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A Perceptual Image Coding method of High Compression Rate

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Abstract**—**In the framework of the image compression by Wavelet Transforms, we propose a perceptual method by incorporating Human Visual System (HVS) characteristics in the quantization stage. Indeed, human eyes haven't an equal sensitivity across the frequency bandwidth. Therefore, the clarity of the reconstructed images can be improved by weighting the quantization according to the Contrast Sensitivity Function (CSF). The visual artifact at low bit rate is minimized. To evaluate our method, we use the Peak Signal to Noise Ratio (PSNR) and a new evaluating criteria witch takes into account visual criteria. The experimental results illustrate that our technique shows improvement on image quality at the same compression ratio.

Keywords**—**Contrast Sensitivity Function, Human Visual System, Image compression, Wavelet transforms.

I. INTRODUCTION

THE compression is an important area of research in image processing and has been widely studied in the last decades. Compression algorithms can restitute the exact information (Lossless methods) or introduce a little distortion (lossy methods). The lossless image compression is designed to reduce or remove the image's redundancy. They have weak compression ratio but benefit from an exact reconstruction of the image. The purpose of lossy image compression is to minimize the number of bits needed to represent an image without introducing an important degradation. Natural images have an important redundancy among the space-image pixels. A linear transformation is applied to minimize redundancy in the images since it can decorrelate pixel values in the transform domain. The international standard for still image compression, called Joint Photographic Experts Group or JPEG standard [1]-[2], uses the Discrete Cosine Transform (DCT) [3]-[4]. The JPEG2000 [5] uses The Discrete Wavelet Transforms (DWT). The quantization assigns to each transform coefficient a number of bits according to its position. This step is not conservative and attempts to reduce the number of samples. Finally, an entropy encoder codes theses samples [6]-[8]. The main objective of the image compression is to achieve the lowest bit rate without loss of the visual information. It implies a distinction between the visible and invisible information contained in an image. This distinction is done by the exploitation of a human visual model incorporated within the compressive process, precisely at the quantization stage. The key element of such a model is the Contrast Sensitivity Function (CSF). This Function describes the human visual sensitivity to different spatial frequencies by varying their contrast. Its curve shows essentially that the sensitivity of the visual system is reduced for structures of high spatial frequencies. The exploitation of the CSF at the quantization phase permits to select the truncation of the information contained in the image. In other words, the truncation affects intensively the spatial high frequency information and assures the visually important spatial frequency preservation. Therefore this approach permits to improve the visual quality of the compression significantly.

II. THE HVS CHARACTERISTICS AND IMAGE COMPRESSION

A. Presentation

The human visual system (HVS) reached during the evolution an important level of complexity. It is capable to execute several tasks that can't be achieved by the present technology. Nevertheless, it has some limitations concerning the visual perception. These minor imperfections don't make uncomfortable the vision. However these limitations can be exploited in image compression. One of the most important limitations of the HVS system concerns the sensitivity reduced for the spatial high frequency structures. This phenomenon is shown by the contrast sensitivity function (CSF).

B. The Contrast Sensitivity Function

The function of sensitivity to the contrasts, commonly called Contrast Sensitivity Function (CSF), describes the capacity of the human visual system to detect differences of luminance. The researchers studied the variation of the contrast sensitivity according to the different spatial frequencies. They are represented by a stimulus with a periodic structure formed of alternate strips. The gotten curve constitutes the contrast sensitivity function (CSF) of the examined person considering the conditions of the experimentation: shape of the stimulus, distance of vision,

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angle of vision, binocular or monocular vision, etc.

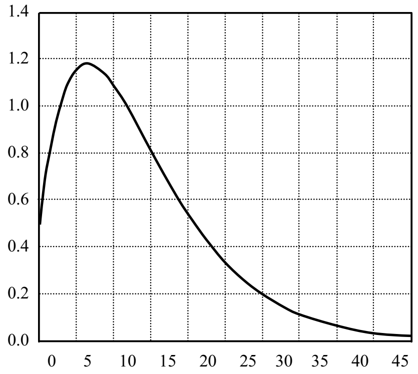


Fig. 1: The contrast sensitivity function

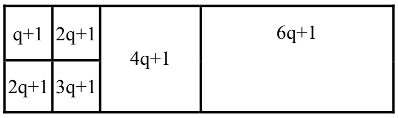
Studies have been led to find some analytic formulas close to the experimental results. Among the most known, we mention the formula of Mannos and Sakrison [9]. It is one of the first solutions and it is used in many studies.

$$CSF(f) = 2.6\,(0.0192 + 0.114f)\,e^{-(0.114f)^{1.1}} \qquad (1)$$

Other formulas have been proposed [10]-[11]. The most recent is the one of Ngan [12].

C. *Quantization and Contrast Sensitivity Function*

The compression by Discrete Wavelet Transforms (DWT) is accomplished with a quantization and an entropy encoder. Typically, one uses a constant quantifier implemented by a division of the wavelet coefficients by a constant factor Q. The result is approximated to the nearest integer [13]. The factor Q can be different for different intervals of frequency. It is then appropriate to speak of a quantization matrix to make reference to a set of factors. It corresponds to a particular matrix related to a level of decomposition. A matrix that illustrates the increasing quantization is given by the fig. 2. The integer q is the quantum chosen to determine the step of the quantization. The idea of this method consists to reduce the precision of the coefficients of the DWT while moving away of the region of low frequencies (coefficients of the approximation). Indeed, it is not necessary to maintain an important precision on the coefficients of high frequencies because these values are less relevant than the ones of low frequencies. Our aim is to define the terms of a new matrix of quantization by taking into account the HVS characteristics and particularly the Contrast Sensitivity Function. These terms have to increase while moving to the region of high frequencies.



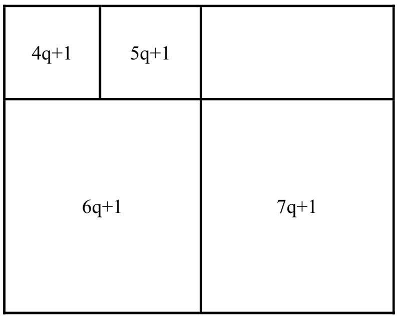


Fig. 2: The matrix of quantization

III. CSF BASED QUANTIZATION

To exploit the CSF in the process of the wavelet transform based quantization, we use the invariable unique weight. In other words, only one factor is affected for every wavelet subband. This factor remains constant during the whole phase of quantization. The set of these quantization factors is called CSF Quantifier. Fig. 3 illustrates the incorporation of the CSF Quantifier in the compression process.

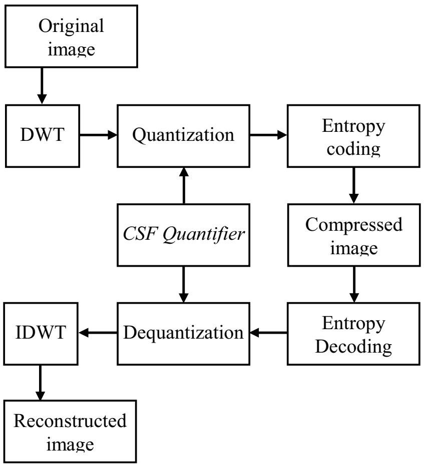


Fig. 3: The incorporation of the CSF Quantifier

IDWT is the inverse DWT. The advantages of this method reside in the simplicity of the determination of the quantization factors and the reduction of the computational time. The quantization factors are inversely proportional to the sensitivity average of the HVS on the frequency band related to each subband of the wavelet transform. Indeed, every subband of the wavelet transform occupies an interval on the spatial frequencies. Therefore, we compute the average of the CSF on every interval of the spatial frequency and we define the CSF quantifier factors as the inverses of these averages. Then they are normalized so that the smallest of these factors is equal to 1 (Fig. 4). On given one interval, more the CSF is raised, more its spatial frequencies are relevant and more the coefficient of quantization is low. For a wavelet decomposition of level 5, this method gives 6 CSF weights.

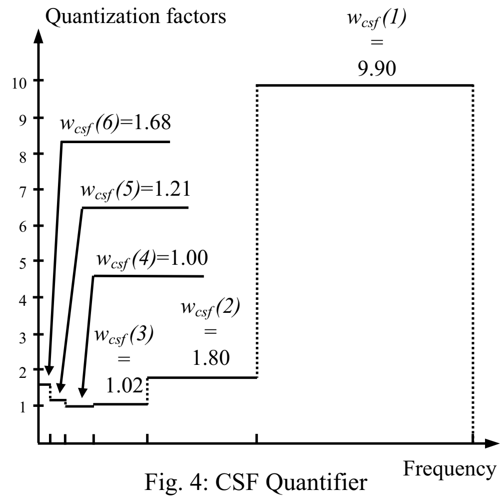


Fig. 4: CSF Quantifier

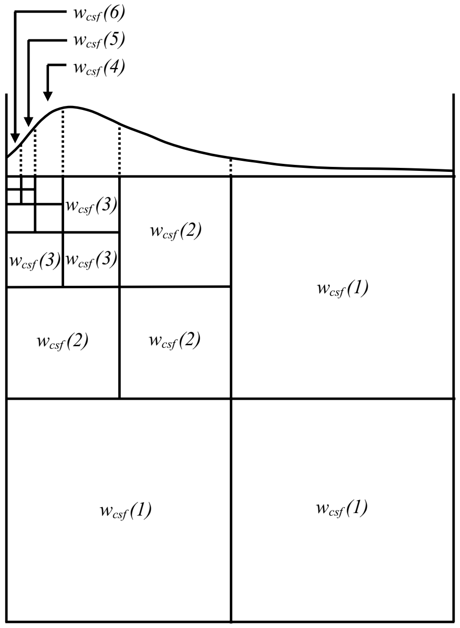


Fig. 5: The matrix of quantization

Let us define $w_{csf}(\lambda)$ as the CSF weight related to the level λ of the wavelet decomposition. Fig. 5 shows the new matrix of quantization where the details coefficients of level $\lambda \in \{1,2,3,4,5\}$ are pondered by the coefficients $w_{csf}(\lambda)$, and the approximation coefficients are pondered by the factor $w_{csf}(6)$. To optimize our method, we introduce two parameters in the CSF quantifier. The first is noted m. It multiplies the coefficients of the CSF quantifier to adjust the compression ratios. The second is a parameter that raises the coefficients of the CSF quantifier to a power noted p. The main interest of this factor is to increase the truncation of the coefficients corresponding to the high spatial frequencies. Indeed, the sensitivity of the SVH system is reduced for these frequencies. On the other hand, our method preserves the perceptible information. In fact, the coefficients of the CSF quantifier related to spatial frequencies of this perceptible information have a value very close to 1. Therefore, an elevation to the power of p nearly preserves the totality of the information after the phase of quantization. Let us define $\Omega_{csf}(\lambda)$ as the CSF weight $w_{csf}(\lambda)$ optimized by the parameters m and p. They are given by:

$$\Omega_{csf}(\lambda) = m.(w_{csf}(\lambda))^{p} \tag{2}$$

IV. IMAGE QUALITY ASSESSMENT

To evaluate our method, we use the Peak Signal to Noise Ratio *(PSNR)*, which is defined as:

$$PSNR = 10\log_{10}\left(\frac{(255)^2}{MSE}\right) \tag{3}$$

where *MSE* is the Mean Square Error:

$$MSE = \frac{1}{MN}\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}\left|x(m,n)-\hat{x}(m,n)\right|^2 \tag{4}$$

where M and N are the number of lines and columns of the image, $x(m,n)$ and $\hat{x}(m,n)$ are the pixels of the original and the processed image. However, the PSNR do not correlate well with subjective quality evaluation. In fact, the HVS is sensitive to the noise on the uniform zones. Its perception on the textured zones is more difficult. To take in account this characteristic of the HVS, we use the weighted PSNR *(wPSNR)* that use the local variance of the image to ponder the error:

$$wPSNR = 10\log_{10}\left(\frac{(255)^2}{wMSE}\right) \tag{5}$$

where

$$wMSE = \frac{1}{MN}\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}\left|\frac{x(m,n)-\hat{x}(m,n)}{1+var(m,n)}\right|^2 \tag{6}$$

V. RESULTS

We applied our method to four images: two medical images, Lena and Bird. The size of these images is of 256×256. We used the 5/3 wavelet of Le Gall. We compare the HVS quantifier and a conventional quantization by using the matrix shown in fig. 2.

(a) Image forearm

(b) Reconstructed image with perceptual method at 0.125 bits/pixel

(c) Reconstructed image with conventional method at 0.125 bits/pixel

(d) Image Lena

(e) Reconstructed image with perceptual method at 0.3 bits/pixel

(f) Reconstructed image with conventional method at 0.3 bits/pixel

Fig. 6: Original and reconstructed images

TABLE I
PERFORMANCE METRICS WITH THE HVS QUANTIFIER AND THE CONVENTIONAL QUANTIZATION

Images	bit rate	HVS quantifier		conventional quantization	
		PSNR	wPSNR	PSNR	wPSNR
shoulder	0.417	29.153	78.858	30.475	76.911
	0.142	29.153	78.586	28.606	75.529
	0.106	27.588	77.792	27.758	74.883
Forearm	0.274	32.466	70.524	30.457	65.95
	0.201	31.676	71 .28	29.752	65.960
	0.126	29.839	69.263	28.648	65.581
Lena	0.638	28.435	87.795	28.229	87.662
	0.418	26.765	86.365	26.598	85.673
	0.296	25.304	85.21	25.208	84.216
bird	0.450	33.964	83.927	31.098	80.838
	0.255	32.502	81.773	30.331	79.671
	0.155	30.428	79.228	29.00	78.853
	0.09	28.180	77.103	27.341	75 .461

Table 1 shows that the HVS quantifier performs better results than the conventional quantization. This is reasonable since the HVS quantifier allocates less bits to the wavelets coefficients related to the frequencies bands which are weakly perceptible. Subjective testing performed on the Forearm image and Lena image (Fig. 6) shows that the reconstructed images by using the perceptual method have a better quality. We notice that the reconstructed images by using the conventional method are blurred. Perceptual method preserves the edges better on the reconstructed images.

VI. CONCLUSION

A perceptual image coding method by using the wavelet transform was proposed in this paper. This method takes into account the characteristics of the Human Visual System (HVS) by incorporating the Contrast Sensitivity Function (CSF) in the quantization step. This function describes the capacity of the human visual system to detect differences of luminance according to the different spatial frequencies. To evaluate our method, we use the weighted Peak Signal to Noise Ratio (wPSNR) that uses the local variance of the image to ponder the error. The objectives results showed that the perceptual method outperforms the conventional method. The subjective testing showed that the perceptual method has a better quality.

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