Spatiotemporal Characteristics of the Visual Brain and Their Effects on Colour Quality Evaluation

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ABSTRACT

Understanding contrast sensitivity has been in the focus of human psychophysics for more than 3 decades. This effort, despite certain success, is far from closure. We present a study on the spatiotemporal characteristics of the Human Visual System. This study consists on how to integrate both spatial and temporal effects in a CSF curves and how to exploit the constructed CSF for quality evaluation. The obtained results are very encouraging and show that the new CSF allows some improvement of the quality evaluation scheme.

1. INTRODUCTION

Quality evaluation is becoming an unavoidable way in order to characterize a method or an application. Objective quality metrics provide a method by which the quality of an image or a video sequence can be measured without the need for human evaluation. A strong correlation between the output of such a metric and a quality evaluation as performed by human observers is therefore necessary. As a result, human visual models have been increasingly used to generate accurate quality measurements.

Thus, a thorough knowledge of the human system visual is essential. Very few studies have looked at the temporal characteristics of the human visual system and their consequences on colour appearance. Fairchild & Reniff[2] in 1995 and Rinner & Gegenfurtner[6], in 1999 have explored the dynamics of appearance changes under different daylights but these results are not enough used in colour image quality evaluation, neither to optimize colour processes like filtering or compression[7].

In this paper, first, we present the result of the effect of HVS spatiotemporal characteristics on the quality evaluation. These characteristics are introduced thanks to the spatiotemporal CSF. The remainder of this paper is organized as follow: In section 2, we describe the spatiotemporal characteristics of the Human Visual System. The section 3 is dedicated to the quality evaluation measure that includes the constructed CSF. Section 4 presents some results and discussions. Finally, we give some conclusions about this work.

2. SPATIO-TEMPORAL CHARACTERISTICS OF THE HVS

To study the Human Visual System (HVS), mathematical models have been developed for example to characterize human's sensitivity to brightness and colour[9], over spatial frequencies. One of these models is the Contrast Sensitivity Function (CSF). We can model spatial and temporal properties of the HSV by a computation of a spatial-temporal chromatic CSF. Some works in ophthalmology showed that the CSF is an important property of the HVS. This property plays a role in the filtering of visual information simultaneously-processed in the various visual "channels". The high frequency active channels allow detail perception, the medium frequency active channels allow shape recognition, whereas the low-frequency active channels are more sensitive to motion. Our sensitivity to contrast depends on the colour as well as the spatial and temporal frequency of the stimuli. Contrast sensitivity functions (CSF) are generally used to quantify these dependencies. Contrast sensitivity is defined as the inverse of the contrast threshold, i.e. the minimum contrast necessary for an observer to detect a stimulus. Achromatic contrast sensitivity is generally higher than chromatic, especially for high frequencies. The full range of colours is perceived only at low frequencies. As frequencies increase, sensitivity to blue-yellow stimuli declines first. At even higher frequencies, sensitivity to red-green stimuli diminishes as well, and perception becomes achromatic. On the other hand, achromatic sensitivity decreases slightly at low frequencies, whereas chromatic sensitivity does not.

We can distinguish two types of CSF: the spatial and the temporal correlated together. These CSFs allow modelling the human vision with regards to spatial frequencies on the one hand and temporal frequencies on the other hand. The design of spatio-temporal vision models is complicated by the fact that much less attention of vision research has been devoted to temporal aspects than to spatial aspects.

For spatial effects, it is well known that the eye is much more sensitive to low spatial frequencies than to high ones. Campbell & Robson[1] were the first trying to demonstrate this effect, using a representation as the one presented in Figure 1. The luminance of pixels varies in a sinusoidal way on the horizontal direction. The frequency of this modulation increases exponentially from left to right.

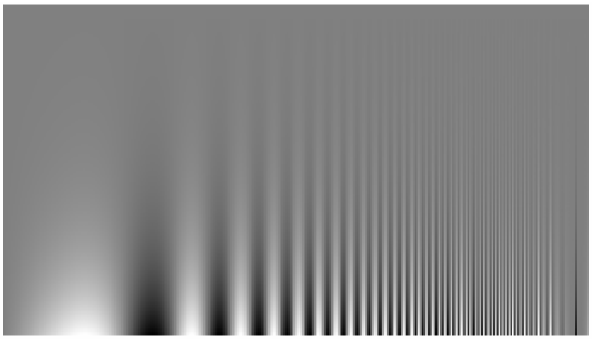

Figure 1. Campbell and Robson experiment for the CSF detection: modulation of a luminance sine waves grating.

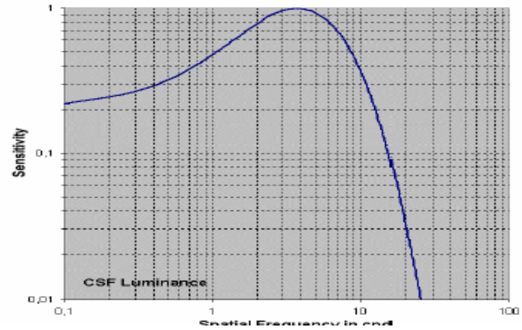

Figure 2. A CSF luminance curve computed from equation of Mannos[5]

What the human observer sees on figure 1 is almost his proper spatial contrast sensitivity function. If he could only draw a line through the imaginary points where the stimulus is confound with the background, the result will be his own luminance CSF curve, as the one presented in Figure2.

The human visual system varies in sensitivity not only with spatial frequency but also with motion. Kelly[4] has studied this effect by measuring threshold contrast for viewing travelling sine waves. Kelly's experiment used a special technique to stabilize the retinal image during measurements and therefore his models use the retinal velocity, the velocity of the target stimulus with respect to the retina. The following figure 4 summarizes these measurements.

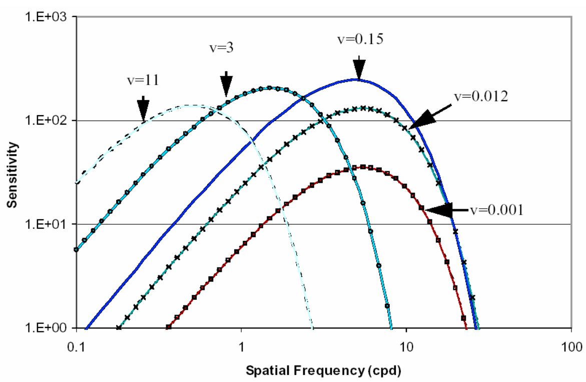

Figure 4 : Velocity dependent CSF, plotted from Kelly's sensitivity measurements

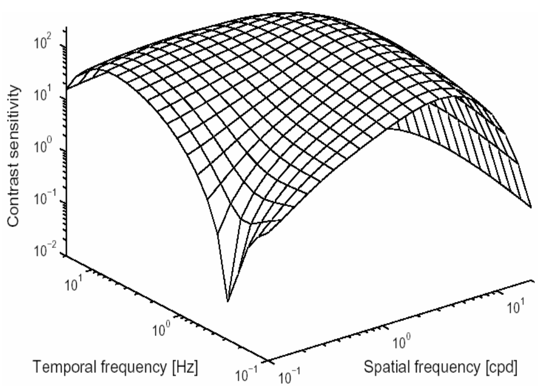

Figure 5 : Spatio-temporal CSFs of the achromatic channel according to[4].

From figure 4, we can notice that the contrast sensitivity changes significantly with the retinal velocity. Above the retinal velocity of 0.15 deg/sec, the peak sensitivity drops and the entire curve shifts to the left. The measurements also showed that the sensitivity function obtained at the retinal velocity of 0.15 deg/sec matched with the static CSF function. The figure 5 above gives an approximation of the achromatic spatiotemporal contrast sensitivity according to the experiments and recommendations given by Kelly.

In this paper, first, we have used a protocol for psychophysical experiments in order to construct the Spatiotemporal Contrast Sensitivity Function (ST-CSF) for both Achromatic and chromatic channels. All the stimuli are presented on the neutral middle grey background. The background was chosen in order to avoid the effect of flare or the incorrect perception of colours due to their correlation. The measures were made for different spatial and frequencies. The viewing distance can vary, but it usually corresponds to the normal computer working situations, generally between 50 and 100cm. The subjective tests are performed with a significant panel of 20 observers, which were evaluated for both the visual acuity and colour vision using well known tests (Snellen and Ishihara).

The experiments are conducted in a dedicated room, which was arranged according to the international standards ITU-R 500-10[3] and ISO 3664. The room illumination and the display intensity are very important because the retina sensitivity at different wavelengths varies with the ambient illumination. This variation is translated by a bigger sensitivity at short wavelengths as the illumination decreases. In those conditions, we have chosen a scotopic environment with stimulation (evaluation display) in the photopic domain. The stimuli of a spatial frequency are shown progressively to the observer using a given temporal frequency. The observer is asked to respond when he starts to see a contrast. This way allows to combine the spatial and temporal characteristics in a unique CSF which differs from the spatial one in the shape and in the position of the pic.

The obtained curves will be used in a quality evaluation process as described in the next section. The study consists on how the ST-CSF could improve the correlation between a colour difference metric like CIED2000, and a human assessment.

3. DISTANCE MEASUREMENT

We can summarize the operation of the HVS by the following diagram. A first stage consists in the transformation of the received signal by the retina into three ways corresponding to short, medium and long wavelength. Then, these three ways are coded in an opponent colour space[10] where the information is represented by an achromatic way and two chromatics ways. Finally, the last stage filters these three ways to obtain the visual information which is really perceived. The filtering is done thanks to the CSF curves.

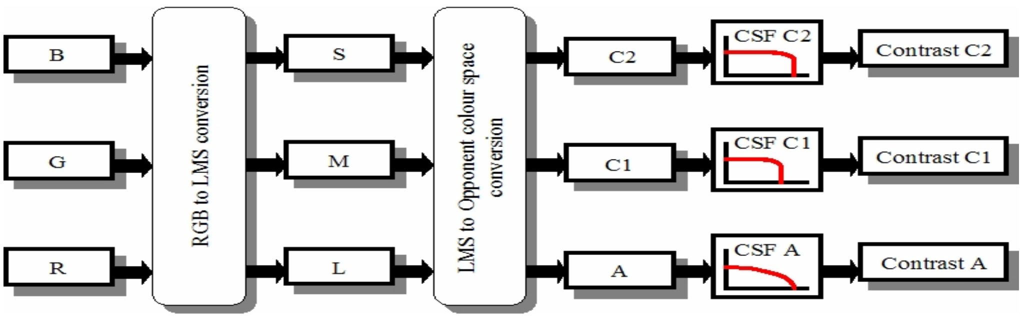

Figure 6. Gabori sine-wave gratings for the CSF detection: low frequencies on the left, high on the right.

In order to compute the differences between two images for quality evaluation, one can convert the obtained representation into the LAB colour space and then carry out a distance measurement (pixel to pixel difference) thanks to the formulation CIEDE2000[11]. More details on this work could be found in[12].

4. RESULTS AND DISCUSSIONS

This section presents some results of quality evaluation of JPEG2000 compressed image using the difference measure of section 3. The figure 7 shows the original image (a), the JPEG2000 compressed image at 0.125 bpp (b). The images (c) and (d) show respectively the difference distribution using the spatiotemporal CSF (proposed one) and a spatial CSF. In order to better see the improvement generated by the spatiotemporal CSF, we made a zoom on a contour area of the image (images (e) and (f)). According to the difference scale, we can notice that the use of spatiotemporal CSF generate less errors than the spatial CSF.

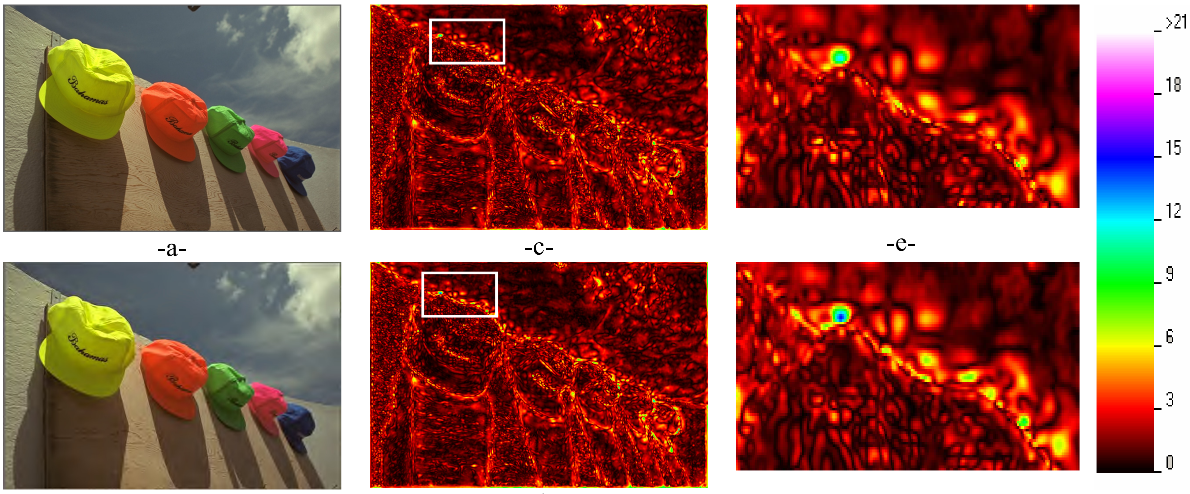

Figure 7. Evaluation of a JPEG2000 compressed image using the distance measure described in section 3.

Globaly, we can see that the major differences between the two CSF lie in the contour areas. It means that for moving objects the HVS could not distinguish degradations in the rupture areas. It could be explained by the fact that the peak of the ST-CSF is around 2.5 – 3 while the one of the spatial CSF is around 4.

5. CONCLUSIONS

In this paper, we have presented how to exploit the spatiotemporal characteristics of the visual brain in order to improve the task of colour quality evaluation. The comparison has been done thanks to the distance described in [12]. The results are very concluding and the ST-CSF generate less errors than the spatial CSF. The future works concerns some uses of the spatial-temporal chromatic CSF to optimize colour image processes like compression scheme..

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