An Efficient Design and FPGA Implementation of JPEG Encoder using Verilog HDL

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Abstract— Image compression is the reduction or elimination of redundancy in data representation in order to achieve reduction in storage and communication cost. For this we use the simple computational method, 2D-DCT, using two 1D-DCT performed on matrix of (8X8). The DCT is a technique that converts a signal from spatial domain to frequency domain. Here we first convert the image into minimum code units. Then 2-D DCT is applied on each block. Then further process of Quantization, Zig-Zag approach and encoding is applied on the processed data. The architecture uses 3049 slices, 2,457 LUT, 46 I/Os of Xilinx Spartan-3 XC3S1600.

Keywords*:* DCT, JPEG encoder, zigzag, quantization, VLC, compression ratio

I. INTRODUCTION

Image compression aims to minimize the number of bits required in representing an image so as to produce new image representation that can be stored and transmitted efficiently. An image is a 2-D signal usually in analog form. But for processing (storage and transmission) by computer, they are converted from analog to digital form. Digital image or data is represented as a combination of information and redundancy. The raw digital image contain huge amount of information and therefore require a large channel or storage capacity. In spite of advances in communications channel and storage capacity, the implementation cost often put constraint on capacity. As the bandwidth requirement increase parallel the transmission or storage cost also increase, so it is necessary to employ compression techniques, which reduce the data rate while maintaining the subjective quality of the decoded image or video signal. Compression of data is the technique to minimize the redundancies in data representation in order to decrease data storage requirements and hence communication costs. Image compression techniques achieve compression by exploiting statistical redundancies in the data and eliminating or reducing data to which the human eye is less sensitive. A common characteristic of most images is that the neighboring pixels are correlated and thus contain redundant information. The main goal of image compression is to reduce or remove this redundancy. In general, two types of redundancy:

A. Spatial redundancy

This refers to the correlation between neighboring pixels. This is the only redundancy for grayscale images.

B. Spectral redundancy

This refers to the correlation between different color planes or spectral bands. This redundancy occurs in color images or multispectral images and exists together with the spatial redundancy.

Image compression techniques aim at reducing the number of bits needed to represent an image by removing the spatial and spectral redundancies as much as possible. The compression is lossless if the redundancy reduction does not result in any loss of information in the original image [1].
DCT is mainly used for digital processing application because of its energy compaction characteristics. The development of efficient algorithms for the computation of DCT began soon after Ahmed et al [8] reported their work on DCT. Many algorithms for fast computation of DCT are reported in the literature [6-7].

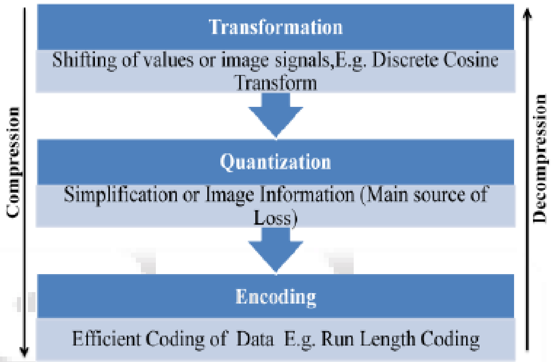


Fig 1: Flow of Image Compression

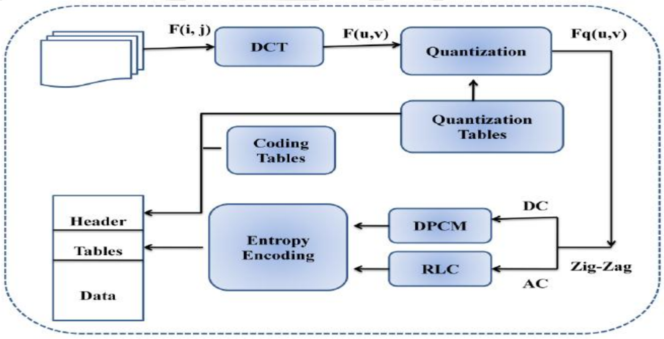


Fig. 2: Block diagram of Image compression

II. METHODOLOGY

A. Discrete Cosine Transform

The DCT is a technique that converts a signal spatial domain to frequency domain.DCT has property of higher energy compaction compared to DFT, DST, WHT and DWT. Hence, DCT is generally used for image and video compression. The image is first converted into minimum code units. Then 2-D DCT is applied on each block.

B. 2.2 2-D Discrete Cosine Transform

The 2-D DCT of a data matrix is defined as equation (1)

$$Z = C\,X\,C^T \ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

Where X is the data matrix, C is the matrix of DCT Coefficients, and Ct is the Transpose of C. An expanded form of (1) is as followed:

$$Z = \begin{bmatrix} C_{00} & \cdots & C_{07} \\ \vdots & \ddots & \vdots \\ C_{70} & \cdots & C_{77} \end{bmatrix} \begin{bmatrix} X_{00} & \cdots & X_{07} \\ \vdots & \ddots & \vdots \\ X_{70} & \cdots & X_{77} \end{bmatrix} \begin{bmatrix} C_{00} & \cdots & C_{07} \\ \vdots & \ddots & \vdots \\ C_{70} & \cdots & C_{77} \end{bmatrix}$$

Where, for an $N \times N$ data matrix,

$$C_{k,l} = \sqrt{\frac{2}{N}} \cos\left[\frac{(2k-1)(l-1)\pi}{2N}\right]$$

For k= 1, 2… N, l= 2, 3… N, $C_{k,1} = N^{1/2}$ for l= 1

The 2-D DCT is implemented by the row-column decomposition technique. We first compute the 1-D DCT (8 x 1 DCT) of each column of the input data matrix X to yield XTC after appropriate rounding or truncation, the transpose of the resulting matrix, C^TX, is stored in an transpose buffer. We then compute another 1-D DCT (8 x 1 DCT) of each row of C^TX to yield the desired 2-D DCT as defined in equation (1).

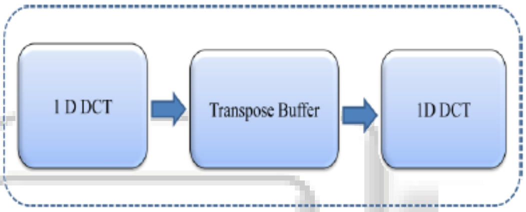


Fig. 3: 2D- DCT Process

C. JPEG

The term "JPEG" means Joint Photographic Experts Group. JPEG mainly used for lossy compression of digital photography (image). The degree of compression can be adjusted, allowing a selectable tradeoff between storage size and image quality. JPEG typically achieves 10:1 compression with little perceptible loss in image quality JPEG compression is used in a number of image file formats. JPEG is the most common image format used by digital cameras and other photographic image capture devices; along with JPEG, it is the most common format for storing and transmitting photographic images on the Web. These format variations are often not distinguished, and are simply called JPEG.

D. Quantization

DCT-based image compression relies on two techniques to reduce the data required to represent the image. The first is quantization of the image's DCT coefficients; the second is entropy coding of the quantized coefficients. Quantization, involved in image processing, is a lossy compression technique achieved by compressing a range of values to a single quantum value. When the number of discrete symbols in a given stream is reduced, the stream becomes more compressible. For example, reducing the number of colors required to represent a digital image makes it possible to reduce its file size. Specific applications include DCT data quantization in JPEG and DWT data quantization in JPEG 2000.

A typical video codec works by breaking the picture into discrete blocks (8×8 pixels). These blocks can then be subjected to discrete cosine transform (DCT) to calculate the frequency components, both horizontally and vertically. The resulting block (the same size as the original block) is then pre-multiplied by the quantization scale code and divided element-wise by the quantization matrix, and rounding each resultant element. The quantization matrix is designed to provide more resolution to more perceivable frequency components over less perceivable components (usually lower frequencies over high frequencies) in addition to transforming as many components to 0, which can be encoded with greatest efficiency. Typically the quantized matrix which is obtained from quantization has values primarily in the upper left (low frequency) corner. By using a Zig-Zag ordering to group the non-zero entries and run length encoding, the quantized matrix can be much more efficiently stored than the non-quantized version.

This is an example of DCT coefficient matrix:

$$\begin{bmatrix} -415 & -33 & -58 & 35 & 58 & -51 & -15 & -12 \\ 5 & -34 & 49 & 18 & 27 & 1 & -5 & 3 \\ -46 & 14 & 80 & -35 & -50 & 19 & 7 & -18 \\ -53 & 21 & 34 & -20 & 2 & 34 & 36 & 12 \\ 9 & -2 & 9 & -5 & -32 & -15 & 45 & 37 \\ -8 & 15 & -16 & 7 & -8 & 11 & 4 & 7 \\ 19 & -28 & -2 & -26 & -2 & 7 & -44 & -21 \\ 18 & 25 & -12 & -44 & 35 & 48 & -37 & -3 \end{bmatrix}$$

A common quantization matrix is:

$$\begin{bmatrix} 16 & 11 & 10 & 16 & 24 & 40 & 51 & 61 \\ 12 & 12 & 14 & 19 & 26 & 58 & 60 & 55 \\ 14 & 13 & 16 & 24 & 40 & 57 & 69 & 56 \\ 14 & 17 & 22 & 29 & 51 & 87 & 80 & 72 \\ 18 & 22 & 37 & 56 & 68 & 109 & 103 & 77 \\ 24 & 35 & 55 & 64 & 81 & 104 & 113 & 92 \\ 49 & 64 & 78 & 87 & 103 & 121 & 120 & 101 \\ 72 & 92 & 95 & 98 & 112 & 100 & 103 & 99 \end{bmatrix}$$

For example, using −415 (the DC coefficient) and rounding to the nearest integer

$$\begin{bmatrix} -26 & -3 & -6 & 2 & 2 & -1 & 0 & 0 \\ 0 & -3 & 4 & 1 & 1 & 0 & 0 & 0 \\ -3 & 1 & 5 & -1 & -1 & 0 & 0 & 0 \\ -4 & 1 & 2 & -1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\text{round}\left(\frac{-415}{16}\right) = \text{round}\,(-25.937) = -26$$

Typically this process will result in matrices with values primarily in the upper left corner.

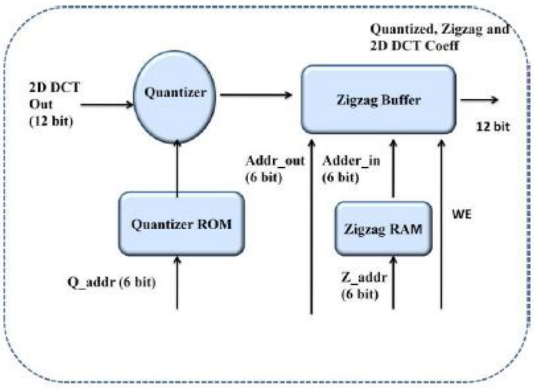
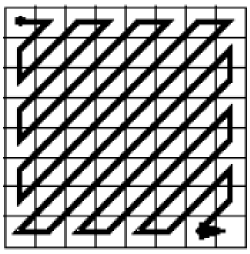


Fig. 4: Quantization & Zig-zag Architecture

E. Zig-Zag Reordering

Each block of data that is output by the quantization module needs to be reordered, so we use zigzag reordering. This reordering is achieved using an 8 x 8 array of register pairs organized in a fashion similar to the transpose buffer. Quantized output is sent sequentially byte-by-byte in zigzag pattern. Zigzag operation is done for every 8X8 block (fig 5).



F. Entropy Coder

This is the final processing step of the JPEG encoder. Entropy Coding (EC) achieves additional compression lossless by encoding the quantized DCT coefficients more compactly based on their statistical characteristics.

1) Huffman encoding

Huffman coding uses a specific method for choosing the representation for each symbol, resulting in a prefix code (sometimes called "prefix-free codes", that is, the bit string representing some particular symbol is never a prefix of the bit string representing any other symbol) that expresses the most common source symbols using shorter strings of bits than are used for less common source symbols.

2) Run length encoding

JPEG uses Run length encoding for the coefficients that remain after transforming and quantizing image blocks. RLE is a very simple form of data compression in sequences in which the same data value occurs in many consecutive data elements are stored as a single data value and count, rather than as the original run. In our example, let take a screen containing plain black text on a solid white background.

Let us take a hypothetical single scan line, with B representing a black pixel and W representing white. WWWWWWWWWWWWBWWWWWWWWWWWWBBBWWWWWWWWWWWWWWWWWWWWWWWWBWWWWWWWWWWWWWW.

If we apply the run-length encoding data compression algorithm then 12W1B12W3B24W1B14W Interpret this as twelve W's, one B, twelve W's, three B's, etc.

III. SIMULATION RESULTS

In this paper an area efficient JPEG image compression using VHDL has been implemented.

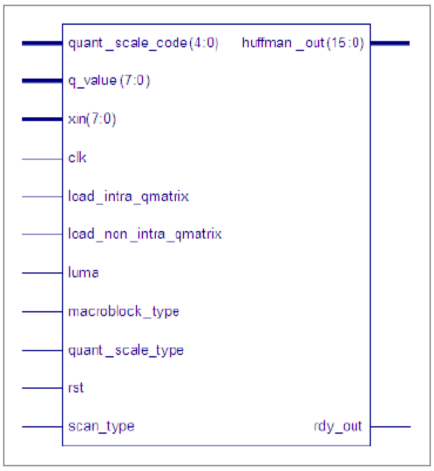


Fig. 6: RTL view of JPEG Encoder

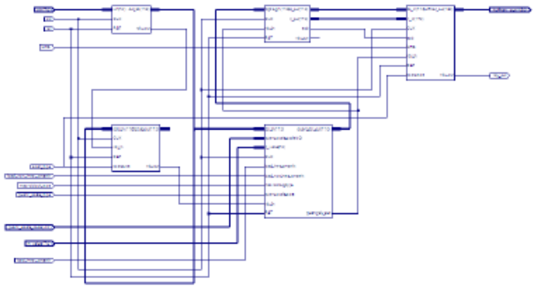


Fig. 7: RTL Schematic Design of JPEG compression modules

Device Utilization Summary				
Logic Utilization	Used	Available	Utilization	Note(s)
Total Number Slice Registers	3,049	29,504	10%	
Number used as Flip Flops	3,047			
Number used as Latches	2			
Number of 4 input LUTs	2,457	29,504	8%	
Logic Distribution				
Number of occupied Slices	2,494	14,752	16%	
Number of Slices containing only related logic	2,494	2,494	100%	
Number of Slices containing unrelated logic	0	2,494	0%	
Total Number 4 input LUTs	2,521	29,504	8%	
Number used as logic	2,457			
Number used as a route-thru	64			
Number of bonded IOBs	46	250	18%	
IOB Flip Flops	42			
Number of Block RAMs	1	36	2%	
Number of GCLKs	1	24	4%	

Fig. 8: Device Utilization Summary

We have tested our design using Modelsim and simulation, synthesis has been done using Xilinx ISE Spartan3 device.

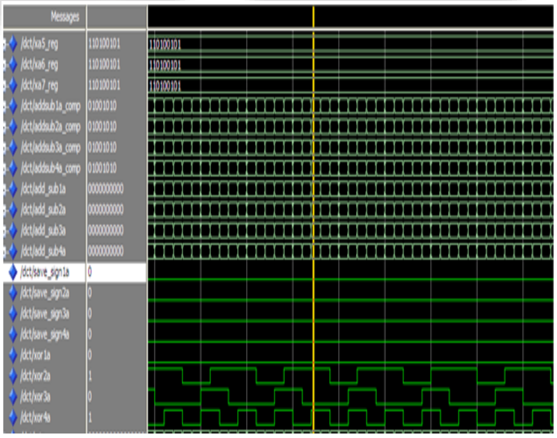


Fig. 9: Simulation Result for 2D- DCT

Simulation of VHDL values are compared with paper presented in [1]. The complete synthesis results of Xilinx Spartan-3 XC3S1600 FPGA are presented in table 1.

Logic Units	Used	Available	Utilization
Number of slices	2410	14752	16%
Number of slices FFs	3090	29504	10%
Number of 4 input LUTs	2408	29504	8%
Number of Bonded IOBs	46	376	18%
Number of multipliers	13	36	36%

Table 1: Device utilization using Xilinx spartran-3E for total architecture proposed in this paper

The architecture uses 2410 slices, 2408 LUT, 46 I/Os of Xilinx Spartan-3 XC3S1600.

IV. CONCLUSION

In this work implementation of JPEG encoder architecture for JPEG image compression standard is described. The architectures for the various stages are based on efficient and high performance designs suited for VLSI implementation. The implementation was tested for functional correctness using Verilog with Xilinx tool. The design is tested with grey scale image. Pipeline process causes latency in the system. Maximum frequency can be achieved by this system is 66.55MHz. The design takes less device resources and suitable for FPGA like Xilinx xc3s1500. The latency produced by design is less compared to previous works. Finally it is designed as a balanced architecture compared to previous works.

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