An Efficient Image Compression Using Bit Allocation based on Psychovisual Threshold

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Abstract

One of the main part of image compression is a quantization process which give a significant effect to the compression performance. However, image compression based on the quantization produces blocking effect or artifact image. This research proposes a novel bit allocation strategy which assigning an optimal budget of bits in image compression. The bit allocation is proposed to replace the role of the quantization process in image compression. The principle of psychovisual threshold is adopted to develop bit allocation strategy in the image compression. This quantitative research measures the optimal bit of image signals and manages the image quality level. The experimental results show the efficiency of the proposed bit allocation strategy, and that the proposed bit allocation can achieve the almost same compression rate performance while can significantly produces high quality image texture. When compared to JPEG compression, the image compression using bit allocation achieves bit rate savings of up to 4%. The quality image output provides minimum errors of artifact image. The quality image reconstruction improvement is up to 14% and the error reconstruction is reduced by up to 37%.

Key Words: Bit allocation, Quantization table, Psychovisual threshold, Image compression

1. Introduction

An image requires large bits to store the image data, bits redundancy need to be exploited. In general, the bit allocation process is based on rate-distortion and aims to minimize the distortion subject to a constraint on the available bitrate [1]. Bit allocation provides a critical role in compression and it prescribes bit budget for a compressed file. The bit allocation algorithms perform to realize the target bit rates or quality levels (usually represented by quantization) for different regions [2]. In this paper, the author consider the bit allocation problem represented by quantization process in image compression. The quantization process under regular 8×8 block produces interchange block on the overall visual quality caused by sub-block image coding.

The bit allocation strategies have been studied extensively in image compression and video coding. The bit allocation strategies are more frequently implemented in ROI based coding [3], multi-view image coding [4]-[8], lossy image set compression [9] and video compression [10][11].

This paper proposes bit allocation strategy in image compression based on psychovisual threshold. The assigning bit on the image signals will influence to the quality of compressed image. The uniform bit will cause large quality deviation in image compression [2]. By assigning more bits on low frequency order and fewer bits on high frequency order, this strategy can keep the quality stability and avoid too serious degradation.

2. Psychovisual Threshold on 256×256 DCT

This research proposes bit allocation strategy based on psychovisual threshold to overcome artifact image in image compression. The psychovisual prescribes the noticeable difference of the compressed image from the original image at each frequency order [12]. The psychovisual threshold has been implemented on image processing application such as image watermarking [13] and image compression [14]-[21]. The psychovisual threshold on 256×256 DCT [12] for each frequency order on the grayscale image is shown in Fig. 1.

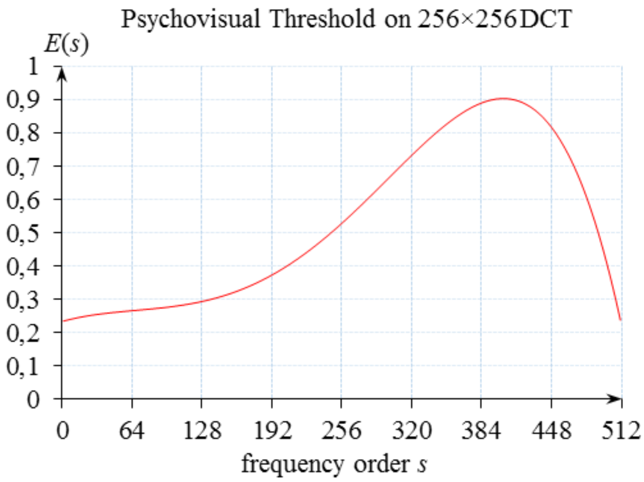

Fig. 1. Psychovisual error threshold on 256×256 DCT for 40 real grayscale images.

$E(s)$ represents the noticeable difference of compressed image from the original image by absolute reconstruction error (ARE) on each frequency order.

3. Experimental Setup

This experiment uses 80 RGB images to develop a set of bit allocation based on psychovisual threshold in image compression. Originally, the images have an image size of 512×512 raw image. First, an image is divided by 256×256 image block. Each block is transformed by two-dimensional Discrete Cosine Transform (DCT). The image signals on each regular block of 256×256 DCT are listed as a traversing array in a zigzag pattern. A linear array of image signals is divided into local block of 8 coefficients. Each local block of

8 coefficients is classified into peak signals and non-peak signals. The local peak signals are identified by finding a maximum of absolute local coefficients and the remains are the non-peak signals. The peak signals and non-peak signals are separately encoded.

The peak signals are rounded into integer values. While, the non-peak signals are masked by assigning bit allocation into an optimal bits for each local block. The directive to reduce bits of image signals will leave an effect on the image quality. The effect of assigning bit on image signals is measured by the reconstruction error per pixel. The assigning non-peak signals is increased by one bit at a time and the psychovisual threshold is set as a reference to the maximum reconstruction error for the effect of assigning bit allocation. The author proposes the assigning bit allocation on the non-peak signals as follows:

$$M = round\left(2^n\left(\frac{C(\mathrm{x})}{P}\right)\right) \tag{3.1}$$

M is the frequency masking, *x* is the local frequency block, *C* represents non-peak signals, *P* is the peak signal of local blocks and *n* represents the number of assigned bits. The inverse of non-peak coding is given as follows:

$$C(\mathrm{x}) = \left(\frac{M}{2^n}\right)P \tag{3.2}$$

M is masking result of frequency non-peak signals, *P* is the same local peak signal and *n* represents budget of bit on the local blocks. The decoded non-peak signals are closer towards the original image signals. The budget of bit allocation on each block based on psychovisual threshold 256×256 DCT is listed in Table 1.

Table 1. The budget of bit allocation for the local blocks of 8 coefficients on 256×256 DCT

Block No	Frequency Order	Bit
1	1-3	9
2-4	4-7	8
5-16	8-15	7
17-49	16-27	6
50-170	28-51	5
171-479	52-87	4
480-1097	88-131	3
1098-1831	132-170	2
1832-2977	171-217	1
2978-8191	218-507	0

The budget of bit image signals is investigated on the across frequency order. This bit budget on image signals can provide an optimal balance between image quality and compression rate. The peak image signals generalize extreme value of AC coefficients distribution. The extreme distributions of the peak AC coefficients are shown in Fig. 2.

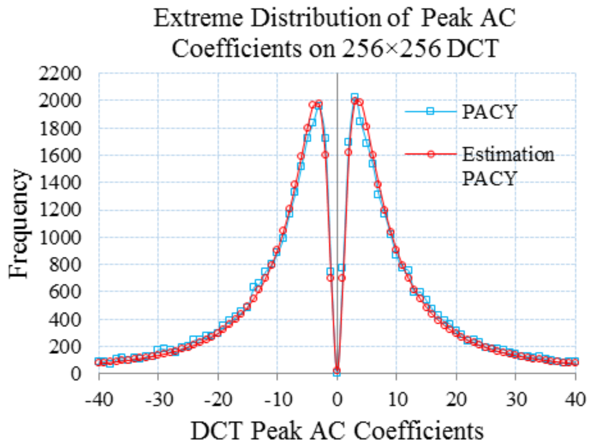

Fig. 2. The extreme distribution of peak AC coefficients for 40 real images.

Referring to Fig. 2, a red curve represents generalize of extreme distribution estimation at each frequency signal. These results are used to calculate the probability density function (pdf). For non-peak AC coefficients, the normal distribution is implemented to estimate the probability density function after assigning bit allocation. The use of the probability density functions is to make simplify computation in the encoding process. The Huffman tree does not perform repeatedly to compute the probability frequency distribution when the new input images come to be processed. The probability density function is utilized to estimate the probability distribution in Huffman coding rapidly. Three popular quality metrics, absolute reconstruction error (ARE), peak signal to noise ratio (PSNR) and structural similarity (SSIM) index are adopted in the experiment.

4. Experimental Results and Discussion

The comparison of the image quality from image compression using bit allocation and JPEG image compression are listed in Table 2. The average bit length of Huffman code on the peak and non-peak AC coefficients are listed in Table 3.

Table 2. The average image quality from image compression using bit allocation and JPEG compression for 40 real images and 40 graphical images

Method	Bit Allocation		JPEG Compression	
	40 real image	40 graphical image	40 real image	40 graphical image
ARE	2.7523	3.1761	4.3724	4.0503
PSNR	38.5525	38.936	33.0548	34.1590
SSIM	0.9865	0.9854	0.9803	0.9838

Table 3. The average bit length of Huffman code from image compression using bit allocation and JPEG compression for 40 real images and 40 graphical images

Method	Bit Allocation		JPEG Compression	
	40 real image	40 graphical image	40 real image	40 graphical image
DC Coefficients	16	16	5.7468	5.6722
AC Coefficients	2.7943	2.8314	2.8680	2.9653

Since there are only four DC coefficients under regular 256×256 DCT, they are maintained as the original DC coefficients. The DC coefficients do not give a significant effect to the average bit rate under regular 256×256 DCT, while they give most a crucial impact in the image quality. The maximum possible value on the DCT DC coefficient is coded as 16 bits. Therefore, the average bit length of DC coefficients as listed in Table 3 is estimated by 16 bits on each DC coefficient. Otherwise, JPEG image compression has 4096 DC coefficients under regular 8×8 DCT which give an effect to the average bit rate. The comparison of the proposed bit allocation and JPEG compression in terms of compression rate and total bit size is shown in Table 4.

Table 4. The average compression rate and total bit size from the compressed image using a set of bit allocation and JPEG quantization tables for 40 real images and 40 graphical images

Method	Bit Allocation		JPEG Compression	
	40 real image	40 graphical image	40 real image	40 graphical image
Compression rate	2.8628	2.8252	2.7463	2.6599
Total bit size	89.423 kb	90.611 kb	93.215 kb	96.244 kb

The implementation of bit allocation in image compression provides high image quality than JPEG compression. The proposed bit allocation strategy produces high image quality caused by the number of peak AC coefficients on low frequency order. The peak signals on low frequency order contains a most significant impact to the image quality. The sample Lena images is selected from 80 images in order to analyse the bit allocation strategy in image compression. The comparison of visual output from samples Lena image, JPEG compression and image compression using local bit allocation are shown in Fig. 3. In order to observe the visual quality, Lena right eye are zoomed in to 200% as depicted in Fig. 4.

(a) (b) (c) (d)

Fig. 3. The comparison of visual outputs among original Lena image (a), original Lena image cropped (b), 8×8 JPEG quantization table (c) and image compression using local bit allocation based on psychovisual threshold (d).

Fig. 4. The comparison of visual outputs between 8×8 JPEG quantization table (left) and image compression using local bit allocation (right) zoomed in to 200%.

The JPEG compression always produces artifact images and blur in image output when the visual image is zoomed in to 200%. The proposed bit allocation strategy is able to overcome the artifact image in the visual image output. The visual image quality produces significantly texture image and closely to the original Lena image.

5. Conclusion

This research has proposed the bit allocation strategy in image compression to overcome the artifact image. The bit allocation strategy has been designed to replace the main role of quantization process in image compression. A quantitative experiment has been conducted by measured the noticeable difference of compressed image from the original image based on budget of bit allocation. The proposed a set of bit allocation on the across frequency is believed that provides an optimal budget of bits in image signals and maintains the finer visual image quality. The experimental results show that bit allocation strategy in image compression produces higher visual image quality at a minimum bit rates than JPEG compression. The visual image quality produces rich texture image pixels and less artifact image than JPEG image compression.

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