An Algorithm for Image Compression Using 2D Wavelet Transform

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Abstract: *Wavelet Transform has been successfully applied in different fields, ranging from pure mathematics to applied sciences. Numerous studies carried out on Wavelet Transform have proven its advantages in image processing and data compression. Recent progress has made it the basic encoding technique in data compression standards. Pure software implementations of the Discrete Wavelet Transform, however, appear to be the performance bottleneck in real-time systems. Therefore, hardware acceleration of the Discrete Wavelet Transform has become a topic of interest. The goal of this paper is to investigate the feasibility of hardware acceleration of Discrete Wavelet Transform for image compression applications, and to compare the performance improvement against the software implementation. In this paper, a design for efficient hardware acceleration of the Discrete Wavelet Transform is proposed. The hardware is designed to be integrated as an extension to custom-computing platform and can be used to accelerate multimedia applications as JPEG2000.*

Keywords: *Wavelet transforms, Image compression, Haar wavelet.*

I. INTRODUCTION

A majority of today's Internet bandwidth is estimated to be used for images and video [4]. Recent multimedia applications for handheld and portable devices place a limit on the available wireless bandwidth. The bandwidth is limited even with new connection standards. JPEG image compression that is in widespread use today took several years for it to be perfected. Wavelet based techniques such as JPEG2000 for image compression has a lot more to offer than conventional methods in terms of compression ratio. Currently wavelet implementations are still under development lifecycle and are being perfected. Flexible energy-efficient hardware implementations that can handle multimedia functions such as image processing, coding and decoding are critical, especially in hand-held portable multimedia wireless devices.

II. BACKGROUND

Computer data compression is, of course, a powerful, enabling technology that plays a vital role in the information age. Among the various types of data commonly transferred over networks, image and video data comprises the bulk of the bit traffic. For example, current estimates indicate that image data take up over 40% of the volume on the Internet. [4] The explosive growth in demand for image and video data, coupled with delivery bottlenecks has kept compression technology at a premium. Among the several 1 compression standards available, the JPEG image compression standard is in wide spread use today. JPEG uses the Discrete Cosine Transform (DCT) as the transform, applied to 8-by-8 blocks of image data. The newer standard JPEG2000 is based on the Wavelet Transform (WT). Wavelet Transform offers multi-resolution image analysis, which appears to be well matched to the low level characteristic of human vision. The DCT is essentially unique but WT has many possible realizations. Wavelets provide us with a basis more suitable for representing images. This is because it cans represent information at a variety of scales, with local contrast changes, as well as larger scale structures and thus is a better fit for image data. Field programmable gate arrays (FPGAs) provide a rapid prototyping platform. FPGAs are devices that can be reprogrammed to achieve different functionalities without incurring the non-recurring engineering costs typically associated with custom IC fabrication. In this work, DWT architecture is implemented on a reconfigurable FPGA hardware. The target platform is the Xilinx Virtex FPGA. The design is based on the multi-level decomposition implementation of the Discrete Wavelet Transform. The design utilizes various techniques and specific features of the Xilinx Virtex XSV FPGA to accelerate the computation of the transform. Performance analysis includes the investigation of the performance enhancement due to the hardware acceleration. It is expected that the proposed design can substantially accelerate the DWT and the inherent scalability can be exploited to reach a higher performance in the future. The implementation can be easily modified to act as a co-processing environment for wavelet compression/decompression or even as a part of the algorithms to be used in future mobile devices for image encoding/decoding using wavelets. One drawback of the FPGA, however, is that due to the rather coarse grained reconfigurable blocks, an implementation on an FPGA is often not as efficient, in terms of space and time, as on a custom IC.

III. WAVELET TRANSFORM BASED IMAGE COMPRESSION

III.1 Introduction

Image compression is different from binary data compression. When binary data compression techniques are applied to images, the results are not optimal. In lossless compression, the data (such as executables, documents, etc.) are compressed such that when decompressed, it gives an exact replica of the original data. They need to be exactly reproduced when decompressed. For example, the popular PC utilities like Winzip or and Adobe Acrobat perform lossless compression. On the other hand, images need not be reproduced exactly. A 'good' approximation of the original image is enough for most purposes, as long as the error between the original and the compressed image is tolerable. Lossy compression techniques can be used in this application. This is because images have certain statistical properties, which can be exploited by encoders specifically 4 designed for them. Also, some of the finer details in the image can be sacrificed for the sake of saving bandwidth or storage space. In digital images the neighboring pixels are correlated and therefore contain redundant information. Before the image is compressed, the pixels, which are correlated is to be found. The fundamental components of compression are redundancy and irrelevancy reduction. Redundancy means duplication and irrelevancy means the parts of signal that will not be noticed by the signal receiver, which is the Human Visual System (HVS). There are three types of redundancy that can be identified:

Spatial Redundancy *is the correlation between neighboring pixel values.*

Spectral Redundancy *is the correlation between different color planes or spectral bands.*

Temporal Redundancy *is the correlation between adjacent frames in a sequence of images (in video applications).* Image compression focuses on reducing the number of bits needed to represent an image by removing the spatial and spectral redundancies. Since our work focuses on still image compression, therefore temporal redundancy is not discussed.

III.2 Principles of Image Compression

A typical lossy image compression scheme is shown in Figure 3.2.1. The system consists of three main components, namely, the source encoder, the quantizer, and the entropy encoder. The input signal (image) has a lot of redundancies that needs to be removed to achieve compression. These redundancies are not obvious in the time domain. Therefore, some kind of transform such as discrete cosine, fourier, or wavelet transform is applied to the input signal to bring the signal to the spectral domain. The spectral domain output from the transformer is quantized using some quantizing scheme. The signal then undergoes entropy encoding to generate the compressed signal. The wavelet transform mainly applies on the source encoder component portion.

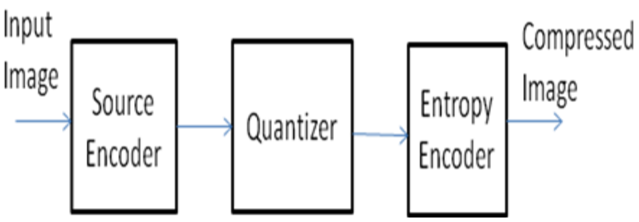


Figure 3.2.1 Image compression scheme

Source Encoder

An encoder is the first major component of image compression system. A variety of linear transforms are available such as Discrete Fourier Transform (DFT), Discrete Cosine Transform (DCT), and Discrete Wavelet Transform (DWT). The Discrete Wavelet Transform is main focus of my work.

Quantizer

A quantizer reduces the precision of the values generated from the encoder and therefore reduces the number of bits required to save the transform co-coefficients. This process is lossy and quantization can be performed on each individual coefficient. This is known as Scalar Quantization (SQ). If it is performed on a group of coefficients together then it is called Vector Quantization (VQ).

Entropy Encoder

An entropy encoder does further compression on the quantized values. This is done to achieve even better overall compression. The various commonly used entropy encoders are the Huffman encoder, arithmetic encoder, and simple run-length encoder. For improved performance with the compression technique, it's important to have the best of all the three components.

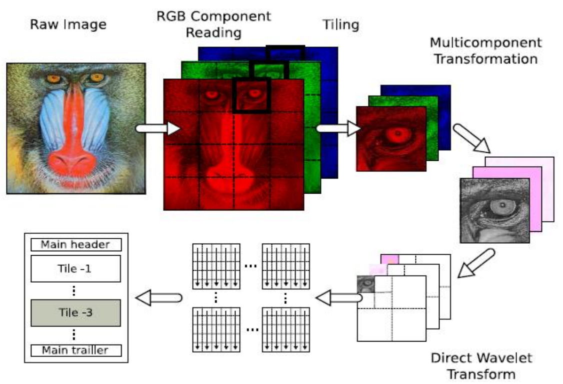
III.4 JPEG 2000

JPEG 2000 is a wavelet-based image compression standard created by the Joint Photographic Expert Group (JPEG) committee in 2000 with the aim of replacing the original discrete cosine transform-based JPEG.This part specifies the core and minimal functionality and is known as JPEG2000 codec.[5]

The main advantages of JPEG2000 against the classical JPEG are:

- Superior compression performance: specially at low bitrate (e.g. less that 0.25 bits/pixel).
- Multiple resolution representation.
- Progressive transmission: after a smaller part of the whole file has been received, the viewer can see a lower quality version of the final picture.
- Lossless and lossy compression.
- Random codestream access and processing: different grades of compression could be given to some Regions of Interest (ROI) of the image.
- Error resilience: small independent block avoid error propagation.

The JPEG2000 algorithm flow shown in Figure 3.4.1 reveals the first and simple stages: The whole raw image in divided in the three Red-Green-Blue (RGB) components. Each component is divided in equal smaller pieces called tiles, which are coded independently. The RGB components are transformed in YUV model that requires less memory. The last stages: Discrete Wavelet Transform (DWT) and T1 Entropy Encoding.



Compressed File Entropy Encoding

Figure 3.4.1 JPEG 2000 algorithm flow.

IV. WAVELET TRANSFORM AS THE SOURCE ENCODER

Just as in any other image compression schemes the wavelet method for image compression also follows the same procedure. The discrete wavelet transform constitutes the function of the source encoder. The theory behind wavelet transform is discussed below.

IV.1 Measuring Frequency Content by Wavelet Transform

Wavelet transform is capable of providing the time and frequency information simultaneously. Hence it gives a time-frequency representation of the signal. When we are interested in knowing what spectral component exists at any given instant of time, we want to know the particular spectral component at that instant. In these cases it may be very beneficial to know the time intervals these particular spectral components occur. Wavelets are functions defined over a finite interval and having an average value of zero. The basic idea of the wavelet transform is to represent any arbitrary function $f(t)$ as a superposition of a set of such wavelets or basis functions. These basis functions are obtained from a single wave, by dilations or contractions (scaling) and translations (shifts). The discrete wavelet transform of a finite length signal x(n) having N components, for example, is expressed by an N x N matrix similar to the discrete cosine transform .

V. WAVELET-BASED COMPRESSION

Digital image is represented as a two-dimensional array of coefficients, each coefficient representing the brightness level in that point. We can differentiate between coefficients as more important ones, and lesser important ones. Most natural images have smooth color variations, with the fine details being represented as sharp edges in between the smooth variations. Technically, the smooth variations in color can be termed as low frequency variations, and the sharp variations as high frequency variations.

The low frequency components constitute the base of an image, and the high frequency components add upon them to refine the image, thereby giving a detailed image. Hence, the smooth variations are more important than the details. Separating the smooth variations and details of the image can be performed in many ways. One way is the decomposition of the image using the discrete wavelet transform. Digital image compression is based on the ideas of discrete wavelet transforms. Wavelets which refer to a set of basis functions are defined recursively from a set of scaling coefficients and scaling functions. The DWT is defined using these scaling functions and can be used to analyze digital images with superior performance than classical short-time Fourier-based techniques, such as the DCT. The basic difference between wavelet-based and Fourier-based techniques is that short-time

Fourier-based techniques use a fixed analysis window, while wavelet-based techniques can be considered using a short window at high spatial frequency data and a long window at low spatial frequency data. This makes DWT more accurate in analyzing image signals at different spatial frequency, and thus can represent more precisely both smooth and dynamic regions in image. The compression system includes forward wavelet transform, a quantizer, and a lossless entropy encoder. The corresponding decompressed image is formed by the lossless entropy decoder, a de-quantizer, and an inverse wavelet transform.

V.1 Wavelet Decomposition

There are several ways wavelet transforms can decompose a signal into various sub bands. These include uniform decomposition, octave-band decomposition, and adaptive or wavelet-packet decomposition. Out of these, octave-band decomposition is the most widely used.

The procedure is as follows: wavelet has two functions "wavelet "and "scaling function". They are such that there are half the frequencies between them. They act like a low pass filter and a high pass filter. The decomposition of the signal into different frequency bands is simply obtained by successive high pass and low pass filtering of the time domain signal. This filter pair is called the analysis filter pair. First, the low pass filter is applied for each row of data, thereby getting the low frequency components of the row. But since the low pass filter is a half band filter, the output data contains frequencies only in the first half of the original frequency range. By Shannon's Sampling Theorem, they can be sub-sampled by two, so that the output data now contains only half the original number of samples. Now, the high pass filter is applied for the same row of data, and similarly the high pass components are separated.

This is a non-uniform band splitting method that decomposes the lower frequency part into narrower bands and the high-pass output at each level is left without any further decomposition. This procedure is done for all rows. Next, the filtering is done for each column of the intermediate data. The resulting two-dimensional array of coefficients contains four bands of data, each labeled as LL (low-low), HL (high-low), LH (low-high) and HH (high-high). The LL band can be decomposed once again in the same manner, thereby producing even more sub bands. This can be done up to any level, thereby resulting in a pyramidal decomposition as shown in figure 5.1.1

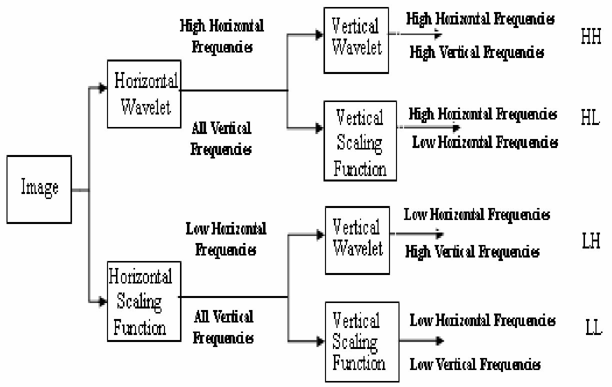


Figure 5.1.1 Pyramidal Decomposition of an image

V.2 Haar Wavelet Transform

The first DWT was invented by the Hungarian mathematician Alfréd Haar. For an input represented by a list of $2n$ numbers, the Haar wavelet transform may be considered to simply pair up input values, storing the difference and passing the sum. This process is repeated recursively, pairing up the sums to provide the next scale: finally resulting in $2n - 1$ differences and one final sum (The Haar scaling function) Let be defined by

$\emptyset : R \rightarrow R$

Define as

$$\emptyset(t) = \begin{cases} 1 & t \in [0,1) \\ 0 & t \in [0,1) \end{cases} \quad (1)$$

$$\emptyset_i^j : R \rightarrow R$$

$$\emptyset_i^j(t) = \sqrt{2^j}\,\emptyset(2^j - i) \quad j=0,1,\ldots \quad (2)$$

$$i=0,1,\ldots 2^j$$

Defines the vector space

$$V^j = sp\left\{\emptyset_i^j\right\} \quad i = 0,\ldots\ldots 2^j - 1$$

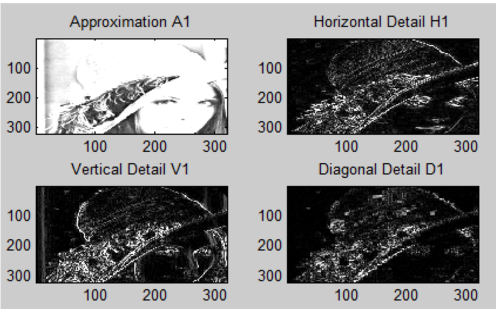
For encoding the transform image used various type. For example Huffman coding, EZW coding, Run length encoding , thresholding technique is also used for encoding .In this scheme i used soft & hard thresholding technique

VI. EXPERIMENTAL RESULT

Original image of Lena of size 320 x 320 pixel which is compressed by using Harr wavelet & thresholding technique .By developing a code in Matlab for compression of image using wavelet transform results are shown in following figure.

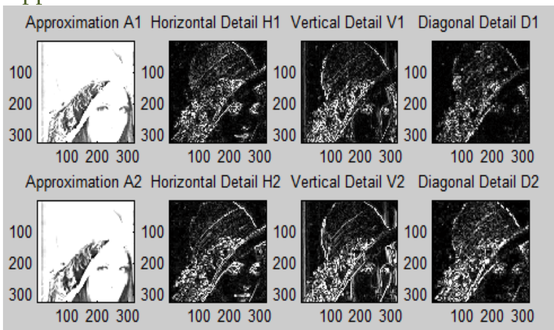
Original still image of Lenna 320 x 320 pixel true colure image.

First Approximation component.

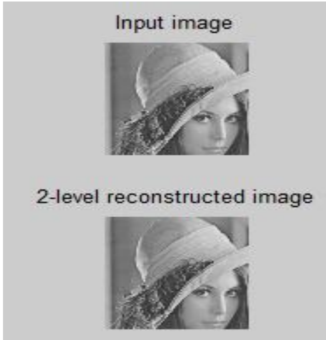


First level reconstruction image.

Second level Approximation component



Second level Reconstructed image.



Output image at 1 st level compression.

Output image at 2nd level compression.

The number of rows in input image are 320

The number of coloums in input image are 320 The decomposition level 2

Decomposition vector of size 1*524288 .

Coressponding book keeeping matrix

80	80
80	80
160	160
320	320

Level-dependent thresholds 0.5000

The entropy used is threshold

The type of thersholding is Hard Thresholding

Approximation coefficients are 1

Wavelet packet best tree decomposition of XD

Wavelet Packet Object Structure

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Size of initial data : [320 320]
Order : 4
Depth : 2
Terminal nodes : [5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20]

Wavelet Name : haar
Low Decomposition filter : [0.7071 0.7071]
High Decomposition filter: [-0.7071 0.7071]
Low Reconstruction filter : [0.7071 0.7071]
High Reconstruction filter : [0.7071 0.7071]

Entropy Name : threshold
Entropy Parameter : 0.5

The compression scores in percentages 23.6035

VII. CONCLUSION

This paper introduced the basic wavelet theory used for wavelet transform based image compression. Wavelet based image compression is ideal for adaptive compression since it is inherently a multi-resolution scheme. Variable levels of compression can be easily achieved. The number of wave-letting stages can be varied, resulting in different number of sub bands. Different filter banks with different characteristics can be used. Efficient fast algorithm for the computation of discrete wavelet coefficients makes a wavelet transform based encoder computationally efficient. BY using this method the compression ratio is 23.60% and this will be increase more using different entropy encoding technique.

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