USE OF SPATIAL ADAPTATION FOR IMAGE RENDERING BASED ON AN EXTENSION OF THE CIECAM02

Olivier Tulet, Mohamed-Chaker Larabi and Christine Maloigne Fernandez
SIC Laboratory, University of Poitiers
Bat. SP2MI, Téléport 2, BP 30179, 86962 – FUTUROSCOPE Chasseneuil Cedex, France

Keywords: Rendering model, image quality, subjective assessment, spatial frequencies, s-CIECAM.

Abstract: With the development and the multiplicity of imaging devices, the color quality and portability have become a very challenging problem. Moreover, a color is perceived with regards to its environment. In order to take into account the variation of perceptual vision in function of environment, the CIE (Commission Internationale de l'éclairage) has standardized a tool named color appearance model (CIECAM97*, CIECAM02). These models are able to take into account many phenomena related to human vision of color and can predict the color of a stimulus, function of its observations conditions. However, these models do not deal with the influence of spatial frequencies which can have a big impact on our perception. In this paper, an extended version of the CIECAM02 was presented. This new version integrates a spatial model correcting the color in relation to its spatial frequency and its environment. Moreover, a study on the influence of the background's chromaticity has been also performed. The obtained results are sound and demonstrate the efficiency of the proposed extension.

1 INTRODUCTION

In order to answer the constant evolution in the domain of color appearance and image rendering, many rendering models have appeared. These models become more and more complex and give a good simulation of the human vision. They are often based on color appearance models (CAM) that allow the decomposition of a color into perceptual features based on the environment.

Several CAMs exist and are dedicated to different applications. They take into account several visual phenomena like chromatic adaptation, simultaneous contrast, crispening, spreading…

These models answer the request of industries which asked for standardized tools. It is for this reason, that the CIE has normalized in 1997 the CIECAM97 which has been thereafter improved in order to lead to the CIECAM02 (Fairchild 1997).

Thus, these models allow correcting many phenomena that modify the appearance of a color stimulus (Moroney, Fairchild, Hunt, C.J Li, Luo, and Newman 2002, Luo and Hunt 1997). However they do not take into account the spatial aspect that can be contained in a stimulus (Johnson 2005, Wandell 1995).

As a first contribution to the CIECAM02, we have integrated a model that deals with both spatial frequencies and background luminance. The obtained results were very encouraging since the appearance of the stimuli was adapted to the contained spatial frequency. However, this model addressed only a single input color and was unable to correct the content of an image which is more complex (Larabi and Tulet 2006).

It is to respond to this lack that an image extension of this model is proposed in this paper. This extension is carried out by using Fourier decomposition in different frequency bands. Indeed, in this space, it is possible to have a direct access to the orientation and the energy for all the frequencies. A study of the neighborhood and the orientation of a pixel allow extracting the background luminance that will be used to correct the pixel.

The main difference between the proposed model and the other rendering models like the iCAM developed by *Fairchild et al.* (Fairchild and Johnson 2004) lies in the fact of taking into account the spatial repartition of a pixel in addition to its environment. The others rendering model are just using a general CSF filter to take into account the spatial information and are not looking to the

Tulet O., Larabi M. and Maloigne Fernandez C. (2008).
USE OF SPATIAL ADAPTATION FOR IMAGE RENDERING BASED ON AN EXTENSION OF THE CIECAM02.
In *Proceedings of the Third International Conference on Computer Vision Theory and Applications*, pages 128-133
DOI: 10.5220/0001086101280133

environment of each pixel.
The remainder of this paper is organized as follows: Section 2 describes the model already developed and the experiments which allowed its construction. A recent study of the influence of background chromaticity, on spatial frequencies, is exposed. Section 3 is dedicated to the extension of this s-CIECAM model to images. In this last section some results are described and different tests to validate our method are realized. We finish by some conclusions and we introduce some future works.

2 S-CIECAM FRAMEWORK

An extension of the CIECAM02 has been developed in order to allow this color appearance model takes into account the influence that can have the spatial frequencies on our vision.

For that a study based on psychophysical experiments has been realized in a dedicated room. This room respects standardized conditions (lightness, display calibration…).

Figure 1: Psychophysical test room.

With regards the recommendations given by standards ISO 3664 (ISO3664 2005) and ITU-R 500-10 (ITU-R Recommendation 2000) this environment should respect many conditions as for example the color of walls which should be neutral or the background chromaticity which should correspond to the illuminant D65.

The experiment realized was based on the adjustment of the hue angle, the lightness and the chroma of the stimuli in order to appear similar to the input color. The figure 2 gives a snapshot of the tests run for blue stimulus.

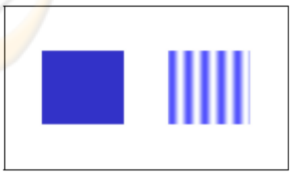
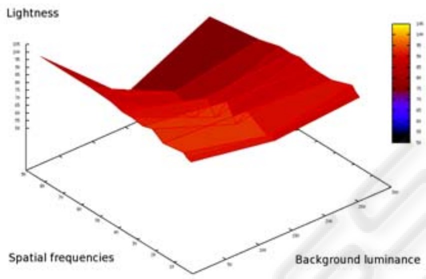


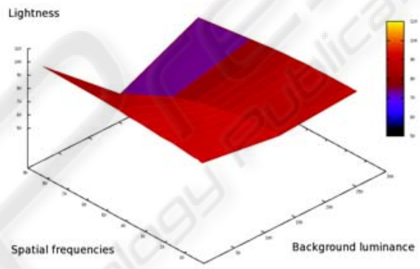
Figure 2: Example of test pattern.

Thanks to this test, the influence of the spatial frequency on our perception has been measured for several frequencies on three different achromatic backgrounds with different luminance.

The figure 3 illustrates the results obtained for the red lightness.



-a-



-b-

Figure 3: Results for red lightness: a-measured, b-modeled.

The obtained results from the described experiments represent the difference perceived on the hue angle, the lightness and the chroma according to the spatial frequency and the background luminance.
For modeling the results, curves of degree two were chosen and have been fitted using the least square method. An example is given by figure 3-b for the red lightness.
The figure 4 shows the diagram of the s-CIECAM. It represents the integration of a spatial module in the standard CIECAM02

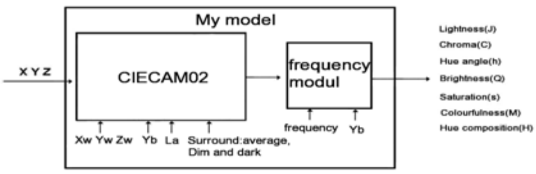


Figure 4: Diagram of input/output of s-CIECAM.

Thus, this model is able to predict all effect predicted by the CIECAM02 in addition to the spatial adaptation.

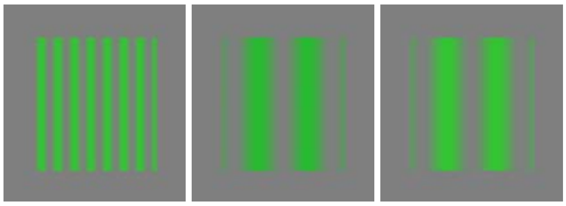


Figure 5: Example of corrected pattern. a- input stimulus at frequency *f*. b- stimulus at frequency *f'* and same color as (a). c- Spatially corrected stimulus from f to *f'*.

In figure 5, an example of correction for a green stimulus on a grey background is given. The input stimulus is at a given frequency *f*. When this frequency is decreased to *f'*, we obtain the stimulus of figure 5-b. It is easy to notice that the two colors seem different. By using the s-CIECAM, for the spatial correction, the corrected stimuli (figure 5-c) are closer to the input one.
Even if the obtained results are quite encouraging, the s-CIECAM is designed to correct only one stimulus and is not adapted to the correction of images.

2.1 Influence of Background's Chromaticity

At this stage, the S-CIECAM is only taking into account the frequency and of the background luminance. New experiments have been conducted in order to study the influence of background's chromaticity on human perception. In these experiments, the background of a stimulus is no longer achromatic but really chromatic.

The preparation and the conduction of subjective experiments are tedious and time consuming. Our selection of background has lead to two colors having same luminance as the grey used in precedent campaign to have a maximum of different chromaticity with the same luminance.

Thus the perceived difference between a flat stimulus and a stimulus modulated by a spatial frequency, on three different backgrounds which have the same luminance , is measured on the three perceptual components *J*, *C* and *h*. An example of results is shown by the figures 6, 7, 8:

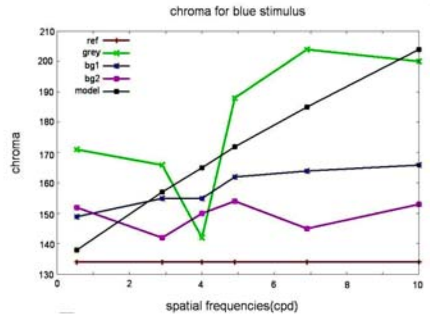


Figure 6: Average of chroma perceived on a blue pattern, on different backgrounds with the same luminance on several frequencies (*ref* : reference color, *grey* : achromatic background, *bg1*: 1st chromatic background, *bg2*: 2nd chromatic background and model: s-CIECAM predicted values).

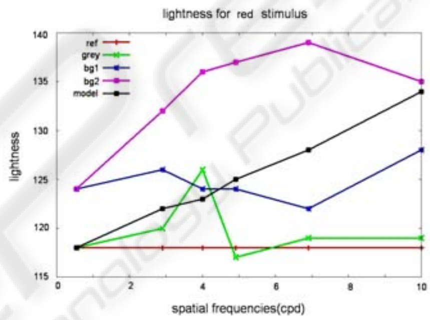


Figure 7: Average of lightness perceived on a red pattern, on different backgrounds with the same luminance on several frequencies (same labels than figure 6).

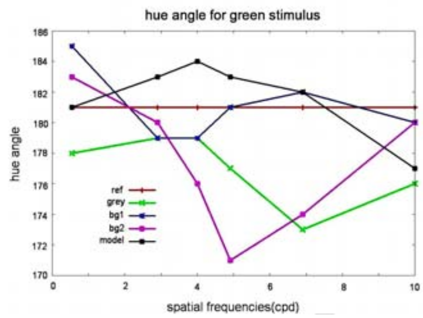


Figure 8: Average of hue angle perceived on a green pattern, on different backgrounds with the same luminance on several frequencies (same labels than figure 6).

The obtained results show that the perceived differences are quite similar for the hue angle and the lightness comparatively to their scale. But the figure 7 presents an important gap in the chroma for high frequencies.
These figures show also that the s-CIECAM model has a sound prediction of the spatial effect related for the hue angle and the lightness.

3 IMAGE APPLICATION

In order to use this spatial model for image rendering, an extension was necessary because the S-CIECAM is able to correct single stimuli only.

3.1 Model Description

It is very important to deal with image correction since it is the main material we use in different applications. The extension of the s-CIECAM to images is not obvious. Indeed, the image is composed by pixels where each of them could be considered as a stimulus. Moreover, there is a different meaning to be given to background luminance, to surround and so on.

Starting from these remarks, we have to retrieve for each pixel its inherent frequency and its background.

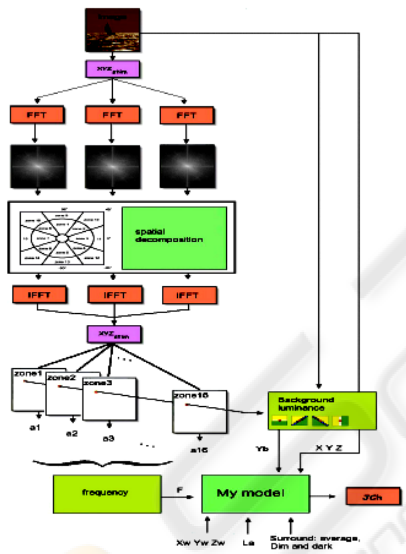


Figure 9: Flowchart of the images s-CIECAM.

The approach that we have adopted could be summarized by figure 9. The input image is transposed in the *XYZ* color space and then in the Fourier domain. After that, the Fourier space is decomposed in 17 frequency bands as shown in figure 10. It corresponds to low, medium and high frequencies and 8 major orientations.

As a first step, the low frequencies are removed from the frequency domain in order to preserve the quality of the image. The other zones with higher frequencies will be processed using a methodology that will be discussed hereafter.

- For each of the 16 frequency bands, an average value is defined based on the size of the picture and the distance between the display and the observer.
- Then the inverse Fourier transform is applied separately for each of these frequency bands to obtain 16 different pictures representing the content of each band with the dedicated frequency and orientation.

For example, the first zone gives an image which has a high correlation with horizontal medium frequencies whereas the 11th zone gives an image with a high correlation with high vertical frequencies.

For each pixel and for each component (*J*, *C* and *h*), 16 coefficients are calculated in function of the frequency band like describe by the equation 1:

$$a_i^k = \frac{B^k(i)}{\sum_{i=0}^{16} a_i^k} \qquad (1)$$

where *k* represents the perceptual component (*J*, *C* or *h*) and the $B^k(i)$ are the value of the component k at the considered point, for the frequency band *i*.

These coefficients will be used after to balance the background luminance and the average frequency of the pixel area.

The equation 2 describes how a component frequency is obtained for a given pixel.

$$F_k = \frac{\sum_{i=1}^{8} a_i^k M1 + \sum_{i=9}^{16} a_i^k M2}{\sum_{i=1}^{16} a_i^k} \qquad (2)$$

where *M1* and *M2* are the average frequencies of the medium and the high frequencies computed using the image size and the distance display/observer.

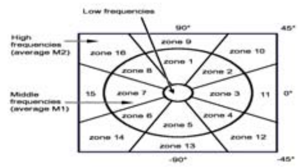


Figure 10: Decomposition in Fourier domain.

The final frequency *F* is obtained with an average of the three frequencies F_J, F_C and F_h.

At this stage, for each pixel we have determined a spatial frequency that could be used directly to correct it using the s-CIECAM. However, we need to know the other inputs of this model such as the background luminance that depends on the neighborhood of this pixel. The other inputs are considered as fixed values because they are common to the whole pixels of the image. It concerns the tristimulus values of the source white in the source conditions (X_w Y_w Z_w), the luminance of the adapting field (L_a) and the viewing conditions (F_l,c,n_c).

As the same manner to the frequency, a background luminance is calculated for each pixel and the same coefficients a_k balance the value of the background luminance. This value is taken directly from the input image and is depending on the orientation of the considered neighborhood like shows the figure 11.

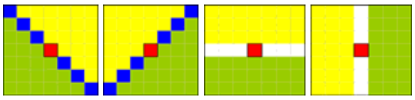


Figure 11: The pixel (in red) and its neighborhood function of processed band.

For example, in the first area there is a high correlation with the horizontal frequencies. So, to specify a background luminance, the pixels which are above and below are considered for the computation. If the average luminance of the pixels above the processed one is close to its luminance, the average luminance of the pixels below is considered as the background luminance. If the two averages are very different from the processed pixel, the background luminance is considered as their medium value.

After the background luminance computation, we can consider that we have the necessary inputs for s-CIECAM in order to correct the image appearance. So the first step will be to transpose each pixel into the perceptual color space composed by the lightness, the chroma and the hue angle. Then, from the perceived values for each pixel, it is possible to apply the inverse s-CIECAM to obtain the corrected pixel with regards to the input values depending on varying viewing conditions

In order to obtain a better image and so to validate the advantages of this proposed approach, we opted for varying the spatial frequency only. To do that, the input pixel is considered as belonging to a flat stimulus at zero-frequency and the inverse model is used with the frequency obtained by equation1.

3.2 Results

The figure 12 shows an example of the obtained results using the s-CIECAM adapted to images. In this figure, we can compare the original picture (figure 12-a) and its correction with our model (figure 12-b). It is easy to notice that the corrected image seems more natural than the original one.

We have done a lot of tests in order to quantify the improvement done by our approach. Among the tests, we have performed a similarity measurement between the original and the corrected images using the SSIM (Wang, Bovik, Sheikh, and Simoncelli 2004) metric that evaluate the fidelity of the reproduction. Table 1 gives the fidelity values for the image of figure 12.

The model has been applied on 17 images coming from the Kodak image database and the fidelity between the corrected and the original images is always high. The CIE ΔE2000 (Sharma, Wu, Dalal 2005) was also used and the results are similar to SSIM.

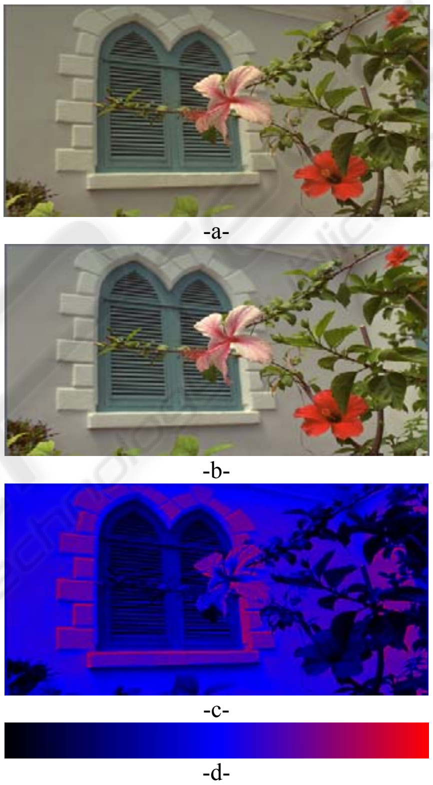


Figure 12: Example of results. a- original picture. b-Picture corrected.c-ΔE2000 differences between a and b. d-ΔE2000 scale increasing from black to red.

The Figure 12-c shows the error generated by the correction using the CIE ΔE2000. In this figure, black represents unmodified pixel, blue represents zones with a medium difference and red zones have higher differences.

Table 1: Fidelity measures between original and corrected images of figure 12 on the three components RGB.

Component	Red	Green	Blue
Fidelity	99.5%	99.4%	97.9%

From this figure, one can remark that the textured areas are corrected whereas the relatively uniform zones.

Another statistical measure has been performed to prove the consistency of our method which is not only based on lightness adjustment. Table 2 gives the average adjustment performed on the 3 perceptual components (*J*, *C* and *h*) for the image of figure 12.

The values of this table demonstrate that not only lightness is adjusted but also the chroma and the hue even if for this latter the deviations are small.

Table 2: Average adjustment values obtained from the corrected image of figure 12.

Component	*J*	*C*	*h*
Average adjustment	2.64	9.25	0.05

3.3 Validation

In order to validate our adaptation of s-CIECAM to images, we have managed a psychophysical experiments based on a forced choice paradigm. These subjective experiments were performed on 17 images from the Kodak database. They were performed with a panel of 15 observers which were evaluated for the visual acuity and a normal color vision.

The observers were only asked to choose the image that seems to them better (more natural) between an original and a corrected image in a blind way. Three repetitions are made for each of the 17 pictures to see if the observer has a stable opinion.

The obtained results are presented by figure 13 which shows number of choice of corrected image against original.

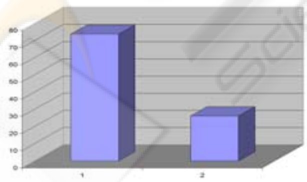


Figure 13: Diagram which show the percentage of choice for the corrected image (1) against the original (2).

On this histogram we can see that in 75% of case the image corrected by our model was preferred by the observers.

The standard deviation is very weak and no observers have been rejected because of the stable evaluation they have given.

4 CONCLUSIONS

In this contribution a model based on psychophysical experiments has been described. A study of the influence of the chromaticity of the background was realized with the same experiment.

This s-CIECAM was extended to images with a method allowing taking into account spatial information.

Different tests to validate our results were presented and corrected pictures seem more naturally than the original. Those results are very encouraging and the future direction of this work is its inclusion for High Dynamic Range rendering.

Finally another prospect is the study and the integration of the temporal frequencies with digital cinema as an application.

REFERENCES

M.D.Fairchild, "*Color appearance model*". Addison-Wesley, Massachussets (1997).

N. Moroney, M.D. Fairchild, R.W.G. Hunt, C.J Li, M.R. Luo, and T. Newman, "*The CIECAM02 color appearance model,*" IS&T/SID 10th Color Imaging Conference, Scottsdale, 23-27 (2002).

ITU-R Recommendation BT.500-10, "*Methodology for the subjective assessment of the quality of television pictures* ", ITU, Switzerland (2000).

ISO3664, "*Viewing Conditions for Graphic Technology and Photography*", ISO (1999).

M.R. Luo and R.W.G. Hunt, "*The Structure of the CIE 1997 Colour Appearance Model (CIECAM97s),*" Color Res. Appl., 23, (1997).

G.M. Johnson, "*The quality of appearance*", AIC 2005, Granada Spain, (2005).

B.A. Wandell "*Foundations of vision*", Sinauer Associates, Inc, Sunderland, Massachussetts(1995).

C. Larabi and O. Tulet, "*Study of the influence of background on colour appearance of spatially modulated patterns*", CIE, Paris(2006)

G. Sharma, W. Wu, E. N. Dalal, "*The CIEDE2000 Color difference Formula: Implementation Notes, Supplementary Test Data, and Mathematical Observations,*" CR&A, 30(1), pp. 21-30, 2005.

M.D. Fairchild and G.M. Johnson, "*The iCAM framework for image appearance, differences, and quality,*" Journal JEI 13, 126-138 (2004).

Z. Wang, A. C. Bovik, H. R. Sheikh, and E. P. Simoncelli, "*Image quality assessment: From error visibility to structural similarity*", IEEE TIP 13 pp.600-612, Apr. 2004.