An Study of Removal of Subjective Redundancy in JPEG for Low Cost, Low Power, Computation efficient Circuit Design and High Compression Image

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Abstract—**As the circuit complexity is increasing in demand for the more computations on a single VLSI chip, low power VLSI design has become important specially for portable devices powered by battery. Digital camera is one of them where real-time image capturing, compression and storage of compressed image data is done. Most of the digital camera implement JPEG baseline algorithm to store highly compressed image in camera memory. In this paper we report and present low cost, low power and computationally efficient circuit design of JPEG for digital camera to get highly compressed image by exploiting removal of subjective redundancy from the image.**

Keywords— **Discrete cosine transform (DCT), Image compression, JPEG, Quantization matrix, Subjective redundancy.**

I. INTRODUCTION

Low power design is becoming a new era in VLSI technology as it impacts many applications such as battery-powered portable systems, PDAs (Personal Digital Assistants) which require large amount of data processing with multimedia capabilities etc [1, 2]. Digital camera is one of them where real-time image capturing, compression and storage of compressed image data is done [3–6]. To obtain high compression and hence less storage with little distortion, JPEG baseline compression method is used in digital camera [7, 8]. 8x8 block-wise discrete cosine transform (DCT), quantization and entropy coding are the three steps used in JPEG baseline compression system [9], [10].

DCT is a computation intensive operation in JPEG which has many additions and multiplications. It requires complex hardware circuitry for its implementation. Most of the 8x8 2-D DCT implementation algorithms are implemented in hardware by row-column decomposition method where 1-D DCT is taken to all rows followed by 1-D DCT to all columns. This requires sixteen 8 point 1-D DCT computations along with a transposition memory to store intermediate 1-D DCT results [11–13] causing high cost and high power consumptions. Removal of subjective redundancy from transform coded images is done by the psychovisual thresholding and quantization of the image transform coefficients [14]. High frequency DCT coefficients carry very less visual information (not noticeable to eye). By exploiting this fact we can have a simple low cost hardware circuitry for DCT computation which computes only required DCT coefficients for a required image quality. A circuitry which computes 2-D DCT direct without transposition memory in recursive way (one coefficient at a time) is given in literatures [15, 16].

In this paper we have presented low cost, low power and computation efficient circuit design for computation of 2-D DCT targeting JPEG for digital camera by exploiting removal of subjective redundancy from the image.

This paper is organized as follows. Section II briefs the computation efficient quantization and scanning. Image reconstruction by taking selected DCT coefficients is presented in section III. Computation of zig-zag ordered first fifteen DCT coefficients is described in section IV. Future work is proposed in section V. Conclusions are drawn in section VI.

II. COMPUTATION EFFICIENT QUANTIZATION AND SCANNING

DC Coefficient contains the very high energy among other AC coefficients of an 8x8 block. The power of DC coefficients can be seen from fig.1 which shows the original lena image and image reconstructed after taking 8x8 block wise FDCT then making all AC coefficients zero and then reconstructing image by taking Inverse DCT (IDCT). From fig.2 which shows basis function image of 8x8 DCT matrix it is evident that first row and first column have only horizontal and vertical frequencies respectively. Also horizontal frequency increases from left to right and vertical frequency increases from top to bottom. Other rows and columns have both horizontal and vertical frequencies. Low frequency coefficients (carrying most of the visual information) are near top left corner and high frequency coefficients are near bottom right corner. By utilizing these facts we can reconstruct the entire image by taking only DC, first row and first column AC coefficients or few coefficients near top left corner. The advantage of this is that we can have a very computation efficient circuit for 8x8 2-D DCT computation which computes DCT coefficients direct (one coefficient in each

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clock cycle) without any transposition memory. So by calculating few important coefficients for acceptable image quality (quality degrades as number of coefficients used for reconstruction decrease) we can save computations as well as hardware. At the same time high image compression is achieved by discarding high frequency coefficients.

III. Image Reconstruction by Taking Selected DCT Coefficients

A typical quantization matrix used to quantize each 64 DCT coefficient by division with a corresponding quantization level is shown in fig.3. This matrix can further be scaled to reduce the amount of data by multiplying with a scaling parameter [9] named 'quality' in this literature. Fig.4 shows the original and reconstructed images from left to right by taking coefficients in zig-zag order [9] for coding in three cases.

Case 1: All coefficients are taken.
Case 2: Only first row and first column coefficients are taken.
Case 3: Only first 15 coefficients are taken.

Two values of scaling parameters are used for each image type. Table I shows the compression ratio obtained in three cases and also percentage improvement in compression ratio when only first row and first column coefficients are taken and when only first 15 coefficients are taken in zig-zag order as compared to all coefficients taken. It is evident from fig.4 that a slight distortion in visual quality is obtained in case of high gradient images when only first row and first column coefficients are taken for reconstruction as compared to all coefficients taken. But visual quality of images reconstructed in case 1 and case 2 are same. Also it is evident from table I that high compression is achieved when scaling parameter is small (quality=1). This is because high frequency coefficients are still present significantly after quantization which carry little (negligible) visual information. But at higher scaling parameter they almost become zero.

IV. Computation of Zig-zag Ordered First Fifteen 2-D DCT Coefficients

8x8 2-D DCT is given by,

$$F(u,v) = \frac{2}{8} C(u)C(v) \sum_{i=0}^{7}\sum_{j=0}^{7} x(i,j) \times \cos\left(\frac{(2i+1)u\pi}{16}\right)\cos\left(\frac{(2j+1)v\pi}{16}\right) \quad (1)$$

where $u, v = 0,1,\ldots,7$, and C(u), C(v) = $\sqrt{1/2}$ for $u, v = 0$ and C(u), C(v) = 1 otherwise. DC coefficient $F(0,0)$ is given by,

$$F(0,0) = \frac{2}{8} C(0)C(0) \sum_{i=0}^{7}\sum_{j=0}^{7} x(i,j)$$

$$= \frac{2}{8}\left(\sqrt{\frac{1}{2}}\right)\left(\sqrt{\frac{1}{2}}\right)\sum_{i=0}^{7}\sum_{j=0}^{7} x(i,j)$$

$$= \frac{1}{8}\sum_{i=0}^{7}(x(i,0)+x(i,1)+x(i,2)+x(i,3)+x(i,4) + x(i,5)+x(i,6)+x(i,7)) \quad (2)$$

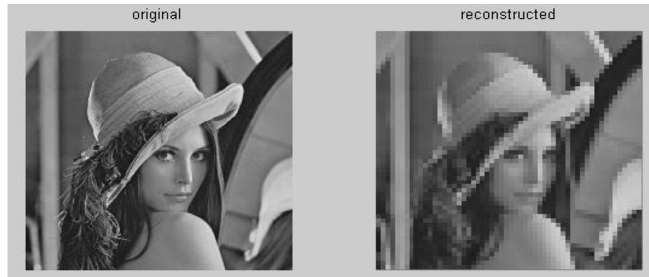


Fig.1. Original and Reconstructed lena image after taking only DC coefficients of each block.

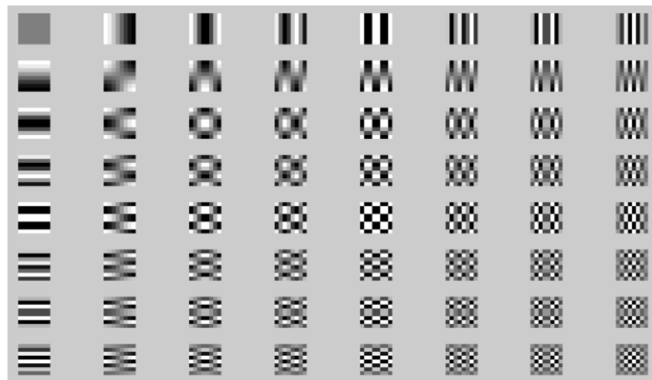


Fig.2. 64 basis functions image of an 8x8 DCT matrix.

```
[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]*quality;
```

Fig.3. 8x8 block quantization matrix with scaling parameter 'quality'.

Let,

$$\sum_{i=0}^{7} x(i,0) + \sum_{i=0}^{7} x(i,7) = c1pc8$$

$$\sum_{i=0}^{7} x(i,1) + \sum_{i=0}^{7} x(i,6) = c2pc7$$

$$\sum_{i=0}^{7} x(i,2) + \sum_{i=0}^{7} x(i,5) = c3pc6$$

$$\sum_{i=0}^{7} x(i,3) + \sum_{i=0}^{7} x(i,4) = c4pc5$$

and

$$\sum_{i=0}^{7} x(i,0) - \sum_{i=0}^{7} x(i,7) = c1mc8$$

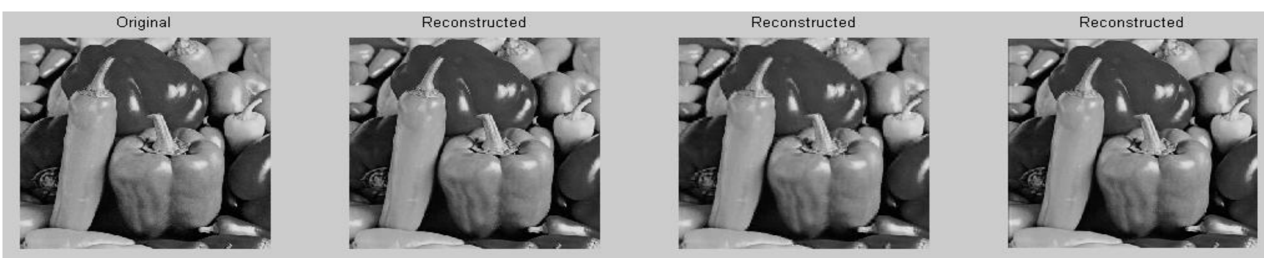
TABLE I

COMPRESSION RATIO OBTAINED FOR DIFFERENT QUALITY PARAMETER AND ITS PERCENTAGE IMPROVEMENT FOR DIFFERENT IMAGES

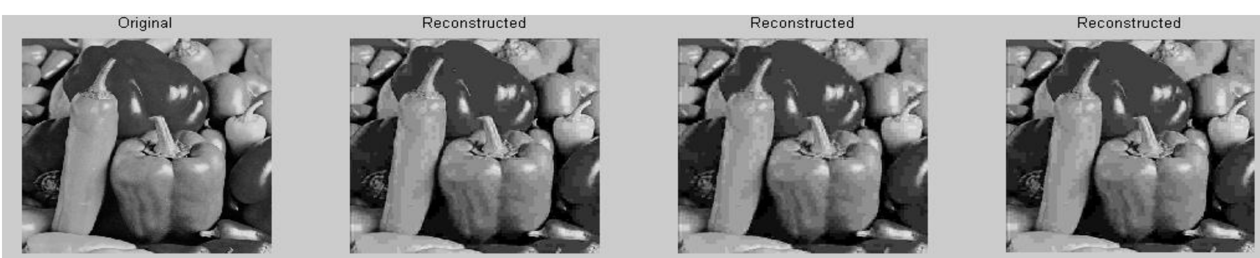
Images		**Compression ratio in case 1 (all 64 DCT coefficients taken)**	**Compression ratio in case 2 (first row and first column DCT coefficients taken)**	**Compression ratio in case 3 (first 15 coefficients taken)**	**% improvement in compression ratio in case 2 (as compared to case 1)**	**% improvement in compression ratio in case 3 (as compared to case 1)**
Lena (448x448)	quality=1	12.66	19.08	14.16	50.7	11.84
	quality=5	33.74	39.96	34.09	18.4	1.0
Peppers (512x512)	quality=1	12.50	18.17	14.02	45.3	12.1
	quality=8	41.50	45.24	41.58	9.0	0.1
Crowd (512x512)	quality=1	6.88	11.61	7.96	68.7	15.7
	quality=5	17.48	23.87	17.62	36.5	0.8
Cameraman (256x256)	quality=1	9.64	16.58	13.30	72	37.9
	quality=3	19.42	27.98	22.06	44.0	13.6

(a)

(b)



(c)

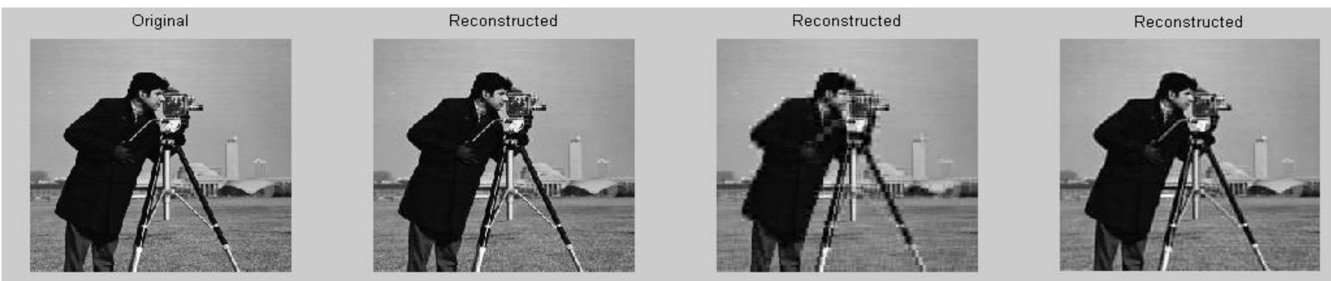


(d)

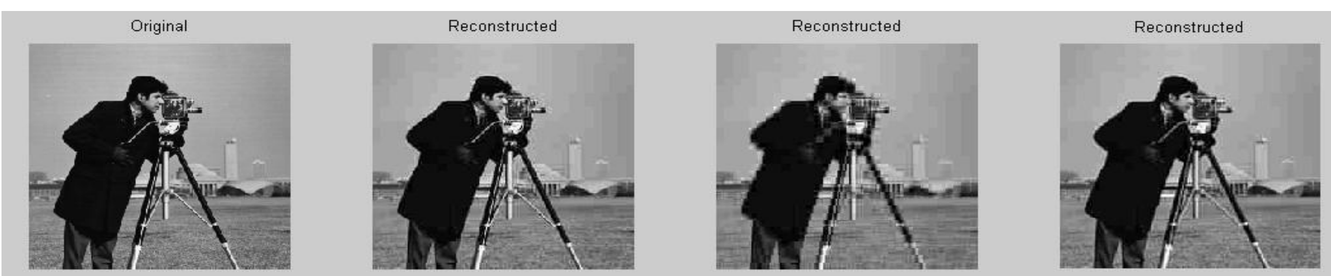
Fig.4. From left to right, original image, reconstructed images by taking all dct coefficients, reconstructed images by taking first row and first column dct coefficients, reconstructed images by taking first 15 coefficients in zig-zag order [9] of (a) 448x448 lena, quality=1, (b) 448x448 lena, quality=5, (c) 512x512 peppers, quality=1, (d) 512x512 peppers, quality=8.

(e)

(f)



(g)



(h)

Fig.4. (*continued*), (e) 512x512 crowd, quality=1, (f) 512x512 crowd, quality=5, (g) 256x256 cameraman, quality=1, (h) 256x256, cameraman, quality=3.

$$\sum_{i=0}^{7} x(i,1) - \sum_{i=0}^{7} x(i,6) = c2mc7$$

$$\sum_{i=0}^{7} x(i,2) - \sum_{i=0}^{7} x(i,5) = c3mc6$$

$$\sum_{i=0}^{7} x(i,3) - \sum_{i=0}^{7} x(i,4) = c4mc5$$

Then DC Coefficient $F(0,0)$ from (2) is,

$$F(0,0) = 1/8(c1pc8 + c2pc7 + c3pc6 + c4pc5) \tag{3}$$

Simplifying the 2-D DCT (1) in similar way 14 AC coefficients sequenced in zig-zag order can be calculated by a general equation given by,

$$F(u,v) = R \times [ACC1 \times (\frac{1}{8}\cos(\beta 1)) + ACC2 \times (\frac{1}{8}\cos(\beta 2)) + ACC3 \times (\frac{1}{8}\cos(\beta 3)) + ACC4 \times (\frac{1}{8}\cos(\beta 4))] \tag{4}$$

where accumulator values *ACC1, ACC2, ACC3, ACC4* and angles $\beta 1, \beta 2, \beta 3, \beta 4$ can be obtained from the help of table IV and table V respectively. Table II and table III shows the short notations of terms used for the pre-computation of accumulator values. For angle group 3 an extra constant term ‘c’ is to be added in (4) whose values are given in angle group column in table IV.

V. Future Work

From (4) required DCT coefficients can be implemented for the required image quality. Also it is evident that each additional coefficient will increase the computation of the DCT and hence required circuitry and power.

TABLE II
Short Notations Used

Image data values				notations n1=(c1–c2) – (c3–c4) n2=(c1–c2) + (c3–c4) n3=(c1+c2) – (c3+c4) n4=(c1+c2) + (c3+c4)			
c1	c2	c3	c4	n1	n2	n3	n4
x(0,0)	x(0,7)	x(7,0)	x(7,7)	A	Ap	pA	pAp
x(1,0)	x(1,7)	x(6,0)	x(6,7)	B	Bp	pB	pBp
x(2,0)	x(2,7)	x(5,0)	x(5,7)	C	Cp	pC	pCp
x(3,0)	x(3,7)	x(4,0)	x(4,7)	D	Dp	pD	pDp
x(0,1)	x(0,6)	x(7,1)	x(7,6)	E	Ep	pE	pEp
x(1,1)	x(1,6)	x(6,1)	x(6,6)	F	Fp	pF	pFp
x(2,1)	x(2,6)	x(5,1)	x(5,6)	G	Gp	pG	pGp
x(3,1)	x(3,6)	x(4,1)	x(4,6)	H	Hp	pH	pHp
x(0,2)	x(0,5)	x(7,2)	x(7,5)	I	Ip	pI	pIp
x(1,2)	x(1,5)	x(6,2)	x(6,5)	J	Jp	pJ	pJp
x(2,2)	x(2,5)	x(5,2)	x(5,5)	K	Kp	pK	pKp
x(3,2)	x(3,5)	x(4,2)	x(4,5)	L	Lp	pL	pLp
x(0,3)	x(0,4)	x(7,3)	x(7,4)	M	Mp	pM	pMp
x(1,3)	x(1,4)	x(6,3)	x(6,4)	N	Np	pN	pNp
x(2,3)	x(2,4)	x(5,3)	x(5,4)	O	Op	pO	pOp
x(3,3)	x(3,4)	x(4,3)	x(4,4)	P	Pp	pP	pPp

TABLE III
Short Notations of Terms Used

term	notation	term	notation
A+F+K+P	S0	pB–pN+pD–pP	S25
A+B+E+G	S1	pE–pI–pG+pK	S26
J+L+O–P	S2	pC–pO–pD+pP	S27
B+E+C+I	S3	pE–pI–pF+pJ	S28
H+N–L–O	S4	Ap–Dp+Ep–Hp	S29
C+I+D+M	S5	Jp–Kp+Np–Op	S30
F–H–N–K	S6	Ap–Dp+Fp–Gp	S31
E–L–N–C	S7	Ip–Lp–Np+Op	S32
A-G-D-K	S8	Bp–Cp+Ep–Hp	S33
M+J+P–F	S9	Kp+Mp–Pp–Jp	S34
A–G–C–H	S10	Bp–Cp–Fp+Gp	S35
I–J–P+N	S11	Ip–Lp–Mp+Pp	S36
B+O+D+K	S12	pAp–pDp–pMp+pPp	S37
E+F–M+L	S13	pFp–pGp–pJp+pKp	S38
H+I+O–B	S14	pBp–pCp+pEp–pHp	S39
A–J+D-F	S15	pLp–pNp+pOp–pIp	S40
G+P–K–M	S16	pA+pE+pI+pM	S41
D–F+E-B	S17	pB+pF+pJ+pN	S42
L+K+M–O	S18	pC+pG+pK+pO	S43
A–J+C–N	S19	pD+pH+pL+pP	S44
H–G–P–I	S20	pAp+pEp+pIp+pMp	S45
pA–pM+pB–pN	S21	pBp+pFp+pJp+pNp	S46
pG–pK+pH–pL	S22	pCp+pGp+pKp+pOp	S47
pA–pM+pC–pO	S23	pDp+pHp+pLp+pPp	S48
pF–pJ–pH+pL	S24		

TABLE IV
Accumulator and Cosine Angle Values For Computation of 14 AC Coefficients

AC Coeff.	R	*ACC1*	*ACC2*	*ACC3*	*ACC4*	Angle Group
F(1,0)	$\sqrt{2}$	S41	S42	S43	S44	2
F(2,0)	$\sqrt{2}$	S45	–S48	S46	–S47	4
F(3,0)	$\sqrt{2}$	–S43	S41	–S44	–S42	2
F(4,0)	$\sqrt{2}$	S45	–S46	–S47	S48	3, c=0
F(0,1)	$\sqrt{2}$	c1mc8	c2mc7	c3mc6	c4mc5	2
F(0,2)	$\sqrt{2}$	c1pc8	–c4pc5	c2pc7	–c3pc6	4
F(0,3)	$\sqrt{2}$	–c3mc6	c1mc8	–c4mc5	–c2mc7	2
F(0,4)	$\sqrt{2}$	c1pc8	–c2pc7	–c3pc6	c4pc5	3,c=0
F(1,1)	1	S0	S3+S4	S1+S2	S5+S6	1
F(2,1)	1	S29 +S30	S31 +S32	S33 +S34	S35 +S36	2
F(1,2)	1	S21 +S22	S23 +S24	S25 +S26	S27 +S28	2
F(3,1)	1	S7	S8+S9	S10 +S11	S13 –S12	1
F(2,2)	1	S37 –S38	S39 +S40	0	0	3, c= (S37 +S38)/8
F(1,3)	1	–S14	S15 +S16	S19 +S20	–(S17 +S18)	1

TABLE V
Angle Group and Its Values Used in Table IV

Angle Group	$(\beta 1, \beta 2, \beta 3, \beta 4)$
1	$(0, \pi/4, \pi/8, 3\pi/8)$
2	$(\pi/16, 3\pi/16, 5\pi/16, 7\pi/16)$
3	$(\pi/4, \pi/4, \pi/4, \pi/4)$
4	$(\pi/8, \pi/8, 3\pi/8, 3\pi/8)$

VI. Conclusions

Subjective redundancy can be removed by discarding the high frequency coefficients. Matlab simulation is done for compression and decompression of four types of images for two scaling parameters of quantization matrix. Three cases have been taken for the coding after discrete cosine transform. In first case (conventional) all DCT coefficients are taken, in second case only first row and first column coefficients are taken making other coefficients zero while in third case zig-zag ordered first 15 coefficients are taken. Decompressed images show little distortion in second case in high gradient portion of images while in third case visual quality obtained is same as first case. By exploiting this fact, direct 2-D DCT computation method is described computes first 15 zig-zag ordered 2-D DCT coefficients. Also by proposed implementation method additional coefficient increases the computation and hence more hardware requirement as well as power consumption.

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