Impact of Quantization Matrix on the Performance of JPEG

[1]Mr.S. V. Viraktamath, [2]Dr. Girish V. Attimarad

[1]S.D.M College of Engineering. & Technology. Dharwad-580002, Karnataka, India.
[2]Dayanand Sagar College of Engineering, Bangalore-560078, Karnataka, India
svvmath@gmail.com

Abstract

With the increase in imaging sensor resolution, the captured images are becoming larger and larger, which requires higher image compression ratio. Discrete Cosine Transform (DCT) quantization and entropy encoding are the two main steps in the Joint Photographic Experts Group (JPEG) image Compression standard. In order to investigate the impact of quantization matrix on the performance of JPEG, a sample DCT was calculated, images were quantized using several quantization matrices. The results are compared with the standard quantization matrix. The performance of JPEG is also analyzed for different images with different compression factors.

Keywords: *Compression, Discrete Cosine Transform (DCT), JPEG, Quantization.*

1. Introduction

Well known JPEG based on DCT is lossy compression techniques with relatively high compression ratio which is done by exploiting human eye perception [1, 2]. JPEG is a commonly used compression standard and has been widely used in the Internet and other applications. JPEG compression is the most popular scheme for image compression nowadays. Fig. 1 shows the block diagram of the JPEG compression. In this scheme, source image samples are firstly grouped into non-overlapped and consecutive 8×8 blocks and each block is transformed by forward DCT into a set of 64 values referred to as DCT coefficients. The value located in the upper-left corner of the block is called DC (Direct Current) coefficients and the other 63 values are called Alternate Current (AC) coefficients.

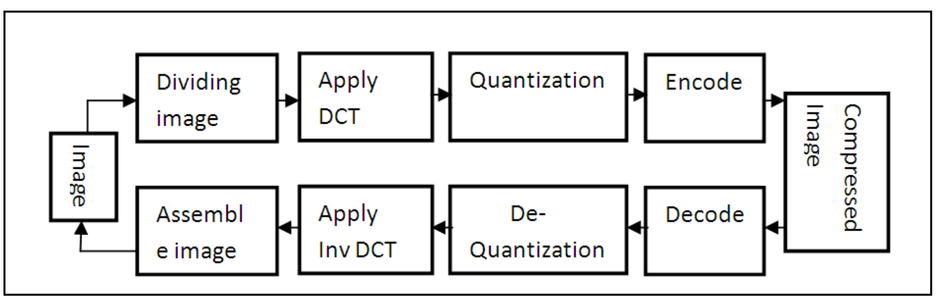

Figure1: Block diagram of JPEG

All the coefficients located in the same position within each of the 8×8 block form a mode (or called sub-band). Then, an 8×8 quantization table, consisting of 64 integer-valued quantization steps (QSs), is used to quantize the DCT coefficients. DCT coefficients from the same mode share the same QS. Although the quantization table can be arbitrarily defined, there is a standard quantization table recommended by JPEG standard. Trade-off between visual quality and compression rate can be achieved by using a proper quality factor (QF); the quantized DCT (QDCT) coefficients are further encoded into a bit-stream by applying entropy coding [3]. The DCT is like a discrete Fourier transform in that it turns the spatial domain of an image into its frequency domain. The spatial domain contains numbers that reflect the intensity of every channel at a given pixel, while the frequency domain contains the change of intensity from one pixel to the next.

This paper is organized as follows. We briefly review the related work in Section II. In section III methodology is described. Experimental results and performance analysis is presented Section IV gives. Section V concludes the paper.

2. Related Work

Two image characteristics, the smoothness and the similarity, which give rise to local and global redundancy in image representation studied in [4], the smoothness means that the gray level values within a given block vary gradually rather than abruptly. The similarity means that any patterns in an image repeat itself anywhere in the rest of the image. Lossless compression techniques can be implemented by entropy coding such as Huffman coding, Lempel-Ziv coding, and arithmetic coding [5, 6, and 7]. Customized JPEG quantization matrices for compressing iris polar images to positively impact the recognition performance is discussed in [8]. A copy-paste block detection method based on characteristics of double JPEG compression is discussed in [3]. The JPEG compression will bring JPEG compression characteristics to the DCT coefficients, these characteristics are closely related with the quality factor. Concepts that optimize image compression ratio by utilizing the information about a signal's properties and their uses are introduced in [9]. This additional information about the image is used to achieve further gains in image compression.

A fast and efficient method is provided in [10] to determine whether an image has been previously JPEG compressed. After detecting a compression signature, compression parameters are estimated. A method for the maximum likelihood estimation of JPEG quantization steps has been developed. An adaptive regression method applied to the standard JPEG compression for archiving higher compression ratios presented in [11]. Overview of the JPEG standard, and detail on the Baseline method have been discussed in [12]. Procedure by which JPEG compression may be customized for gray-scale images that are to be compressed, halftoned, and printed are described in [13]. The development of a JPEG chip which employs a single chip implementation and an efficient architecture of Huffman codec described in [14]. The chip is mainly composed of four modules: DCT/Inverse DCT, quantizer/dequantizer, zig-zag, and Huffman coding and decoding. Customized JPEG quantization matrices for compressing iris polar images to positively impact the recognition performance is proposed in [15].

3. Methodology

Some of the common characteristic of most of the images is that the neighboring pixels are correlated and therefore contain redundant information. The foremost task is to find less correlated representation of the image. Two fundamental components of compression are redundancy and irrelevancy reduction. Redundancy reduction aims at removing duplication from the signal source (image/video). Irrelevancy reduction omits part of the signal that will not be noticed by the signal receiver, namely the Human Visual System (HVS).

JPEG was designed to compress color or gray-scale continuous-tone images of real-world subjects: photographs, video stills, or any complex graphics that resemble natural subjects. The DCT-based algorithms have since made their way into various compression methods. DCT-based encoding algorithms are always lossy in nature. DCT algorithms are capable of achieving a high degree of compression with only minimal loss of data. The JPEG compression scheme is divided into the following stages and Fig.1 represents block diagram JPEG.

The following is a general overview of the JPEG process.

1. Import the image.
2. Break the image into 8x8 blocks of pixels.
3. Working from left to right, top to bottom, apply a DCT to each block, thus removing redundant.
4. Quantize each block of DCT coefficients using weighting functions optimized for the human eye.
5. Encode the resulting coefficients (image data) using a Huffman variable word-length coding to remove redundancies in the coefficients.

At the decoder reverse process takes place as shown in Fig. 1. IDCT is used to reconstruct the image. Code is written for the compression as well as for decompression. Three different images are given as input. For different compression factors Compression Ratio, Signal to Noise Ratio, Peak NSR and MSR are computed. The different sets of quantization matrix are tested and the results which are near to the standard are shown in this paper.

3.1. Discrete Cosine Transform

The image data is divided up into 8x8 blocks of pixels. A DCT is applied to each 8x8 block. DCT converts the spatial image representation into a frequency map: the low-order or "DC" term represents the average value in the block, while successive higher-order "AC" terms represent the strength of more and more rapid changes across the width or height of the block. The highest AC term represents the strength of a cosine wave alternating from maximum to minimum at adjacent pixels. High-frequency data can be discarded easily without losing low-frequency information.

Because the DCT uses cosine functions, the resulting matrix depends on the horizontal, diagonal, and vertical frequencies. Therefore an image block with a lot of change in frequency has a very random looking resulting matrix, while an image matrix of just one color, has a resulting matrix of a large value for the first element and zeroes for the other elements.

3.2. Quantization

The human eye is fairly good at visualizing small differences in brightness over a relatively large area, but not so good at distinguishing the exact strength of a high frequency brightness variation. This fact allows one to get away with a greatly reduced amount of information in the high frequency components. This is done by simply dividing each component in the frequency domain by a constant for that component and then rounding to the nearest integer. This is the main lossy operation in the compression process. As a result of this, it is typically the case that many of the higher frequency components are rounded to zero, and many of the rest of the components become small numbers. 8x8 block of DCT coefficients is further quantized. A remarkable and highly useful feature of JPEG process is that in this step, varying levels of image compression and quality are obtained through selection of specific quantization matrices. This enables the user to decide on quality levels ranging from 1 (poorest) to 100 (Best Quality).

A common quantization matrix is given below:

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

3.3. Entropy coding

Coding for DC coefficients and AC coefficients are done separately. DC coefficients are not encoded directly. Instead, the difference of the DC coefficient of the present block from that of the previous block is used for encoding. To obtain AC code words for a sequence, the 63 AC coefficients are interpreted into runs of zeros each of which ends with a non-zero coefficient. Then each run of zeros and its following non-zero coefficient are used for encoding. A DC codeword is derived from two parts, size and amplitude, and each AC codeword is derived from run-length/size and amplitude.

Run length encoding is applied to the AC coefficients of the matrix. Differential coding modulation is applied to the DC co-efficient. Instead of taking a difference relative to a previous input sample, take the difference relative to the output of a local model of the decoder process; in this option, the difference can be quantized, which allows a good way to incorporate a controlled loss in the encoding.

Huffman coding is the variable length coding, wherein the length of each code word is a function of frequency of occurrence of a symbol. JPEG standard defines the Huffman tables which are used to encode output of differential and run-length process.

4. Results and Discussions

JPEG image compression and decompression is implemented using MATLAB. There are various quantitative factors that are calculated are Signal to Noise Ratio (SNR), Peak Signal to Noise Ratio (PSNR), Compression Ratio (CR) and Mean Square Error (MSE). Meaning of the above performance measures is as follows:

SNR: It is defined as the ratio of signal power to the noise power corrupting the signal.

PSNR: The PSNR is most commonly used as a measure of quality of reconstruction of lossy compression CODECs (e.g., for image compression). The signal in this case is the original data, and the noise is the error introduced by compression.

CR: Compression ratio is the number of bits required to represent the image before compression to the number of bits required to represent the image after compression.

MSE: In statistics, the mean square error or MSE of an estimator is one of many ways to quantify the difference between an estimator and the true value of the quantity being estimated. MSE is a risk function, corresponding to the expected value of the squared error loss or quadratic loss. MSE measures the average of the square of the error.

Tabulation of results is carried out for 6 test images namely cameraman.tiff, rice.png moon.tiff, tree.tif, coin.tif and circuit.tiff which are shown in Fig. 2 and Fig. 3. Compression factor is the factor by which the quantization matrix is multiplied. It is substituted with 5 values namely 0.5, 1, 2, 3, 4 for each quantization matrix and CR, SNR, PSNR, MSE are measured. Compression factor decides the CR and hence the number of bits required to represent the compressed image.

Fig2. Images - Cameraman, Moon and Rice

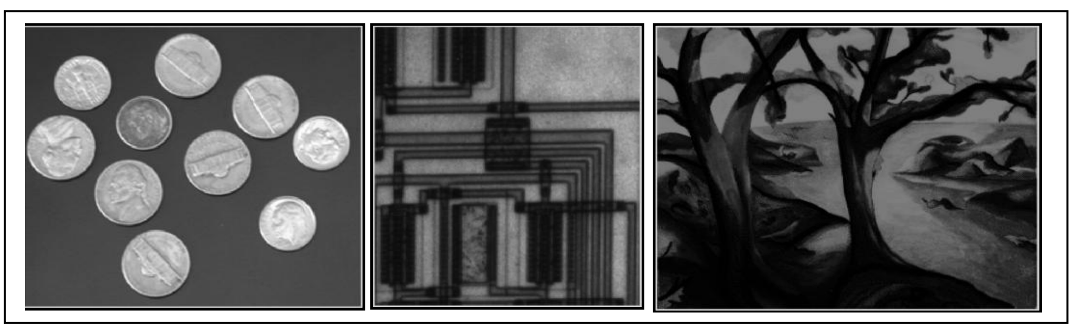

Fig3. Images - Coin, Circuit and Tree

To analyze the impact of quantization matrix on the performance of JPEG, many quantization matrices are considered. The standard quantization matrix elements are varied from 0% to 10% and performance of JPEG is studied for these quantization matrices for different images. Only few quantization matrices whose performance is near to the standard quantization matrix are considered. Out of many quantization matrices only eight quantization matrices performance (QM2 through QM9) are discussed whose performance is around the common quantization matrix (QM1).

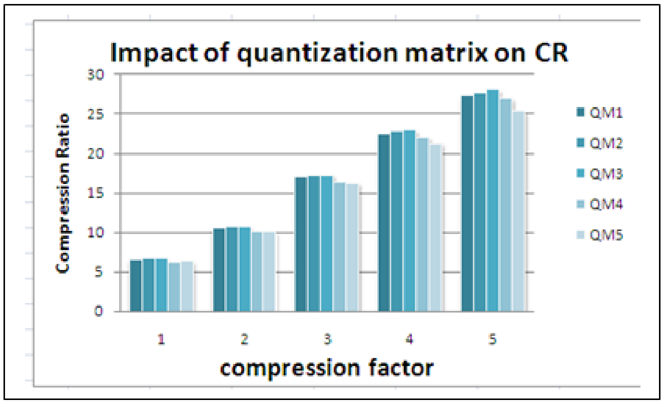

Fig.4: Impact of QM1-QM5 on compression ratio for image Rice

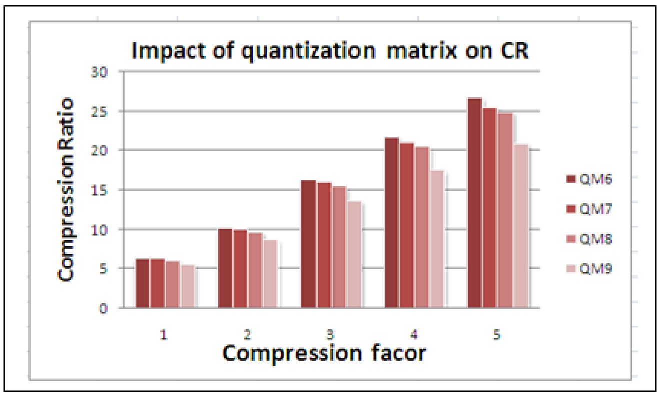

Fig.5: Impact of QM6-QM9 on compression ratio for image Rice

Impact of selection of quantization matrix on compression ratio for image Rice is shown in Fig.4 and Fig.5. QM1 is a standard matrix and QM2 to QM9 are other quantization matrices whose compression ratio is near to standard quantization matrix. In Fig.4 to Fig.9, X - axis 1, 2, 3, 4 and 5 indicates the different compression factors 0.5, 1, 2, 3 and 4 for each quantization matrix.

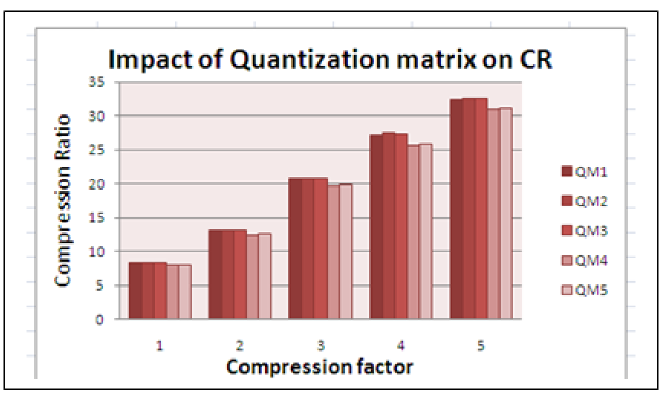

Fig.6: Impact of QM1-QM5 on compression ratio for image Cameraman

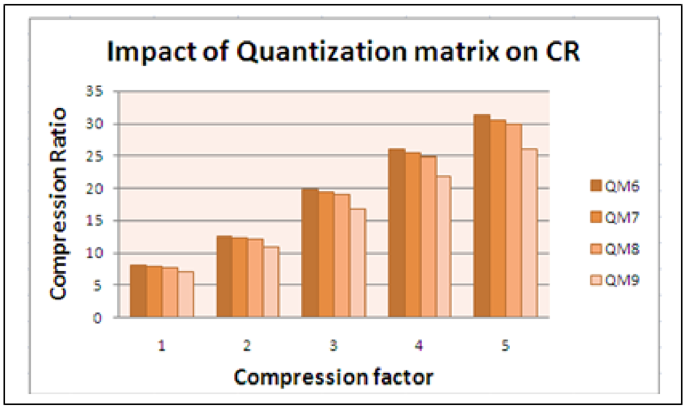

Fig.7: Impact of QM6-QM9 on compression ratio for image Cameraman

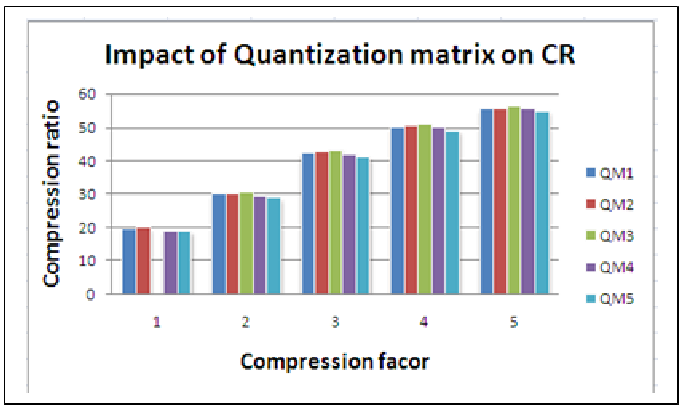

Fig.8: Impact of QM1-QM5 on compression ratio for image Moon

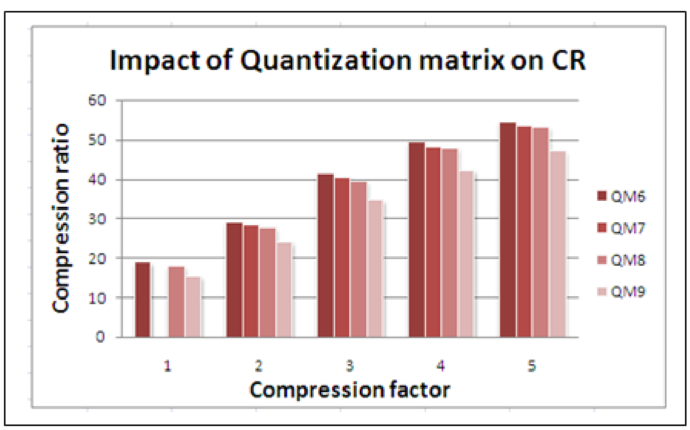

Fig.9: Impact of QM6-QM9 on compression ratio for image Moon

Impact of quantization matrix on compression ratio for image Cameraman is also studied according to Fig.6 and Fig.7 with different compression factors. Similarly another image

Moon was taken and compression ratio is computed considering the same set of quantization matrices. The results are shown in figures Fig. 8 and Fig.9. From the Fig.4 to Fig.9 it may be concluded that the compression ratio changes for the given compression factor when the quantization matrix changes. It may also be concluded that even though the compression factor, quantization matrix is same the compression ratio changes from one image to another image.

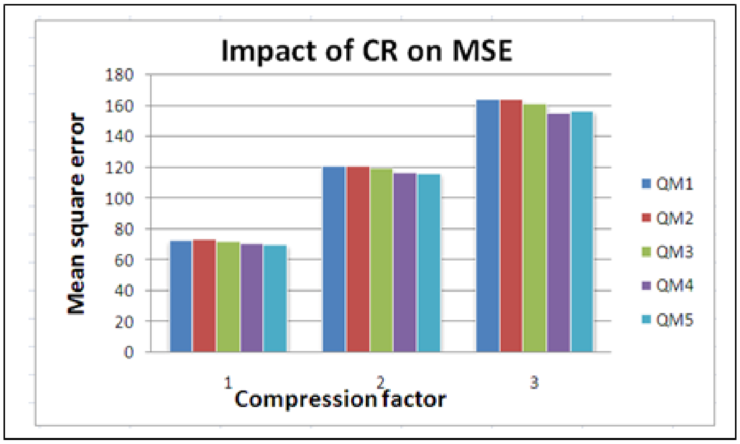

Fig.10: Impact of compression ratio on mean square error

Similarly the mean square error is also computed considering the same set of images, compression factors and same set of quantization matrices. Fig.10 shows the variation in the mean square error for different quantization matrix and for different compression factors. From Fig.10 it may be concluded that as the compression factor increases the mean square error also increases. The MSE varies for different quantization matrices, as well as for different compression factors. It is also observed that MSE varies for different images even though the compression factor and quantization matrix remain same. The impact of compression factor on the mean square error for the compression factor 1, 2 and 3 are considered for five different quantization matrices.

Mean square errors for all the compressed images considering the same set of compression factors, quantization matrices are also computed. Mean square error considering compression factor 1 for different quantization matrices for different images are shown in Fig. 11. From this figure it may be concluded that mean square error will change when the quantization matrix changes and also it may be concluded that MSE changes from image to image even though the quantization matrix remain same. In Fig.11 and Fig.12 X - axis indicates the quantization matrices.

Compression ratio for six different images keeping same set of quantization matrix and compression factor is studied and the results are shown in Fig.12. Even though quantization matrix remains same the compression ratio changes from image to image. From this Figure it may be concluded that as compression ratio varies from image to image even though the quantization matrix as well as compression ratio remains constant.

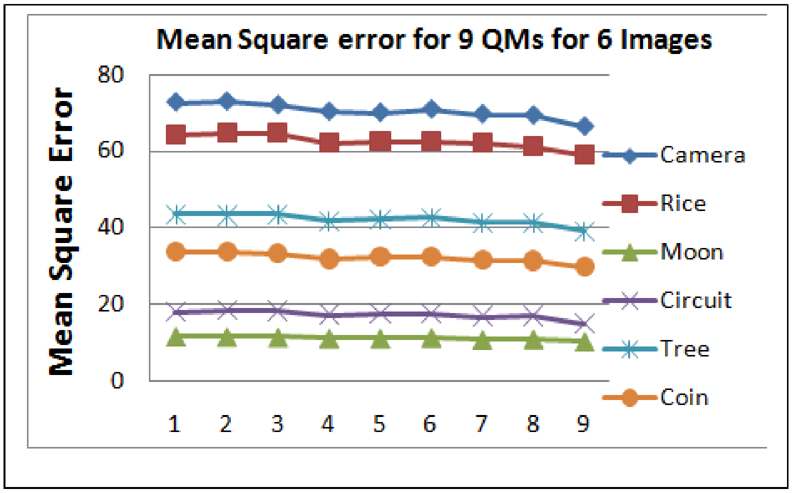

Fig.11: Impact of QM1-QM9 on Mean Square Error for all the 6 images

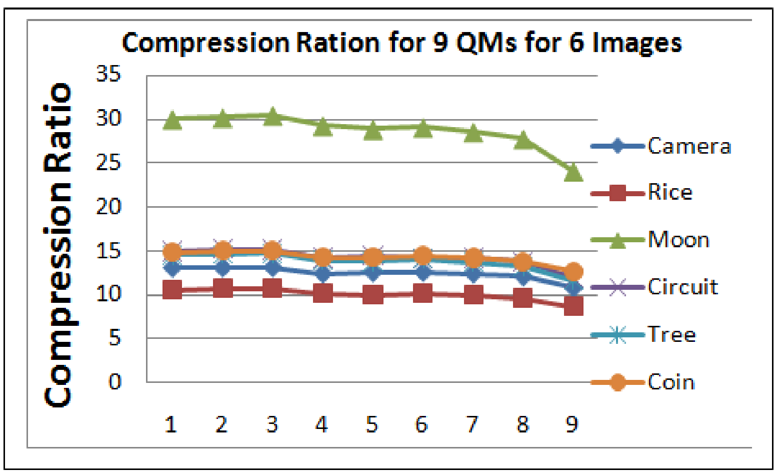

Fig.12: Impact of QM1-QM9 on Compression ratio for all the 6 images

Simulation is also carried out to find the PSNR and SNR for different images for different compression ratios as well as for different quantization matrices. Fig.13 shows the variation of PSNR for five different images for nine different quantization matrixes. From this figure it may be concluded that PSNR varies from image to image even though the quantization matrix as well as compression ratio remain same. Fig.14 shows the variation of SNR for five different images for nine different quantization matrixes. From this figure it may be concluded that SNR varies from image to image even though the quantization matrix as well as compression ratio remain same.

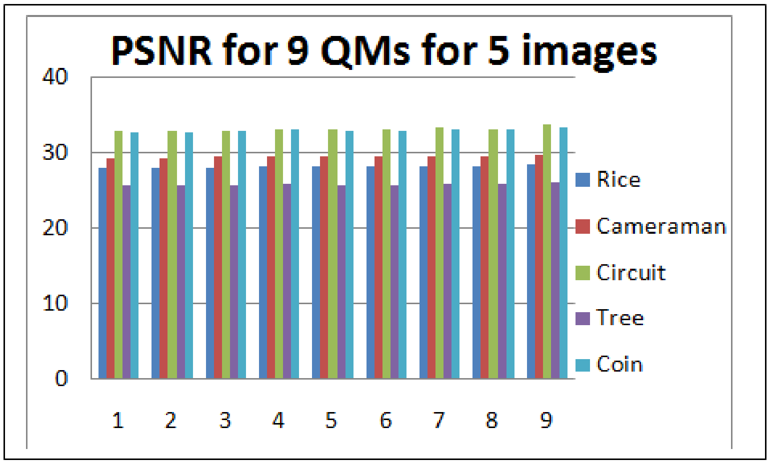

Fig.13: Impact of QM1-QM9 on PSNR for 5 images

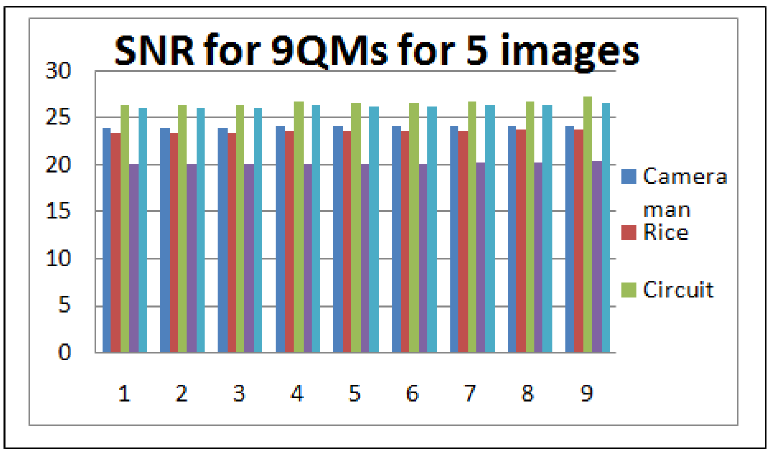

Fig.14: Impact of QM1-QM9 on SNR for 5 images

5. Conclusion

Performance analysis of the JPEG standard for the different class of image is studied for the standard quantization matrix. The impact of quantization matrix on the performance of JPEG is studied. From the results it may be concluded that compression ratio changes for the given compression factor when the quantization matrix changes. Even though the compression factor, quantization matrix is same the compression ratio changes from one image to another image. As the compression factor increases the mean square error also increases. The MSE varies for different quantization matrices, as well as for different compression factors. It is also observed that MSE varies for different images even though the compression factor and quantization matrix remain same. Mean square error will change when the quantization matrix changes and also it may be concluded that MSE changes from image to image even though the quantization matrix remains same. The compression ratio varies from image to image even though the quantization matrix as well as compression ratio remains constant. The PSNR varies from image to image even though the quantization matrix as well as compression ratio remain same. The SNR varies from image to image even though the quantization matrix as well as compression ratio remain same.

References

[1] William B. Pennebaker, Joan L. Mitchell, JPEG Still image Data Compression Standard, VNR, New York, 1993.

[2] ISO/IEC 10918-1, "Digital compression and coding of continuous-tone still images : Requirements and guidelines," Feb., 1994.

[3] Meng Xian-zhe, Niu Shao-zhang, ZOU Jian-chen, "Tamper Detection for Shifted Double JPEG Compression", 2010 Sixth International Conference on Intelligent Information Hiding and Multimedia Signal Processing DOI 10.1109/IIHMSP.2010.111

[4] Se-Kee Kil, Jong-Shill Lee, Dong-Fan Shen, Je-Goon Ryu, Eung-Hyuk Lee, Hong-Ki Min, Seung-Hong Hong "Lossless Medical Image Compression using Redundancy Analysis", IJCSNS International Journal of Computer Science and 50 Network Security, VOL.6 No.1A, January 2006

[5] Al-Saiegh, M.Y., Krishnan. S., "Fixed block-based lossless compression of digital mammograms", Electrical and Computer Engineering, 2001. Canadian Conference on, vol. 2, pp. 937-942, 2001.

[6] MEMON, N.D., and SAYOOD, K. " Lossless image compression: A comparative study", Proc. SPIE-Int. Soc. Opt. Eng., pp. 8-20, 1995.

[7] MEMON, N., and WU, X.L. "Recent developments in context-based predictive techniques for lossless image compression"

[8] Mario Konrad, Herbert Stögner, Andreas Uhl, "Evolutionary Optimization of JPEG Quantization Tables for Compressing Iris Polar Images in Iris Recognition Systems", Proceedings of the 6th International Symposium on Image and Signal Processing and Analysis (2009), 534-539

[9] Mitchell A. Golner, Wasfy B. Mikhael, Arun Ramaswamy and Venkatesh Krishnan, "Region Based Variable Quantization for JPEG Image Compression", Proc 43rd IEEE Midwest Symp on Circuits and Systems. Lansing MI, Aug 8-1 1, 2000.

[10] Zhigang Fan and Ricardo L. de Queiroz, "Identification of Bitmap Compression History: JPEG Detection and Quantizer Estimation", IEEE Transactions on Image Processing, VOL. 12, NO. 2, FEBRUARY 2003, 230-235.

[11] Chin-Chen Chang, Yeu-Pong Lai, "An Enhancement of JPEG Still Image Compression with Adaptive Linear Regression and Golomb-Rice coding", 2009 Ninth International Conference on Hybrid Intelligent Systems. 978-0-7695-3745-0/09 $25.00 © 2009 IEEE; DOI 10.1109/HIS.2009.220.

[12] Gregory K. Wallace, "The JPEG still picture compression standard", IEEE Transactions on Consumer Electronics, Vol. 38, No. 1, FEBRUARY 1992.

[13] Rick A. Vander Kam, Ping Wah Wong, "Customized JPEG Compression for Grayscale Printing", 1068-031U94 $3.00 0 1994 IEEE.

[14] SUNG-HSIEN SUN AND SHIE-JUE LEE, "A JPEG Chip for Image Compression and Decompression", Journal of VLSI Signal Processing 35, 43–60, 2003 Kluwer Academic Publishers. Manufactured in The Netherlands.

[15] Mario Konrad, Herbert Stögner, Andreas Uhl, "Evolutionary Optimization of JPEG Quantization Tables for Compressing Iris Polar Images in Iris Recognition Systems", Proceedings of the 6th International Symposium on Image and Signal Processing and Analysis (2009).

Acknowledgement

The authors wish to thank the authorities of SDMCET Dharwad, for facility extended to carry out the present work. Mr. S. V. Viraktamath wishes to thank Mr. S. S. Navalgund, Mr. S. A. Joshi and Mr. Mahendra M. Dixit of SDMCET for their support.

Authors

Mr. S. V. Viraktamath is with Shree Dharmasthala Manjunatheshwara College of Engineering and Technology Dharwad, Karnataka, India. He is serving as an Assistant Professor Sr. Grade in the Department of Electronics and Communication Engineering. He has rece ived a gold medal from VTU Belgaum for securing First rank in M. Tech (DC&N). He is the life member of IETE, IE and ISTE. He has served as a reviewer for many International conferences. He has been awarded as best teacher from SDMCET Dharwad. His research interests include Error control coding, Wireless communication and Networking.

Dr. G. V. Attimarad is with Dayanand Sagar College of Engineering Bangalore, Karnataka, India. He is serving as Professor in the Department of Electronics and Communication Engineering. His research interests are in the area of Waveguides and Wireless communications. He is guiding many research scholars. He has published many papers in reputed National and International journals. He is the Life Mem ber of IETE, IE and ISTE. He has served as a reviewer for many International conferences.