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Implementation of ASIC For High Resolution Image Compression In Jpeg Format

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Abstract: *Increase in multimedia applications drastically increased the demand for digital information. Reduction in the size of this data for transmission and storage is very important. This is done by Image compression. JPEG (Joint Photographic Experts Group) is an international compression standard for continuous-tone still image, both grayscale and color. There are software solutions as well as hardware solutions for JPEG compression depending upon the application. Hardware solutions are mainly used for high speed and parallel processing applications. As the distinct requirement for each of the applications, the JPEG standard has two basic compression methods. The DCT-based method is specified for lossy compression, and the predictive method is specified for lossless compression. Simple lossy technique is baseline, which is a DCT-based method, has been widely used and is sufficient for a large number of applications. In this paper, introduce the JPEG standard and focuses on the baseline method. The objective is to implement hardware based Discrete Cosine Transform (DCT/IDCT) Processor and Controller for high throughput Image compression. Images have certain statistical properties which can be exploited by specifically designed encoders. Some of the finer details in the image can be sacrificed for less storage space. Images need not be reproduced 'exactly'. An approximation of the original image is enough for most purposes, as long as the error between the original and the compressed image is tolerable. The main aim of this project is to develop a method for JPEG encoding to process large images of size 10M pixel or more. Encoding such a large size images in short duration is difficult in traditional software or hardware methods. This paper involves development of JPEG encoder with parallel processing techniques to compress 10M pixels or more in size images in 40 milliseconds time frame. Project implementation involves development of digital blocks, coding of logic in VHDL, Verification of functionality with Verilog HDL test-bench, synthesis of logic in Altera Cyclone-III FPGA and demonstrate the functionality.*

Keywords: *image Compression, jpeg Encoder, JPEG Decoder, DCT compression*

I. Introduction

Advances over the past decade in many aspects of digital technology – especially devices for image acquisition, data storage and bitmapped printing and display have brought about many applications of digital imaging. These applications tend to be specialized due to their relatively high cost. The key obstacle is the vast amount of data required to represent a digital image directly. Use of digital images often is not viable due to high storage or transmission costs. Modern image compression technology offers a possible solution. To perform image processing on digital images an efficient compression algorithm can be used to reduce memory requirement. This leads to develop an efficient compression algorithm which will give the same result as that of the existing algorithms with low power consumption. Compression techniques result in distortion and also additional computational resources are required for compression-decompression of the data. The objective of image compression is to reduce redundancy of the image data is able to store or transmit data in an efficient form. It also reduces the time and bandwidth requirement for images. The basic image compression block diagram is shown in the figure: 1.

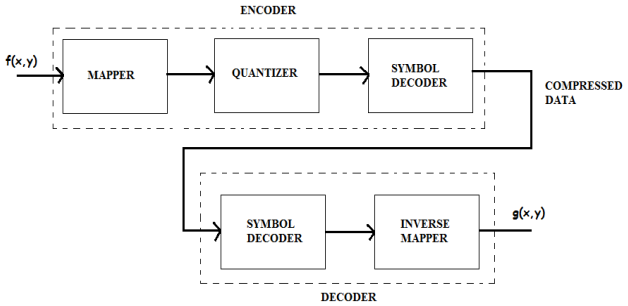

Fig:1: Functional block diagram of a general image compression system

Need for Image Compression: The need of image compression becomes apparent when number of bits per image are computed resulting from typical sampling rates and quantization methods. For example, the amount of storage required for given images is (i) a low resolution, TV quality, color video image which has 512 x 512 pixels/color,8 bits/pixel, and 3 colors approximately consists of 6 x 10^6 bits;(ii) a 24 x 36 mm negative photograph scanned at 12 x 10^{-6}mm:3000 x 2000 pixels/color, 8 bits/pixel, and 3 colors nearly contains 144 x 10^6 bits; (iii) a 14 x 17 inch radiograph scanned at 70 x 10^{-6}mm: 5000 x 6000 pixels, 12 bits/pixel nearly contains 360 x 10^6 bits. Thus storage of even a few images could cause a problem.

Image Compression Methods: Image compression can be lossy or lossless. Lossless compression is sometimes preferred for artificial images. This is because of low bit rates using, introduces compression artifacts. Lossless compression methods may be preferred for high value content, such as medical images. Lossless compression techniques work by removing redundant information as well as removing or reducing information that can be recreated during decompression. Lossless compression is ideal, as source data will be recreated without error. However, this leads to small compression ratios and will most likely not meet the needs of many applications The main benefit of lossy compression is that the data rate can be reduced. This is necessary as certain applications require high compression ratios along with accelerated data rates. Lossy compression algorithms attempt to maximize the benefits of compression ratio and bit rate, while minimizing loss of quality. Lossy methods are especially suitable for natural images such as photos in applications where minor loss of fidelity is acceptable to achieve a substantial reduction in bit rate. The lossy compression produces imperceptible differences can be called visually lossless. Run-length encoding and entropy encoding are the methods for lossless image compression. The codeword is of variable length to enhance compression. The varying length is typically determined by the frequency that a certain piece of data appears. Some algorithms generate code words after analyzing the data set, and others use standard code- words already generated based of average statistics. Shorter code words are assigned to those values appearing more frequently, where longer code words are assigned to those values that occur less frequently. The best known lossless image compression algorithm is the Graphics Interchange Format (GIF). Unfortunately the GIF format cannot handle compression of images with resolutions greater than 8-bits per pixel. Another lossless format called the Portable Network Graphics (PNG) can compress images with 24-bit or 48-bit color resolutions. Transform coding, where a Fourier-related transform such as DCT or the wavelet transform are applied, followed by quantization and entropy coding can be cited as a method for lossy image compression.

II. JPEG COMPRESSION ALGORITHM

JPEG is a standardized image compression mechanism. The first international standard for continuous tone still images both grayscale and color is proposed by joint collaboration of CCITT and ISO. It develops a general-purpose compression to meet the needs of almost all continuous-tone still image applications. Variables such as a quality factor which is used to scale the quantization tables used in JPEG can either reduce the resulting image quality with higher compression ratios, or conversely improving image quality with lower compression ratios. JPEG, although lossy, can give higher compression ratios than GIF while leaving the human observer with little to complain of loss inequality. Minimizing the variance between source and compressed image formats, otherwise known as Mean Square Error, is the ultimate goal for lossy compression algorithms. In Lossless mode, image is encoded to guarantee exact recovery of every pixel of original image even though the compression ratio is lower than the lossy modes. In sequential mode, the image is compressed in a single left-to-right, top-to-bottom scan. In progressive mode, the image compresses in multiple scans. In hierarchical mode, the image compress at multiple resolutions so that the lower resolution of the image can be accessed first without decompressing the whole resolution of the image [1]. Sequential, progressive and hierarchical modes are DCT-based modes and are lossy because precision limitation to compute DCT and the quantization process introduce distortion in the reconstructed image. The most widely used mode in practice is called the baseline JPEG system and is shown in the Fig.2, Which is based on sequential mode, DCT-based coding and Huffman coding for entropy encoding.

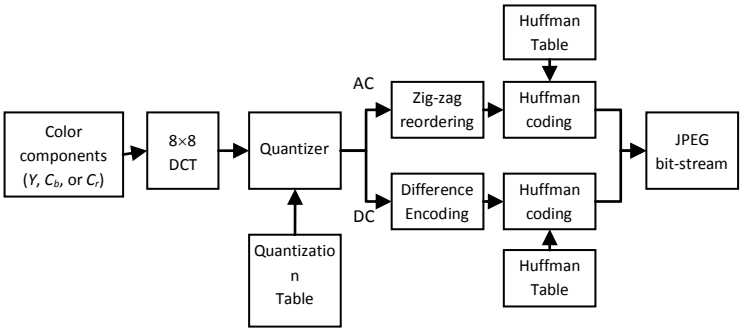

Fig. 2 Baseline JPEG encoder

Basic Compression Steps:

1. First image is divided into blocks of 8x8 pixel values. These blocks then fed to the encoder.
2. The next step is mapping of the pixel intensity value to another domain. The mapper transforms images into a format designed to reduce spatial and temporal redundancy. It can be done by applying various transforms to the images. Here discrete Hartley transform is applied to the 8x8 blocks.
3. Quantizing the transformed coefficients results in the loss of irrelevant information for theS specified purpose.
4. Source coding is the process of encoding information using less than un encoded representation would use, through use of specific encoding schemes.

III. DISCRETE COSINE TRANSFORM

It is the basis for the JPEG compression. The DCT is a special case of the well known Fourier transform which can represent a given input signal with a series of sine and cosine terms. It becomes most popular transform for image and video. The DCT encoder is shown in the fig 3. Many compression techniques take advantage of transform coding as it de correlates adjacent pixels from the source image. For JPEG, this allows efficient compression by allowing quantization on elements that are less sensitive. It has two useful products of the DCT algorithm. First it has the ability to concentrate image energy into a small number of coefficients. Second, it minimizes the interdependencies between coefficients. These two points essentially state why this form of transform is used for the standard JPEG compression technique. To apply the DCT, the image is divided into 8×8 blocks of pixels. If the width or height of the original image is not divisible by 8, the encoder should make it divisible. The 8×8 blocks are processed from left-to-right and from top-to-bottom.

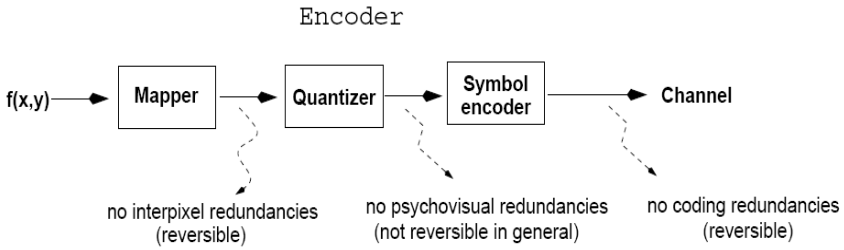

Fig.3: DCT encoder simple diagram

The purpose of the DCT is to transform the value of pixels to the spatial frequencies. These spatial frequencies are much related to the level of detail present in an image. High spatial frequencies correspond to high levels of detail, while lower frequencies correspond to lower levels of detail. Fig .4 shows the 8x8 DCT basis and fig.5 represents the coefficients of 8x8 DCT after applied to the F(u,v).

The mathematical definition of DCT is:

Forward DCT:

$$F(u,v) = \frac{1}{4}C(u)C(v)\sum_{x=0}^{7}\sum_{y=0}^{7} f(x,y)\cos\left[\frac{\pi(2x+1)u}{16}\right]\cos\left[\frac{\pi(2y+1)v}{16}\right]$$

for $u = 0,...,7$ and $v = 0,...,7$

where $C(k) = \begin{cases} 1/\sqrt{2} & \text{for } k = 0 \\ 1 & \text{otherwise} \end{cases}$

Inverse DCT: $$f(x,y) = \frac{1}{4}\sum_{u=0}^{7}\sum_{v=0}^{7} C(u)C(v)F(u,v)\cos\left[\frac{\pi(2x+1)u}{16}\right]\cos\left[\frac{\pi(2y+1)v}{16}\right]$$

for $x = 0,...,7$ and $y = 0,...,7$

The F(u,v) is called the DCT coefficient, and the DCT basis is:

$$\omega_{x,y}(u,v) = \frac{C(u)C(v)}{4}\cos\left[\frac{\pi(2x+1)u}{16}\right]\cos\left[\frac{\pi(2y+1)v}{16}\right]$$

Then we can rewrite the inverse DCT to :

$$f(x,y) = \sum_{u=0}^{7}\sum_{v=0}^{7} F(u,v)\omega_{x,y}(u,v) \quad \text{for } x = 0,...,7 \text{ and } y = 0,...,7$$

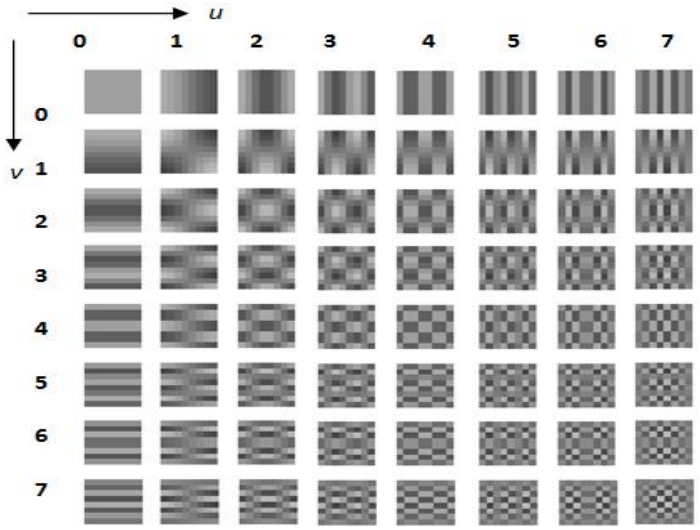

Fig. 4: The 8×8 DCT basis $\omega_{x,y}(u,v)$

48	39	40	68	60	38	50	121
149	82	79	101	113	106	27	62
58	63	77	69	124	107	74	125
80	97	74	54	59	71	91	66
18	34	33	46	64	61	32	37
149	108	80	106	116	61	73	92
211	233	159	88	107	158	161	109
212	104	40	44	71	136	113	66

(a) f (x,y) : 8×8 values of luminance

699.25	43.18	55.25	72.11	24.00	-25.51	11.21	-4.14
-129.78	-71.50	-70.26	-73.35	59.43	-24.02	22.61	-2.05
85.71	30.32	61.78	44.87	14.84	17.35	15.51	-13.19
-40.81	10.17	-17.53	-55.81	30.50	-2.28	-21.00	-1.26
-157.50	-49.39	13.27	-1.78	-8.75	22.47	-8.47	-9.23
92.49	-9.03	45.72	-48.13	-58.51	-9.01	-28.54	10.38
-53.09	-62.97	-3.49	-19.62	56.09	-2.25	-3.28	11.91
-20.54	-55.90	-20.59	-18.19	-26.58	-27.07	8.47	0.31

(b) F(u,v) : 8×8 DCT coefficients

Fig. 5: DCT coefficients for a 8×8 block

IV. Color Space Conversions and Down sampling

The encoding process of the JPEG starts with color-space conversion. This process is not applicable to gray-scale image, where there is only one luminance component for gray-scale image. Color image data in computers is usually represented in RGB format. Each color component uses 8 bits to store, thus, a full color pixel would require 24 bits. From the fact that human eyes are more sensitive to intensity change rather than color change, the JPEG algorithm exploits this by converting the RGB format to another color space called YCbCr. The Y component represents the brightness of a pixel, the Cb and Cr represent the chrominance. After converting the color space, the encoder stores the luminance Y in more detail than the other two chrominance components. The advantage of converting the image into luminance-chrominance color space is that the luminance and chrominance components are very much de-correlated between each other. Moreover, the chrominance channels contain much redundant information and can easily be sub-sampled without sacrificing any visual quality for the reconstructed image. The transformation from RGB to YC_bC_r, is based on the following mathematical expression:

$$\begin{bmatrix} Y \\ C_b \\ C_r \end{bmatrix} = \begin{bmatrix} 0.299000 & 0.587000 & 0.114000 \\ -0.168736 & -0.331264 & 0.500002 \\ 0.500000 & -0.418688 & -0.081312 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} + \begin{bmatrix} 0 \\ 128 \\ 128 \end{bmatrix}$$

The value Y = 0.299R + 0.587G + 0.114B is called the luminance. The values C_b and C_r are called chromimance values and represent 2 coordinates in a system which measures the nuance and saturation of the color. These values indicate how much blue and how much red are in that color, respectively. Accordingly, the inverse transformation from YC_bC_r to RGB is:

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1.0 & 0.0 & 1.40210 \\ 1.0 & -0.34414 & -0.71414 \\ 1.0 & 1.77180 & 0.0 \end{bmatrix} \begin{bmatrix} Y \\ C_b - 128 \\ C_r - 128 \end{bmatrix}$$

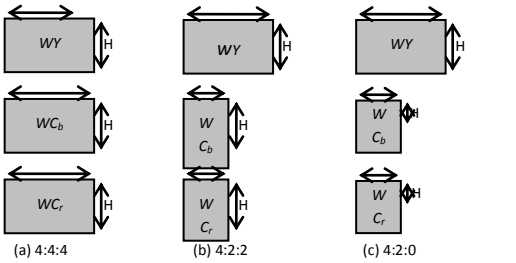

Fig.6: Three color formats in the baseline system

Because the eye seems to be more sensitive at the luminance than the chrominance, luminance is taken in every pixel while the chrominance is taken as a medium value for a 2×2 block of pixels. And this way will result a good compression ratio with almost no loss in visual perception of the new sampled image. There are three color formats in the baseline system:

(a) 4:4:4 format: The chrominance components have identical vertical and horizontal resolution as the luminance component. (b)4:2:2 format: The chrominance components have the same vertical resolution as the luminance component, but the horizontal resolution is half one. (c)4:2:0 format: Both vertical and horizontal resolution of the chrominance component is half of the luminance component as shown in the fig.6.

Quantization: The transformed 8×8 block consists of 64 DCT coefficients. The first coefficient F(0,0) is the DC component and the other 63 coefficients are AC component. The DC component F(0,0) is essentially the sum of the 64 pixels in the input 8×8 pixel block multiplied by the scaling factor (1/4)C(0)C(0)=1/8 as shown in equation for F(u,v). The next step in the compression process is to quantize the transformed coefficients. Each of the 64 DCT coefficients is uniformly quantized. The 64 quantization step-size parameters for uniform quantization of the 64 DCT coefficients form an 8×8 quantization matrix. Each element in the quantization matrix is an integer between 1 and 255. Each DCT coefficient F(u,v) is divided by the corresponding quantizer

step-size parameter Q(u,v) in the quantization matrix and rounded to the nearest integer as :

$$F_q(u,v) = Round\left(\frac{F(u,v)}{Q(u,v)}\right)$$

The quantization is the key role in the JPEG compression. This removes the high frequencies present in the original image. This is done by dividing values at high indexes in the vector with larger values than the values by which are divided the amplitudes of lower frequencies. The bigger values in the quantization table is the bigger error introduced by this lossy process, and the smaller visual quality. Another important fact is that in most images the color varies slowly from one pixel to another. So, most images will have a small quantity of high detail to a small amount of high spatial frequencies, and have a lot of image information contained in the low spatial frequencies. The JPEG does not define any fixed quantization matrix. It is the prerogative of the user to select a quantization matrix. There are two quantization matrices provided in Annex K of the JPEG standard for reference, but not requirement. These two quantization matrices are shown below in the fig.7 and fig.8:

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	62
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

(a) Luminance quantization matrix

17	18	24	47	99	99	99	99
18	21	26	66	99	99	99	99
24	26	56	99	99	99	99	99
47	66	99	99	99	99	99	99
99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99

(b) Chrominance quantization matrix

Fig. 7: Quantization matrix

699.25	43.18	55.25	72.11	24.00	-25.51	11.21	-4.14
-129.78	-71.50	-70.26	-73.35	59.43	-24.02	22.61	-2.05
85.71	30.32	61.78	44.87	14.84	17.35	15.51	-13.19
-40.81	10.17	-17.53	-55.81	30.50	-2.28	-21.00	-1.26
-157.50	-49.39	13.27	-1.78	-8.75	22.47	-8.47	-9.23
92.49	-9.03	45.72	-48.13	-58.51	-9.01	-28.54	10.38
-53.09	-62.97	-3.49	-19.62	56.09	-2.25	-3.28	11.91
-20.54	-55.90	-20.59	-18.19	-26.58	-27.07	8.47	0.31

(a) F (u,v) : 8×8 DCT coefficients

44	4	6	5	1	-1	0	0
-11	-6	-5	-4	2	0	0	0
6	2	4	2	0	0	0	0
-3	1	-1	-2	1	0	0	0
-9	-2	0	0	0	0	0	0
4	0	1	-1	-1	0	0	0
-1	-1	0	0	1	0	0	0
0	-1	0	0	0	0	0	0

(b) F_q(u,v) : After quantization

Fig. 8: An example of quantization for a 8×8 DCT coefficients

Zig-Zag Scan: After DCT transform and quantization over a block of 8x8 values, a new 8×8 block will results and is traversed in zig-zag as shown in the Fig. 7. After this with traversing in zig-zag the 8×8 matrix can get a vector with 64 coefficients (0,1,...,63). The reason for this zig-zag traversing is that the traverse the 8×8 DCT coefficients in the order of increasing the spatial frequencies as shown in the fig.9..

0	1	5	6	14	15	27	28
2	4	7	13	16	26	29	42
3	8	12	17	25	30	41	43
9	11	18	24	31	40	44	53
10	19	23	32	39	45	52	54
20	22	33	38	46	51	55	60
21	34	37	47	50	56	59	61
35	36	48	49	57	58	62	63

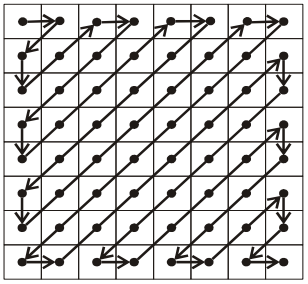

Fig. 9: Zig-Zag reordering matrix

DPCM on DC Components: Besides DCT another encoding method is employed i.e DPCM on the DC component. This is adopted because DC component is large and varied, but often close to previous value. Encode the difference from previous 8x8 blocks – DPCM.

Run Length encoding on AC Components: Another simple compression technique is applied to the AC component: 1x64 vector has lots of zeros in it. Encode as (skip, value) pairs, where skip is the number of zeros and value is the next non-zero component and send (0, 0) as end-of-block sentinel value. In Zig-ZagIn scan, consequences in the quantized vector at high spatial frequencies have a lot of consecutive zeroes. This can be exploiting by run length coding of the consecutive zeroes. Let's consider the 63 AC coefficients in the original 64 quantized vectors first. For example, we have:

57, 45, 0, 0, 0, 0, 23, 0, -30, -16, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0,..., 0

Encode each value which is not 0, than add the number of consecutive zeroes preceding that value in front of it. The RLC (run length coding) is: (0,57) ; (0,45) ; (4,23) ; (1,-30) ; (0,-16) ; (2,1) ; EOB. EOB (End of Block) is a special coded value. If reached to the end of the vector only zeroes, mark that position with EOB and finish the RLC of the quantized vector. Note that if the quantized vector does not finishes with zeroes (the last element is not 0), we do not add the EOB marker. Actually, EOB is equivalent to (0,0), so we have :

(0,57) ; (0,45) ; (4,23) ; (1,-30) ; (0,-16) ; (2,1) ; (0,0)

Quantized vector for another example as follows:

57, eighteen zeroes, 3, 0, 0, 0, 0, 2, thirty-three zeroes, 895, EOB

The JPEG Huffman coding makes the restriction that the number of previous 0's to be coded as a 4-bit value, so it can't overpass the value 15 (0xF). So, this example would be coded as : (0,57) ; (15,0) ; (2,3) ; (4,2) ; (15,0) ; (15,0) ; (1,895) ; (0,0)

(15,0) is a special coded value which indicates that there are 16 consecutive zeroes.

Differences Coding of DC Coefficients: Because the DC coefficients contain a lot of energy, it usually has much larger value than AC coefficients, and there is a very close connection between the DC coefficients of adjacent blocks. So, the JPEG standard encode the difference between the DC coefficients of consecutive 8×8 blocks rather than its true value. The mathematical represent of the difference is:

$$Diff_i = DC_i - DC_{i-1}$$

And we set $DC_0 = 0$. DC of the current block DC_i will be equal to $DC_{i-1} + Diff_i$. So, in the JPEG file, the first coefficient is actually the difference of DCs as shown in Fig. 8.

V. HARDWARE IMPLEMENTATION

JPEG compressor shown in the fig 2 can be implemented in verilog Hardware Description language and synthesised in FPGA to improve the compression ratio. Implementations of different algorithms for 1-DCT using Verilog HDL as the synthesis tool are carried out and their comparison gives the optimum technique for compression. And 2-D DCT is implemented using the optimum 1-D technique for 8x8 matrix input. The data can be precisely recovered through the IDCT.

VI Results

Consider10 images starting from image #0 to image #9 .The original image coefficients are represented by the DCT. The representation of the with respective to 8x8 DCT blocks are shown in fig.11 **.**

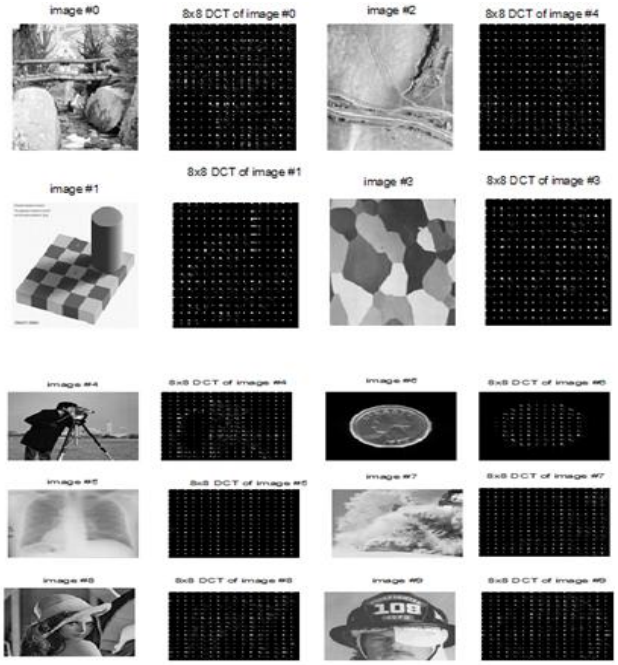

Fig. 10: representing images with 8×8 DCT blocks

Power of DCT coefficients

1 95.5db	2 52.6db	4 42.3db	9 33.9db	12 29.0db	19 22.5db	31 15.8db	42 9.6db
3 51.2db	5 40.8db	7 34.7db	13 28.9db	18 24.3db	24 20.2db	35 13.4db	39 10.6db
6 40.2db	10 33.3db	11 29.6db	16 25.0db	22 21.3db	30 16.3db	37 11.3db	45 9.3db
8 34.2db	15 27.4db	17 24.8db	23 20.9db	27 17.3db	33 14.3db	46 8.6db	51 4.3db
14 28.2db	21 22.3db	25 19.7db	29 16.7db	34 14.2db	44 9.3db	50 5.0db	56 -0.8db
20 22.4db	28 17.1db	32 15.6db	38 10.9db	41 10.1db	49 6.0db	55 0.5db	58 -3.3db
26 17.7db	36 12.4db	43 9.6db	48 7.1db	52 2.9db	57 -1.6db	59 -4.0db	61 -7.4db
40 10.5db	47 7.8db	53 1.9db	54 1.3db	60 -4.2db	62 -8.5db	63 -12.1db	64 -15.3db

Fig. 11: Power coefficients of 8×8 DCT blocks

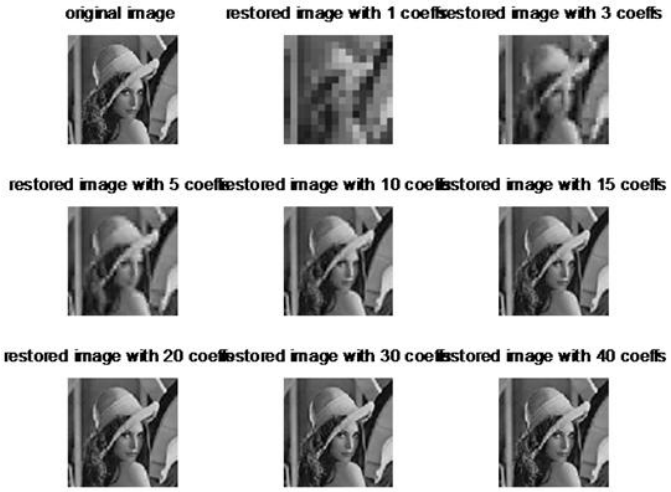

Fig. 12: Image restoration with power coefficients

We get the power coefficients from the 8x8 DCT images which are shown in fig.11and image restoration of the 8x8 DCT blocks with the power coefficients are shown in the fig. 12

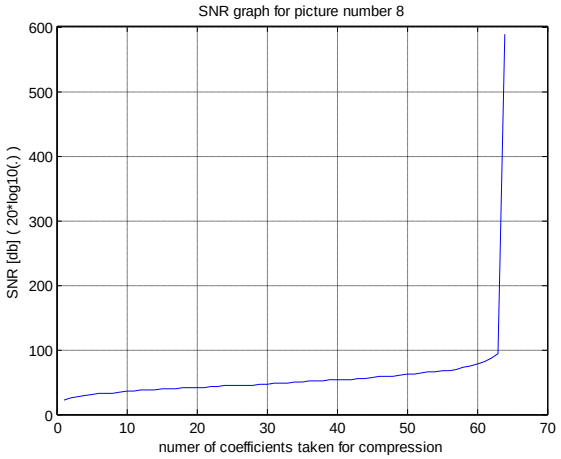

Fig.13: SNR values with the restoration of image coefficients

The signal to noise ratio of the restored image is shown below in fig14.The bandwidth of image is very high so that the time taken for transmission is very high because in practical cases band limited channels exist.

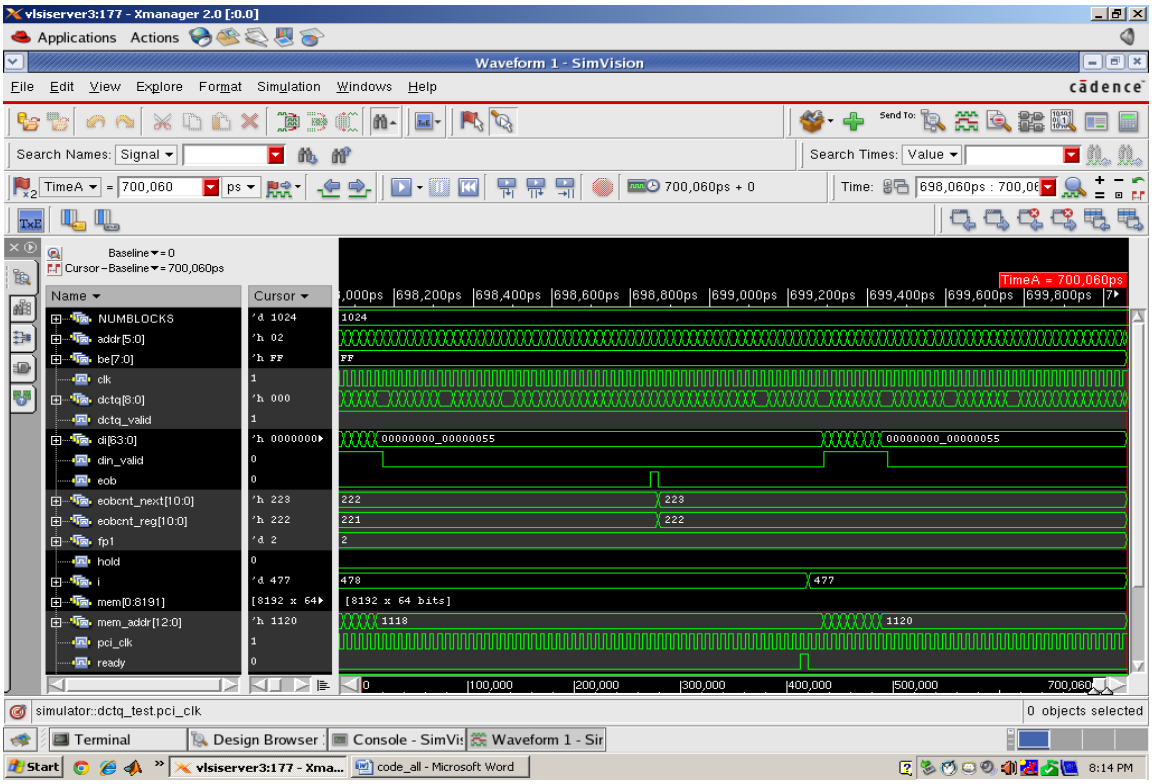

Fig. 14: Differences of 8×8 blocks

VII. Conclusions

We have introduced the basic compression methods of JPEG standard. Although this standard has become the most popular image format, it still has some properties to improvement. For example, the new JPEG 2000 standard use wavelet-based compression method, and it can operate at higher compression ratio without generating the characteristic 'blocky and blurry' artifacts of the original DCT-based JPEG standard.

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