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Image Compression using Frequency Band Suppression in VLSI Design based Discrete Wavelet Transform

K. Lakshmi Narayanan[a] and G.P. Ramesh[b]

[a]*Research Scholar, St. Peter's University, Chennai - 600054, Tamil Nadu, India. Email: lakshminarayanankvlsi@gmail.com*
[b]*Professor and Head, ECE Department, St. Peter's University, Chennai - 600054, Tamil Nadu, India*

Abstract: Discrete Wavelet Transform is an important tool in image processing. The Discrete Wavelet Transform is used for significant compression of web images that are to be displayed in short page loading time with bandwidth as major constraint. The Discrete Wavelet Transform provides spatial frequency information and the spatial location at which the frequency in consideration occurs. The biggest advantage of this nature is that concurrent information helps us to reduce redundancy more efficiently. The spatial locations of the image may or may not contain variations and at certain times may be constants also. A signal which is constant does not carry significant information. If the coefficients of constant signal are encoded along with other spatial location coefficients it is memory wastage. Discrete Wavelet Transform if applied to the image as a whole results in better frequency resolution and good spatial resolution. But still this spatial resolution is not that good. This work aims in improving the spatial resolution further. The image is segmented in space into small sub-images and Discrete Wavelet Transform is applied recursively to each sub image. Since the target image is spatially small in resolution as well, the same operation can be achieved with smaller Discrete Wavelet Transform Unit. Since there are only few pixels at any given time the processing is faster and the throughput is high. Because of large throughput the entire operation can be pipelined and done in a serial manner. This greatly reduces the number of Discrete Wavelet Transform Units required.

Keywords: Image Processing, Discrete Wavelet Transform, Image Compression.

1. INTRODUCTION

The image processing finds prominent applications in three important aspects. The three aspects are improvement of pictorial information for human perception, image processing for application in autonomous machines, image storage and retrieval. Typical applications of this type are noise filtering. Sometimes the image is very noisy. So the noise has to be filtered so that the image appears better. The second aspect is that there are times at which we have to improve the contrast of the image. Captured image sometimes looks blurred. We have to make sure the image processing techniques rectifies the blurred image and improves the contrast of the image so that we get the better version of the same image. The third aspect is with regard to compression. Image when stored as raw data, consumes large amount of memory which makes high end multimedia capabilities of todays digital equipment impossible. The raw image data contains lots of redundant information and this is the reason why it occupies large amount of memory. The frequency information gives valuable insights into the properties of image and gives us a clear view of the way redundancy has to be removed without loss of significant information.

2. RELATED WORK

Tran, M. Q. et. al., [1] described the Discrete Wavelet Transform based solution to Graphical Processing Units. It was discussed that the Discrete Wavelet Transform based solutions to Graphical Processing Units did not leverage the full power of the units under consideration. GPU optimizing strategies using Discrete Wavelet Transform like shared memory, registers, warp shuffling instructions, and thread- and instruction-level parallelism. Hybrid approach to boost up the performance is discussed.

Shih-Hau, F. et. al., [2] described, channel state information was preferred over Received Signal Strength indicator for indoor Wi-Fi positioning systems. Channel State Information has rich details regarding the channel, but the problem is that the accuracy is affected for channels with higher dimensions. The method for fingerprinting based indoor localization is described. The algorithm operates on the channel state information sequence by taking multilevel Discrete Wavelet Transform and normalizing the coefficients using histogram equalization. The robust features are then reconstructed by taking inverse Multilevel Wavelet Transform of the normalized coefficients.

Paul, H. et. al., [3] detailed a method for image compression based on contrast sensitivity of the perception of the human visual system. Contrast sensitivity functions were conventionally obtained using fixed size Gabor functions. The basis functions of multi-resolution decompositions such as wavelets often resemble Gabor functions. They are of variable size and shape. Conventional Contrast Sensitivity Functions cannot be used here. A set of tests are conducted and Contrast Sensitivity Functions for a range of multi resolution transforms are obtained which are Discrete Wavelet Transform, the steerable pyramid, the dual-tree complex wavelet transform, and the curvelet transform.

Min, L. [4] et. al., described that conventionally watermark was embedded by degrading the host audio signal. The zero audio watermarking is done by using Discrete Wavelet Transform, Discrete Cosine Transform and Singular Value Decomposition methods. Registration of the watermark is done by taking Singular Value Decomposition of the generated coefficients, so that the watermark is embedded without degrading the host audio signal quality. The watermark method is robust to most of the signal processing operations.

Arrais Junior, ED. [5] et. al., stated that the electrocardiogram analysis gives valuable information about the state of the heart. The QRS complex detection is one of the fundamental issue in the electrocardiographic signal analysis. Real Time QRS detection based on Redundant Discrete Wavelet Transform is presented. The method uses scales, wavelet coefficients and wavelet coefficient’s energy for detection.

3. WAVELET TRANSFORM

Several forms of the Fourier Transform exist depending on the space where the transform is defined. In the same manner since Wavelet Transform is an extension of the Fourier Transform, there are also several forms of Wavelet Transform, each for a particular space of sequences or functions.

The Discrete Wavelet Transform (DWT) is a fundamental form of Wavelet Transform and is defined on $l^2(Z_N)$, a group of N-dimensional vectors in Hilbert space over which the theory of the Discrete Fourier Transform is built. The simplicity of the Wavelet Transform lies within the finite dimension of the space $l^2(Z_N)$. The observations yield the completeness of the orthonormal wavelet basis.

The other form is declared on $l^2(Z)$ which is a Hilbert space of infinite generally non-periodic complex signals. The operation is in Discrete Time signals and therefore the background theory used is Discrete Wavelet Transform. The infinite dimensionality makes the theory more demanding, requiring a more complete set of orthonormal basis functions.

The third and most complicated fact about the theory of Wavelet Transform is the Continuous Wavelet Transform which is defined on $L^2(R)$, a Hilbert space of complex square-integrable functions. The construction of Wavelets is reduced to construction of Multi Resolution Analysis.

4. MULTIRESOLUTION ANALYSIS

Multiresolution analysis decomposes the image space into two subspaces, namely V and W. The V subspace contains approximations and H subspace contains details. This is the first level analysis. Hilbert space of approximations is closed and has countable basis, it is separable and can be decomposed further. In general this is known as the analysis at the p^{th} level. Let V_j and W_j denote the space of approximations at the jth level and space of details at the *j*th level respectively. Then the following equations are valid.

$$l^1(Z_N) = v_1 \oplus w_1$$

$$v_1 = v_2 \oplus w_2$$

$$v_{p-1} = v_p \oplus w_p$$

A more compact form is

$$l^2(Z_N) = v_p \oplus w_p \oplus w_{p-1} \oplus \ldots \oplus w_1$$

For a particular value of $j V_j$ and W_j have same dimension. The spaces V_j and W_j have dimension $N/2^j$. If p is the maximum level of analysis then 2^p should be a factor of N. Figure 1 shows the block diagram of Multiresolution Wavelet Analysis.

5. DISCRETE WAVELET TRANSFORM IN SEGMENTED SPATIAL DOMAIN

The Discrete Wavelet Transform if implemented as such is a very complex operation. The Discrete Wavelet Transform Operation consumes most of the hardware resources. The 2D dimensional Discrete Wavelet Transform adds to the complexity of the 1D Discrete Wavelet Transform. The complexity even grows with the number of spatial points in the 2D transform and the duration of the signal for which the transform is to be taken in the case of 1D wavelet transform assuming that time is considered as the independent variable.

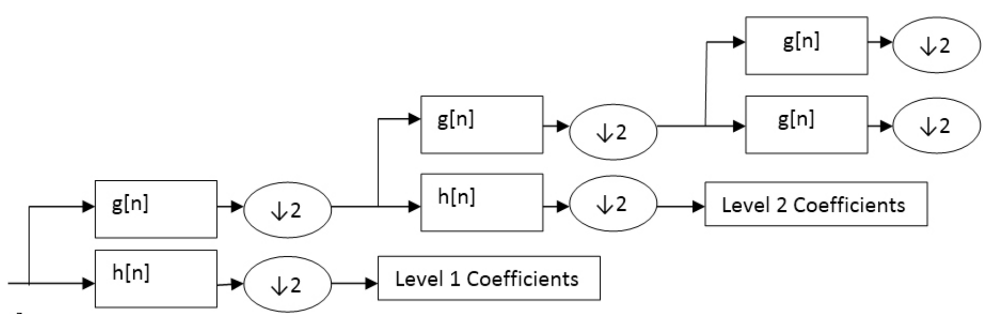

Figure 1: Architecture of Multiresolution Wavelet Analysis

A new design for the Discrete Wavelet Transform unit is proposed which takes the Discrete Wavelet Transform for the subset of the input image. The hardware resources required to compute the Discrete Wavelet

Transform for a subset of the input image is far less than the resources required to compute the same transform for the entire image all at once. The sequential processing of the image subsets of same dimensions comprising the original image allows the redesign of the unit using pipelined structures. The sequential processing reduces the hardware resource required by a substantial amount. The input and output of the Discrete Wavelet Transform unit are buffered using registers. The block diagram of the proposed Discrete Wavelet Transform unit is shown in Figure 2.

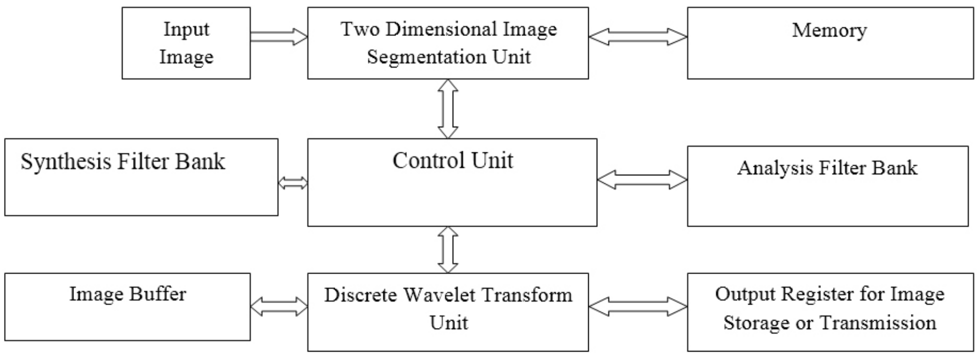

Figure 2: Architecture of Discrete Wavelet Transformation Unit by Spatial Segmentation of the Input Image

6. SIMULATION RESULTS

The simulation tool used was Modelsim. The synthesis tool used was Xilinx ISE 10. The area occupied by the Multiresolution DWT unit is shown in Figure 3.

JP2K Project Status (08/28/2016 - 11:47:13)			
Project File:	JP2K.ise	Current State:	Synthesized
Module Name:	dwt2d_top	• Errors:	No Errors
Target Device:	xc2s200e-6pq208	• Warnings:	30 Warnings
Product Version:	ISE 10.1 - WebPACK	• Routing Results:	
Design Goal:	Balanced	• Timing Constraints:	
Design Strategy:	Xilinx Default (unlocked)	• Final Timing Score:	

JP2K Partition Summary	[-]
No partition information was found.	

Device Utilization Summary (estimated values)			[-]
Logic Utilization	Used	Available	Utilization
Number of Slices	427	2352	18%
Number of Slice Flip Flops	287	4704	6%
Number of 4 input LUTs	792	4704	16%
Number of bonded IOBs	4	142	2%
Number of GCLKs	1	4	25%

Detailed Reports					[-]
Report Name	Status	Generated	Errors	Warnings	Infos
Synthesis Report	Current	Sun 28. Aug 11:47:11 2016	0	30 Warnings	2 Infos
Translation Report					
Map Report					
Place and Route Report					
Static Timing Report					
Bitgen Report					

Figure 3: The Synthesis report of the Multiresolution DWT Unit

The area occupied by the Segmented Spatial Domain Discrete Wavelet Transform is shown in Figure 4.

JP2K Project Status (12/21/2016 - 17:46:57)			
Project File:	JP2K.ise	Current State:	Synthesized
Module Name:	dwt2d_top	• Errors:	No Errors
Target Device:	xc2s200e-6pq208	• Warnings:	32 Warnings
Product Version:	ISE 10.1 - WebPACK	• Routing Results:	
Design Goal:	Balanced	• Timing Constraints:	
Design Strategy:	Xilinx Default (unlocked)	• Final Timing Score:	

JP2K Partition Summary	[-]
No partition information was found.	

Device Utilization Summary (estimated values)			[-]
Logic Utilization	Used	Available	Utilization
Number of Slices	403	2352	17%
Number of Slice Flip Flops	279	4704	5%
Number of 4 input LUTs	753	4704	16%
Number of bonded IOBs	4	142	2%
Number of GCLKs	1	4	25%

Detailed Reports					[-]
Report Name	Status	Generated	Errors	Warnings	Infos
Synthesis Report	Current	Wed 21. Dec 17:46:55 2016	0	32 Warnings	2 Infos
Translation Report					
Map Report					
Place and Route Report					
Static Timing Report					
Bitgen Report					

Figure 4: The Synthesis report of the Segmented Spatial Domain Discrete Wavelet Transform Unit

Table 1 compares the Forward Discrete Wavelet Transform Unit of the Multiresolution Analysis with Segmented Spatial Domain Method.

Table 1
Area and Delay of Multiresolution DWT Unit and Segmented Spatial Domain DWT Unit

Method	*Area (LUTs)*	*Delay(ns)*
Multiresolution Wavelet Analysis	792	16.791
Segmented Spacial Domain Wavelet Analysis	753	16.091

The area occupied by the Multiresolution IDWT unit is shown in Figure 5.

The area occupied by the Segmented Spatial Domain IDWT unit is shown in Figure 6.

Table 2 compares the Forward Discrete Wavelet Transform Unit of the Multiresolution Analysis with Segmented Spatial Domain Method.

Table 2
Area and Delay comparison of Multiresolution IDWT Unit and Segmented Spatial Domain IDWT Unit

Method	*Area (LUTs)*	*Delay(ns)*
Multiresolution Wavelet Analysis	787	19.530
Segmented Spacial Domain Wavelet Analysis	724	15.480

JP2K Project Status (08/28/2016 - 11:42:25)			
Project File:	JP2K.ise	Current State:	Synthesized
Module Name:	idwt2d_top	• Errors:	No Errors
Target Device:	xc2s200e-6pq208	• Warnings:	54 Warnings
Product Version:	ISE 10.1 - WebPACK	• Routing Results:	
Design Goal:	Balanced	• Timing Constraints:	
Design Strategy:	Xilinx Default (unlocked)	• Final Timing Score:	

JP2K Partition Summary	[-]
No partition information was found.	

Device Utilization Summary (estimated values)			[-]
Logic Utilization	Used	Available	Utilization
Number of Slices	420	2352	17%
Number of Slice Flip Flops	263	4704	5%
Number of 4 input LUTs	787	4704	16%
Number of bonded IOBs	4	142	2%
Number of GCLKs	1	4	25%

Detailed Reports					[-]
Report Name	Status	Generated	Errors	Warnings	Infos
Synthesis Report	Current	Sun 28. Aug 11:42:25 2016	0	54 Warnings	2 Infos
Translation Report					
Map Report					
Place and Route Report					
Static Timing Report					
Bitgen Report					

Figure 5: The area occupied by the Multiresolution Discrete Wavelet Transform Unit

JP2K Project Status (12/21/2016 - 16:56:57)			
Project File:	JP2K.ise	Current State:	Synthesized
Module Name:	idwt2d_top	• Errors:	No Errors
Target Device:	xc2s200e-6pq208	• Warnings:	57 Warnings
Product Version:	ISE 10.1 - WebPACK	• Routing Results:	
Design Goal:	Balanced	• Timing Constraints:	
Design Strategy:	Xilinx Default (unlocked)	• Final Timing Score:	

JP2K Partition Summary	[-]
No partition information was found.	

Device Utilization Summary (estimated values)			[-]
Logic Utilization	Used	Available	Utilization
Number of Slices	385	2352	16%
Number of Slice Flip Flops	247	4704	5%
Number of 4 input LUTs	724	4704	15%
Number of bonded IOBs	4	142	2%
Number of GCLKs	1	4	25%

Detailed Reports					[-]
Report Name	Status	Generated	Errors	Warnings	Infos
Synthesis Report	Current	Wed 21. Dec 16:56:56 2016	0	57 Warnings	2 Infos
Translation Report					
Map Report					
Place and Route Report					
Static Timing Report					
Bitgen Report					

Figure 6: The area occupied by the Segmented Spatial Domain IDWT Unit

7. CONCLUSION

The simulation and synthesis reports show that the Segmented Spatial Domain method of Discrete Wavelet Transform provides significant reduction in area and delay. The reduction comes to 4.92% in area and 4.17% in delay for the Forward Discrete Wavelet Transform. For the inverse Discrete Wavelet Transform the area is reduced by 8.01% and delay is reduced by 20.74%. This opens opportunities for the use of the unit in large number of portable applications. Since the method is sequentially processing the image the same unit can be arbitrarily scaled to be applicable to image of any resolution.

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