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Analysis of Lossy JPEG Compression Technique

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***Abstract*— This paper describes compression of images with the help of JPEG compression technique. JPEG compression is a lossy technique because the redundant data is selectively discarded to achieve good compression ratio. The images are compressed using Discrete Cosine Transform. The paper also discusses how different levels of compression can be achieved.**

***Index Terms*— JPEG, Discrete Cosine Transform (DCT), compression, quantizer, encoder**

I. Introduction

Image data compression is done to minimize the number of bits required to represent an image without significant loss of information. The space that the data occupies on the disk is reduced after compression and makes the transmission of data easy.

In most of the images neighbouring pixels are correlated, therefore, they hold redundant information. Hence the foremost task is to find less correlated representation of the image. The elementary components of compression are redundancy and irrelevancy reduction.

Redundancy reduction aims at removing duplication from the source image. Irrelevancy reduction omits the part of the signal that is not noticed by signal receiver. There are three types of redundancy which can be identified namely spatial redundancy, spectral redundancy and temporal redundancy.

A lossy image compression system is shown in the image below.

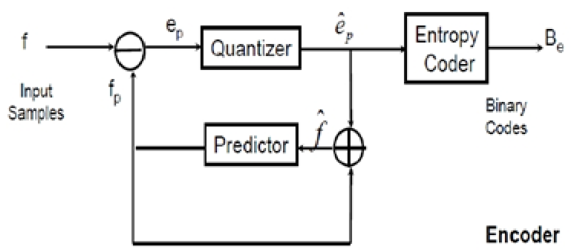

Fig. 1: Block Diagram of Data Compression Process

It consists of a source encoder, quantizer and an encoder. Compression is achieved by applying linear transform to de-correlate the image data, quantizing the resulting transform coefficients and entropy coding the quantized values. To de-correlate, various linear transforms like Discrete Cosine Transform, Discrete Fourier Transform and Discrete Wavelet Transform are used. Quantizer is used to reduce the number of bits needed to store the transformed coefficients by reducing the precision of those values. The process becomes a lossy compression technique as it is a many to one mapping. Quantization can also be performed on individual coefficients i.e. Scalar Quantization or on a group of coefficients i.e. Vector Quantization. Once the quantization is done, the entropy encoder supplementary compresses the quantized values in a lossless way to provide a better overall compression. The most commonly used entropy encoders are the Huffman encoder and the arithmetic encoder.

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Image compression can be classified into different compression techniques. First categorization is based on the information content of the reconstructed data; they are lossless compression and lossy compression. The second categorization of various coding schemes is based on the space where the coding is being applied; these are predictive coding and transform coding.

II. Introduction to JPEG

JPEG is an acronym for the Joint Photographic Experts Group which created the standard. It is mostly used to store and transmit images over the web. JPEG is one of the most common image format used by photographic image capturing devices. This technique is capable of producing highly compressed data which is far smaller than the original size of the data. Using this technique compression ratio of 25:1 can be achieved. To compress images, redundant data is removed in a way that the reconstruction of the image is possible, this is called information preserving compression. This is one reason as to why the JPEG compression technique is a lossy one. JPEG presents a simple form of data compression as it samples band limited images, here an infinite number of pixels per unit are reduced to one sample without much loss in the information. It is an excellent way to store 24 bit images and is superior in appearance as compared to the 8 bit images on VGA display.

JPEG, which is a transform based compression technique, preserves image quality, and is less sensitive to image property changes. While transmitting compressed images is an important property is insensitivity to noise in the transmission channel and any transform based compression technique is less sensitive to channel noise. If the transform coefficients get corrupted during transmission, the resulting disturbance is spread homogeneously through the image. Since JPEG uses Discrete Cosine Transform (DCT), it is very well suited for image compression even though it's a lossy process as high degree of compression is achieved with minimal loss of data.

The JPEG compression technique works well with continuous tone images as the difference between the adjacent pixels is minimal. Also, the compression would be effective on images having depths of at least four to five bits per color channel. The standard actually specifies eight bits per input sample and data with lesser bit depth are handled by scaling it up to eight bits per sample. The result is bad for low bit depth source data, as there are large jumps between adjacent pixel values.

III. JPEG PROCESS

JPEG compression is not a single step algorithm. It converts each frame from spatial domain to frequency domain. The image is first broken down into 8*8 blocks of pixels, and then DCT is applied to the whole block moving from left to right and top to bottom. DCT is suitable because it is a convenient representation of the image because of the high frequency coefficients. Each block is compressed through quantization once the DCT is applied to the blocks. Quantization reduces the large number scale into a smaller one. Finally the quantized coefficients are sequenced and losslessly packed into an output bit stream.

The DCT applied is either one dimensional (in case of data) or two dimensional in case of images. The one dimensional DCT definition for length N is

$$C(u) = \propto(u) \sum_{x=0}^{N-1} f(x) \cos\left[\frac{\pi(2x+1)u}{2N}\right] \quad \text{....1}$$

$$\propto(u) = \begin{cases} \sqrt{\frac{1}{N}} & for\ u = 0 \\ \sqrt{2/N} & for\ u \neq 0 \end{cases} \quad \text{....2}$$

The two dimensional DCT definition for length N is

$$D(i,j) = \frac{1}{\sqrt{2N}} C(i)C(j) \sum_{x=0}^{N-1}\sum_{y=0}^{N-1} p(x,y) \cos\left[\frac{(2x+1)i\pi}{2N}\right] \cos\left[\frac{(2y+1)j\pi}{2N}\right] \quad \text{....3}$$

Since N is 8, the equation is rewritten as

$$D(i,j) = \frac{1}{4} C(i)C(j) \sum_{x=0}^{N-1}\sum_{y=0}^{N-1} p(x,y) \cos\left[\frac{(2x+1)i\pi}{16}\right] \cos\left[\frac{(2y+1)j\pi}{16}\right] \quad \text{....4}$$

$$C(u) = \begin{cases} \frac{1}{\sqrt{2}} & for\ u = 0 \\ 1 & for\ u > 0 \end{cases} \quad \text{....5}$$

P(x, y) is the x^{th}, y^{th} element of the image represented by the matrix p and N is the size of the block. With the help of the above equation we can calculate one entry (i, j^{th}) of the transformed image from pixel values of the original image matrix.

IV. JPEG COMPRESSION

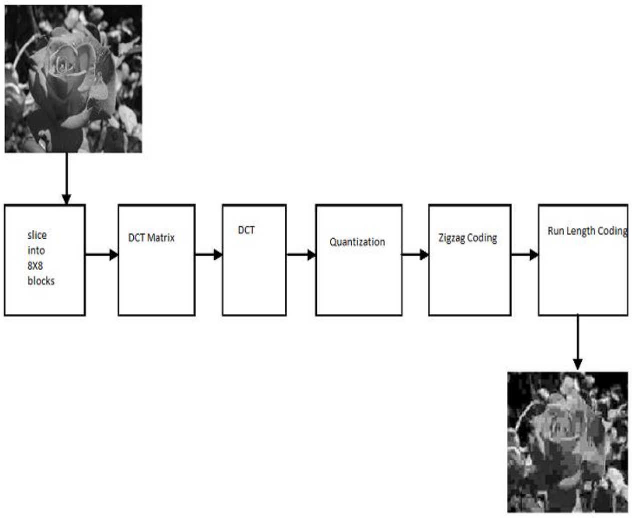

Fig 2: Block Diagram of JPEG Compression Process

Figure 2 represents the block diagram of the JPEG compression process. The input is an image which consists of data in terms of pixels. The image usually consists of 6025 pixels. The DCT matrix used for compression is an 8X8 matrix. Formula used to obtain the matrix is

$$T_{ij} = \begin{cases} \frac{1}{\sqrt{N}} & for\ i = 0 \\ \sqrt{\frac{2}{N}} \cos\left(\frac{(2j+1)i\pi}{2N}\right) & for\ i > 0 \end{cases} \quad \text{....6}$$

The resultant matrix is

$$Original = \begin{bmatrix} 154 & 123 & 123 & 123 & 123 & 123 & 123 & 136 \\ 192 & 180 & 136 & 154 & 154 & 154 & 136 & 110 \\ 254 & 198 & 154 & 154 & 180 & 154 & 123 & 123 \\ 239 & 180 & 136 & 180 & 180 & 166 & 123 & 123 \\ 180 & 154 & 136 & 167 & 166 & 149 & 136 & 136 \\ 128 & 136 & 123 & 136 & 154 & 180 & 198 & 154 \\ 123 & 105 & 110 & 149 & 136 & 136 & 180 & 166 \\ 110 & 136 & 123 & 123 & 123 & 136 & 154 & 136 \end{bmatrix}$$

The columns of the above matrix form an orthonormal set, hence it is an orthogonal matrix. The orthogonality of the above matrix is important as inverse of T will be T' and is easy to calculate.

The pixel values in a black and white image range from 0 to 255, here 0 represents pure black and 255 represents pure white. An image comprises of thousands of 8X8 blocks of pixels. A typical 8X8 matrix is shown below.

$$T = \begin{bmatrix} .3536 & .3536 & .3536 & .3536 & .3536 & .3536 & .3536 & .3536 \\ .4904 & .4157 & .2778 & .0975 & -.0975 & -.2778 & -.4157 & -.4904 \\ .4619 & .1913 & -.1913 & -.4619 & -.4619 & -.1913 & .1913 & .4619 \\ .4157 & -.0975 & -.4904 & -.2778 & .2778 & .4904 & .0975 & -.4157 \\ .3536 & -.3536 & -.3536 & .3536 & .3536 & -.3536 & -.3536 & .3536 \\ .2778 & -.4904 & .0975 & .4157 & -.4157 & -.0975 & .4904 & -.2778 \\ .1913 & -.4619 & .4619 & -.1913 & -.1913 & .4619 & -.4619 & .1913 \\ .0975 & -.2778 & .4157 & -.4904 & .4904 & -.4157 & .2778 & -.0975 \end{bmatrix}$$

Since DCT can perform only on pixel values ranging from -128 to 127, the original block is levelled off by subtracting 128 from each entry, resulting in the matrix given above. DCT can now be applied on the above matrix, and is accomplished by matrix multiplication.

$$D = TMT' \qquad ....7$$

The matrix multiplication should be done in the same order as given in the above equation. On applying the above equation, the following matrix is obtained

$$D = \begin{bmatrix} 162.3 & 40.6 & 20.0 & 72.3 & 30.3 & 12.5 & -19.7 & -11.5 \\ 30.5 & 108.4 & 10.5 & 32.3 & 27.7 & -15.5 & 18.4 & -2.0 \\ -94.1 & -60.1 & 12.3 & -43.4 & -31.3 & 6.1 & -3.3 & 7.1 \\ -38.6 & -83.4 & -5.4 & -22.2 & -13.5 & 15.5 & -1.3 & 3.5 \\ -31.3 & 17.9 & -5.5 & -12.4 & 14.3 & -6.0 & 11.5 & -6.0 \\ -0.9 & -11.8 & 12.8 & 0.2 & 28.1 & 12.6 & 8.4 & 2.9 \\ 4.6 & -2.4 & 12.2 & 6.6 & -18.7 & -12.8 & 7.7 & 12.0 \\ -10.0 & 11.2 & 7.8 & -16.3 & 21.5 & 0.0 & 5.9 & 10.7 \end{bmatrix}$$

The above obtained matrix consists of 64 DCT coefficients, c (i, j) where i and j range from 0 to 7. Coefficient c (0, 0) corresponds to the low frequencies of the original image and as we move away from it, the coefficients correlate to higher frequencies of the image with c (7, 7) corresponding to the highest frequency of the image. The high frequencies are represented by lower numbers and the lower frequencies are represented by higher numbers.

Once the DCT coefficients are obtained, the matrix is ready for compression by quantization. The advantage which JPEG holds over other compression techniques is that the levels of image compression and quality can be varied by selecting specific quantization matrices with the quality levels ranging from 1 to 100. 1 gives poorest image quality with highest compression and 100 gives the best image quality with lowest compression. To obtain highest compression with decent image quality, quality level of 50 is used.

$$Q_{50} = \begin{bmatrix} 16 & 11 & 10 & 16 & 24 & 40 & 51 & 61 \\ 12 & 12 & 14 & 19 & 26 & 58 & 60 & 55 \\ 14 & 13 & 16 & 24 & 40 & 57 & 69 & 56 \\ 14 & 17 & 22 & 29 & 51 & 87 & 80 & 62 \\ 18 & 22 & 37 & 56 & 68 & 109 & 103 & 77 \\ 24 & 35 & 55 & 64 & 81 & 104 & 113 & 92 \\ 49 & 64 & 78 & 87 & 103 & 121 & 120 & 101 \\ 72 & 92 & 95 & 98 & 112 & 100 & 103 & 99 \end{bmatrix}$$

The quantization matrix given above is the matrix which is generally used for image compression with a quality level of 50. However, if the user wants to achieve higher compression scalar multiples of the standard matrix can be used. For quantization level more than 50 the standard matrix is multiplied by $\{\frac{[100-(quality\ level)]}{50}\}$ and for quantization levels less than 50 the standard matrix is multiplied by $\frac{50}{quality\ level}$. Quantization is achieved by dividing each element in the transformed matrix D by corresponding element in the quantization matrix, and then rounding it off to the nearest integer value.

$$C_{ij} = round\left(\frac{D_{i,j}}{Q_{i,j}}\right) \qquad ....8$$

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The resultant C matrix is

$$C = \begin{bmatrix} 10 & 4 & 2 & 5 & 1 & 0 & 0 & 0 \\ 3 & 9 & 1 & 2 & 1 & 0 & 0 & 0 \\ -7 & -5 & 1 & -2 & -1 & 0 & 0 & 0 \\ -3 & -5 & 0 & -1 & 0 & 0 & 0 & 0 \\ -2 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

The coefficients in the upper left hand corner of the matrix correspond to the lower frequencies and the zeros in the matrix correspond to the less important data or the high frequency data which has been discarded, giving rise to the lossy part of the compression. Only non-zero coefficients are used for the compression of the image. The final stage for data compression is entropy encoding. It involves arranging the coefficients of the image in a zig-zag manner including run length encoder algorithm which groups similar frequencies together, inserting length coding zeros, and then using Huffman coding on what is left. The advantage of using zig-zag coding is that it consolidates large runs of zeros, which can be compressed easily.

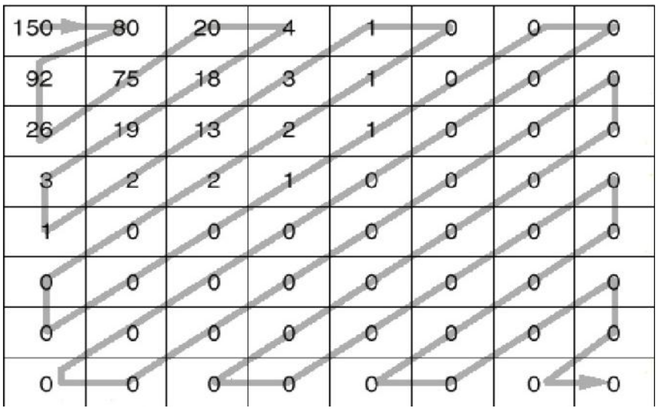

Fig 3 Zigzag Coding on 8X8 quantized matrix

V. ADVANTAGES AND DISADVATAGES OF JPEG

The JPEG compression algorithm is best suited for photographs and paintings with smooth variations in tone and colour. For web usage, where the amount of data used is important, JPEG is very popular. Since JPEG is transform based and uses DCT, it is highly efficient. Also, all pixel values are represented by real numbers and the pixels themselves don't affect each other. JPEG is an excellent way to store 24 bit photographic images, and the 24 bit images are superior in appearance as compared to the 8 bit images. In JPEG high compression ratios can be achieved without any noticeable degradation in the quality of the image.

The JPEG compression technique has its disadvantages as well. JPEG is not well suited for line drawings and other textual or iconic graphics, as the sharp contrast between adjacent pixels can cause noticeable artefacts. Also, since it's a lossy compression process, it can't be used for compression of data whose exact reproduction is required. If the image has to undergo multiple edits the image quality is usually lost each time the image is compressed or decompressed especially when the image is cropped or shifted, the JPEG compression technique is not advisable as there is a noticeable degradation in the quality of the image.

VI. CONCLUSION AND FUTURE SCOPE

High levels of data compression can be achieved using JPEG compression technique. Compression ratio of 25:1 can be achieved without any noticeable degradation in the quality of the output data as compared to the input data. This not only reduces the size occupied on the disk but also reduces the transmission time across data networks. After sufficient compression and decompression on the image, there is very less change in the original and decompressed image. Furthermore JPEG does not require a lot of information about the image that has to be compressed and the execution time is also very less.

The future works can be focused on enhancing the DCT method. This can be used as a natural technique for handling increased spatial resolution of imaging sensors. It can also be used to control remotely piloted vehicles in the military. This can also be used for visual control of robotic arm for complicated operations.

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