COLOR IMAGE ENHANCEMENT BASED ON PERCEPTUAL SHARPENING

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ABSTRACT

In this paper we present a sharpening operator for color images that is based on perceptual considerations about how human visual behaves for color scenes. Color contrast is an induction phenomenon of the visual system that varies the chromaticity of a color region depending on the color of its surround, provoking an enhanced perception of color scenes. This effect can be simulated by a sharpening operator based on a laplacian of gaussian filtering combined with an interpolation process. This operator presents interesting properties to remove noise in regions of similar color, to enhance edges without destroying region structures and not prevent the creation of false color edges.

keywords: *color contrast, perceptual sharpening, colour enhancement*

1. INTRODUCTION

Enhancement of digital color images is a current interest in color research. Traditional gray level enhancement techniques performed on each color channel of a given image do not assure a desirable result, since the dependency between color channels must be taken into account if we do not want to create false colored edges or break image structures. Some previous works have been devoted to color enhancement in the pursuit of different goals, such as, sharpening edges [1], maintaining flow-like structures [2], or removing image noise [3]. In this paper we present a color sharpening operator inspired in an induction phenomenon of the human visual system and we propose a color enhancement algorithm that tries to sharpen edges in a perceptual sense, blur noisy high frequencies and maintain region structures, all at the same time.

To this end, we have organized the paper as follows, firstly we introduce the color contrast phenomenon of the human visual system and the opponent-color representation as a suitable space to be the basis for induction mechanisms. Secondly, we present the perceptual sharpening as an edge enhancement process that combines color information in a perceptual sense. In section 4, we show some results on applying the perceptual sharpening to low-quality color images of natural scenes and we compare them to the same process performed by a popular digital image editor. Finally, we discuss these results and explain further open work.

2. COLOR CONTRAST

Before presenting the algorithm, let us introduce some ideas on color perception. Among the different color induction effects, we are interested in those involving changes in the perception of color. Color induction is a perceptual phenomenon that changes the color appearance of a stimulus due to the influence of the scene contents in the field of view. The surrounding color of a given stimulus is called the inductor [4]. Depending on the direction of the chromatic change provoked by the inductor, we can distinguish different types of color induction, and in this paper we will focus on chromatic contrast phenomenon.

Color contrast provokes a change in the perceived chromaticity of a stimulus moving it away from the chromaticity of the inductor in the immediate surround, and thus, helping us to better distinguish between areas of the scene with different color. In figure 2(a) we can see an image with a clear color contrast effect: the same stimulus appears as bluish when surrounded by yellowish region, on the right side, and it appears as yellowish when surrounded by blue, on the left side. This color contrast effect has its equivalent for achromatic stimuli, usually known as simultaneous contrast.

This effect can be seen as an interesting way to enhance color image regions. Defining a computational operator that simulates color contrast will provide a color enhanced representation of a digital image in a perceptual sense. For this purpose we will consider some conclusions derived from psychophysical works [5, 6] that suggest the induction mechanism that tries to simulate the influences between color

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and pattern of a perceived surface is a two step process: a color transformation to a new coordinate space that is independent of the image content, followed by the change on color information provoked by the induction effects that is computed separately on each color channel.

The best correspondence of the derived data is given by the opponent-color transformation. Color opponency process was firstly described by Hering in 1878, who made some interesting observations about some pairs of colors one never sees together at the same place and at the same time. While we are able to see a reddish or a yellowish orange, and a bluish or a greenish cyan, we can never observe a greenish red or a bluish yellow neither the opposite. These two hue pairs, red-green and blue-yellow are called opponent colors. From this observation Hering hypothesized the existence of a unique visual pathway to encode red and green, and a unique visual pathway to encode blue and yellow. The same hypothesis was done for a visual pathway encoding achromatic black and white signals. This allows to formulate a neural representation of colors. This opponent model schema can be derived from Hurvich and Jameson measurements [7].

A usual procedure to get color opponent representation of color digital images is given by a linear transformation of the RGB pixel representation, we will use a normalised version of the transform used in [8], this is

$$\begin{pmatrix} O_1 \\ O_2 \\ O_3 \end{pmatrix} = \begin{pmatrix} \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{6}} \\ \frac{1}{\sqrt{3}} & \frac{-1}{\sqrt{2}} & \frac{1}{\sqrt{6}} \\ \frac{1}{\sqrt{3}} & 0 & \frac{-2}{\sqrt{6}} \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix} \quad (1)$$

where the first dimension, O_1, represents the intensity or dark-white channel, the second, O_2, represents the red-green chromaticity channel and the third, O_3 represents the yellow-blue chromaticity channel. We denote as $Opp(I)$ the linear transform of all the pixels of the image I with equation 1.

3. A PERCEPTUAL SHARPENING

As we have already explained in previous section, color contrast induction moves chromaticities of regions with spatial low frequency, away from the chromaticity of its surround. In this section we define a computational operator that simulates this effect: it has to enhance differences in the transitions among colors of regions presenting low frequencies. It seems quite natural that the contrast effect will have to be achieved by a sharpening operator. A detailed discussion of different color sharpening operators can be found in [9].

To this purpose we will define a new color operator, taking as a basis one of the most common sharpening operators, that is

$$S(I,\gamma,\sigma) = (S_R, S_G, S_B) \;\; where \;\; S_c = I_c - \gamma LoG_\sigma(I_c), \quad (2)$$

where I_c is the c–th channel of a colour image I, usually given by a RGB representation, γ is a constant controlling the amount of the enhancement and $LoG_\sigma(I_c)$ is the laplacian of the image I_c blurred with a gaussian, that is, convolved with the function

$$\nabla^2 G_\sigma = -\frac{1}{\pi\sigma^4}\left[1 - \frac{x^2+y^2}{2\sigma^2}\right] e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (3)$$

Considering the conclusions on pattern-colour separability presented in [5] an inductor operator should act on an opponent-colour space. Then, an inductor operator that implements chromatic contrast, and that we will call perceptual sharpening, is defined by

$$PSharp(I)^{\vec{\sigma}}_{\vec{\gamma}} = RGB(S(Opp(I), \vec{\gamma}, \vec{\sigma})), \quad (4)$$

being S a sharpening operator that applies to each channel of the image, with parameters γ_i and σ_i, where i is the channel number, with a similar meaning to that defined in eq. 2.

Based on the classical sharpening defined by S, and taking into account the considerations about simultaneous contrast done in the work of Grossberg [10], we propose a sharpening that will allow to simulate chromatic contrast induction. We will use the fact that the Laplacian indicates the edge location by a zero crossing, i.e: a change between positive an negative response or vice versa. Lets call $Z(I_c)$ the binary image having 1 at those points where there is a zero-cross in the image I_c. The idea is to scatter the intensity of inhibition/activation in the points where there is a transition between two different colour areas. We can compute the local inhibition or activation of an image by taking the values of LoG on the points in $Z(I_c)$.

The following step is to build a surface where the value in a certain point indicates its level of activation, using the activation level of the points in $Z(I_c)$.

Let us call $\mathcal{I}(X,Y)$ the operator that constructs this surface from the energies of a set of boundary points, X, whose activation energy is given by Y. An immediate solution is to use some kind of surface interpolation, and for simplicity and because it copes with the above mentioned restrictions we will use linear interpolation, with a Delaunay triangulation as a previous step to achieve a uniform spaced set of points from X and Y. Then, for a given channel I_c

$$SLoG(I_c,\sigma) = \mathcal{I}(Z(I), LoG(I_c,\sigma)) \quad (5)$$

is the spread LoG taking the energy of the points where there is a change on the inhibition / activation as control points, and evaluated all over the points of the image I_c. In

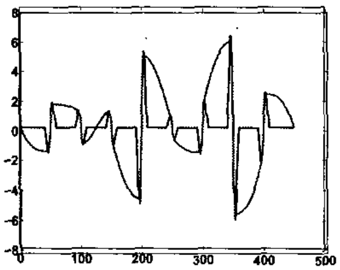

Fig. 1. Profile of the response of $SLoG$ in red and of LoG in blue.

figure 1 we can see a profile of how it behaves. Following the same schema as in the classical sharpening operator of eq. 2 we define the operator $\mathcal{S}$ on a colour image, I, as

$$\mathcal{S}(I, \vec{\gamma}, \vec{\sigma}) = (\mathcal{S}_1, \mathcal{S}_2, \mathcal{S}_3) \qquad \text{where}$$
$$\mathcal{S}_c = I_c - \gamma_c SLoG(I_c, \sigma_c) \tag{6}$$

In figure 2 we show the effects of this perceptual sharpening on a synthetic image and the corresponding profiles of an image line. Suitable values for $\vec{\gamma}$ and $\vec{\sigma}$ parameters can be easily found for images of natural scenes.

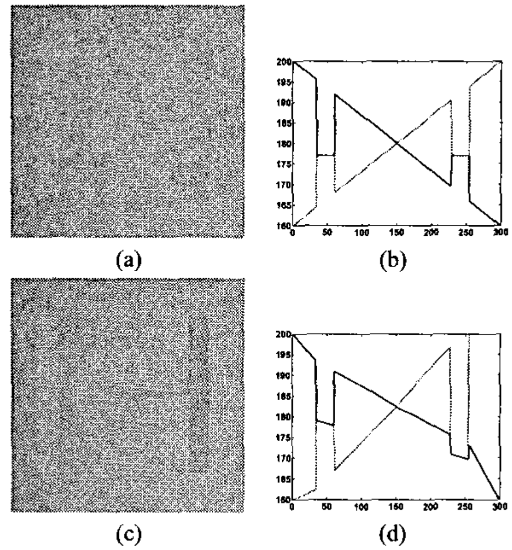

Fig. 2. (a) Original Image. (c) Perceptual sharpening of (a). (b) and (d) present a profile of an horizontal line of images (a) and (c) respectively.

4. EXAMPLES

To see how the proposed operator behaves, we show its effect on different images (see figure 3) together with the result obtained by an enhancement process from a commercial image editor widely used. The first two are webcam images, with very low quality. In this case the operator performs quite well enhancing the edges of main structures, without introducing false colors and lower noise enhancement. The third image belongs to the VisTex database, with very good quality. Both enhancements performs quite well, but it can be seen the commercial image editor creates double boundaries, while the perceptual sharpening does not. The last example is a compressed jpeg image, where colors and edges are also preserved.

In fig. 4 we show the effect on the structure of the image blobs. Fig. 4(a) is the original image with the observed patch outlined. Our proposal does not affect the structure of the blobs, whereas other sharpenings distort them at the point that they could not be processed.

5. DISCUSSION AND FUTURE WORK

We showed that the operator presented in this paper copes with the problem of colour enhancement without the problems that have the usual process presented in Eq. 2: false colors appearance, edge distortion, and over enhancement of high frequency noise. It also maintains the structure of the objects in the image, what makes this operator more suitable for a posterior processing of the image. Moreover, the new operator approaches the problem of what we actually perceive, taking into account psychophysical models.

From now on, our aim is to evaluate this enhancement operator with some measurable features over a wide set of images from different sources. Another open point is to find and automatic evaluation of the best parameters to apply on an image to fit the HVS perception.

6. REFERENCES

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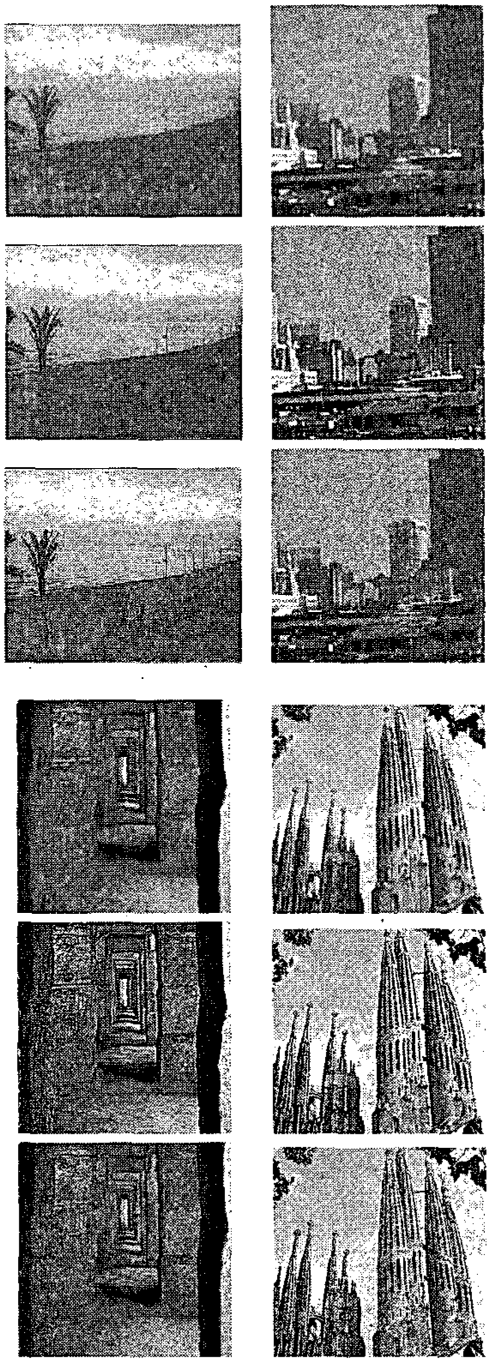

Fig. 3. Comparison of the results between the $PSharp$ operator and commercial software. First image of each example: original image, second image: Perceptually enhanced, third image: enhanced using commercial software.

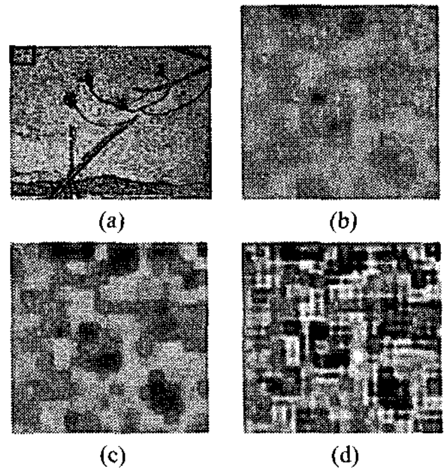

Fig. 4. Details of the effects of the operator on to the structure. (a): original image, (b): small patch to analyse, (c): result of the $PSharp$ operator, (d) result using commercial software.

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