Implementation of 2-D Discrete Wavelet Transform using MATLAB and Xilinx System Generator

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Abstract

This paper presents a small detail of implementation of 2D-discrete wavelet transform in Matlab and Xilinx system generator which offers decomposition of images using Haar Wavelet. This design is focused on less hardware utilization, efficient technique of algorithm, lower complexity than the other existing architecture schemes. The design incorporates a gray image in JPEG2000 standard which is further decomposed into (approximate, horizontal, vertical and diagonal) by applying 2D-DWT. Matlab is used to implement and verify the decomposition. The colored image is segmented into r bands, g bands and b bands. The objective of this paper is to give DWT decomposition using Haar wavelet transform which utilize lifting scheme that reduces complexity of the architecture thereby saving the power.

Keywords—*2D-DWT, Haar transform, Matlab, Simulink, Xilinx System Generator.*

I. INTRODUCTION

Wavelet transforms are the most powerful presentation of frequency-time domain simultaneously; unlike Fourier transform and short-time Fourier transform which has limited capability to work in multi-resolution analysis [1]-[5]. In wavelet transforms, the discrete wavelet transforms has an edge over its continuous-wavelet counterparts on long signals [6]. The realization of 2D-DWT is an important step, has been achieved in digital signal processing that demands less hardware requirement and lower utilization of bandwidth than the other existing schemes previously achieved [7]. Efficient data storage is another constraint over which 2D-DWT employs its implication on JPEG 2000 images for achieving a reasonable image compression. A sub-band coding is employed to obtain 2D-DWT multi-resolution analysis [8]. Image/signal processing is well established by strong DWT filter banks [9]. C.E. Gautis et al offered a good comparison of unlike 2D-DWT architectures and classed them in grades, lines and block based methods [7]. The Sub-band coding is a way to implement discrete wavelet transforms which find its application in image processing because of its feature of simultaneous localization of signals in time-frequency scale, where as other transforms like DCT or DFT localize signals only in frequency domain. The proposed work uses the line based architecture using lifting scheme [10]. The need to store entire row for processing has been replaced by parallel processing rows and columns after transformation of number of rows. Due to these results, requirement of memory block has been greatly reduced.

- Many authors use different models to achieve DWT computation on various platforms in order to provide fast accessing and less resources requirement. In this paper, a proposed work of implementing 2D-DWT with minimum resources and less hardware utilization has been included. In section II, a mathematical formulation for computing 2D-DWT with efficient architecture has been incorporated. The proposed architecture has been shown in section III. Hardware software co-simulation implementation has been included in section IV.Section V consists of results and discussions of 2D- discrete wavelet transform using Haar wavelet. Conclusion of the work has been forwarded in section VI.

II. FORMULATIONS FOR COMPUTING OF 2D-DWT

The wavelet transform decomposes an image into various sub-bands of different frequencies which is of different resolutions. The multi-resolution of an image provides an analysis both in time and in frequency domain simultaneously. This is desirable feature of image compression, but the problem with cosine and Fourier transforms is that it gives good localization only in one domain [6].

A 2-D finite impulse response (FIR) filter bank is used to process the input data which resulted in sub-band; approximation and detail sub-images. Let the input image A_{n-1} of pixels N×N is given to the pair of low-pass (approximate) and high-pass (detail) filters represented by h and g respectively. The input image is decomposed into sub-images which undergo dyadic down-sampling. Firstly, the filters operate on column-wise in which only one out of two columns is retained and the rest is discarded. Here, the sub-images are of pixel N/2×N/2 due to dyadic down-sampling. The decomposed part of the images further processed to the pair of low-pass and high-pass filters resulting into four sub-bands of input: A_n, Dv_n, Dh_n, Dd_n. This pyramidal flow architecture is shown in

Fig.1. It is interesting to note that only A_n that is coarse approximation sub-band is of our interest and the rest components; Dv_n (vertical detail), Dh_n (horizontal detail), Dd_n (diagonal detail) has been discarded. In this work, we focus on the computation of coarse approximation A_n, $n \geq 1$.

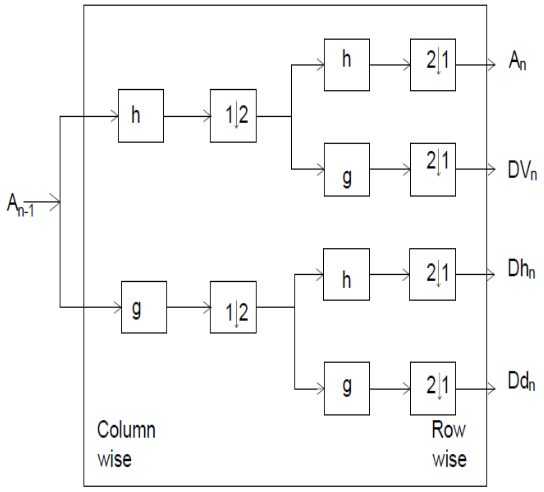

Fig. 1: Forward 2D discrete wavelet transforms [11]

As we already mentioned, the wavelet transforms provides a time-frequency representation of the signal. The limitation of STFT can be overcome by the development of wavelet transforms. The wavelet transforms ruled out the resolution problem in STFT which gives a constant resolution at all the frequencies. Thus, wavelet transforms is used for multi-resolution in which different frequencies are analysed at different resolutions. The property of wavelet transforms which provides approximation with its big wavelets and small details with its smaller wavelets is termed as mathematical microscope. Thus, wavelet transforms incorporates the idea of analysing the signal as a superposition of wavelets.

The Discrete Wavelet Transform (DWT) is obtained by filtering the signal through a series of digital filters at different scales. The scaling operation is done by changing the resolution of the signal by the process of sub-sampling. The DWT can be computed using either convolution-based or lifting-based procedures. In both methods, the input sequence is decomposed into low-pass and high-pass sub-bands, each consisting of half the number of samples in the original sequence.

III. PROPOSED ARCHITECTURE

Lifting scheme is an efficient method to implement wavelet transform proposed by Sweden. It was established to improve the wavelet transform. A basic method was introduced to achieve second generation wavelet. The second generation wavelets do not necessarily use the same function prototype at different levels. Second-generation wavelets are known for its flexible and strong presentation. The lifting procedure consists of three phases, namely, (i) split phase, (ii) predict phase, and (iii) update phase as shown in Fig.2. The first step includes the separation of input signal into even-indexed sub-samples (X_e) and odd-indexed sub-samples (X_o), this is called lazy wavelet transform and is given by [6]:

$$X_0 : d_i \leftarrow x_{2i+1} \tag{1}$$

$$X_e : S_i \leftarrow x_{2i} \tag{2}$$

The whole idea of lifting is based on primal lifting (U) and dual lifting (P). The sequences Xo and Xe are odd and even respectively. The idea is to predict and differentiate one sequence from the other. For this purpose, a predictor is used which can identify the odd sequence from the neighboring even sequence. A predictor detail (error) is recorded in place calculation.

$$d_i : d_i - p(S_A) \tag{3}$$

where A= (i-[N/2]+1,….i+[N/2],N), N is the number of dual vanishing moments which also sets P function smoothness.

The second lifting step plays even more crucial role. In this step, primal lifting U( ) altered by smooth values which is even-indexed samples with the help of update operator U( ) which performed on previous calculated data. The role of update operator U( ) is to maintain running average of main sequence thus is useful to eliminate aliasing.

$$S_i \leftarrow S_i + U(d_B) \tag{4}$$

Where B=(i-[Ṅ/2],…..,i+[Ṅ/2]-1). Here, N represents real vanishing moment. The update operator U ( ) secures the moments N in the s sequence. The pair of primal and dual operation collectively shapes the lazy wavelet to a transform with one or more operations. Ultimately, k is used to normalize the output streams.

$$d_i \leftarrow d_i - {}^{1}/_{k} \tag{5}$$

$$S_i \leftarrow S_i \times K \tag{6}$$

Here, the s channel output is a low-pass filtered version which is obtained after dual lifting. In the same manner, a high-pass filtered version is obtained through d channel which is also achieved after dual lifting.

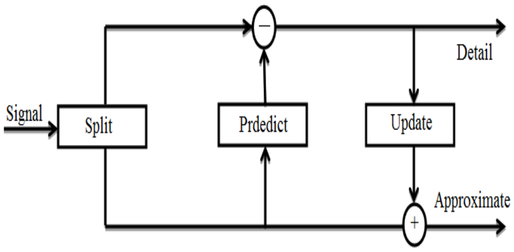

Fig. 2: Analysis Stage in Lifting Scheme [6]

A. Haar Wavelet

In 1910, Haar wavelet was introduced as the modified form of Daubechies wavelets. It is bipolar function with the expression given by [6]:

$$\psi(t) = \begin{cases} -1, & 0 < t < 1/2 \\ 1, & 1/2 < t < 1 \\ 0, & \text{otherwise} \end{cases} \quad (7)$$

Haar wavelet is described as anti-symmetric, real and discontinuous in time domain. It exists for a time-period of 0 to 1. From the equation, it is obvious that Haar wavelet is localized in time-domain but its localization in frequency domain is very poor.

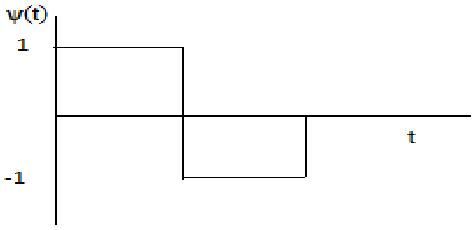

Fig. 3: Haar Wavelet [3]

IV. HARDWARE SOFTWARE CO-SIMULATION IMPLEMENATION PROCESS

This part comprises the development of algorithm using hardware software co-simulation for hardware realization. Firstly, the JPEG 2000 image has been pre processed with the Simulink blocks in MATLAB R2012a; gray scale is obtained from colored image which has been resized to 128×128 pixels as per the less memory allocation to FPGAs. The resized image is then converted into 2D to 1D using Simulink block to create bit streaming, then it is given to the system generator block for FPGA implementation process.

A. Designing of Sub blocks (Pre-processing)

This section includes the building blocks in Simulink such as low-pass filter, high-pass filter, conversion of an image from 2D to 1D, resize in Fig.4 and system generator blocks used for implementation to FPGA board. The JPEG2000 standard image cannot be directly dumped to the FPGA boards as it requires pre-processing. First, we convert the colored image into gray scale and resize it to 128×128 pixels. The new converted image is fed to the transposed block in Simulink library and is then converted to 1-D. As the FPGA boards accept only bit files and that too in serial form, thus a frame conversion block is used to make the samples which goes to unbuffered block in order to get the independent time-sample. This is required to set the sample-period same at both the input and the output.

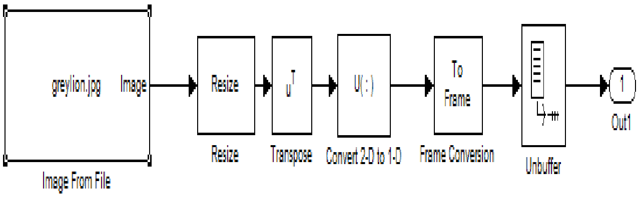

Fig. 4: Conversion of input image in 2D-1D block (pre- processing)

B. Dwt Decomposition using Xilinx System Generator

The data applied to DWT building block to Gateway In of Xilinx system generator in serial bit-streaming which passes through the blocks of low-pass and high-pass filters. Here, the role of filters is to separate serial data into approximation and detail coefficient values [12]. To obtain these coefficients, there is a convolution of bit-stream with the low-pass filter approximation and high-pass filter detail. This results into combined sub-bands which has relatively lower band-width and slower sample rates [13]. Finally, the 2-D DWT with the four bands namely LL, LH, HL, HH has been obtained which is the decomposition of the original input signal as shown in Fig.5.

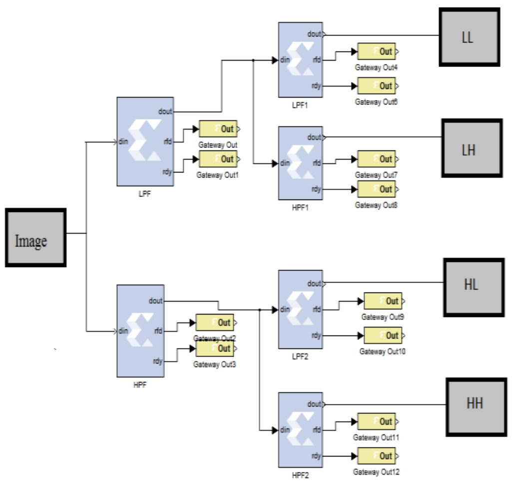

Fig. 5: DWT decomposition using Xilinx System Generator

C. *Post-processing*

The data obtained after the FPGA processing needs to be converted back into its original form which is done with the post-processing sub-system. The pixels obtained after processing first converted into its original data type with the 'Data type conversion' block in Simulink. This data further applied to a block called 'Buffer' which acts as anti-unbuffer block. This convert the high sampled serial data into frames. After obtaining it, the frames are passed serially to 'Reshape' block which convert the 1-D vector into 2-D Matrix. Here, the number of desired rows and columns are supposed to feed. The 2-D matrix is now ready to fed into 'Transpose' block which provides the same dimension to the matrix as that of input image. The 'sub-matrix' block set is used to reshape the image in order to obtain a better output. This work is shown in Fig.6.

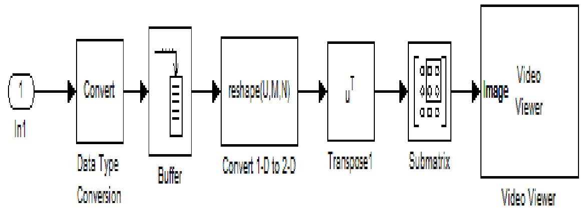

Fig. 6: Conversion of Input Image in 1D-2D Block (post- processing)

V. RESULTS AND DISCUSSIONS

In this section, results of image compression with DWT and its employment with Haar wavelet transform has been shown. Fig.7 shows the original JPEG2000 standard image. Now, the need arises to convert the image into gray scale which has been achieved with the help of MATLAB commands and then DWT has been performed with suitable commands in the MATLAB which is shown in Fig.8 and the image is decomposed into four sub-bands (LL, LH, HL, HH). Here, a special wavelet transform Haar has been used to achieve the DWT due to its flexibility and less resource utilization.

Finally, an improved DWT using Haar transform has been shown in Fig.9 which is the MATLAB processed result of our work.

Fig. 7: Original Image (Gray Scale)

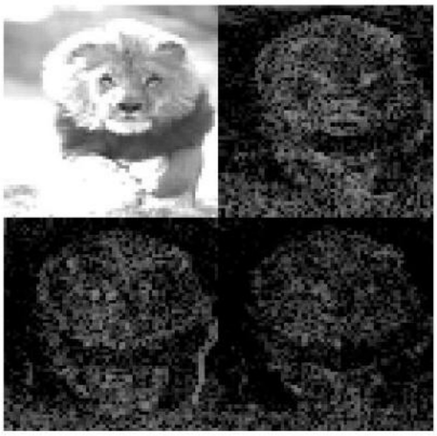

Fig. 8: Matlab Processed Integrated Image (2D DWT)

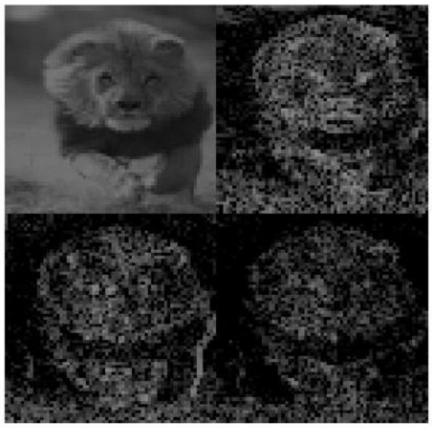

Fig. 9: MATLAB Processed 2D DWT Image (using Haar wavelet)

VI. CONCLUSIONS AND FUTURE WORK

This work primarily focused obtaining image compression using DWT which involves MATLAB platform to achieve the important properties of images required for implementation of DWT and its employment using Haar wavelet transform which shows some better features among

the families of digital filters presently available in image processing.
DWT is known for its higher compression ratio which is some percentage higher than DCT. Thus, it is used for image compression in digital image processing. The first step includes the MATLAB environment to achieve the results of DWT and its Hardware software co-simulation, Simulink based model design work flow has been used. To achieve the Verilog HDL, this model co-simulates the pre-processed image from MATLAB and finally the Xilinx system generator used for the design implementation to achieve the Verilog HDL code generation.

In this work, Hardware software co-simulation includes only single level DWT for JPEG 2000 image compression that can be extended to multi-level with respect to image quality as the third level decomposition showed better results. Thus, a multi-level approach of DWT can be extended to further developed algorithm using hardware software co-simulation.

This research work is the manifestation of a model-design based on system generator has been used for fast execution and low power consumption but it could not be met feasibly. It can be further optimized using abstract level algorithm.

The present work includes a basic wavelet (DWT) and its employment using Haar wavelet transfer function. It can be further achieved with other advanced wavelet families which may provide even better execution time, fast speed and power optimization.

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