

Method for Local Contrast Control in DCT Domain

DCT영역에서의 국부 Contrast 조절 기법

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Abstract

We implement the foveation and frequency sensitivity feature of human visual system in discrete cosine transform (DCT) domain. Resolution of human visual perception decays as distance from the eye-focused point, known as foveation property, and the middle frequency components give most pleasant image quality to human than the low and high frequency components, which is the frequency sensitivity property of human visual system. For satisfying the foveation property, we enhanced the local contrast at the focused regions and smoothed local contrast at the non-focused regions in the DCT domain without bringing the blocking and ringing artifacts. Moreover, the energies at each DCT frequency components is modified with various degree to fulfill the frequency sensitivity property. The proposed method is verified by the subjective and objective evaluations that it can improve the human perceptual visual quality.

1. Introduction

The photoreceptors, in the human eyes, sensing the color and lightness non-uniformly distributes over the retina. The highest density of their distribution is on the fovea aligned with the straight line from the center of eye, that is, visual axis. The photoreceptors density exponentially decreases with respect to the distance away from the fovea [1]. When human view a still image, the attention seems to spread over the whole image causes human eyes have enough time to scan over the whole image. Whereas, motion becomes the most stimuli for human attention in movies, thus human tends pay attention to small regions on the screen during watching movies. In other words, human visual system localizes and tracks some narrow regions on the screen due to the non-uniform distribution of photoreceptors in retina and limited spatial-temporal resolution capacity. Based on this characteristic of human eyes, the conventional foveation filters try to drop out the detail in the non-focused region without enhancing the focused region [2], [3] to archive the compression ration in video coding. The solution for video delivery in case of insufficient network bandwidth is priority video coding. The principle is that the important information gain higher priorities order encoding. One of trend to accomplish this mission is to exploit HVS in coding framework. Wang et al. proposed a foveated visual sensitivity weighting model in wavelet domain to classify the importance of the wavelet coefficients [2]. In [3], Itti uses low level image information such as color, intensity, motion, orientation to

automatically generate saliency map. Fixation point in image is corresponding to the high intensity region in saliency map, therefore, the most attractive region gain higher order coding (MPEG-1 and MPEG-4) than the less attractive regions. Another effort for simple generating saliency map in natural images using phase spectrum of Fourier transform was introduced in [4]. By using that saliency map, Guo and Zhang propose a multiresolution foveation model in Wavelet domain to perform priority coding in image and video compression. A foveation-based DCT domain inverse motion compensation video transcoder framework was proposed in [5]. Foveation helps to reduce the required bit rate of video transcoding to the receiver. However, this method depends on the accuracy of local bandwidth estimation, which can cause heavy distortion in their result.

From our viewpoint, a foveated image does not only contain low local contrast in the non-focused regions but also need high local contrast in the focused regions. This desire can be archived through the energy multiband scaling methods, which can control the local contrast efficiently. The distinction of the developed foveation filter is that it simultaneously performs smoothing and enhancing in different regions, whereas the existing foveation filters perform only smoothing. The proposed filter transfers the bandwidth saved in the smoothed regions to the enhanced regions more efficiently. The experiments confirm that the proposed method provides reliable perceptual quality improvements for various sequences and at various bandwidths.

The outline of the paper is organized as follows. In section 2, we show the typical method to control the local contrast. Section 3

elaborates our adaptive multiband energy scaling proposal. The performances of the developed method are discussed in section 4. Finally, the conclusion is given in section 5.

2. Revisit to multiband energy scaling

The goal of foveation filter is to maintain the high visual quality of the locally designated regions and suppress details of the surrounding regions. Thus, it is essential for a foveation filter to perform local processing. Due to ability of local processing and general usages for image processing, we are motivated to use DCT for realizing the foveation filter. The section addresses how the signal energy distribution in the DCT domain is related to the human visual system.

Let $f(i;j)$ be the pixel value at position $(i;j)$ of an $N \times N$ image block. Then, the DCT coefficient $F(u;v)$ at position $(u;v)$ of the corresponding image block is obtained such as

$$F(u,v) = C_u C_v \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} f(i,j) \cos \frac{(2i+1)u\pi}{2N} \cos \frac{(2j+1)v\pi}{2N}, \quad 0 \leq u,v \leq N-1 \quad (1)$$

where

$$C_p = \begin{cases} \sqrt{1/N} & \text{for } p=0 \\ \sqrt{2/N} & \text{o.w} \end{cases}$$

The collection of DCT coefficients at the same frequency band construct the diamond shape. Denote Ω_n ($0 \leq n \leq 2N+1$) as the vector of the DCT coefficients at the n^{th} frequency band. Then

$$\Omega_n = [F(0,n), \dots, F(u, n-u), \dots, F(n,0)] \quad (2)$$

$L(\Omega_n)$ denoting the number denoting the number of the DCT coefficients at Ω_n

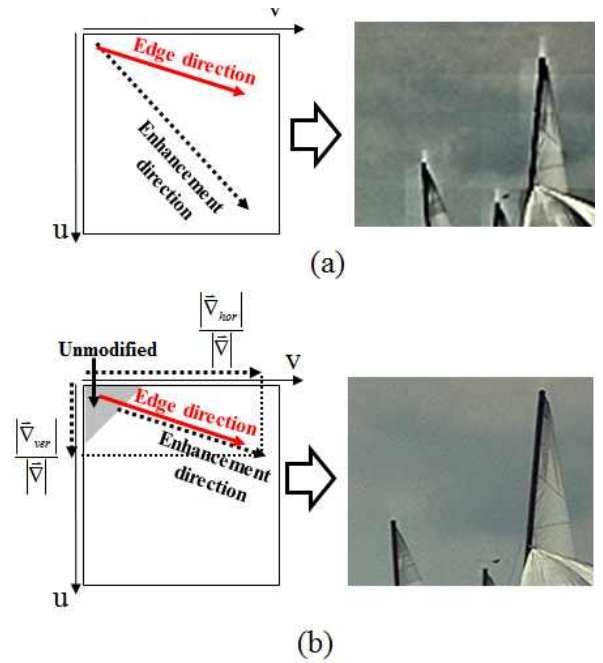
$$L(\Omega_n) = \begin{cases} n+1 & \text{for } 0 \leq n \leq (N-1) \\ 2N-n-1 & \text{for } N \leq n \leq (2N-1) \end{cases} \quad (3)$$

A typical method for enhancing the local contrast is the multiband energy scaling [6]. The method exploits the fact that HVS recognizes the local contrast by the energy accumulation ratio. In the method, the local contrast at the n^{th} frequency band is defined as the ratio of the n th band energy versus the average energy of lower frequency bands. The local contrast c_n , at the n^{th} frequency band, is measured as

$$c_n = \frac{\|\Omega_n\| / L(\Omega_n)}{\sum_{k=0}^{n-1} \|\Omega_k\| / L(\Omega_k)} \quad (4)$$

where $\|\cdot\|$ stands for L1 or L2 norm. The numerator is the energy of the n^{th} frequency band and the denominator is the average of

energies at whose frequency bands are lower than the n^{th} band. For enhancing the local contrast, the existing multiband energy scaling method increases the energy at the middle frequency bands through weighted factor greater than 1. Let $\overline{F}(u,v)$ and $\overline{\Omega}_n$ be the DCT coefficient of the modified local contrast and the set of those DCT coefficients at the n th frequency band, respectively. From (4), the modified and original local contrasts are related such as



$$\frac{\|\overline{\Omega}_n\| / L(\Omega_n)}{\sum_{k=0}^{n-1} \|\overline{\Omega}_k\| / (n+1)} = \lambda \frac{\|\Omega_n\| / L(\Omega_n)}{\sum_{k=0}^{n-1} \|\Omega_k\| / (n+1)} \quad (5)$$

Fig 1. Ringing and blocking artifacts caused by existing method enhancing local contrast. (a) The existing method and (b) Proposed method.

where λ is the energy weight factor. As becomes larger than 1, the local contrast is more enhanced. More explicitly,

$$\|\overline{\Omega}_n\| = \lambda \circ R_n \circ \|\Omega_n\| \quad (6)$$

where the energy variation ratio R_n is

$$R_n = \frac{\sum_{k=0}^{n-1} \|\overline{\Omega}_k\|}{\sum_{k=0}^{n-1} \|\Omega_k\|}$$

As seen in Eq.(6), the local contrast modified frequency bands are recursively calculated from the lower frequency bands with updates using the local energy variation ratio. Using L2-norm, the DCT coefficients of the modified contrast are driven from the original ones in following way:

$$\bar{F}(u, v) = \sqrt{\lambda} \cdot \sqrt{R_n} \cdot F(u, v) \text{ for } n = u + v \quad (7)$$

With enhancing the local contrast, the local image signals become more apparent against the overall luminance or the background. However, the existing method increases the local contrasts in all directions without considering the directions of the edge images. As a result, it may bring out overshooting in perpendicular direction to the edges and cause the ringing artifact around the edges. Also, the adjustment of the DCT coefficients at the frequency bands may cause the sudden variations in low frequency energies, which occurs the blocking artifacts making unnatural boundary lines between blocks. Fig. 1 shows the blocking and ringing artifacts caused by the existing multiband energy scaling method and the result of the proposed method.

3. Signal direction adaptive multiband energy scaling

In this section, we propose the new multiband energy scaling method that avoids both blocking and ringing artifacts and is able to enhance local contrast in the high visually stimulated regions and smooth the contrast in the regions with less visual stimuli, simultaneously. For reducing the ringing artifact, we devise a method estimating the gradients of underlying image signals and then enhance or smooth the local contrast in parallel with image signal directions. For avoiding the blocking artifact, we prevent the modification of signal energies at low frequency band. Finally, we control the energy weight factor for controlling the degree of enhancement and smoothness.

3.1 Block gradient

For estimating the gradient of the image signals directly from the DCT coefficients, we adopt the block gradient. The block gradient estimates the overall direction within a block. It is obtained from the variations of sums of half blocks. Previous works had reported the satisfactory accuracies of the block gradient [7]. The block gradient of a $N \times N$ block is calculated as

$$\vec{\nabla} = \nabla_{ver} \cdot \hat{i} + \nabla_{hor} \cdot \hat{j} \quad (8)$$

where the horizontal block gradient is

$$\nabla_{hor} = \frac{1}{N^2} \sum_{i=0}^{N-1} \sum_{j=0}^{N/2-1} [f(i, j) - f(i, N-j-1)]$$

and the vertical block gradient is

$$\nabla_{ver} = \frac{1}{N^2} \sum_{i=0}^{N/2-1} \sum_{j=0}^{N-1} [f(i, j) - f(N-i-1, j)]$$

The block gradient can be directly derived from DCT coefficients. The DCT coefficients at odd rows of the first column can be derived from Eq. (1):

$$\begin{aligned} & F(2l+1, 0) \\ &= \frac{\sqrt{2}}{N} \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} f(i, j) \cos \frac{(2i+1)(2j+1)\pi}{2N} \\ &= \frac{\sqrt{2}}{N} \sum_{i=0}^{N/2-1} \sum_{j=0}^{N-1} [f(i, j) - f(N-i-1, j)] \quad (9) \\ & \quad \cos \frac{(2i+1)(2l+1)\pi}{2N} \\ &= \frac{\sqrt{2}}{N} \sum_{i=0}^{N/2-1} X_i \cos \frac{(2i+1)(2l+1)\pi}{2N} \end{aligned}$$

where

$$X_i = \sum_{j=0}^{N-1} [f(i, j) - f(N-i-1, j)]$$

3.2 Signal gradient adaptive multiband energy scaling

Based on the block gradient, we optimally adjust the direction of the local contrast modification. We decompose the DCT frequency bands in the horizontal and vertical directions. Let Ω_u^{ver} and Ω_v^{hor} be the u^{th} vertical and v^{th} horizontal frequency bands, respectively. Then,

$$\begin{aligned} \Omega_u^{ver} &= [F(u, 0), F(u, 1), \dots, F(u, N-1)] \quad (10) \\ \Omega_v^{hor} &= [F(0, v), F(1, v), \dots, F(N-1, v)] \end{aligned}$$

Also, denote the local contrast modified u^{th} and v^{th} frequency bands to each direction as $\overline{\Omega_u^{ver}}$, $\overline{\Omega_v^{hor}}$, respectively. In similar way to Eq.(6),

$$\begin{aligned} \overline{\Omega_u^{ver}} &= \lambda \cdot R_u^{ver} \cdot \|\Omega_u^{ver}\| \quad (11) \\ \overline{\Omega_v^{hor}} &= \lambda \cdot R_v^{hor} \cdot \|\Omega_v^{hor}\| \end{aligned}$$

where the energy ratio are

$$R_u^{ver} = \frac{\sum_{l=0}^{u-1} \|\overline{\Omega_l^{ver}}\|}{\sum_{l=0}^{u-1} \|\Omega_l^{ver}\|}, R_v^{hor} = \frac{\sum_{l=0}^{v-1} \|\overline{\Omega_l^{hor}}\|}{\sum_{l=0}^{v-1} \|\Omega_l^{hor}\|}$$

From Eq.(7), the local contrast modified DCT coefficients for each direction becomes

$$\begin{aligned} \overline{F^{ver}}(u, v) &= \sqrt{\lambda} \cdot \sqrt{R_u^{ver}} \cdot F(u, v) \quad (13) \\ \overline{F^{hor}}(u, v) &= \sqrt{\lambda} \cdot \sqrt{R_v^{hor}} \cdot F(u, v) \end{aligned}$$

Then, we can set the directional local controlled DCT coefficient in such way as:

$$\bar{F}(u, v) = \gamma \cdot \overline{F^{ver}}(u, v) + (1 - \gamma) \cdot \overline{F^{hor}}(u, v) \quad (14)$$

where γ is the direction weight.

To avoid the blocking effect, we should prevent the modifications of the illuminance that is the overall brightness of a block. Since the energy at the low frequency bands controls the illuminance, we control the local contrast without modifying the components of which frequencies are lower than one third of the

highest frequency. Finally, the signal direction adaptive local contrast controlled DCT coefficient is set as

$$\overline{F}^{HVS}(u,v) = \begin{cases} F(u,v) & \text{for } u+v \leq \left\lfloor \frac{2N-1}{3} \right\rfloor \\ \overline{F}(u,v) & \text{otherwise.} \end{cases}$$



Sequences	Method	Bit rates (bps)		
		0.3M	0.5M	1M
Paris	Unprocessed	0.68	0.69	0.70
	Conv.	0.70	0.73	0.74
	Prop.	0.74	0.76	0.78
Silent	Unprocessed	0.48	0.52	0.57
	Conv.	0.52	0.57	0.63
	Prop.	0.58	0.63	0.69
Night(HD)	Unprocessed	0.43	0.44	0.47
	Conv.	0.46	0.47	0.50
	Prop.	0.48	0.49	0.53

Fig. 2. The "Paris" sequences (a) Original image, (b) Proposed method given the fixation point at the human faces..

Table I. The CPBD scores that presented scores of unprocessed, conventional and proposed method.

4. Experiments

In order to analyze how the proposed method affects the coding performance, we evaluate their decoded sequences by adopting H.264/AVC JM17.2 for the codec. Fig. 2 demonstrates the result of our proposal on the "Paris" sequences.

We compare three categories of decoded sequences: the sequences processed with the conventional foveation filter, the sequences processed with the proposed foveation filter, and the unprocessed sequences. We measure the CPBD [8] scores of each frame and take average of the scores. Table I shows the average CPBD scores. As seen in the table, the sequences processed by the proposed foveation filter produce the best scores. At the same bit rate, the CPBD scores of the proposed method are better by a minimum of 0.02 and a maximum of 0.07 than the CPBD scores of the conventional method.

5. Conclusion

We presented a video processing method that allows more advanced human perception-oriented video coding. The motivation

of this study is based on the observation that human perceptual visual quality is affected by the visual stimuli, the limited capacity of spatial-temporal resolution, and the non-uniform distribution of photoreceptors, collectively. The proposed foveation filter model for video coding was realized by updating the block gradient as signal direction. The devised foveation filter locally smoothen or enhances the video signals. Objective and subjective quality evaluations confirmed that the proposed method achieved reliable perceptual improvements for various sequences.

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