving much higher compression. Under viewing conditions, no visible loss is perceived (Visually lossless) .

1.3.2 PREDITIVE AND TRANSFORM CODING:

In predictive coding, information already sent or available is used to predict future values, and the difference is coded. Since this is done in the image or spatial domain, it is relatively simple to implement and is readily adapted to local image characteristics. Differential pulse code modulation (DPCM) is one particular example of predictive coding.

Transform coding, on the other hand, first transform the image from its spatial domain representation to the different types of representation using some well–known transform and then codes the transformed value(coefficients). This is method provides the greater data compression compared to predictive methods, although at the expense of greater computation.

1.4 LITERATURE REVIEW:

Wavelet transform has gained widespread acceptance in image compression research in particular. Up to now, much work has been proposed. Andra et al. proposed a 2-D DWT architecture which composes of simple processing units and computes one stage of DWT at a time.Dillen et al. presented a combined architecture for (9,7)transforms with minimum area.In this project ,memory efficient, high performance, low power and convolution based architecture design for the 2D-DWT is proposed.

2.PROJECT DESCRIPTION

2.1 INTRODUCTION:

The Discrete Wavelet Transform (DWT) has become one of the most used techniques for image compression and is applied in a large category of applications DWT can provide significant compression ratios without great loss of visual quality than the previous techniques such as the Discrete Cosine Transform(DCT) and the Discrete Fourier Transform (DFT). The DWT present the main part of the JPEG2000 standard, which permits both lossy and lossless compression of digital images. It allows an encoded image to be reconstructed progressively.

The compression phase is mainly divided into three Sequential steps:

(1) Discrete Wavelet Transform,

(2) Quantization, and

(3) Entropy Encoding.

Conventionally, programmable DSP chips are used to implement such algorithms for low-rate applications and the VLSI application specific integrated circuits(ASICs) for higher rates.

The FPGAs are programmable logic devices that provide sufficient quantities of logic resources that can be adapted to support a large parallel distributed architecture. Lifting and convolution present the two computing approaches to achieve the discrete wavelet transform.

2.2 WAVELET TRANSFORM:

There are two approaches to make a wavelet transform. Scaling function and wavelets(the dilation equation and wavelet equation) by mathematicians Filter banks ∑(low-pass filter and high-pass filter) by engineers. The two approaches produce same results, proved by Daubechies. Wavelet Transform is a type of signal representation that can give the frequency content of the signal at a particular instant of time.

Wavelet analysis has advantages over traditional Fourier methods in analyzing physical situations where the signal contains discontinuities and sharpspikes.

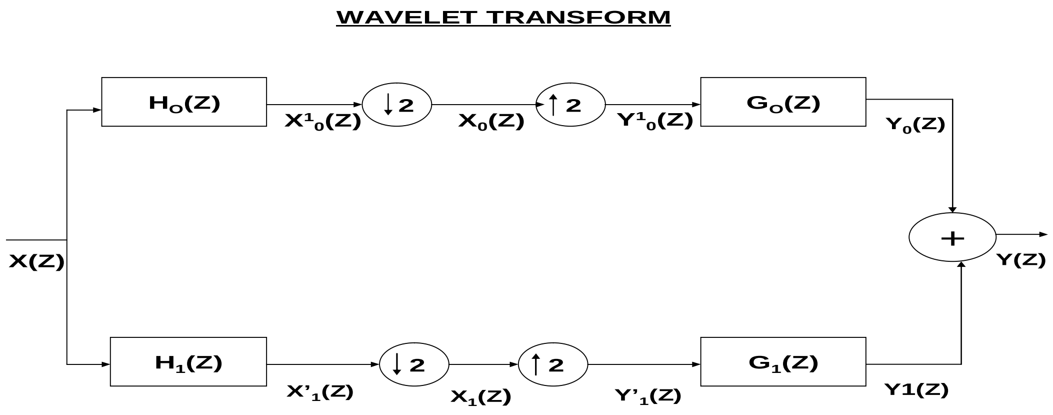


Fig 1 Block diagram Ideal low-pass and high-pass filter.

2.3 DISCRETE WAVELET TRANSFORM:

The discrete wavelet transform(DWT) has been developed as an efficient DSP tool for signal analysis, image compression, and even video compression. There are many architectures proposed for the implementation of DWT. For the 1D-DWT, the architectures can be categorized into the convolution-based, lifting-based, and B-spline-based.

The first one is to implement two-channel filter banks directly. The second one is to exploit the relationship of low pass and high pass filters for saving multipliers and adders. The third one can reduce the multipliers based on the B-spline factorization .

The b-spline-based architectures could provide fewer multipliers while the lifting scheme fails to reduce the complexity.

The 1D-DWT is a two channel sub-band decomposition of an input signal X(n)that produces two sub-band coefficients YL(n) and YH(n)for one-stage of decomposition according to the following equations.

$$Y_L(n) = \sum_{i=0}^{\tau_L - 1} H(i)x(2n-1) \qquad (1)$$

$$Y_H(n) = \sum_{i=0}^{\tau_H - 1} G(i)x(2n-1) \qquad (2)$$

In the synthesis stage, scaling and wavelet coefficients YL(n) and YH(n) are treated inversely by up-sampling and filtering with low pass H(z) and high pass G(z) filters to perform reconstruction. This stage is also called Inverse Discrete Wavelet Transform (IDWT).

Original and reconstructed signals are generally different, unless the two filters H and G satisfy some relationships . The perfect reconstruction condition consists in ensuring no distortion and no aliasing of the reconstructed data.

Early research on filter-bank design proved that the execution of 1D-DWT can be accelerated by using the poly phase matrix of the filter-bank, instead of the conventional filtering and down-sampling structure .

The signal is split into two signals (poly phase components) at half of the original sampling rate. The poly phase components of the signal are filtered in parallel by the corresponding filter coefficients, producing the same result as if the down-sampling was performed . The convolution-based implementation of the 1D-DWT by using the poly phase matrix. The analysis poly phase matrix E0(Z) is defined (in the Z-domain) as:.

$$E_0(z) = \begin{bmatrix} H_e(z) & H_o(z) \\ G_e(z) & G_o(z) \end{bmatrix} \qquad (3)$$

Where (*z He* and) (*z Ho* denote the even and odd poly phase components of the corresponding low-pass analysis filter, and) (*z Ge* and *z Go* denote the even and odd poly phase components of the corresponding high pass analysis filter.

The wavelet decomposition can be written using Eq.3 (in the Z-domain) as:

$$\begin{bmatrix} Y_L(z) \\ Y_H(z) \end{bmatrix} = E_o(z) \begin{bmatrix} X_e(z) \\ X_o(z) \end{bmatrix} \qquad (4)$$

Where *z YL* denotes the approximation at the coarser resolution, *z YH* denotes the detail signal, and *z Xe* and *z Xo* denote the even and odd poly phase components of the signal) (*z X* Lifting based DWT).

The convolution-based 1-D DWT requires both a larger number of arithmetic computations and a large memory for storage. Such features are not desirable for either high speed or low-power image processing applications. Recently, a new mathematical formulation for wavelet transformation has been proposed by Swelden as alight-weighted computation method for performing wavelet transform. The main feature of the lifting-based wavelet transform is to break-up the high pass and the low pass wavelet filters into a sequence of smaller filters.

The lifting scheme requires fewer computations compared to the convolution-based DWT. Therefore the computational complexity is reduced to almost a half of those needed with a convolution approach.

DISCRETE WAVELET TRANSFORM

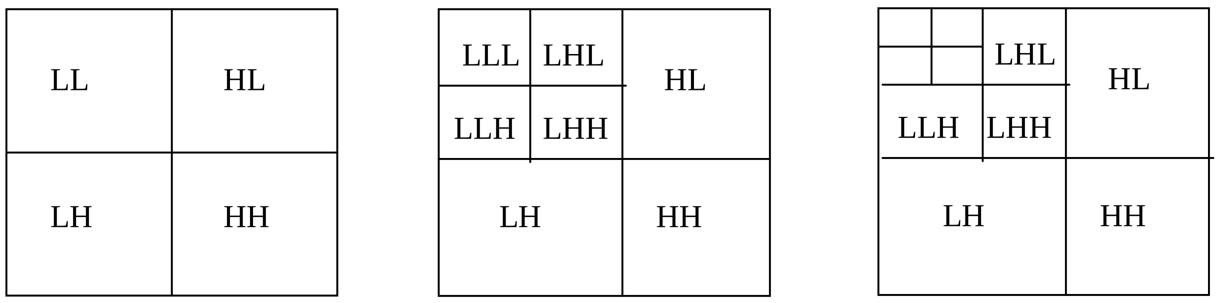


Fig. 2 Pyramidal Decomposition

An Example of Wavelet Decomposition

Octave-band wavelet decomposition is a non-uniform band splitting that decomposes the lower frequency part into narrower bands and the high-pass output at each level is left without any further decomposition.It shows the various sub band images of a two-level octave-band decomposed Women using the popular CDF-9/7 biorthogonal wavelet.

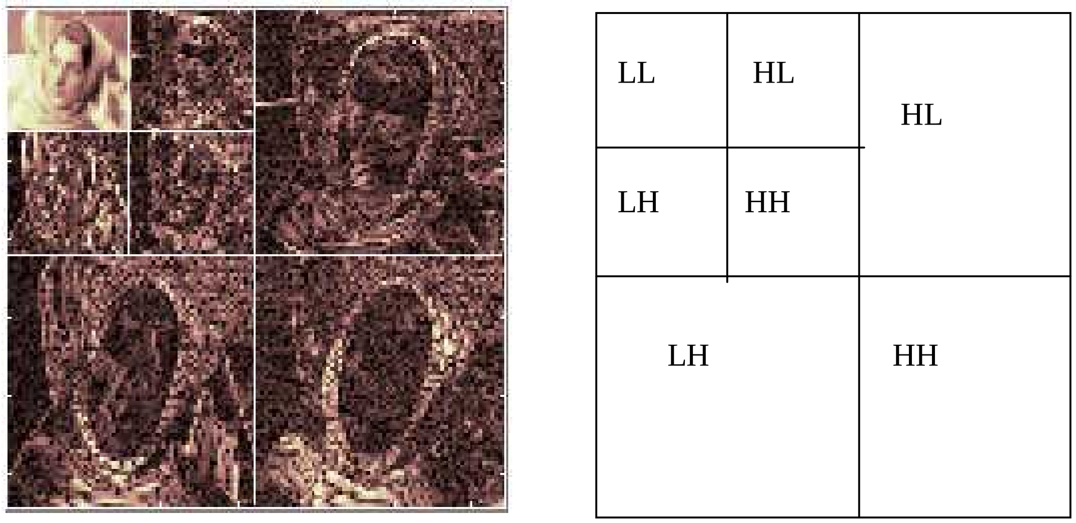


Fig. 3 Two level decomposition

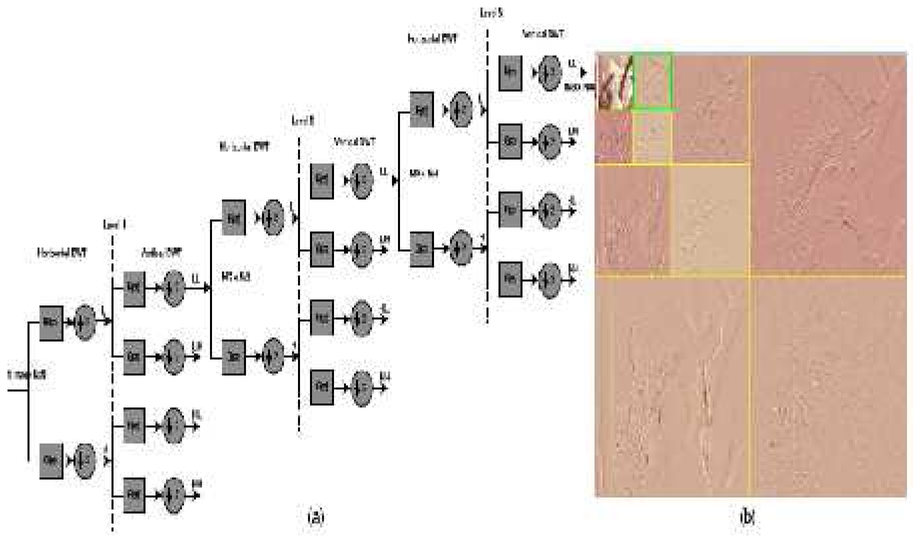


Fig.4 Three level decomposition

3.WAVELET FAMILIES

3.1. DAUBECHIES WAVELETS:

The Daubechies wavelets are orthogonal wavelets which is energy or norm preserving. There are a number of Daubechies wavelets, DaubJ, where J = 4, 6.....20.

The easiest way to understand this transform is just to treat them as simple generations of the Daub4 transform with the scaling and translation factors. The most apparent difference between each of them is the length of the supportsof their scaling signals and wavelets. Daub4 wavelet is the same as the Haar wavelet. Daub4 wavelet preserves the energy due to its orthogonality. Daub6 often produces smaller size fluctuation values than those produced by Daub4 transform.

The types of signals for which this occurs are the ones that are obtained from the sample of analog signals that are at least three times continuously differentiable. These kinds of signals are approximated better, over a large proportion of their values by quadratic approximations. The curve graphs of quadratic functions enable then to provide superior approximations to the parts of the signal that are near to the turning points in its graph. So for signal compression Daub6 transform generally does a better job .

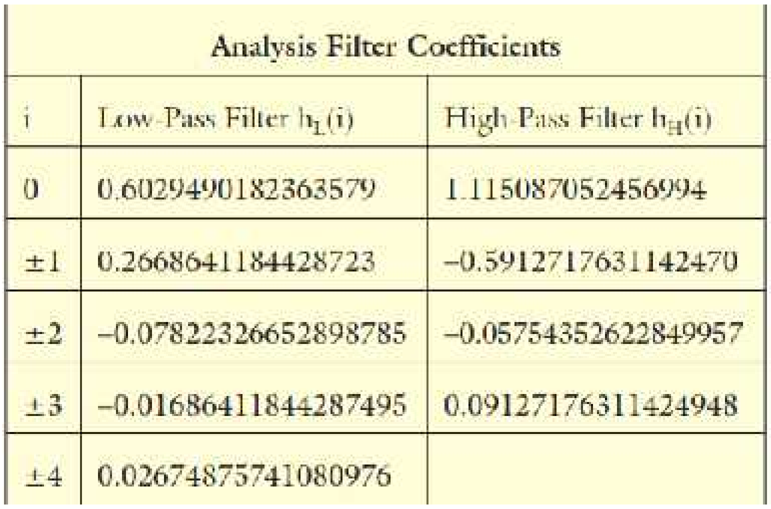
The scaling coefficients are :

$$h_0 = \frac{1+\sqrt{3}}{4\sqrt{2}}$$

$$h_1 = \frac{3+\sqrt{3}}{4\sqrt{2}}$$

$$h_2 = \frac{3-\sqrt{3}}{4\sqrt{2}}$$

$$h_3 = \frac{1-\sqrt{3}}{4\sqrt{2}}$$



Analysis Filter Coefficients		
i	Low-Pass Filter $h_L(i)$	High-Pass Filter $h_H(i)$
0	0.6029490182363579	1.115087052456994
±1	0.2668641184428723	−0.5912717631142470
±2	−0.07822326652898785	−0.05754352622849957
±3	−0.01686411844287495	0.09127176311424948
±4	0.02674875741080976	

Fig.5 Analysis Filter Cofficients

3.2. BIORTHOGONAL WAVELETS:

The biorthogonal wavelets have bases that are defined in a way that has weaker definition of the bases of orthogonal wavelet bases. Though the orthogonal wavelet's filter has self-duality only, the biorthogonal wavelet's filter has duality. Since the orthogonality of the filter makes the wavelet energy preserving, the biorthogonal wavelets are not energy preserving.

4.CONVOLUTION THEOREM

Convolution is a simple mathematical operation which is fundamental to many common image processing operators. Convolution provides a way of `multiplying together' two arrays of numbers, generally of different sizes, but of the same dimensionality, to produce a third array of numbers of the same dimensionality.

4.1 Overview

Most of filters are using convolution matrix. With the Convolution Matrix filter,it's possible to get a rough idea of it without using mathematical tools that only a few ones know. Convolution is the treatment of a matrix by another one which is called “kernel”.

The Convolution Matrix filter uses a first matrix which is the Image to be treated. The image is a bi-dimensional collection of pixels in rectangular coordinates. The used kernel depends on the effect that is wanted.

GIMP uses 5x5 or 3x3 matrices. Considering 3x3 matrices, they are the most used and they are enough for all effects that is wanted. If all border values of a kernel are set to zero, then system will consider it as a 3x3 matrix.

The filter studies successively every pixel of the image. For each of them, which is called the “initial pixel”, it multiplies the value of this pixel and values of the 8 surrounding pixels by the kernel corresponding value. Then it adds the results, and the initial pixel is set to this final result value.

5.SOFTWARE ARCHITECTURE

5.1 INTRODUCTION

Due to down-sampled filtering, the computational complexity after each level of decomposition steadily decreases by factor of four. In order to achieve 100% HUE, hardware resource of the processing units (PUs) should be reduced byfactor of 4 after every DWT level. But it do not have any suitable straightforward approach to map the DWT computation of successive levels to the PU with one-fourth complexity. Maximum (100%) HUE may be achieved by introducing four times more parallelism in two-level DWT computation.Similarly, for three-level DWT, it need to have 16 times more parallelism which could be too high for many applications. Alternatively, if it is assumed hardware resource of a PU can be reduced upto one subcell comprised of a pair of low-pass and high-pass filters, then PU-J corresponding to Jth level is comprised of one subcell and processes two samples in every cycle for 100% HUE, where the row and column computations are time multiplexed.

The overall throughput rate of PU-J is one sample per cycle. It is estimated the minimum input block size for different DWT levels to achieve 100% HUE of the possible structures based on the proposed scheme. Based on these observations,a pipeline structure for three-level 2-D DWT is derived. However, similar structures can be derived for higher DWT levels as well. The proposedstructure is shown in Fig. 6. It consists of three processing units (PUs), where PU1, PU-2, and PU-3, respectively, performcomputations of first-level, second-level and third-level.

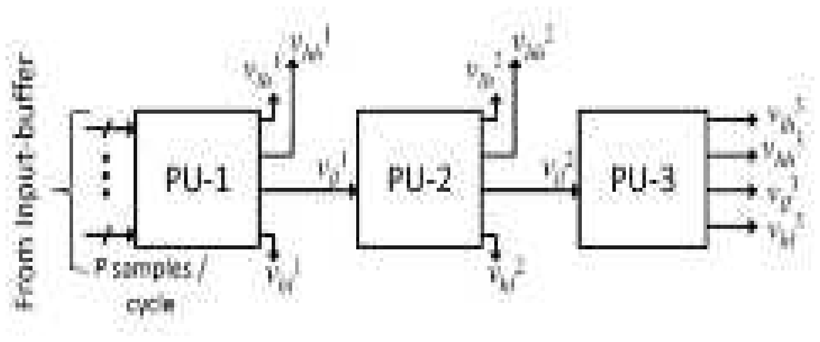


Fig. 6. Block diagram of three-level 2-D DWT.

5.2 PROCESSING UNIT -1

The minimum input block size forPU-1 is P = 16. Structure of PU-1 is shown in Fig. 7. It consists of eight processing elements (PEs). Each input block is extended by (K-2) samples such that adjacent input blocks of a row are overlapped by (K - 2) samples, where K is the filter order. From the input matrix (**X**), extended input blocks (**I**(m, i)) are fed to PU-1 block-by-block in every cycle. The input block **I**(m, i) corresponding to the mth row of (**X**) contains the samples {x(m, 16i),x(m, 16i +1),...,x(m, 16i +K + 12),x(m, 16i + K + 13)}, for 0 = m = M - 1 and 0 = i = (N/16) - 1.

A set of eight data vectors (**B**, for 0 = q = 7) of size are derived from each input block **I** where the q+1 adjacent data vectors are overlapped by (K - 2) samples.These data vectors are fed in parallel to the PEs, such that (q + 1)th PE receives the data-vector **B**q+1. Structure of PE is shown in Fig. 9(a). It consists of a pair of identicalsubcells (subcell-1 and subcell-2) and one delay-unit (DU-1).Subcell-1 performs the necessary DWT computation along the row-direction where K consecutive samples of a particular row constitute the data-vector. Structure of the subcell using orthogonal wavelet filters is shown in Fig. 10(a). It consists of K multiplier-units (MUs), where each MU performs multiplications corresponding to a pair of low-pass (h(k) and high-pass g(k)) filter coefficients, for 0 = k = K - 1.

Internal structure of the (k + 1)th MU is shown in Fig. 10(b). The low-pass and the high-pass partial results are added in two separate adder-trees to compute a pair of low-pass and high-pass filter outputs. Besides, each subcell involves an additional adder unit to perform the computation of biorthogonal filters. The structure of the subcell using 9/7 filter is shown in Fig. 11. The adder-unit (shown in Fig. 12) generates intermediate signals si, for (0 = i = 4) for low-pass filter and r, for (0 = i = 3) for high-pass filter to exploit the symmetric property of the biorthogonal filters. The intermediate results pass through the MU and then the adder-tree to produce the low-pass and highpass filter outputs.

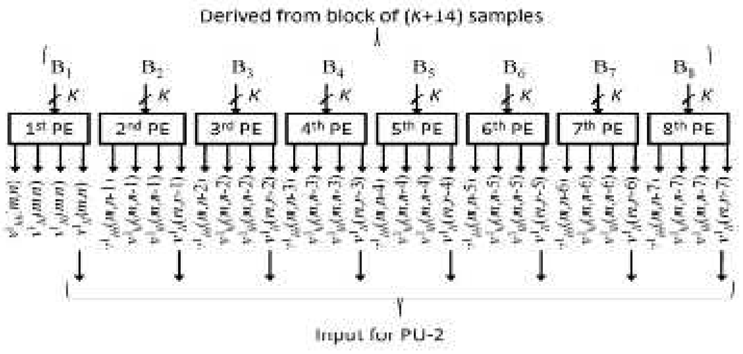


Fig. 7. Structure of PU-1 for block size P = 16.

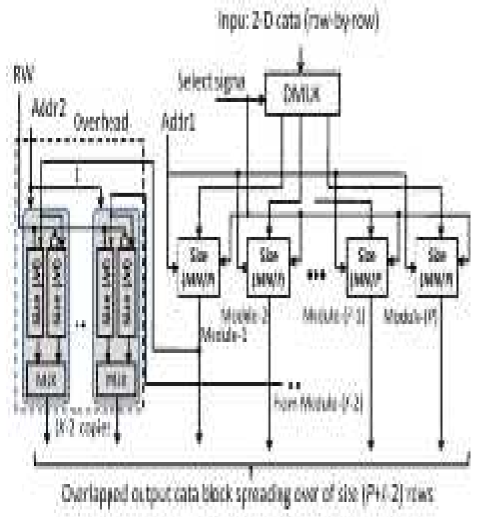


Fig. 8. Structure of the input buffer using interleaved-memory and single-port RAM to enable overlapped data blocks of size $(P+K-2)$. M and N, respectively, are the height and width of the image. P is the block size and K is the order of the wavelet filter.

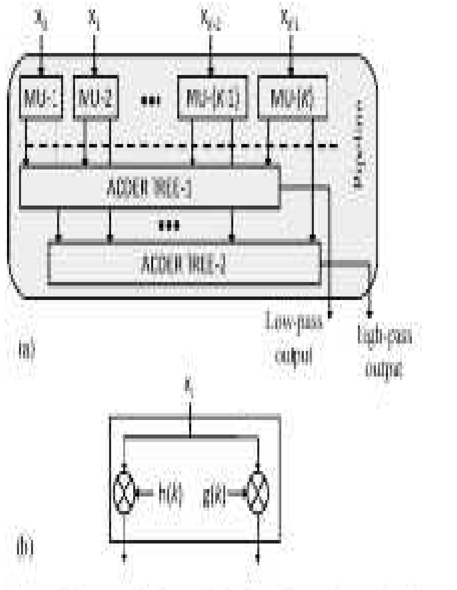


Fig. 10. (a) Structure of the subcell for orthogonal wavelet filters. (b) Structure of (k + 1)th MU

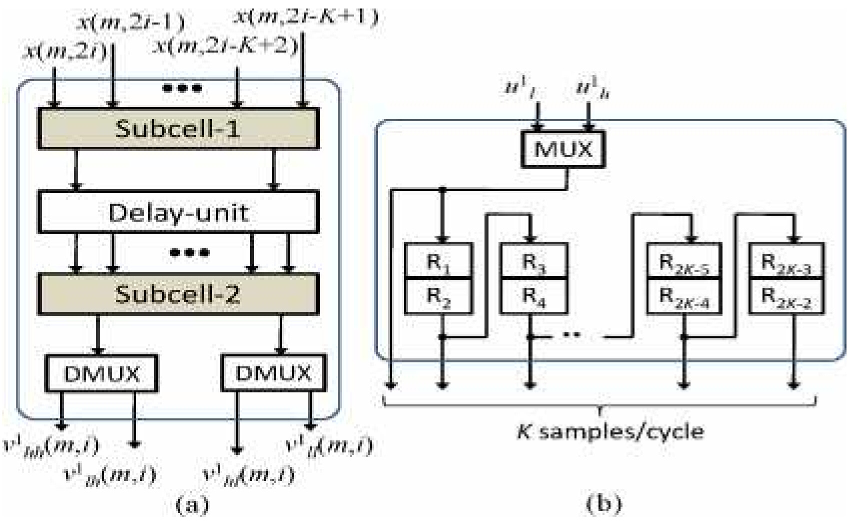


Fig. 9. (a) Structure of the processing element (PE). (b) Structure of delayunit

(DU-1).

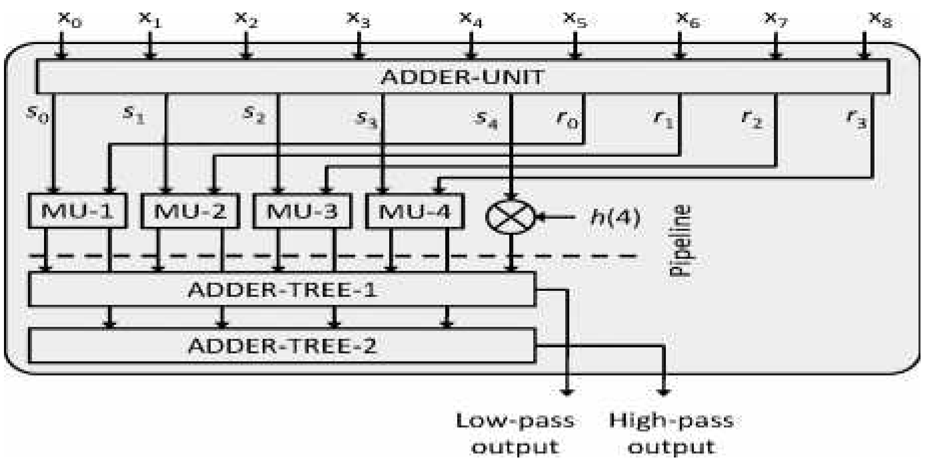
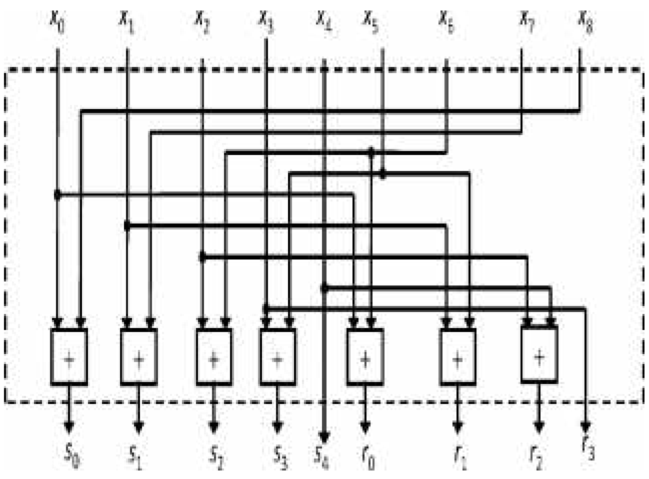


Fig. 11. Structure of the subcell for 9/7-biorthogonal wavelet filter.

Subcell-1 of PE generates a pair of low-pass (u) and highpass(u) intermediate components in each cycle. Successive outputs of subcell-1 belong to the same column. Subcell-2 does the processing of the intermediate matrices [Uhll] and[U] columnwise in time-multiplexed form to take the advantage of down-sampled DWT computation. The delayunit (DU-1) provides the necessary column delay to the intermediate results and feeds them into subcell-2 in time multiplexed form to perform down-sampled DWT computation. Internal structure of DU-1 is shown in Fig.9(b).



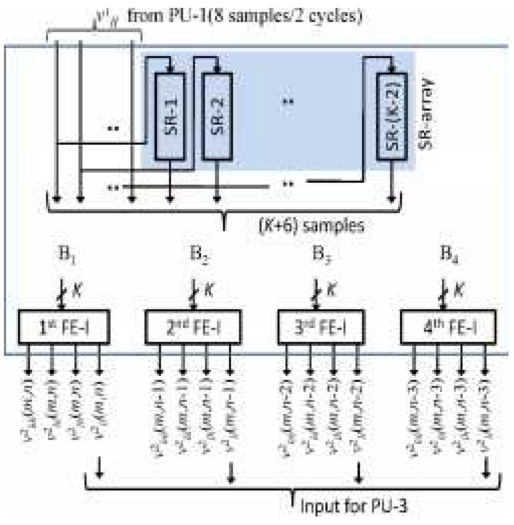


Fig. 12. Structure of the adder-unit.

Fig. 13. Structure of PU-2.

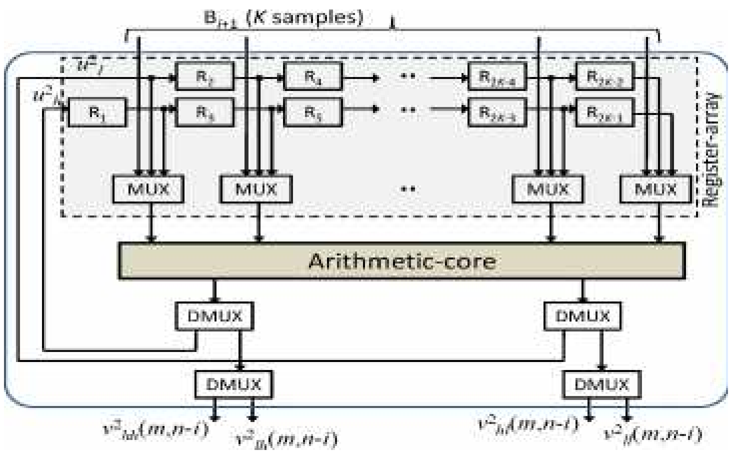


Fig. 14. Structure of (i + 1)th FE-I

During every even-numbered cycles, suppose the low-pass components u (m, n) are available at the MUX so that during the same cycle, (K - 1) consecutive components of the nth column {u ll m - 1,n),ul (m - 2,n),...,u(m - K +1,n)} are available at the even-numbered registers. During the odd-numbered cycles, high-pass components of the same nth column {uh(m, n, uh(m - 1,n),...,ul(m - K +1,n)} are, respectively, available at the MUX and the same evennumbered registers. Subcell-2, therefore, receives components of ulh during every even-numbered cycles and those of u during every-odd numbered cycles. One component of a pair subbands [v1ll,v1lh] or [v1hl,v1hh] is obtained from each PE in every cycle and one component of each of four subbands is obtained in a couple of cycles.

5.3 PROCESSING UNIT -2

Components of low-low subband v1ll are processed by PU-2 to compute DWT components of second-level. PU-2 receives a block eight components of a particular row of v1ll from PU-1 in every alternate cycle. The structure of PU-2 is shown in Fig. 13. It consists of one SR-array and four functional elements (FEs) of type FE-I.The data-input format of PU-2 is the same as that of PU-1. Each input block is extended by (K - 2) samples and theadjacent input block of a row is overlapped by (K - 2) samples.

The (K - 2) previous columns of v1ll are, therefore, required to be stored to provide Zh the necessary data extension and block overlapping. The SRarray, therefore, contains (K - 2) SRs of M/2 words each. SR-array also introduces embedded down-sampling along the rows for second-level DWT computation. Input blocks of v arrives at PU-2 columnwise in alternate cycles such that one column of the input blocks of v1ll arrives at the PU-2 in M cycles, and input blocks of the entire subband v1 ll in MN/16 cycles.

Each input block arriving at PU-2 are extended by (K -2) samples (available in the SR array). Four overlapped data vectors of size K are derived from each extended-block of size (K + 6) in similar format as that of the first-level. The data vectors are fed to the FEs in parallel, such that $(i + 1)^{th}$ FE-I receives the data-vector **B**i+1, where **B** of input block **I**(m, n) contains the samples {v1lli+1(m, 8n +2i),v1ll(m, 8n +2i +1),...,v1ll(m, 8n +2i + K - 1), for 0 = m= (M/2) - 1,0 = n = (N/16) - 1 and 0 = i = 3. Structure of FE-I is shown in Fig. 14. It consists of one arithmetic-core (ARC),one register array and four DMUXes.

All registers of register array and SRs of SR-array are clocked by CLK2 whose frequency is half of the frequency of CLK1 used by PU-1. Multiplexer selects the delayed samples of u2l, and ui2h alternately and feeds them to the ARC during idle cycles. A pair of DWT components of two subbands (v2 ll,v2 lh)or(v2 hl,v2 hh) are obtained from each FE-I after every couple of cycles and one component of each of four subbands in every four cycles.

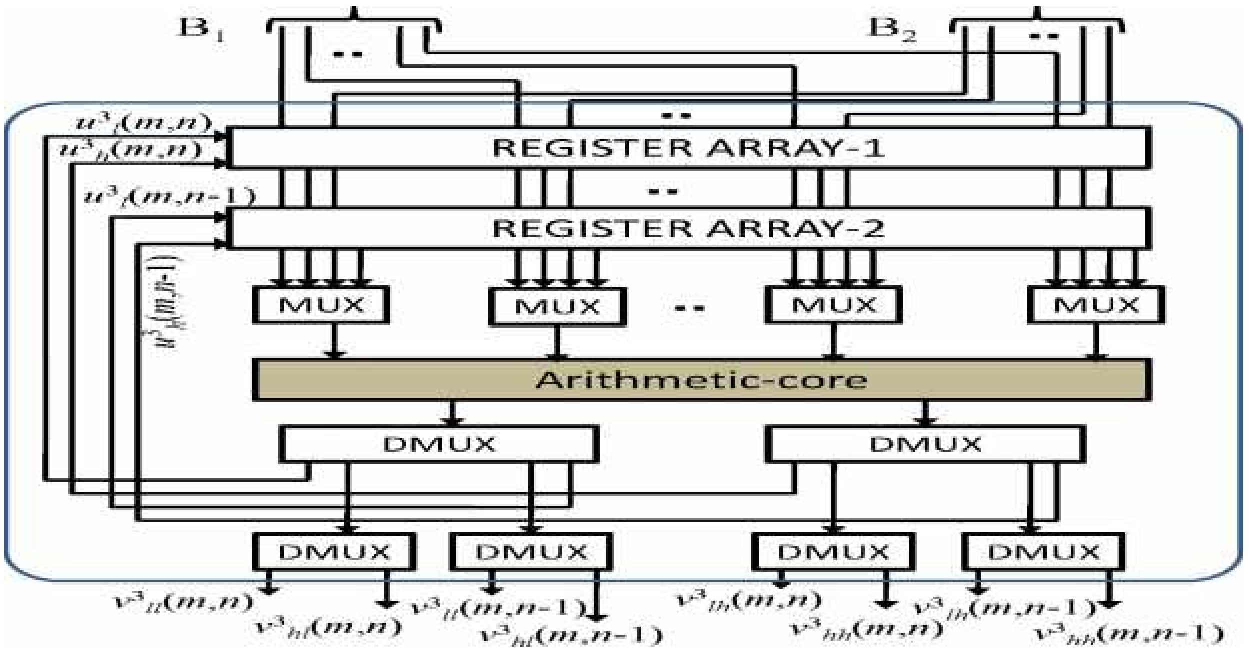


Fig. 15. Structure of PU-3.

Similarly, register array-2 provides the column-delay to u3li(m, n - 1)i and u3h(m, n - 1). Finally, MUXes of DU-3 select the output signals of register-array1 and register-array-2 in order to feed them to the ARC for the computation of column-DWT. Each MUX of the MUXarray select samples of **B**, outputs of register-array-1, samples of **B**21 and outputs of register-array-2 during every $(4n)^{th}$,$(4n+1)^{th}$, $(4n+2)^{th}$, and $(4n+3)^{th}$ cycles, respectively.

5.4 PROCESSING UNIT -3

Components of subband v2 ll are sent to PU-3 to compute third-level DWT. PU-3 receives a block of four components corresponding to four consecutive columns of v2 ll from PU-2 in every fourth cycle. The data-input format of PU-3 is the same as that of PU-2. (K - 2) previous columns of v2 ll are buffered in the SR-array to provide the necessary data extension to each input block. The size of each SR in this case is M/4words. The structure of PU-3 is shown in Fig. 15. It consists of one delay-unit (DU-3) and one FE-II. Input blocks of v arrives at PU-3 columnwise after every fourth cycle such that one column of the input blocks of v2 ll arrives at the PU-2 in M cycles and all input blocks of the entire subband v in MN/16 cycles.

Two overlapped data vectors of size K are derived from each extended block (of size K+2). Data-vectors (**B**) of a particular extended-block are fed to FE-II in alternate cycles. In this way,**B**1 and **B** of all the input blocks are time multiplexed and fed to FE-II during every (4n)th and (4n + 2)th cycles. Data-vector **B**2 is latched in DU-3 and the MUXes of FE-II select **B**22 two cycles after **B**. Structure of FE-II is shown in Fig. 16. It consists of two register arrays and one ARC. The ARC receives the data vectors (**B**1) of a particular input block through the 4-to-1 MUXes after a gap of two cycles.

It computes a pair of intermediate components u3l (m, n) and u3h(m, n) corresponding to data-vector **B**1 during every (4n + 1)th cycle. During every (4n + 3)th cycle, it computes (u3l(m, n - 1), u3 h1 and **B** and **B**1(m, n - 1)) corresponding to **B**.The successive intermediate outputs corresponding to **B** or **B**2 belong to the same columns.

Since the ARC receives the data-blocks at alternate cycle, it remains idle during odd cycles. These idle cycles of the ARC are utilized by computing column-DWT of all the intermediate components in a time-multiplexed form. Computation components in a time-multiplexed form. Computation of u3l(m, n) and u3h(m, n) are scheduled at every (8n + 1)th and (8n + 5)th cycles, respectively, to take advantage of the down-sampled filter computation. Similarly, the computation of u3l(m, n - 1) and u3h(m, n - 1) are scheduled at every(8n + 3)th and (8n+7)th cycles, respectively.

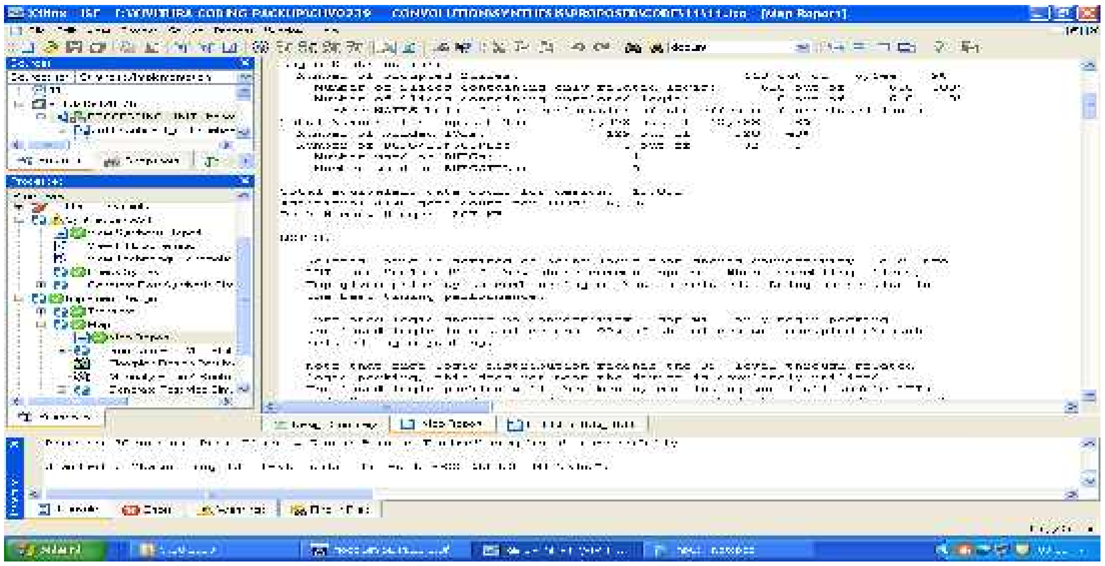
The register array-1 provides the necessary column delay to the samples of u3 l(m,n)i and u3 h(m, n). Similarly, register-array-2 provides the column-delay to u3 l(m, n - 1)i and u3 h(m, n - 1). Finally, MUXes of DU-3 select the output signals of register-array1 and register-array-2 in order to feed them to the ARC for the computation of column-DWT. Each MUX of the MUXarray select samples of **B**, outputs of register-array-1, samples of **B**21 and outputs of register-array-2 during every $(4n)^{th}$,$(4n+1)^{th}$, $(4n+2)^{th}$, and $(4n+3)^{th}$ cycles, respectively.

All the registers of DU-3 and SRs of SR-array are clocked by CLK3 whose frequency is one-fourth of the frequency of CLK1. A pair of DWT components corresponding to two adjacent columns of two subbands (v2 ll,v2 lh) are obtained from FE-II during even-numbered period of eight cycles. During the odd numbered sets of eight cycles, a pair of components of other two subbands (v3 hl,v3 hh) of the same two columns are produced. Two columns of each of four subbands are obtained in M cycles and subband components of the third-level DWT are obtained in NM/16 cycles

6.RESULTS

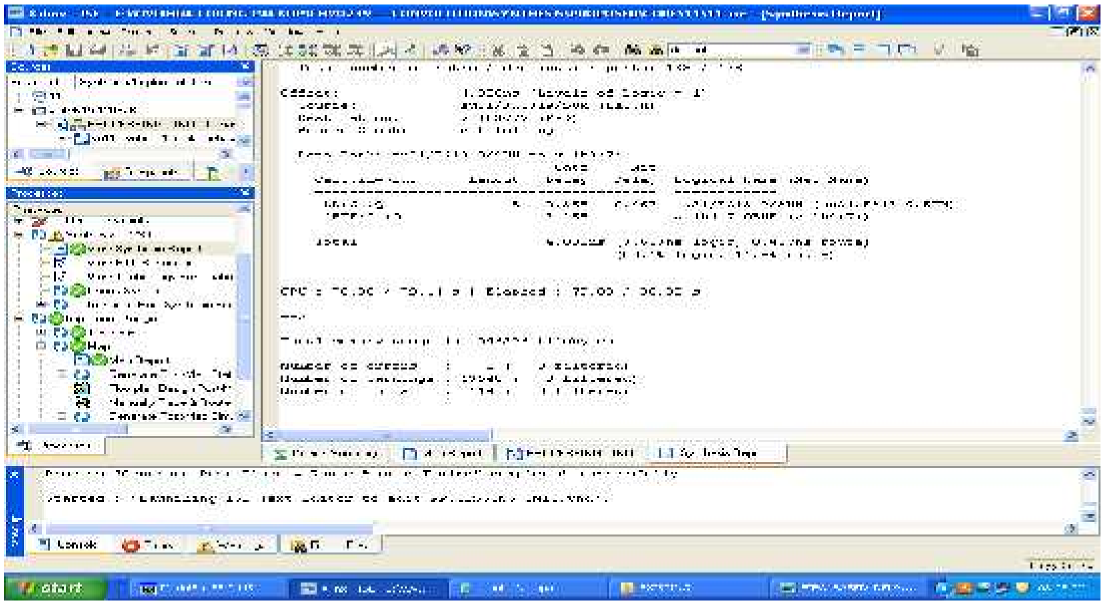
6.1 PROPOSED SYSTEM OUTPUTS

6.1.1 AREA



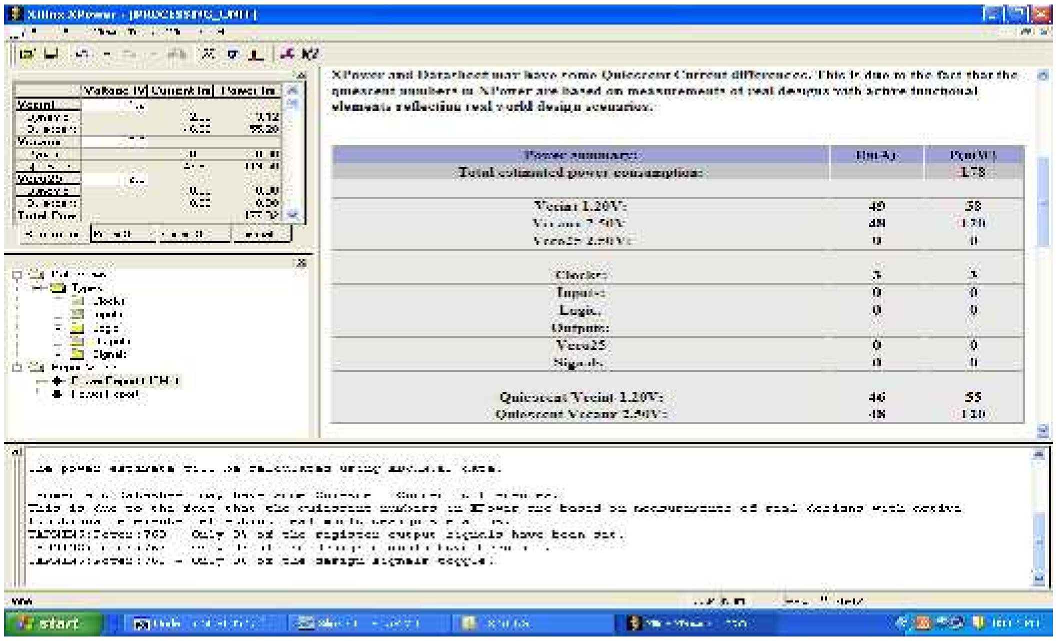
[illegible]

6.1.2 DELAY



[illegible]

6.1.3 POWER



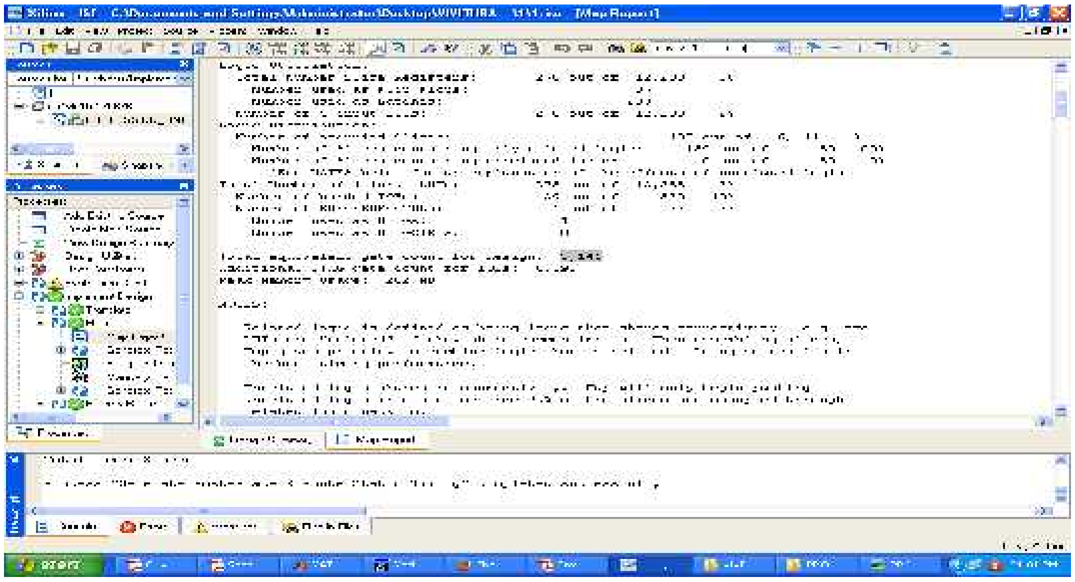
XPower and Datasheet may have some Quiescent Current differences. This is due to the fact that the quiescent numbers in XPower are based on measurements of real designs with active functional elements reflecting real world design scenarios.

Power summary:	I(mA)	P(mW)
Total estimated power consumption:		178
Vccint 1.20V:	49	58
Vccaux 2.50V:	48	120
Vcco25 2.50V:	0	0
Clocks:	3	3
Inputs:	0	0
Logic:	0	0
Outputs:		
Vcco25	0	0
Signals:	0	0
Quiescent Vccint 1.20V:	46	55
Quiescent Vccaux 2.50V:	48	120

```
This is due to the fact that the quiescent numbers in XPower are based on measurements of real designs with active
[illegible]
Only 0% of the registed output signals have been set.
[illegible]
```

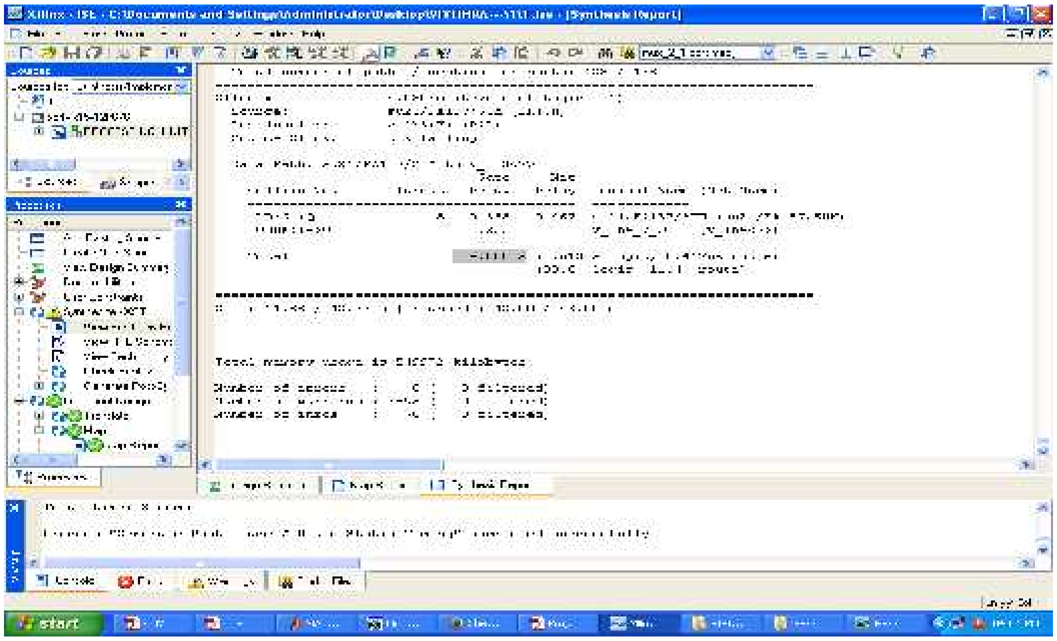
6.2 MODIFIED SYSTEM OUTPUTS

6.2.1 AREA

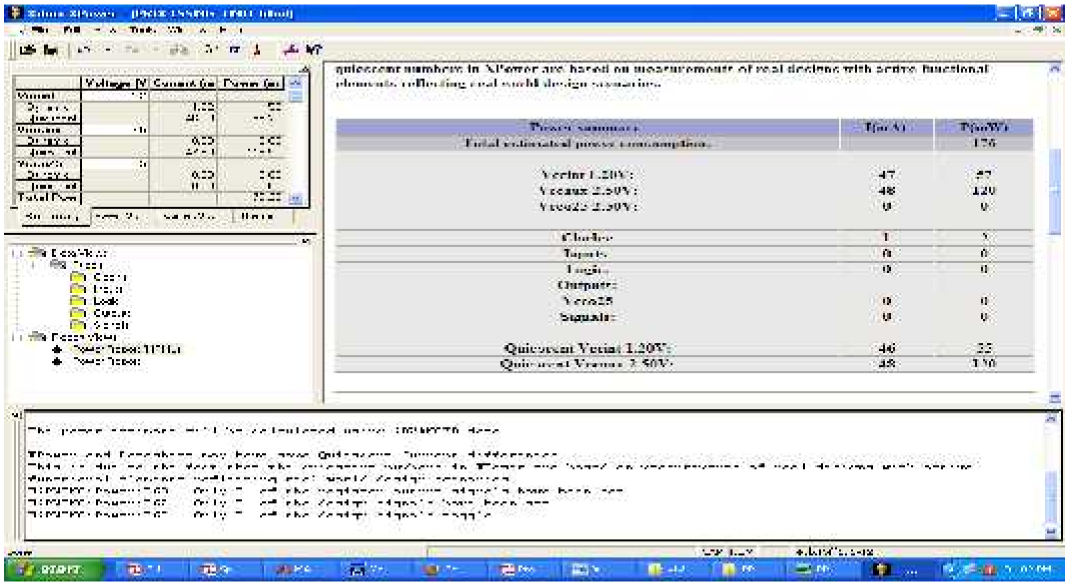


```
[illegible]
```

6.2.2 DELAY



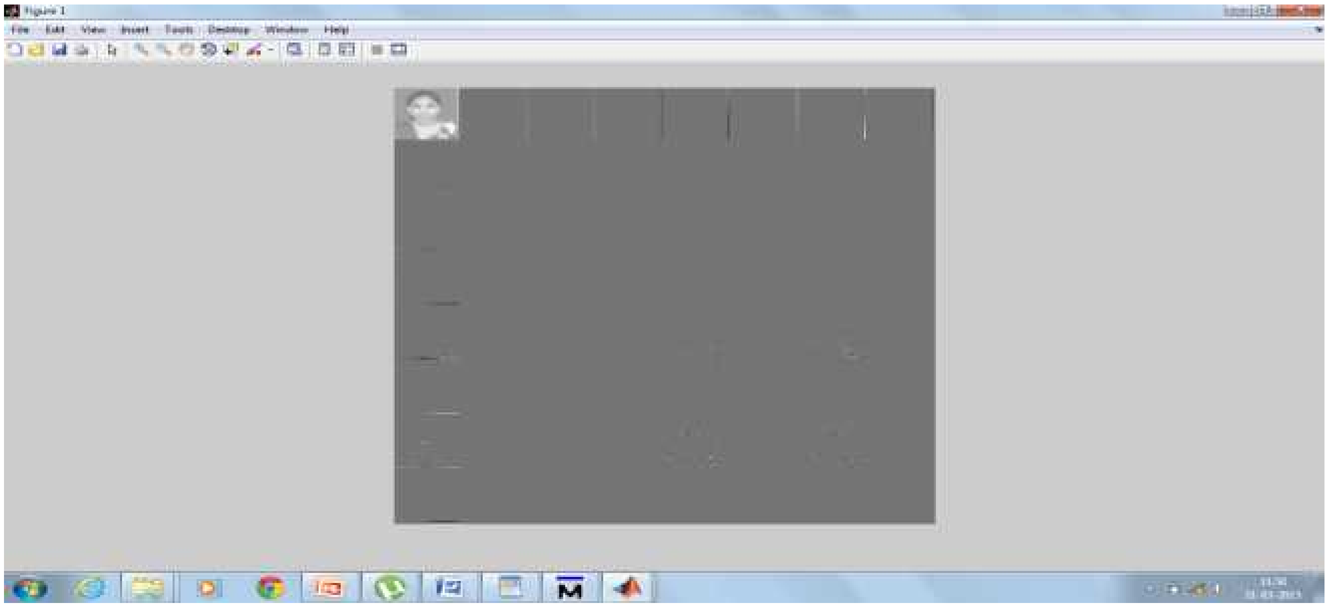
6.2.3 POWER



quiescent numbers in XPower are based on measurements of real designs with active functional elements reflecting real world design scenarios.

Power summary	I(mA)	P(mW)
Total estimated power consumption:		176
Vccint 1.20V:	47	57
Vccaux 2.50V:	48	120
Vcco25 2.50V:	0	0
Clocks:	1	5
Inputs:	0	0
Logic:	0	0
Outputs:		
Vcco25	0	0
Signals:	0	0
Quiescent Vccint 1.20V:	46	55
Quiescent Vccaux 2.50V:	48	120

OUTPUT



COMPARISON BETWEEN PROPOSED AND MODIFIED SYSTEM OUTPUTS

PARAMETER	PROPOSED SYSTEM	MODIFIED SYSTEM
AREA	12,038	3,141
DELAY	4.080ns	4.080ns
POWER	178mw	176mW

7. APPENDIX

PROGRAM CODING

```
library IEEE;

use IEEE.STD_LOGIC_1164.ALL;

use IEEE.STD_LOGIC_ARITH.ALL;

use IEEE.STD_LOGIC_SIGNED.ALL;

use work.pack.all;

library std;

use std.textio.all;

entity dwt_conv1_bio9 is

   port(clk:in std_logic);

end dwt_conv1_bio9;

architecture Behav of dwt_conv1_bio9 is

signal dwtt:arr_512_512_real:=(others=>(others=>0.0));

--signal  ul,uh:arr_512_256_real;

signal dwtt1:arr_512_19_real:=(others=>(others=>0.0));

procedure subcell1_bio9(variable x0:in real;

                          variable x1:in real;
```

```
                        variable x2:in real;

                        variable x3:in real;

                        variable x4:in real;

                        variable x5:in real;

                        variable x6:in real;

                        variable x7:in real;

                        variable x8:in real;

                        variable ul1:out real;

                        variable uh1:out real) is

 variable s0,s1,s2,s3,s4:real;

 variable r0,r1,r2,r3:real;

begin

 s0:=x0+x8;

 s1:=x1+x7;

 s2:=x2+x6;

 s3:=x3+x5;

 s4:=x4 ;

 r0:=x0+x6;

 r1:=x1+x5;
 r2:=x2+x4;

 r3:=x3;

ul1:=((0.02674875741080976*s0)+((-0.01686411844287495)*s1)+((-
0.07822326652898785)*s2)+(0.2668641184428723*s3)+(0.6029490183263579*s4
));

uh1:=((0.09127176311424948*r0)+((-0.05754352622849957)*r1)+((-
0.5912717631142470)*r2)+(1.115087052456994*r3));

end procedure subcell1_bio9;

begin

process(clk)

variable line_var : line;

file  text_var : text;

variable data_in1,uout : arr_512_512_real;

variable  ul,uh:arr_512_256_real;

variable u1,h1,a,b,c,d,e,f,g,h,j:real;

variable u2,h2:arr_256_511_real;

variable dwt: arr_512_512_real:=(others=>(others=>0.0));

begin

   file_open(text_var,"input.txt",read_mode);

   for i in 0 to 511 loop
```

```
         for j in 0 to 511 loop
         if(NOT ENDFILE(text_var)) then
              readline(text_var,line_var);
               read(line_var,dwt(i,j));
              --- dwt(i,j):=integer(a1);
          end if;
      end loop;
    end loop;
    file_close(text_var);
dwtt <=dwt;
-------------1 level--------------
for m in 0 to 511 loop
for i in 0 to 255 loop
if(i<=251)then
a:=dwt(m,(2*i));
b:=dwt(m,(2*i+1));
c:=dwt(m,(2*i+2));
d:=dwt(m,(2*i+3));
e:=dwt(m,(2*i+4));
```

```
f:=dwt(m,(2*i+5));

g:=dwt(m,(2*i+6));

h:=dwt(m,(2*i+7));

j:=dwt(m,(2*i+8));

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

elsif(i=252)then

a:=dwt(m,504);

b:=dwt(m,505);

c:=dwt(m,506);

d:=dwt(m,507);

e:=dwt(m,508);

f:=dwt(m,509);

g:=dwt(m,510);

h:=dwt(m,511);

--g:=0.0;

j:=0.0;

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

elsif(i=253)then

a:=dwt(m,506);
```

```
b:=dwt(m,507);

c:=dwt(m,508);

d:=dwt(m,509);

e:=dwt(m,510);

f:=dwt(m,511);

g:=0.0;

h:=0.0;

--g:=0.0;

j:=0.0;

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

elsif(i=254)then

a:=dwt(m,508);

b:=dwt(m,509);

c:=dwt(m,510);

d:=dwt(m,511);

e:=0.0;

f:=0.0;

g:=0.0;

h:=0.0;
```

```
--g:=0.0;

j:=0.0;

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

elsif(i=255)then

a:=dwt(m,510);

b:=dwt(m,511);

c:=0.0;

d:=0.0;

e:=0.0;

f:=0.0;

g:=0.0;

h:=0.0;

--g:=0.0;

j:=0.0;

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

end if;

ul(m,i):=u1;uh(m,i):=h1;

end loop;

end loop;
```

```
for i in 0 to 511 loop

for j in 0 to 255 loop

   dwt(i,j):=ul(i,j);

   dwt(i,j+256):=uh(i,j);

 end loop;

 end loop;

 ---------separation---------

for m in 0 to 511 loop

for i in 0 to 255 loop

if(i<=251)then

a:=dwt((2*i),m);

b:=dwt((2*i+1),m);

c:=dwt((2*i+2),m);

d:=dwt((2*i+3),m);

e:=dwt((2*i+4),m);

f:=dwt((2*i+5),m);

g:=dwt((2*i+6),m);

h:=dwt((2*i+7),m);

j:=dwt((2*i+8),m);
```

```
subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

elsif(i=252)then

a:=dwt(504,m);

b:=dwt(505,m);

c:=dwt(506,m);

d:=dwt(507,m);

e:=dwt(508,m);

f:=dwt(509,m);

g:=dwt(510,m);

h:=dwt(511,m);

--g:=0.0;

j:=0.0;

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

elsif(i=253)then

a:=dwt(506,m);

b:=dwt(507,m);

c:=dwt(508,m);

d:=dwt(509,m);

e:=dwt(510,m);
```

```
f:=dwt(511,m);

g:=0.0;

h:=0.0;

g:=0.0;

j:=0.0;

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

elsif(i=254)then

a:=dwt(508,m);

b:=dwt(509,m);

c:=dwt(510,m);

d:=dwt(511,m);

e:=0.0;

f:=0.0;

g:=0.0;

h:=0.0;

g:=0.0;

j:=0.0;

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

elsif(i=255)then
```

```
a:=dwt(510,m);

b:=dwt(511,m);

c:=0.0;

d:=0.0;

e:=0.0;

f:=0.0;

g:=0.0;

h:=0.0;

g:=0.0;

j:=0.0;

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

end if;

u2(i,m):=u1;h2(i,m):=h1;

end loop;

end loop;

for i in 0 to 511 loop

for j in 0 to 255 loop

   dwt(j,i):=u2(j,i);

   dwt(j+256,i):=h2(j,i);
```

```
 end loop;

 end loop;

-------------2 level--------------

for m in 0 to 511 loop

for i in 0 to 255 loop

if(i<=251)then

a:=dwt(m,(2*i));

b:=dwt(m,(2*i+1));

c:=dwt(m,(2*i+2));

d:=dwt(m,(2*i+3));

e:=dwt(m,(2*i+4));

f:=dwt(m,(2*i+5));

g:=dwt(m,(2*i+6));

h:=dwt(m,(2*i+7));

j:=dwt(m,(2*i+8));

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

elsif(i=252)then

a:=dwt(m,504);

b:=dwt(m,505);
```

```
c:=dwt(m,506);

d:=dwt(m,507);

e:=dwt(m,508);

f:=dwt(m,509);

g:=dwt(m,510);

h:=dwt(m,511);

--g:=0.0;

j:=0.0;

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

elsif(i=253)then

a:=dwt(m,506);

b:=dwt(m,507);

c:=dwt(m,508);

d:=dwt(m,509);

e:=dwt(m,510);

f:=dwt(m,511);

g:=0.0;

h:=0.0;

g:=0.0;
```

```
j:=0.0;

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

elsif(i=254)then

a:=dwt(m,508);

b:=dwt(m,509);

c:=dwt(m,510);

d:=dwt(m,511);

e:=0.0;

f:=0.0;

g:=0.0;

h:=0.0;

g:=0.0;

j:=0.0;

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

elsif(i=255)then

a:=dwt(m,510);

b:=dwt(m,511);

c:=0.0;

d:=0.0;
```

```
e:=0.0;

f:=0.0;

g:=0.0;

h:=0.0;

g:=0.0;

j:=0.0;

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

end if;

ul(m,i):=u1;

uh(m,i):=h1;

end loop;

end loop;

for i in 0 to 511 loop

for j in 0 to 255 loop

   dwt(i,j):=ul(i,j);

   dwt(i,j+256):=uh(i,j);

 end loop;

 end loop;

 ---------separation---------
```

```
for m in 0 to 511 loop

for i in 0 to 255 loop

if(i<=251)then

a:=dwt((2*i),m);

b:=dwt((2*i+1),m);

c:=dwt((2*i+2),m);

d:=dwt((2*i+3),m);

e:=dwt((2*i+4),m);

f:=dwt((2*i+5),m);

g:=dwt((2*i+6),m);

h:=dwt((2*i+7),m);

j:=dwt((2*i+8),m);

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

elsif(i=252)then

a:=dwt(504,m);

b:=dwt(505,m);

c:=dwt(506,m);

d:=dwt(507,m);

e:=dwt(508,m);
```

```
f:=dwt(509,m);

g:=dwt(510,m);

h:=dwt(511,m);

--g:=0.0;

j:=0.0;

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

elsif(i=253)then

a:=dwt(506,m);

b:=dwt(507,m);

c:=dwt(508,m);

d:=dwt(509,m);

e:=dwt(510,m);

f:=dwt(511,m);

g:=0.0;

h:=0.0;

g:=0.0;

j:=0.0;

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

elsif(i=254)then
```

```
a:=dwt(508,m);

b:=dwt(509,m);

c:=dwt(510,m);

d:=dwt(511,m);

e:=0.0;

f:=0.0;

g:=0.0;

h:=0.0;

g:=0.0;

j:=0.0;

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

elsif(i=255)then

a:=dwt(510,m);

b:=dwt(511,m);

c:=0.0;

d:=0.0;

e:=0.0;

f:=0.0;

g:=0.0;
```

```
h:=0.0;

g:=0.0;

j:=0.0;

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

end if;

u2(i,m):=u1;

h2(i,m):=h1;

end loop;

end loop;

for i in 0 to 511 loop

for j in 0 to 255 loop

   dwt(j,i):=u2(j,i);

   dwt(j+256,i):=h2(j,i);

 end loop;

 end loop;

-------------3 level--------------

for m in 0 to 511 loop

for i in 0 to 255 loop

if(i<=251)then
```

```
a:=dwt(m,(2*i));

b:=dwt(m,(2*i+1));

c:=dwt(m,(2*i+2));

d:=dwt(m,(2*i+3));

e:=dwt(m,(2*i+4));

f:=dwt(m,(2*i+5));

g:=dwt(m,(2*i+6));

h:=dwt(m,(2*i+7));

j:=dwt(m,(2*i+8));

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

elsif(i=252)then

a:=dwt(m,504);

b:=dwt(m,505);

c:=dwt(m,506);

d:=dwt(m,507);

e:=dwt(m,508);

f:=dwt(m,509);

g:=dwt(m,510);

h:=dwt(m,511);
```

```
--g:=0.0;

j:=0.0;

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

elsif(i=253)then

a:=dwt(m,506);

b:=dwt(m,507);

c:=dwt(m,508);

d:=dwt(m,509);

e:=dwt(m,510);

f:=dwt(m,511);

g:=0.0;

h:=0.0;

g:=0.0;

j:=0.0;

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

elsif(i=254)then

a:=dwt(m,508);

b:=dwt(m,509);

c:=dwt(m,510);
```

```
d:=dwt(m,511);

e:=0.0;

f:=0.0;

g:=0.0;

h:=0.0;

g:=0.0;

j:=0.0;

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

elsif(i=255)then

a:=dwt(m,510);

b:=dwt(m,511);

c:=0.0;d:=0.0

;e:=0.0;f:=0.0;

g:=0.0;h:=0.0;

g:=0.0;j:=0.0;

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

end if;

ul(m,i):=u1;

uh(m,i):=h1;
```

```
end loop;

end loop;

for i in 0 to 511 loop

for j in 0 to 255 loop

   dwt(i,j):=ul(i,j);

   dwt(i,j+256):=uh(i,j);

 end loop;

 end loop;

 ---------separation---------

for m in 0 to 511 loop

for i in 0 to 255 loop

if(i<=251)then

a:=dwt((2*i),m);

b:=dwt((2*i+1),m);

c:=dwt((2*i+2),m);

d:=dwt((2*i+3),m);

e:=dwt((2*i+4),m);

f:=dwt((2*i+5),m);

g:=dwt((2*i+6),m);
```

```
h:=dwt((2*i+7),m);

j:=dwt((2*i+8),m);

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

elsif(i=252)then

a:=dwt(504,m);

b:=dwt(505,m);

c:=dwt(506,m);

d:=dwt(507,m);

e:=dwt(508,m);

f:=dwt(509,m);

g:=dwt(510,m);

h:=dwt(511,m);

g:=0.0;

j:=0.0;

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

elsif(i=253)then

a:=dwt(506,m);

b:=dwt(507,m);

c:=dwt(508,m);
```

```
d:=dwt(509,m);

e:=dwt(510,m);

f:=dwt(511,m);

g:=0.0;

h:=0.0;

g:=0.0;

j:=0.0;

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

elsif(i=254)then

a:=dwt(508,m);

b:=dwt(509,m);

c:=dwt(510,m);

d:=dwt(511,m);

e:=0.0;

f:=0.0;

g:=0.0;

h:=0.0;

g:=0.0;

j:=0.0;
```

```
subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

elsif(i=255)then

a:=dwt(510,m);

b:=dwt(511,m);

c:=0.0;

d:=0.0;

e:=0.0;

f:=0.0;

g:=0.0;

h:=0.0;

g:=0.0;

j:=0.0;

subcell1_bio9(a,b,c,d,e,f,g,h,j,u1,h1);

end if;

u2(i,m):=u1;

h2(i,m):=h1;

end loop;

end loop;

for i in 0 to 511 loop
for j in 0 to 255 loop
   dwt(j,i):=u2(j,i);
   dwt(j+256,i):=h2(j,i);
 end loop;
 end loop;
file_open(text_var,"1level.txt",write_mode);
    for i in 0 to 511 loop
   for j in 0 to 511 loop
     write(line_var,dwt(i,j));
     writeline(text_var,line_var);
   end loop;
end loop;
  file_close(text_var);
end process;
end behav;
```

8.CONCLUSION

It is found that memory complexity is the most important issue for efficient realization of 2-D DWT in VLSI systems.In this paper it is, therefore, suggested a memory centric design strategy, and based on that derived a convolution-based generic architecture for the computation of three-level 2-D DWT based on Daubechies as well as biorthogonal wavelet filters.

The given structure does not involve FB and involves line-buffers of size 3(K - 2)M/4 which is independent of throughput rate. This is used as a major advantage when the structure is implemented for higher throughput rate. Compared with the best of the existing liftingbased folded structure , given structure using 9/7-filter for the image-size (512 × 512) involves less area complexity and 2.62 times less computation time. ASIC synthesis result shows that, proposed structure using Daub-4 involves 1.7 times less ADP and consumes 1.21 times less EPI than the best of the existing convolution-based folded structure .

Compared with the recently proposed parallel structure , the given structure involves 2.6 times less ADP and consumes 1.48 times less EPI. The proposed structure, therefore, could be used as a generic one for area-delay efficient and energy efficient implementation of multilevel 2-D DWT using Daubechies as well as biorthogonal filters for high-performance image processing applications.

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