World Academy of Science, Engineering and Technology
International Journal of Electrical and Computer Engineering
Vol:7, No:8, 2013

Perceptual JPEG Compliant Coding by Using DCT-Based Visibility Thresholds of Color Images

Kuo-Cheng Liu

Abstract**—**Effective estimation of just noticeable distortion (JND) for images is helpful to increase the efficiency of a compression algorithm in which both the statistical redundancy and the perceptual redundancy should be accurately removed. In this paper, we design a DCT-based model for estimating JND profiles of color images. Based on a mathematical model of measuring the base detection threshold for each DCT coefficient in the color component of color images, the luminance masking adjustment, the contrast masking adjustment, and the cross masking adjustment are utilized for luminance component, and the variance-based masking adjustment based on the coefficient variation in the block is proposed for chrominance components. In order to verify the proposed model, the JND estimator is incorporated into the conventional JPEG coder to improve the compression performance. A subjective and fair viewing test is designed to evaluate the visual quality of the coding image under the specified viewing condition. The simulation results show that the JPEG coder integrated with the proposed DCT-based JND model gives better coding bit rates at visually lossless quality for a variety of color images.

Keywords**—**Just-noticeable distortion (JND), discrete cosine transform (DCT), JPEG.

I. Introduction

EFFECTIVE exploitation of characteristics of human visual system (HVS) is beneficial to increase the performance of the image compression algorithms. For the growing demand for representing high-quality images when the resource of storage or transmission bandwidth is limited, image compression that is lossless or perceptually lossless to human visual perception is expected. Perceptual coding of digital images has long been recognized as a promising approach to achieve high-performance image compression.

When considering image quality as an important performance to be achieved, the image compression scheme taking into account the properties of the HVS is needed [1]-[12]. The goal of the perceptual image compression is to represent a digital image at the lowest possible bit rate without introducing perceivable distortion. To reach this goal, the perceptual coder has to remove not only statistical redundancy but also perceptual redundancy of images. Perceptual redundancy can be quantitatively measured as error detection thresholds or noise amplitudes of JND [1], by which signals are neither undercoded nor overcoded. In [2], the JND threshold for each coefficient in a given subband was estimated to set the quantization level in a DPCM quantizer by combining band sensitivities, background luminance, and texture masking. Lewis et al. [3] determined the quantization step size for each discrete wavelet transform (DWT) coefficient by exploiting sensitivities of the HVS to local noise. In [4] and [5], quantization matrices for the use in DCT-based compression were designed by exploiting visibility thresholds that are experimentally measured for quantization errors of the DCT coefficients. In [6], a JPEG compliant encoder utilizing perceptually based quantization was proposed to produce a perceptually equivalent image that has a higher compression ratio. In [7], the JND threshold determined by the dominant between the luminance masking due to average background luminance and the texture masking was incorporated to tune the step size of a uniform quantizer in the proposed subband image coder. In [8], a model of the HVS based on the wavelet transform is proposed. The model has a number of modifications that make it more amenable to potential integration into a wavelet based image compression scheme. In [9], the masking thresholds derived in a locally adaptive fashion based on subband decomposition were applied to the design of a locally adaptive perceptual quantization scheme for achieving high performance in terms of quality and bit rate. For the perceptual coding designed for color images, Yang et al. [10] proposed a nonlinear additive model to estimate the spatial JND profiles for color image processing. Nadenau et al. [11] presented the wavelet-based color image compression by exploiting the contrast sensitivity function (CSF). The method implements the CSF measure over spatial frequency of luminance and chrominance components into the task of noise spectrum shaping and achieves a visually optimal compression quality. In [12], [13], the approaches to perceptually increase the efficiency of image coders in compressing color images are presented with the perceptual redundancy estimated by the proposed color visual model.

Accurate estimation of the JND profiles of image signals is helpful to increase the efficiency of the image processing algorithm. However, most visual models mentioned above are developed for gray images or apply the luminance properties of the HVS to chrominance components of color image signals directly. Meanwhile, the visual models developed in the pixel domain cannot fully use the sensitivity of human perception for each frequency component. Thus, the DCT-based JND model for color images is investigated in this paper. It is developed to directly incorporate into the JPEG coding standard for better performance with the JPEG compliant coding syntax. Based on the base detection threshold of each DCT coefficient in each color component of color images, the model utilizes the luminance masking adjustment, the contrast

Kuo-Cheng Liu is with the Information Educating Center, Taiwan Hospitality & Tourism College, Taiwan (e-mail: kcliu@mail.tht.edu.tw).

masking adjustment, and cross masking adjustment for luminance component and uses the masking adjustment of considering coefficient variation in the block for chrominance components.

II. Proposed DCT-Based JND Model for Color Images

Based on the luminance-only detection model proposed by Ahumada and Peterson [14] for threshold measurements, the definition of the proposed JND model for color image in the DCT domain is expressed as

$$t_{\mathrm{O},JND}(c_{\mathrm{O},b,u,v}) = t_{\mathrm{O},base}(u,v) \cdot a_{\mathrm{O},m}(c_{\mathrm{O},b,u,v}), \quad \text{for O} = \text{Y, Cb, and Cr} \qquad (1)$$

$$a_{\mathrm{O},m}(c_{\mathrm{O},b,u,v}) = \begin{cases} a_{\mathrm{Y},l}(b)a_{\mathrm{Y},c}(c_{\mathrm{Y},b,u,v})a_{\mathrm{Y},cross}(c_{\mathrm{Y},b,u,v}), if\ O = Y \\ a_{\mathrm{Y},l}(b)a_{\mathrm{Cb},var}(c_{\mathrm{Cb},b,u,v}),\ if\ O = \mathrm{C_b} \\ a_{\mathrm{Y},l}(b)a_{\mathrm{Cr},var}(c_{\mathrm{Cr},b,u,v}),\ if\ O = \mathrm{C_r} \end{cases} \qquad (2)$$

where $t_{\mathrm{O},JND}(c_{\mathrm{O},b,u,v})$ is the JND value of the DCT coefficient $c_{\mathrm{O},b,u,v}$ at location (u,v) in the b-th block in the O (O=Y, $\mathrm{C_b}$, and $\mathrm{C_r}$) color component of the color image. $t_{\mathrm{O},base}(u,v)$ and $a_{\mathrm{O},m}(c_{\mathrm{O},b,u,v})$ are the corresponding base visibility threshold and the masking adjustment, respectively. The base visibility threshold is obtained by using the contrast sensitivity function (CSF) shown in Fig. 1. For luminance component Y, the masking adjustment is the product of the luminance masking adjustment $a_{\mathrm{Y},l}$, the contrast masking adjustment $a_{\mathrm{Y},c}$, and the cross masking adjustment $a_{\mathrm{Y},cross}$, respectively. The cross masking can be found in [18], [19]. For chrominance components Cb and Cr, the masking adjustments are the product of the luminance masking adjustment $a_{\mathrm{Y},l}$ and the variance-based masking adjustments $a_{\mathrm{Cb},var}$ and $a_{\mathrm{Cr},var}$, respectively.

III. Application to JPEG Coder

JPEG is an image compression standard developed by the ISO (International Standards Organization). The DCT-based coding standard can be used to compress an image with high or acceptable quality. Even though the JPEG working committee on JPEG has taken the HVS into consideration, and many approaches have been proposed to improve the visual quality of the compressed image [15], [17], [21], [22], only luminance signals are taken into account in most cases. To visually improve the performance of the JPEG coder, the perceptual redundancy inherent in chrominance signals should also be effectively used for shaping coding errors [16], [20]. We therefore utilize the proposed JND model is into the JPGE standard to verify its performance in this paper, while the coding syntax of the JPEG compression standard for color images is maintained. The functional block diagram of the proposed JPEG compliant coder for color images is shown in Fig. 2, where the standard JPEG coder is composed of the color transform of color images, image block partition, discrete cosine transform, quantization, and entropy coding.

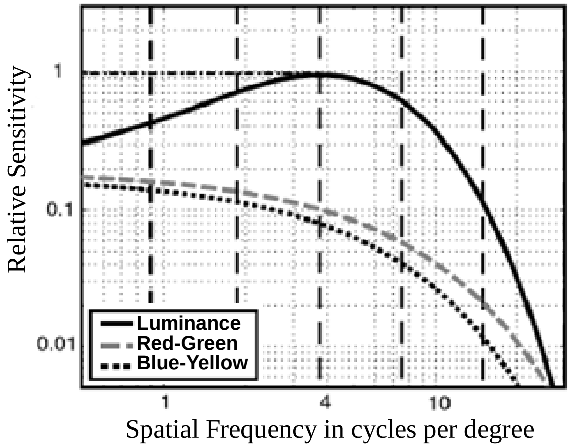

Fig. 1 Typical contrast sensitivity functions for luminance and chrominance channels [11]

The color JND estimator based on the model presented in Section II is used to preprocess the coefficients of the DCT block in each color component of the input color image for the improvement of the coding efficiency. The preprocessor is used to effectively diminish the dynamic range of the input signals such that the required bit rate is reduced for a given objective distortion of the reconstructed color image. The dynamic range of input signals we can reduce, the less objective distortion of the reconstructed color image for a given bit rate we can achieve. In order to shape the input signals for higher performance, the preprocessor utilizes the JND profiles to process the prediction error signals such that the dynamic range of the input signals can be reduced to achieve lower bit rate or better reconstructed image quality. Each input signal is adjusted by the preprocessor and is given by

$$\tilde{c}_{\mathrm{O},b,u,v} = \begin{cases} c_{\mathrm{O},b,u,v} + \tau_{\mathrm{O}} \cdot t_{\mathrm{O},JND}(c_{\mathrm{O},b,u,v}), \\ \text{if } c_{\mathrm{O},b,u,v} < -\tau_{\mathrm{O}} \cdot t_{\mathrm{O},JND}(c_{\mathrm{O},b,u,v}) \\ c_{\mathrm{O},b,u,v} - \tau_{\mathrm{O}} \cdot t_{\mathrm{O},JND}(c_{\mathrm{O},b,u,v}), \\ \text{elseif } c_{\mathrm{O},b,u,v} > \tau_{\mathrm{O}} \cdot t_{\mathrm{O},JND}(c_{\mathrm{O},b,u,v}) \\ c_{\mathrm{O},b,u,v},\ otherwise \end{cases} \qquad (3)$$

where $c_{\mathrm{O},b,u,v}$ and $\tilde{c}_{\mathrm{O},b,u,v}$ are the input signal and the preprocessed signal, respectively, at location (u,v) of the b-th block in the O color component of the color image in the DCT domain. τ_O is the parameter used to make a trade-off between the visual quality and the coding bit rate of the reconstructed color image for the color component O. The constraint of $\tau_O \in [0,1]$ is to avoid introducing the perceptual distortion into input signals in the JND-based preprocessor.

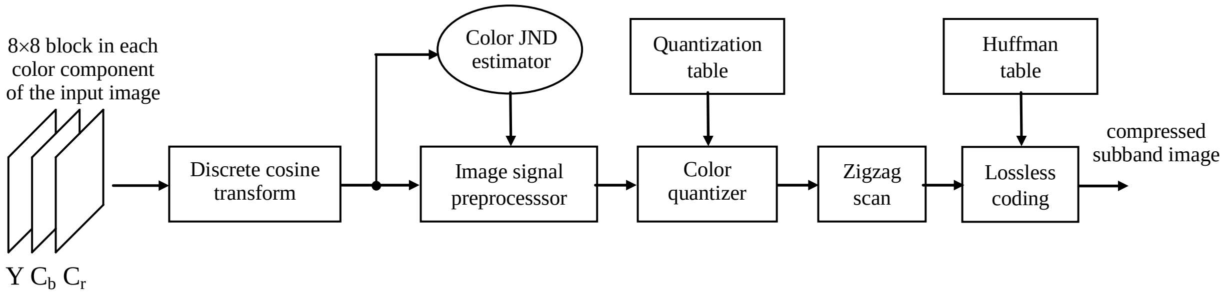

Fig. 2 Functional block diagram of the proposed JPEG compliant coder for color images

(a) (b) (c)

(d) (e) (f)

Fig. 3 Coding results of “Barbara” and “Lena” color images at visually lossless quality. (a) original “Barbara” color image, (b) coding “Barbara” color image (bit rate=0.41) by using the conventional JPEG coder, (c) coding “Barbara” color image (bit rate=0.29) by using the JPEG coder with the perceptually tuned preprocessor, (d) original “Lena” color image, (e) coding “Lena” color image (bit rate=0.36) by using the conventional JPEG coder, and (f) coding “Lena” color image (bit rate=0.24) by using the JPEG coder with the perceptually tuned preprocessor

IV. Simulation Results

To justify the validity of the proposed DCT-based JND model, the simulation of compressing the color images with the perceptually tuned JPEG coder proposed in Section 3 is conducted, where color pixels are represented in 24-bit RGB format. The performance in terms of bit rates of the compressed color image at nearly the same visual quality for various color images is inspected.

In the experiments, the subjective viewing tests based on the perceived quality have been conducted in the simulation. The pair images are composed of the original color image and its coding image. In each viewing test, the pair images are displayed side by side on the screen of the monitor, against which the subject observes the image in a dark room at a viewing distance of 6 times the image height, for evaluating the perceptual difference between the two images. The presentation order of the image pairs is randomized to obtain a fair evaluation. The coding results of “Barbara” color image (Fig. 3 (a)) at visually lossless quality are shown in Fig. 3, where the coding image (bit rate=0.41) by using the conventional JPEG coder is shown in Fig. 3 (b) and the coding image (bit rate=0.29) by using the JPEG coder with the perceptually tuned preprocessor is shown in Fig. 3 (c). The two perceptually lossless coding results are compressed at high quality factor of JPEG. It is observed that the bit rate required by the JPEG coder with the perceptually tuned preprocessor is less than that required by the conventional JPEG coder. The simulation results for various color images are demonstrates in Table I from which the validity of the proposed DCT-based JND model can be verified while it is utilized to preprocess the input color image of the JPEG coder.

TABLE I
BIT RATES COMPARED WITH THE CONVENTIONAL JPEG

	bit rate	
color images	JPEG	JPEG with preprocessor
Barbara	0.41	0.29
Lena	0.36	0.24
Goldhill	0.39	0.28
Zuerit	0.32	0.27

V. CONCLUSIONS

A DCT-based JND model for color images is proposed in this paper. The JND profiles of luminance and chrominance components of the color image in the DCT domain are successfully estimated. By incorporating the model into the JPEG coder, the better coding performance in terms of the lower bit rate at the visually lossless quality is given to justify the validity of the proposed DCT-based JND model.

ACKNOWLEDGMENT

The work was supported by the National Science Council, Taiwan (R.O.C.), under contract NSC101-2221-E-278-001, and Image & Video Processing Laboratory of Department of Computer Science and Information Engineering, National Dong Hwa University, Taiwan.

REFERENCES

[1] N. Jayant, J. Johnston, and R. Safranek, “Signal compression based on models of human perception,” *Proc. IEEE*, vol. 81, no. 10, pp. 1385-1422, Oct. 1993.

[2] R. J. Safranek and J. D. Johnston, “A perceptually tuned subband image coder with image dependent quantization and post-quantization data compression, ”in *Proc. IEEE Int. Conf. Acoust., Speech, Signal Processing*, vol. 3, May 1989, pp. 1945-1948.

[3] A. S. Lewis and G. Knowles, “Image compression using the 2-D wavelet transform,” *IEEE Trans. Image Processing*, vol. 1, no.2, pp. 244-250, Apr. 1992.

[4] H. A. Peterson, A. J. Ahumada, Jr., and A. B. Watson, “Improved detection model for DCT coefficient quantization,” in *Proc. SPIE Int. Conf. Human Version, Visual Processing, and Digital Display-IV*, vol. 1913, Feb. 1993, pp. 191-201.

[5] A. B. Watson, “DCT quantization matrices visually optimized for individual images,” in *Proc. SPIE Int. Conf. Human Version, Visual Processing, and Digital Display-IV*, vol. 1913, Feb. 1993, pp. 202-216.

[6] R. J. Safranek, “A JPEG compliant encoder utilizing perceptually based quantization,” in *Proc. SPIE Int. Conf Human Vision, Visual Processing, and Digital Display - V*, vol. 2179, Feb. 1994, pp. 117-126.

[7] C. H. Chou and Y. C. Li, “A perceptually tuned subband image coder based on the measure of just-noticeable-distortion profile,” *IEEE Trans. Circuits and Syst. Video Technol*, vol. 5, no. 6, pp. 467-476, Apr. 1995.

[8] A. P. Bradley, “A wavelet visible difference predictor,” *IEEE Trans. Image Process.*, vol. 8, no. 5, pp. 717–730, May 1999.

[9] I. Höntsch and L. J. Karam, “Locally adaptive perceptual image coding,” *IEEE Trans. Image Processing*, vol. 9, no. 9, pp. 1472-1483, Sep. 2000.

[10] X. K. Yang, W. S. Lin, Z. Lu, E. P. Ong, and S. Yao, “Just-noticeable-distortion profile with nonlinear additivity model for perceptual masking in color images,”in *Proc. IEEE Int. Conf. Acoustics, Speech, Signal Processing*, vol. 3, Apr. 2003, pp. 609-612.

[11] M. J. Nadenau, J. Reichel, and M. Kunt, “Wavelet-based color image compression: exploiting the contrast sensitivity function,” *IEEE Trans. Image Processing*, vol. 12, no. 1, pp. 58-70, Jan. 2003.

[12] C. H. Chou and K. C. Liu, "Colour image compression based on the measure of just noticeable colour difference," *IETImage Processing*, vol. 2, no. 6, pp.304-322, Dec. 2008.

[13] K. C. Liu, "Prediction error preprocessing for perceptual color image compression," *EURASIP Journal on Image and Video Processing*, vol. 1, no. 3, pp. 1-14, Mar. 2012.

[14] A. Ahumada and H. Peterson, “Luminance-model-based DCT quantization for color image compression,” in Proc. SPIE Human Vision, Visual Process., Digit. Display III, 1992, vol. 1666, pp. 365–374.

[15] K. N. Ngan, K. S. Leong, and H. Singh, “Adaptive cosine transform coding of images in perceptual domain,” IEEE Trans. Acoust., Speech, Signal Process., vol. 37, no. 11, pp. 1743–1750, Nov. 1989.

[16] K. T. Mullen, “The contrast sensitivity of human color vision tored–green and blue–yellow chromatic gratings,” *J. Phys.*, vol. 359, pp.381-400, Feb. 1985.

[17] A. B. Watson, “Perceptual optimization of DCT color quantization matrices,” in Proc. IEEE Int. Conf. Image Processing, Singapore, 1994, pp. 100-104.

[18] Y. Meng andL. Guo, “Color image coding by utilizing the crossed masking,” in Proc. IEEE Int. Conf. on Acoustics, Speech, and Signal Processing, Philadelphia, PA, USA, 2005, pp. 389-3 92.

[19] A. B. Watson and J. A.Solomon, “Model of visual contrast gain control and pattern masking,” J Opt Soc Am A, vol. 14, no. 9, pp. 2379-2391, 1997.

[20] Z. Wei and K. N. Ngan, “Spatio-temporal just noticeable distortion profile for grey scale image/video in DCT domain,” IEEE Transactions on Circuits and Systems for Video Technology, vol. 19, no. 3, pp. 337-346, 2009.

[21] R. Rosenholtz and A. B. Watson, "Perceptual adaptive JPEG coding," in Proc. IEEE Int. Conf. Image Processing, Lausanne, Switzerland, vol. I, 1996, pp. 901-904.

[22] I. Hontsch and L. J. Karam, “Adaptive image coding with perceptual distortion control,” IEEE Trans. Image Process., vol. 11, no. 3, pp. 213–222, Mar. 2002.

Kuo-Cheng Liu received the Ph.D. degrees from the Department of Electrical Engineering, Tatung University, Taipei, Taiwan, in 2009. In 1997, he joined the Department of Information Management, Taiwan Hospitality and Tourism College, Taiwan, as a Lecturer. He became an Assistant Professor in the Department of Information Management in 2005 and is currently an Associate Professor with the Information Educating Center. Since 2009, he was also involved in the research activities and projects of Image & Video Processing Laboratory (IVP Lab.) guided by Prof. Shinfeng D. Lin, Department of Computer Science and Information Engineering, National Dong-Hwa University in Taiwan. His research interests include image processing, perceptual coding of color images, multimedia signal processing, and digital watermarking.