SUBJECTIVE MEASURE OF EDGE DEGRADATION FOR VECTOR QUANTIZED COLOR IMAGES

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ABSTRACT

Edges are of fundamental importance in the analysis of images, and of course in the field of image quality. To incorporate the edge information as coded by the Human Visual System (HVS), we have developped a classification strategy to take into account edges in the codebook. Psychophysical experiments have been performed to adjust the optimal amount of edge information.

1 INTRODUCTION

The success of any product in the field of electronic imaging depends strongly on the judgments of end users, and these judgments will be more favorable if image compression has taken into account psychological and perceptual factors. Better results should be obtained if perceptual criteria are used to guide the allocation of resources [1].

Spatial Vector Quantization (VQ) is used to represent images by decomposing them into collections of symbols chosen from a finite set [2]. One of the main drawbacks of the VQ compression scheme is visible edge degradation that appears in the reconstructed images. This is due to the structure of the VQ which averages input vectors to define output vectors [3].

This paper deals with the problem of edge degradation from reconstructed VQ images. To prevent this phenomena, we have developped a technique to incorporate this information in the construction of the codebook using the LBG algorithm [4]. Thus, we have determined the optimal amount of edge information integrated in the codebook. Psychophysical observations allow us improve the edge quality.

2 EDGE INFORMATION INTEGRATION

Various options have been suggested to improve the edge quality of coding, using classification techniques. The final codebook is determined by separating edge and non-edge blocks before training [5].

A classification strategy of the initial training set $\mathcal{B}$ is used to construct the codebook. First, the edge map of the image is determined. Secondly, using this edge map, we classify the training set into two subsets: 1) the "egde block" set Θ_1 and 2) the "region block" set Θ_2. Then we apply the LBG algorithm on each set to construct the codebook.

2.1 Edge Detection Process

The technique defined by Cumani *et al.* is used to obtain an edge map of the color image [6]. In this algorithm contours are detected at different scales of resolution as the zero crossings of the second-order differential operator that represents an extension of the second directional derivative to the multispectral case. The resulting image is a binary edge image.

This method is efficient in edge detection for color images [7].

2.2 Training Set Classification

For each block from the edge image, we compute the proportion of pixels labelled as "edges" (whose value is equal to 1). If this proportion is greater than $\alpha\%$ of the block size, the corresponding block of the original image is then considered as an edge block. Otherwise, the block is considered as a region block.

2.3 Codebook Construction

For each set $(\Theta_i)_{i=\{1,2\}}$, we compute the two sets $(V_i)_{i=\{1,2\}}$ of ouput codewords using the standard LBG algorithm. The size of each set $(V_i)_{i=\{1,2\}}$ is defined by:

$$\mathrm{card}(V_i) = \frac{\mathrm{card}(\Theta_i)}{\mathrm{card}(\mathcal{B})}.\mathrm{card}(\mathcal{C}),\ \forall i \in [1,2]. \quad (1)$$

In fact, we compute for each set V_i, a number of output codewords proportionally to the cardinality of each set $(\Theta_i)_{i=\{1,2\}}$. Then, we obtain the final codebook $\mathcal{C}$ from these sets V_i as follows:

$$\mathcal{C} = V_1 \bigcup V_2. \quad (2)$$

3 EDGE PROPORTION ADJUSTMENT

These initial edge proportions are obtained using a classification strategy of the initial training set $\mathcal{B}$. Yet, this is not based on psychophysical properties. To incorporate the edge information related to the HVS, we used subjective measures to adjust the cardinality of the output codewords set V_1 from the "training set" Θ_1.

3.1 Experimental Environment

We investigated human sensitivity to edge degradation using a compression rate equal to 25:1. This level corresponds to medium quality images. At this compression rate, images are degraded enough to be distinguished from the original one.

During these subjective tests, images were displayed on an SUN CRT display driven by a CG14/SX graphics card with a spatial resolution of 1152 by 900 pixels and a color depth of 24 bits. All images displayed on the monitor were gamma corrected to avoid colorimetric deviations due to the non-linear response of the device.

Images used were mainly cartoons or synthetic images. Nevertheless, a natural image containing edge structures was included in the data set. Figure 1(a) represents an image with very simple edges. In Figure 1(b), we see simple edges too, but in a greater proportion than in Figure 1(a). In figure 1(c), we see many edge structures. Finally, in Figure 1(d), we see a great proportion of edge structures. Images in Figure 1 vary from a very simple edge structure to a complex edge structure.

3.2 Psychophysical measures of the quality

Psychophysical measures of quality let us define the sensitivity threshold of two image differences. This threshold characterizes the standard subject sensitivity. This sensitivity is performed using a psychophysical approach of performance measures based on detection theory.

To determine the sensitivity of the subject, we used the a forced-choice experiment [8]. This sensitivity measure is defined by the two probabilities $p(H)$ (Hit) and $p(CR)$ (Correct Rejection). This measure *d'* simply represents the distance between the mean of the distribution of the <first stimulus> and the <second stimulus> under the Gaussian distribution assumption of each stimulus.

Nevertheless, *d'* does not characterize the method but only the stimuli pair. Under the assumption of unbias responding, the sensitivity measure *d'* can be expressed as follows [8]:

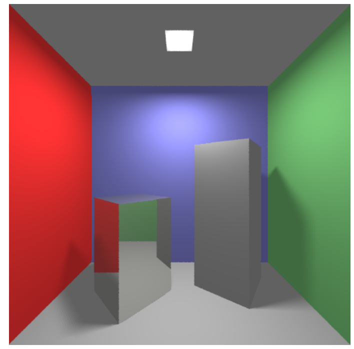
$$d' = 2z[\frac{1}{2}(1 + \sqrt{2p(c) - 1})], \quad (3)$$

where $p(c) = (p(\mathrm{H}) + p(\mathrm{CR}))/2$ and $z[.]$ is the inverse of the normal distribution function.

The differences between the two stimuli are imperceptible if d' is less than 0.5. Between 0.5 and 1.0, differences between the two stimuli are just noticeable. If d' is greater than 1.0, the two stimuli are more and more different.

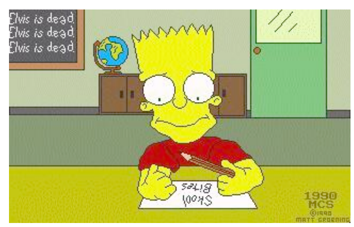
3.3 Psychophysical Experiments

Observers included several subjects who were naïve about the aims of the experiment and who have normal color vision.



(a) Synthetic image.

(b) Natural image.



(c) Cartoon image from SIMPSONS ©.

(d) Cartoon image from BLUEBERRY ©.

Figure 1. Some feature images containing many edge structures.

Observers evaluated pairs of reconstructed VQ images <VQ1,VQ2>. VQ1 represents the reconstructed image encoded using the proposed method with the cardinality of the set V_1 equal to x, whereas VQ2 is the image encoded using the proposed method with the cardinality of the set V_1 equal to $x + 0.1x$.

The question asked to the observers was: "Where is the best image in terms of quality ?". The two images were presented to each observer, with the first one placed randomly on the right in half of the presentations. 160 presentations of each pair were used to obtain a large number of responses and moreover to avoid bias responses. Using such a number, we obtain a more robust value of the observer's sensitivity.

3.4 Results

We evaluated first the initial amount of codewords issued from Θ_1 used to determine the codebook. Results are shown in Table 1.

Synthetic	House	Simpsons	Blueberry
0.1	0.21	0.32	0.58

Table 1. Results of the computation of the initial amount of codewords issued from Θ_1 of the used to determine the codebook for each image of Figure 1.

These initial amount of edge information has been computed using an α value equal to 20%. This value has been determined from some psychophysical evaluations of the edge aspect of the block. If this value is less than 20%, the amount of edge information is not relevant enough to characterize the edge aspect of the block. On the contrary, if this value is greater than 20%, we can forget blocks which contain enough pixels to characterize an edge block. As expected, one can note that results obtained in Table 1 correlate well with the complexity of associated images of Figure 1.

Stimuli	VQ2 on left	VQ2 on right
<VQ2,VQ1>	65	15
<VQ1,VQ2>	18	62

Table 2. Example of the response from a typical observer for a proportion of edge information associated to VQ1 equal to 32% and a proportion of edge information associated to VQ2 equal to 42% for the SIMPSONS© image.

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The sensitivity value obtained is about 1.1. This result can be interpreted as follows: observers could frequently distinguish the reconstructed image whose the proportion of edge information equal to 0.42 from the reconstructed one whose the proportion of edge information equal to 0.32; the first one is so preferred to the second one. Actually, the edges are best preserved in the first reconstructed image.

We calculate the observer's sensitivity for each pair of stimulus. Results of these calculations are shown in figure 2.

In Figure 2(c) we note that the proportion of edge information (equal to 0.32) is not sufficient for the HVS to be insensitive to edge degradation. The observer's sensitivity is equal to 1.11 when one compare the pair of reconstructed images defined by <0.32,0.42>, where 0.32 and 0.42 represent the proportion of amount of edge information used to encode the original image. This sensitivity is equal to 0.3 when the pair is defined by <0.42,0.52>. For the other pairs, the sensitivity increases (0.81 for the pair <0.52,0.62>; 1.69 for the pair <0.62,0.72>, 2.13 for the pair <0.72,0.82>). So, the best amount of edge information is obtained when the observer compare the quality of the pair of reconstructed images defined as the image obtained with a proportion of the amount of edge equal to 0.42 and the one using a proportion of the amount of edge equal to 0.52 (the sensitivity value is equal to 0.3). The minimum amount of edge information necessary to conserve the edge quality is 42%.

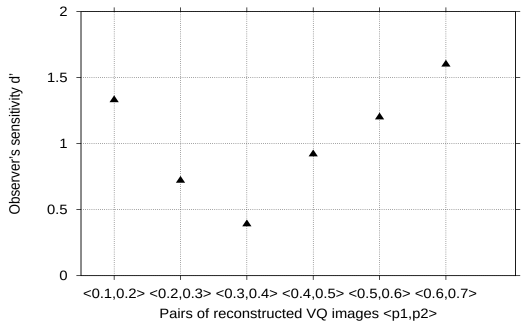
These remarks can be extended to Figure 2(a), 2(b) and 2(d). Actually, for Figure 2(d) the proportion of edge information determined to encode the original image is equal to 0.58. The associated sensitivity measure is equal to 1.37. For the pair <0.68,0.78>, the sensitivity reaches a value equal to 0.39. For the other pairs, this sensitivity value increases with the amount of edge information. For Figure 2(a), the sensitivity value reaches 0.39 when one compare the pair <0.3,0.4>. For Figure 2(b), the sensitivity value reaches 0.22 when one compare the pair <0.31,0.41>.

We note that the initial amount of edge information is never sufficient to judge that edges are not degraded, or rather quite enough conserved. Results of subjective tests indicate that human observers need a greater amount of edge information in the codebook to preserve edge quality. The additional amount is about 15-20 % more than the amount initially determined by the proposed method. Table 3 recapitulates the optimal amount of edge information needed to encode color images while preserving the edge quality.

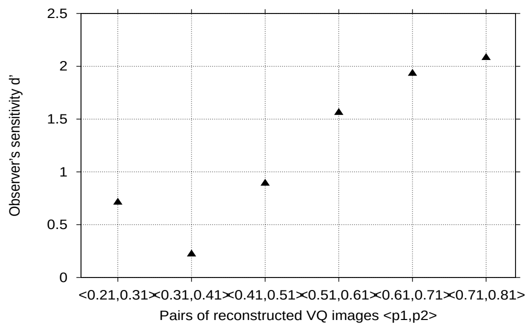
Synthetic	House	Simpsons	Blueberry
0.3	0.31	0.42	0.68

Table 3. Perceptual adjustment of edge information to encode color images while preserving the edge quality, for images of Figure 1.

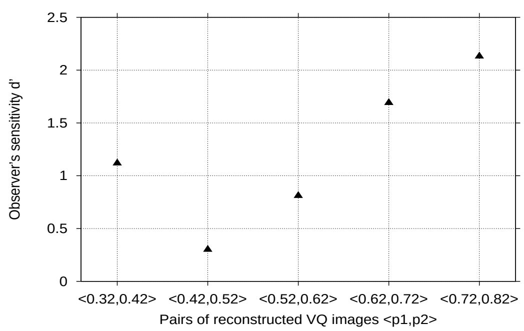
The degradation of the reconstructed image quality for important amount of edge information incorporated



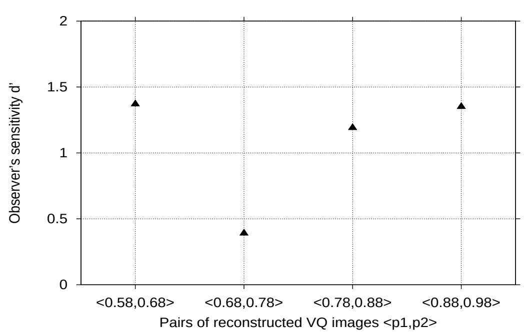
(a) Sensitivity evolution for the synthetic image.



(b) Sensitivity evolution for the natural image.



(c) Sensitivity evolution for the SIMPSONS© image.



(d) Sensitivity evolution for the BLUEBERRY© image.

Figure 2. Results of the observer's sensitivity evolution for each image of Figure 1

in the encoding scheme is due to the loss of color. Actually, the number of codewords determined from edge blocks increases, the number of codewords from region blocks decreases. In such a case, we favor edges at the expense of colors. Even if edge structure is preserved, the loss of color is too much important to keep a good image quality.

4 CONCLUSION

We have presented a procedure to prevent edge degradation during compression using the VQ scheme. We have characterized the evolution of perceptual edge degradation of reconstructed VQ images using psychophysical measurements. Results let us determine a function between "statistical" and "psychophysical" amounts of edge information. We have provided the minimum amount of edge information so that the degradation is imperceptible to the HVS.

Neurophysiologists have shown that neurons in the receptive field of area V1 in the primary visual cortex are orientation-selective. A possible extension of this work is to determine the degree of sensitivity of the HVS for each direction.

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