Optik 126 (2015) 3135–3139

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Mammalian visual characteristics inspired perceptual image quantization using pulse-coupled neural networks

Songlin Du, Yi Huang, Jianlin Ma, Yide Ma*

School of Information Science and Engineering, Lanzhou University, Lanzhou 730000, China

ARTICLE INFO

Article history:
Received 11 June 2014
Accepted 14 July 2015

Keywords:
Image quantization
Mammalian visual characteristics (MVC)
Pulse-coupled neural network (PCNN)
Structural uncertainty

ABSTRACT

As a matter of fact, mammalian visual system do not pay an equivalent attention to different regions in an image, the visual cortex is less sensitive to textures than non-textures. Therefore, to obtain the optimal visual quality and the perfect compression ratio simultaneously in image quantization, textures should be quantized coarsely, and non-textures should be quantized finely. The pulse-coupled neural networks (PCNN) is a model of synchronous pulse bursts in mammalian visual cortex, which has been proved to be extremely effective in image processing because of its biological background. In this work, a mammalian visual characteristics inspired perceptual image quantization strategy is proposed. It employs PCNN to extract textures from original image. Then, pixels in textures are quantized into less gray scale layers than pixels in non-textures. After that, quantized textures and quantized non-textures are consolidated. Experimental results prove validity and efficiency of the proposed method.

1. Introduction

To achieve redundancy reduction in the transmission and storage of images, a large plenty of methods aiming at image compression have been published in recent years. Image coding and image quantization are two principal channels to achieve image compression [1]. Image coding is widely studied, such as the neural network employed image coding [2], wavelet transform based image coding [3], fractal theory based image coding [4], and the most famous JEPG2000 standard [5], etc. The alternative method to achieve image compression is using effective quantization schemes. Image quantization is a lossy compression technique achieved by compressing a range of values to a single quantum value, which is an important procedure in converting analog images to digital images. Unfortunately, as a matter of fact, most of the researches are focused on image coding, on the contrary, the importance of image quantization is apt to be overlooked.

1.1. Image quantization

Uniform quantization and non-uniform quantization are alternative methods of image quantization. Uniform quantizer quantizes all of the pixels in an image with the same step size, regardless of their respective properties. Quantization curve of the uniform quantizer is showed in Fig. 1(a), X_i and X_j are step sizes of the quantizer, they satisfy $X_i = X_j$ all the time. Uniform quantizer is easily to be implemented, but its capability is poor. By contrast, non-uniform quantization retains better performance, because it is able to take properties of pixels into consideration, namely, step sizes of a non-uniform quantizer depend on the properties of the corresponding pixels. Quantization curve of the non-uniform quantizer is showed in Fig. 1(b), X_i and X_j are also step sizes of the quantizer, but X_i and X_j are self-reliant, and the properties of the pixels are the sole determinant of the step sizes.

1.2. Mammalian visual characteristics and structural uncertainty of natural images

In most of the computer vision applications, the mammalian visual system, more specifically, the human visual system (HVS), acts as the end user of the signal chain. A large plenty of human visual characters oriented literatures aiming at image processing have been published. For example, Banks and Salapatek [6] measured the response of the human infant visual system to sine wave gratings of various spatial frequencies, and they obtained the contrast sensitivity function, which is an estimate of the spatial information available to the infant, Netravali and Prasada [7] attempted to apply the sensitivity of the HVS on luminance changes to the adapt image quantizer of a predictive coder. Wu and Sun [8] proposed an image compression scheme by introducing

* Corresponding author.
E-mail address: ydma@lzu.edu.cn (Y. Ma).

http://dx.doi.org/10.1016/j.ijleo.2015.07.072

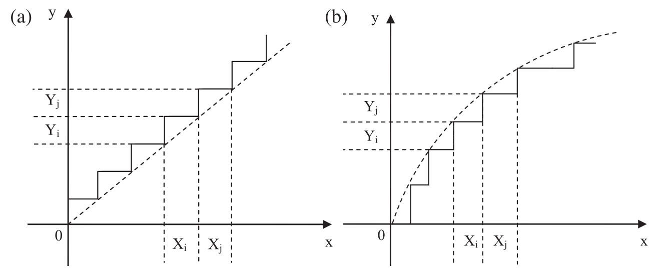

Fig. 1. Uniform quantization and non-uniform quantization curves. (a) Uniform quantization. (b) Non-uniform quantization. The horizontal axis denotes quantization step sizes, and the vertical axis denotes quantized values.

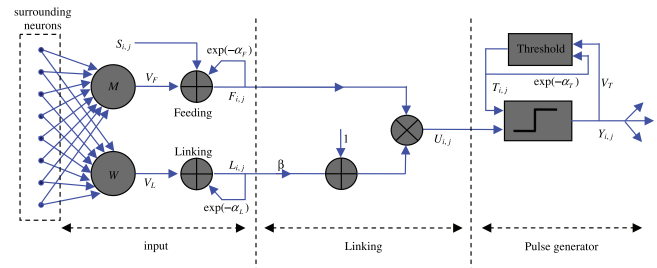

Fig. 3. Neuron model of the PCNN.

visual patterns to nonlinear interpolative vector quantization. Sreelekha and Sathidevi [9] also proposed a human visual system based adaptive quantization scheme, which supports perceptually lossless as well as lossy compression.

However, it is a pity that all of the previous works are based on the contrast sensitivity, in other words, luminance change is the key consideration in these works. Recent biological researches [10,11] indicate that the mammalian visual system is highly adaptive to extract orderly structures and tries to avoid disorderly structures in image perception and understanding. That is to say, mammalian visual system is less sensitive to disordered areas (e.g., textures in digital images) than ordered areas (e.g., uniform regions or non-textures in digital images). Two example images [12] are presented in Fig. 2. Contents of Fig. 2(a) are easily informed to viewers, because most of the areas in Fig. 2(a) are non-textures, mammalian visual system is good at capturing these non-textures. On the contrary, viewers are hard to understand the contents of Fig. 2(b), because most of the areas in Fig. 2(b) are textures, these textures are not easily to be noticed by mammalian visual system [13]. The reduction of perceptive redundancy in natural images is still an open problem, and the image structural uncertainty incited visual masking effect is of great potential in the application of image compression.

The pulse-coupled neural networks (PCNN) is a widely recognized model of the mammalian visual system, it was constructed to simulate synchronous pulse bursts in cat visual cortex. Actually, electrochemical dynamics of mammalian visual cortex neurons was firstly researched by Hodgkin and Huxley, they constructed a neuronal model in [14]. Eckhorn et al. [15,16] studied the cat visual cortex in 1890s, he found that the midbrain creates binary images in an oscillating way, which could extract different features from the visual impression, and an artificial neural network model (called Eckhorn's model) was constructed to simulate the neural behavior of cat visual cortex. Apart from Eckhorn, Rybak, et al. [17,18] studied the visual cortex of guinea pig, they found the similar neural behavior with Eckhorn. Then a similar artificial neural network

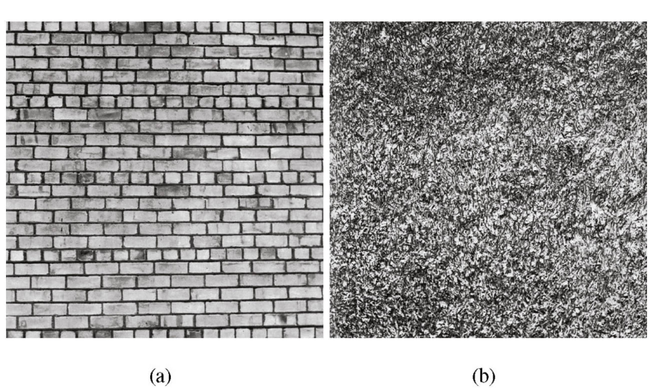

Fig. 2. Structural uncertainty of natural image. (a) Orderly structures. (b) Disorderly structures.

model (called Rybak's model) was also constructed to simulate neural activities in the visual cortex of guinea pig. Based on works of Eckhorn and Rybak, Johnson and Padgett [19] modified Eckhorn's and Rybak's models to make them more applicable in image processing. In the work of Johnson and Padgett, the PCNN was firstly proposed, and it has been proved to be extremely effective in image processing, because of its biological background.

1.3. *Our approach*

In this work, the PCNN is employed to extract textures and non-textures from original image. After that, quantizations are performed on textures and non-textures with different quantization precision to achieve the perfect compression ratio. The rest of this paper is organized as follows. In Section 2, model of the mammalian visual system is discussed, and the neuron model of the PCNN is briefly presented. The proposed perceptual image quantization algorithm is described in detail in Section 3. This will be followed by experiments and experimental results, as well as comparisons between the proposed method and the uniform quantization method, in Section 4. The conclusion follows in Section 5.

2. Pulse-coupled neural networks: a brief review

As mentioned above, PCNN is a widely recognized model of the mammalian visual system, and it has been proved to be extremely effective in image processing. Neuron model of the PCNN is illustrated in Fig. 3, it consists of three parts, i.e., input part, linking part, and pulse generator part [19,20]. The neuron receives information from input signal and neighborhood pixels through its input part, these two kinds of information are linked in its linking part, then its pulse generator part determines to generator an output pulse or not. Each of the pixels in a digital image correspondences to a neuron of the PCNN in the procedure of image processing, and the output pulses represent the processing result. The neuron model in Fig. 3 can be described as iteration by following equations quantitatively [19,20].

$$F_{i,j}[n] = e^{-\alpha_F} F_{i,j}[n-1] + V_F \sum_{k,l} w_{i,j,k,l} Y_{k,l}[n-1] + S_{i,j} \quad (1)$$

$$L_{i,j}[n] = e^{-\alpha_L} L_{i,j}[n-1] + V_L \sum_{k,l} m_{i,j,k,l} Y_{k,l}[n-1] \quad (2)$$

$$U_{i,j}[n] = F_{i,j}[n] \left(1 + \beta L_{i,j}[n]\right) \quad (3)$$

$$Y_{i,j}[n] = \begin{cases} 1, & U_{i,j}[n] > T_{i,j}[n] \\ 0, & \text{otherwise} \end{cases} \quad (4)$$

$$T_{i,j}[n] = e^{-\alpha_T} T_{i,j}[n-1] + V_T Y_{i,j}[n] \quad (5)$$

where the current neuron is located at the pixel (i, j), n is the iteration steps, $S_{i,j}$ is the input signal from current pixel. $F_{i,j}$ and $L_{i,j}$