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A Literature Review on Quantization Table Design for the JPEG Baseline Algorithm

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Abstract: ***JPEG is widely used method for image compression. JPEG image compression involves a sequence of steps in which quantization process plays a major role in compression process. Quantization table decides the quality of the encoded image and also controls the amount by which image should be compressed (compression ratio). Hence generation of quantization table in the JPEG baseline algorithm is viewed as an optimization problem. For the past few decades, numerous researches have been conducted to generate optimal Quantization table for a given image and they are categorized as follows; Rate-distortion approach, Human Visual System approach and Meta-Heuristics approach. In this paper, an extensive survey is made on these methods to generate optimized quantization table for the JPEG baseline algorithm.***

Keywords: Image compression, JPEG, quantization table, optimization problem, Rate-distortion, Human Visual System, Meta-Heuristics.

1. Introduction

Image Compression is the process of reducing the amount of data required to represent an image. The image compression technique is the data compression process in which redundant bits are replaced by fewer bits. Redundancies, namely statistical and psychovisual are generally found in a digital image. Statistical redundancy further classified into spatial redundancy and the coding redundancy. Spatial redundancy occurs due to the similarity between the pixels and coding redundancy occur when the pixel values are represented using the fixed length binary coding. Psychovisual redundancy is based on the fact that low frequency signals are more sensitive to human eyes compared to high frequency signals.

The main goal of image compression is to reduce the size of image file by eliminating the redundancy so that the image can be efficiently stored and transmitted across network. Image compression techniques are broadly classified into Lossless and Lossy compression. In lossless compression no information is lost, when the image is compressed, the compressed image is similar to the original image.
Lossless compression technique is further classified as depicted in the Figure 1.

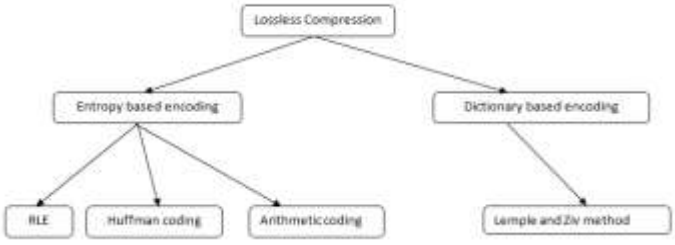


Figure 1: Classification of Lossless Compression

In lossy compression few information are lost and the decompressed image will not be similar to the original image but close to it. Higher compression ratio is achieved by using lossy compression technique when compared to lossless compression technique. . Lossy compression technique is further classified as depicted in the Figure 2 [2].

JPEG is widely used lossy compression technique. The sequence of steps involved in the JPEG image compression algorithm in which quantization process plays a major role in the image compression process. The Quantization table used in quantization process decides the quality of the encoded image and also controls the amount by which image should be compressed (compression ratio). The sequence of steps involved in the JPEG image compression [1] algorithm is depicted in Figure 3.

Figure 2: Classification of Lossy Compression

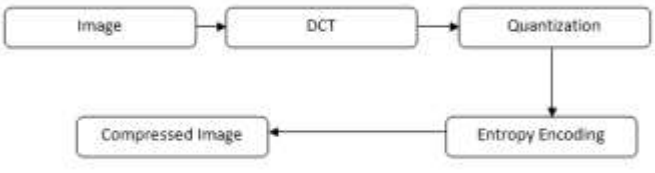


Figure 3: Sequence of steps involved in JPEG image compression algorithm

2. Related Work

The quality of the compressed image is determined by the quantization table used in the quantization process JPEG baseline algorithm. The approaches involved in the

quantization table optimization are broadly classified as shown in Figure 4.

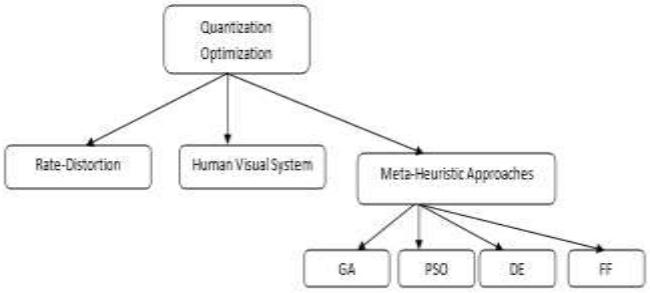


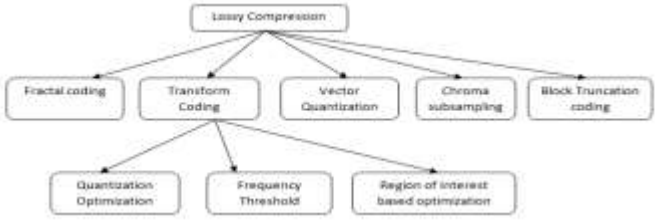
Figure 4: Different Approaches used to generate JPEG Quantization table.

2.1 Rate-Distortion Approach

Starting from a quantization table with large step sizes, which corresponds to low bit rate and high distortion; one entry of the quantization table are updated at a time so that at each step, the ratio of decrease in distortion to the increase in bit rate is approximately maximized.

The following steps are involved to generate the quantization table using Rate-distortion method,

1. Take a quantization table with large step sizes, which corresponds to high distortion and low bit rate.
2. Update an entry of quantization table at a time at each step.
3. So that bit rate increases and distortion decreases.
4. Step 2 and 3 is repeated until the desired bit rate is obtained.



Some of the papers which used Rate-distortion model to generate quantization table for the JPEG baseline algorithm are given below. In 1993, Siu-Wai-Wu and Allen Gersho [3] generated the quantization table by considering rate –distortion model. Until then, quantization table were generated empirically without considering rate-distortion trade off which resulted in suboptimal performance. By applying rate-distorting method to design the quantization table for black and white images the improvement in PSNR value is observed.

In 1994, Kannan Ramchandran and Martin Vetterli [4] formulated Rate-Distortion optimal strategy to threshold the quantized DCT coefficients with the help of fast recursive dynamic programming (DP) technique. 12-15% bit-rate compression improvement is seen by adopting this method and also optimal thresholding has been seen to be beneficial in low to medium bit-rate coding.

In 1995, Hei Tao Fung, Kevin J Parker [5] calculated entropy (amount of information which is needed to be coded by compression algorithm) instead of the bit rate. Because in order to obtain the bit rate of encoded image entire encoding process needed to be done. To reduce the computational complexity, entropy of quantized image is used. Moreover curve of bit rate versus entropy was empirically found to provide linear relationship. Advantage of using this method is that optimized table developed for the particular image can be used to other images with similar content. Disadvantage of this method is that depending on the initial quantization table taken, the final quantization table gets struck at different local minima.

In 2000, Viresh Ratnakar and Miron Livny [6] proposed R-D-OPT to design quantization table for the JPEG baseline algorithm which overcome the drawback of search strategy in paper[4]. The drawback of the search strategy in that paper is its computational complexity. For each quantization table tried, the entire compression-decompression steps is followed as a "black box." The main idea in RD-OPT is to evaluate quantization tables more efficiently, instead of following entire compression-decompression steps.

2.2 Human Visual System Approach

In Human Visual System, the optimum visual quality for a given bit rate is used as a guide to design the quantization table for the jpeg baseline algorithm. Thus the design of quantization table depends on the quantization errors that occur at various DCT frequencies. Two approaches have been used in Human Visual System, to generate the quantization table.

1. Image Independent Perceptual approach (IIP).
2. Image Dependent Perceptual approach (IDP)

Some of the papers which used Human Visual System model to generate quantization table for the JPEG baseline algorithm are given below. In 1991 and 1992 Peterson *et al.* [7][8] have suggested the threshold amplitudes measurements for DCT basis functions. They measured psychophysically for each frequency *ij*, and found out the smallest coefficient that provided a visible signal called threshold t_{ij}. All errors are invisible below the threshold t_{ij}. A quantization table was generated with respect to the threshold t_{ij} for a each frequency *ij*. Same threshold t_{ij} was considered to generate quantization table for different images, hence this approach is known as *Image-Independent Perceptual approach (IIP).*

The quantization table generated using Image-Independent Perceptual approach offers several drawbacks. Some of those are listed here, same threshold *tij* was considered to generate quantization table for different images, and this approach specifies that possibility of single error below threshold. But in reality there are many errors, of varying magnitudes will occur in typical image.

In 1993, Andrew B Watson [9] proposed *Image Dependent Perceptual approach* (IDP), which overcomes all drawbacks provided by Image Independent Perceptual approach (IIP). Andrew computed Perceptual Error Matrix which provide the perceptual threshold(also known as "just noticeable differences") for each frequencies, the quantization table can be generated based on the values in Perpetual Error Matrix. These image dependent quantization tables provide better results when compared to image independent quantization tables. For a given bit rate, this approach provides maximum visual quality.

In 1999, Ching-Yang Wang, Shiuh-Ming Lee, Long-Wen

Chang [10] incorporated human visual system model with a uniform quantizer, to derive a perceptual quantization table. The perceptual importance of the DCT coefficients is indicated by human visual frequency weighting matrix. Improvements in PSNR are achieved by using HVS-based quantization table instead of JPEG default quantization table. The quantization table generated using HVS-model does not add any complexity to the JPEG coder.

In 2011, Yuebing Jiang and Marios S. Pattichis [11] used perceptual image quality assessment to optimize the quantization table (QT) for JPEG compression. The PSNR was founded to be poor measure of perceptual image quality. Hence new measure called Structural Similarity Index (SSIM) has been used for evaluating performance. SSIM is used to evaluate distortion in the compressed images; hence the rate-SSIM curves has been generated instead of rate-distortion curves to determine the suitable quantization table for the given image. To generate globally optimal quantization tables, optimization algorithm called Simulated Annealing is used. The quantization table generated using perceptual image quality assessment generated better quality compressed image than that of image generated using standard quantization table.

In 2013, Nur Azman Abu, Ferda Ernawan and Nanna Suryana [12] investigated a psycho visual error threshold on the grayscale image at DCT frequency. The new quantization table was generated by setting the certain threshold to the psycho visual error. It has been found empirically that the quality of compressed image generated using the psychovisual error threshold is better compared to the quality of compressed image generated using standard JPEG quantization table at lower average bit length of Huffman code.

In 1997, W.C.Fong, S.C.Chan and K.L.Ho [13] used both Rate-distortion model and Human Visual System to generate the quantization table for the JPEG baseline algorithm. They improved Wu-Gersho's algorithm and a new bit allocation algorithm which used Rate-distortion approach to generate adaptive quantization tables. The proposed algorithm reduced the arithmetic complexity involved in Wu-Gersho's algorithm and a new bit allocation algorithm. To improve the visual quality of the compressed image, HVS is also incorporated along with the proposed algorithm. It is empirically found that proposed algorithm executed faster when compared to the Wu-Gersho's algorithm [2] in a same machine.

2.3 Meta-Heuristic Approach

The generation of quantization table for the JPEG baseline algorithm is viewed as the optimization problem. Most of the optimization problems were solved by applying meta-heuristic approach in recent years. Meta-heuristic approach mimics nature to provide optimal solution to the optimization problem. In recent years, most of paper involving Meta-Heuristic approach to generate quantization table for the JPEG baseline algorithm were published. Meta-heuristic approaches such as Genetic Algorithm, Particle Swarm Optimization, Differential Evolution, Firefly Algorithm are explained below.

Genetic Algorithm:

Genetic Algorithm (GA) was developed in 1970s by J. Holland, K. DeJong, D. Goldberg which is typically applied to discrete optimization. Some of the attributed features of genetic algorithm are: not too fast, good heuristic for combinatorial problems [14]. Some of the special feature of genetic algorithm is that it traditionally emphasizes combining information from good parents (crossover). Many variants of GA were proposed with slight modification of simple genetic algorithm.

Particle Swarm Optimization (PSO):

Individuals searching for solutions learn from the experiences of others. Some of the key features of PSO are: individuals learn from their neighbors, individuals that interact frequently become similar, individuals gain benefit by imitating their neighbors, and intelligence arises from interactions among individuals.

Differential Evolution (DE):

Differential Evolution was first proposed by Storn and Price to find the global optimal solution for the optimization problem. DE is a population based stochastic search technique that enhances a problem by iteratively trying to improve a candidate solution with respect to a given measure of quality.

Firefly Algorithm:

Firefly algorithm was developed in Cambridge University by Xin-She Yang, which is a nature-inspired meta-heuristic algorithm used to find optimal solution for the optimization problem. Firefly algorithm is based on the brightness of each firefly, which acts as the objective function to obtain the optimal solution. Firefly algorithm is inspired by the flashing characteristic of fireflies.

Some of the papers which used Meta-Heuristic approach to generate Quantization table for the JPEG baseline algorithm are given below. In 2004, Y.-G. Wu [15], used genetic algorithm (GA) to generate quantization table for JPEG baseline algorithm which produced higher compression performance for medical images. The goal was to generate quantization tables that provide better compression efficiency in terms of bit rate and decoded quality. During each iteration, genetic algorithm made use of unfitness function to eliminate unsuitable chromosome. Experiments were carried out with different medical images and found that the quantization table generated using GA-based search procedures produced better decoded image compared to that of quantization table generated using JPEG 2000 and standard JPEG baseline algorithm.

In 2005, Leonardo Faria Costa and Antônio Cláudio Paschoarelli Veiga [16] detected best JPEG Quantization for the given image using Genetic Algorithm (GA). Each chromosome in the initial population represents different quantization table. During each iteration, algorithm calculates the SNR value of each quantization table and selects the one that provide higher SNR value for the given image. The experimental results shows that the quantization table generated for bridge image using proposed genetic algorithm resulted a better quality compressed image compared to all other quantization table generated by other methods with the compression ratio of 32:1.

In 2009, Beatrice Lazzerini, Francesco Marcelloni, Massimo Vecchio [17] applied a two-objective evolutionary algorithm to generate a family of optimal quantization tables that produced different image compression and quality trade-off. One of the Multi Objective Evolutionary Algorithm called Non-dominated Sorting Genetic Algorithm II (NSGAII) is used to generate optimal quantization table for the JPEG baseline algorithm. The better quality compressed images were generated using the quantization table generated with the help of NSGA II algorithm and also provided better image compression and quality trade-off.

In 2009, Mario Konrad, Herbert Stögner and Andreas Uhl [18] incorporated genetic algorithm to generate JPEG quantization table to compress iris polar images in Iris recognition systems. The identified quantization tables performed significantly better as compared to the default JPEG quantization table in terms of average hamming distances and the ROC behavior. Even though lot of computation is involved in genetic algorithm, the quality of compressed image generated is better compared to compressed image generated using other methods.

In 2012, Huizhu Ma, Qiuju Zhang [19] proposed cultural-based multi-objective particle swarm optimization model to generate quantization tables for different images. The main objective of this paper is to generate quantization which provides the best image compression and quality trade-off. The proposed model solved image compression quality assessment problem. The cultural-based multi-objective particle swarm optimization model was incorporated in Lena image and better quality compressed image was generated.

In 2014, Milan Tuba and Nebojsa Bacanin [20] introduced firefly algorithm to determine the optimal quantization table for different image. Average pixel intensity distance between the original and compressed image was found to be 5.9 by using default JPEG quantization table whereas by using firefly algorithm to generate quantization table Average pixel intensity distance was reduced to 5.1 and quality of compressed image was better compared to compressed image generated by other methods.

In 2014, Vinoth Kumar Balasubramanian, Karpagam Manavalan [21] proposed Knowledge based genetic algorithm (KBGA) to find optimal quantization table. Image characteristics and knowledge about image compressibility are combined with Classical Genetic Algorithm (CGA) operators (initialization, selection, crossover and mutation) in KBGA. Over the default JPEG quantization table the proposed approach produced an average PSNR gain of 3.3% and average MSE gain of 20.6%. Better quality compressed image was generated by using KBGA approach compared to CGA with faster convergence rate.

In 2015, Vinoth Kumar Balasubramanian, Karpagam Manavalan [22] proposed Differential Evolution (DE) to find optimal quantization table. They carried out an extensive performance analysis between GA and DE, in addition it has been proved DE is an promising alternative to GA. A statistical hypothesis test (t-test) was performed to validate the above statement.

In 2015, Vinoth Kumar Balasubramanian, Karpagam Manavalan [23] proposed Knowledge based Differential Evolution (KBDE) to find optimal quantization table. Image characteristics and knowledge about image compressibility is combined with DE operators in order to improve the search capability and to obtain an optimal solution in the fast convergence rate.

In 2015, Vinoth Kumar Balasubramanian, Karpagam Manavalan [24] proposed a problem approximation surrogate model (PASM) to approximate the fitness value used in GA. The proposed approach reduces the computational time of GA without any loss in its performance.

3. Discussion

When rate distortion method is used to generate the image adaptive quantization table following results were observed in common; improvements in PSNR values, improvements in the perceptual quality of the compressed image and bit-rate compression improvements. Advantage of image adaptive quantization table generated using rate-distortion method is that optimized quantization table developed for the particular image can be used to other images with similar content. The major drawback of using rate-distortion method to generate JPEG quantization table is its computational complexity.

When Human Visual System approach is used to generate the image independent quantization table, same threshold was applied to all frequencies of different images, so the quality of encoded image thus obtained was found to be low.

Because of mentioned drawbacks, Human Visual System approach is used to generate the image dependent quantization table. Improvements in the PSNR value of the encoded image were observed by applying quantization table which is generated by Human Visual System approach. In most of the paper to design the image adaptive quantization table using Human Visual System approach following procedure was observed in common; First Error Matrix which provide the perceptual threshold (also known as "just noticeable differences") for each frequencies is generated and then quantization table can be designed based on the values in Error Matrix.

In all the Nature inspired algorithms, the following specific steps are in common. [25]

1. Initialization
2. Fitness function (Objective function)
3. Selection
4. Exploitation
5. Exploration

The first step of any meta-heuristics algorithm is the initialization of population. Initialization plays the crucial role in deciding the convergence speed and the quality of the obtained result. Each chromosome in the initial population represents different quantization table. Each value in the quantization table represents a gene. In general, each gene take a value from 0-511 [15] or 0-255 [21] and initial population found to contain 64 [21] to 100 [15] chromosomes. Most of the paper used random number generator to define chromosomes. In addition to it, some paper suggested to have one or more

default quantization tables in the initial population.

The fitness function is an objective function which is used to evaluate the survival probability of each chromosome. Several quality metrics are used as the fitness function. From all these references it is inferred quality metrics such as Compression ratio (CR), Peak Signal to Noise Ratio (PSNR), Signal to Noise Ratio (SNR), Mean Square Error (MSE), False Acceptance Rate (FAR) and False Rejection Rate (FRR) are used as the fitness function

Selection is a process of selecting best individuals from a population based on their fitness function. The selection methods like Roulette wheel selection, Tournament selection, Rank selection and Steady state selection are available in which Roulette wheel selection is widely employed.

Exploitation is used to identify parts with high quality solutions in the search space. To exploit promising areas in the search spaces the crossover operator is used. A Crossover is a recombination operator that exchange pieces of the genetic information of two parent chromosomes to produce new offspring that contains some good characteristics of both parents. Some of crossover techniques widely employed in genetic algorithm are single point crossover, Partially Mapped Crossover (PMX), cycle crossover and so on. Among which single point crossover is widely employed to generate the optimal quantization table.

The exploitation process in PSO is done with the help of the parameters r1 and c1 in the equation (1).

$$V_{i+1} = w* V_i + c_1 * r_1 * (pBest_i - X_i) + c_2* r_2 * (gBest_i - X_i) \quad (1)$$

In the reference [26] the parameter C1 in equation (1) is set to 1.49455 to get good balance between exploration and exploitation in PSO.

The paper [22] which used DE employed crossover in exploitation process. In firefly algorithm [19], the process of exploitation is based on parameters xj and xi in the equation (2) which represents the movement of the firefly.

$$X_i = X_i + \beta_o \, x \, e^{-\gamma r_{ij}^2} (x_j - x_i) + \alpha \, (rand - 1/2) \quad (2)$$

Exploration is the process of optimizing the promising areas which are found in exploitation process. To explore the promising areas in the search spaces the mutation operator is used. The main disadvantage of crossover is that the offspring will contain only the characteristics of parent; there is no possibility for an offspring to get characteristics other than that of parent. In order to provide additional characteristics to the offspring, mutation is performed. Some of the paper used bit-flipping method (replacing 1's to 0's and 0's to 1's) to explore.

The exploration process in PSO is done with the help of the parameters r2 and c2 in the equation (1). In the reference [26] the parameter c2 in equation (1) is set to 1.49455 to get good balance between exploration and exploitation in PSO.

In DE [21], the mutant vector is represented by V_i,G is generated from the randomly generated initialization process target vector $X_{r1,G}$ $X_{r2,G}$ $X_{r3,G}$ in equation (3)

$$V_{i,G} = X_{r1,G} + F(X_{r2,G} - X_{r3,G}) \quad (3)$$

Where, F is the scale factor $\in$ (0, 1+).

In firefly algorithm [19], the process of exploration is based on the parameter β0 in the equation (2) which specifies the movement of firefly. The value of β_0 is set to zero in many problems.

4. Conclusion

This paper provides detailed survey on various approaches used to generate the image adaptive quantization table for JPEG baseline algorithm. A detailed analysis is made on various methods such as rate-distortion approach, human visual system approach and meta-heuristics approach used to generate JPEG quantization table. Among the methods discussed here, the JPEG quantization table generated using nature inspired meta-heuristics provided the better quality compressed image. Meta-heuristics algorithms such as GA, DE, PSO and FA were used to generate JPEG quantization table. As a future scope, efforts can be taken to increase the convergence rate of meta-heuristic techniques.

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