# OBJECTIVE QUALITY MEASUREMENT BASED ON ANISOTROPIC CONTRAST PERCEPTION

*Vincent Rosselli, Mohamed-Chaker Larabi, and Christine Fernandez-Maloigne*
*XLIM-SIC Laboratory, UMR 6172, University of Poitiers (France)*

## Abstract

*The study of the Human Visual System (HVS) is very interesting to quantify the quality of a picture, to predict which information will be perceived on it, to apply adapted tools ... The Contrast Sensitivity Function (CSF) is one of the major ways to integrate the HVS properties into an imaging system. It characterizes the sensitivity of the visual system to spatial and temporal frequencies and predicts the behavior for the three channels. Common constructions of the CSF have been performed by estimating the detection threshold beyond which it is possible to perceive a stimulus. In this work, we developed a novel approach for spatio-chromatic construction based on matching experiments to estimate the perception threshold in a large range of orientations. It consists in matching the contrast of a test stimulus with that of a reference one. The obtained results are quite different in comparison with the standard approaches as the chromatic CSFs have band-pass behavior and not low pass. The obtained model has been integrated in a perceptual color difference metric. The metric is then evaluated.*

## Introduction

Various processings can be performed on an image and affect the image quality. To quantify the quality or at least the level of impairment, subjective evaluations must be conducted on a panel of observers. However the installation of such tests is tiresome because it must respect established standards. In order to avoid this kind of approach, objective tools have been proposed.

An objective metric is a mathematical model, one of the most known is MSE which. These measures give good results in term of mathematic but it is not always correlated to the results of an observer.

Some objective criteria are based on the study of the Human Visual System (HVS). Their aim is to simulate the behavior of the HVS to know what will be seen or not in an image. A most common way used to characterize HVS is the construction of its Contrast Sensitivity Function (CSF). The construction of this function needs normalized condition and is in general based on the estimation of the detection threshold above which contrast is perceived at a given spatial frequency. The way we have chosen is based on the estimation of perception threshold (discrimination threshold) that is more adapted to quality comparison and matching. So, we have developed a new approach for achromatic and chromatic channels based on matching for a range of orientations and its application into a perceptual colour difference metric.

## Contrast Sensitivity Function

In literature, there are four methods to construct CSF[1] : by appearance, by disappearance, by double-alternative or by fitting. Numbers of psychophysical experiments have been managed following the previously mentioned approaches.

The evidence supports a description of color vision in terms of the responses of an achromatic channel and two chromatic channels, one tuned to a red/green dimension and the other to a yellow/blue dimension[2] . For the construction of chromatic CSF, monochromatic or opponent-color approaches can be used. In the first approach, the contrast is measured between a color and the black, and the obtained shape is band-pass. The second approach is based on chromatic opposition. As shown by *Mullen*[3] , the chromatic CSF has a low-pass shape.

The classical methods for the CSF construction are based on the concept of detection threshold. This threshold is the boundary beyond which the stimulus is perceived. Our method is based on the concept of discrimination threshold (perception threshold). The perception boundary of the difference between two stimuli is measured. This is of a big interest for the evaluation of the fidelity between an image and its impaired version.

For the experimentation of our approach, two stimuli are presented to the observer. The reference stimulus is fixed for the experimentations at a given spatial frequency and the maximum contrast level. The test stimulus has a spatial frequency but its contrast increases progressively from 0 to 1. The observer must tell when he thinks that the contrasts of both stimuli are similar. It can be formalized by:

$$c_p(f) = c'_p(f_{ref}), \tag{1}$$

where $c_p$ and $c'_p$ are the contrast perceived by the observer for the two stimuli, $f$ the spatial frequency of the test stimulus and $f_{ref}$ the spatial frequency of the reference stimulus. Equation 1 could be written:

$$c_m(f) * CSF(f) = c_{ref} * CSF(f_{ref}), \tag{2}$$

where $c_m$ is the measured contrast of the test stimulus for which the observer notices that the two stimuli have a similar contrast level ; $c_{ref}$ is the displayed contrast of the reference stimulus. We thus obtain by this method a relative CSF (noted *rCSF*) at a given frequency and contrast:

$$rCSF(f) = \frac{CSF(f)}{CSF(f_{ref})} = \frac{c_{ref}}{c_m(f)} \tag{3}$$

The values of the measurable CSF lie between:

$$rCSF = \frac{c_{ref}}{c_m(f)} \in \left[\frac{c_{ref}}{c_{max}}; +\infty\right[ \tag{4}$$

### *Experimental Process*

According to *Wandell*[4] , sine-waves stimuli are best perceived because only one frequency is contained in it. Then the grating must have a vertical orientation[5] . The eye is more sensitive to it than to other orientations. However, in this study, several orientations are assessed to increase the accuracy of the future application.

As mentioned above, two stimuli have to be displayed, one beside the other with a significant space between them. But the observer must be able to see them both. To respect the optimal


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cone of binocular vision, which is about $10^o$ of visual angle, the viewing distance is fixed to 1,5 meter. And the size of the stimulus is about $4{,}7^o$ of visual angle (*cf.* fig.1).

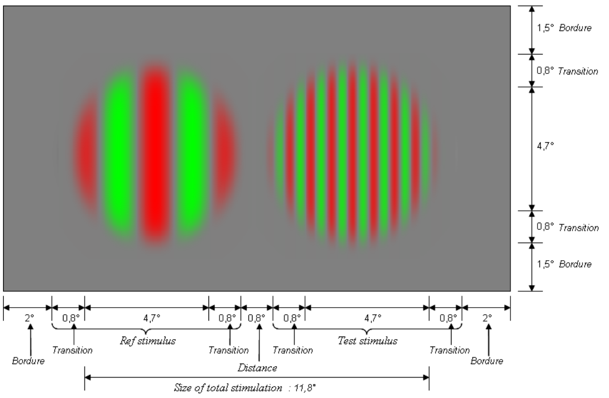


***Figure 1.*** *Position and size of the stimuli on the display*

The quality of the stimulus must be optimal to obtain stable results. We assume that the HVS needs at least two periods to estimate the contrast[1] . This restricts low frequencies. The display and its characteristics restrict the high frequencies. Cosine-wave gratings are preferred because they allow more measuring points.

For each channel, 9 frequencies have been selected. Moreover, 8 orientations in a range of 180 representing in the same time the other opposed orientations are evaluated (cf fig 2). This choice was made to not exceed the fifteen minutes to twenty minutes of assessment[6] . Beyond this duration, the observer starts to lose his attention. Figure 3 gives the diagram that we have developed for the definition of the usable frequencies. This diagram is of a big interest because it integrates both the display and the observer characteristics. It is also adaptable to any type of conditions (cinematographic conditions for example).

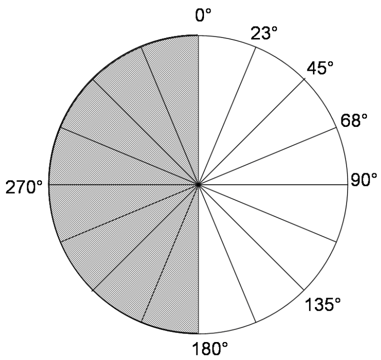


***Figure 2.*** *Selected orientation for the construction of the anisotropic CSF. Gray part represents the equivalent opposed directions.*

The psychophysical tests take place in a psychophysical room, built in our lab with respect to the ITU recommendations. The ambient lightings is about 65 *lux* and there is no direct illumination of the display. parameters were important for this latter : the temperature and the luminance of the white point. To have better and more consistent results, the set-up of the illumination and the display parameters has been made precisely before each experiment.

## Results

Due to the huge amount of collected data, a statistical study was carried out in order to keep the useful results (coherent) and

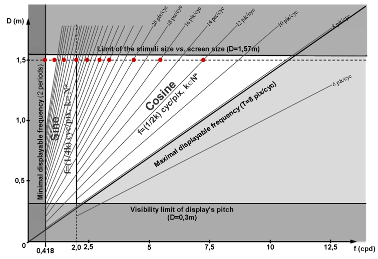


***Figure 3.*** *Displayable frequencies*

to avoid the random observations that could be made by an observer. We have run the test of Kurtosis[6] .

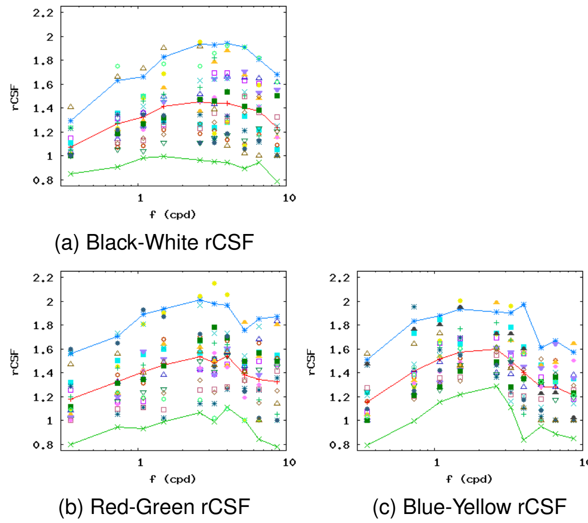


***Figure 4.*** *Experimental results of an orientation*

Figure 4 shows the validated results for each opposition for one orientation. For the achromatic CSF, the results are very encouraging since the amplification effect of the contrast for average frequencies is quite present as well as the decrease of the sensitivity to contrast beyond the peak of the CSF.

We reported previously that the chromatic CSFs have low-pass behaviors. However, the ones constructed in this study (using discrimination threshold) are band-pass as the achromatic CSF. Starting for those results, we wanted to confirm that the experimental conditions are correct and that the effect is not related to them. We made a cross campaign in which we have removed the reference stimulus and only kept the best viewed orientation in order to reach the detection threshold experiments (by appearance).

The figure 5 gathers the obtained results, whose are complying with those from the literature. The achromatic CSF is band-pass and the chromatic CSFs are low-pass. This confirm on the one hand that our experimental protocol is correct and does not influence the results and on the other hand, that this interesting effect is due to the discrimination threshold on which is based our approach.

In other words, when we are stimulated with chromatic stimuli, the fact of matching two stimuli gives us the same shape of sensitivity to contrast than the achromatic. This aspect is very interesting to use in application using image difference such as VDP[5] .

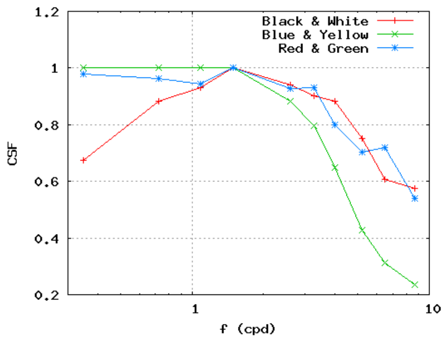


*Figure 5. Cross-experiment for achromatic and chromatic channels by appearance*

### Analytical model

An analytical model allows to obtain, by identification of its parameters with the measurement points, a characteristic usable in other systems requiring a model of CSF. The one used in our experiments is an adaptation of the *Mannos* and *Sakrison* model[7] . It consists in the insertion of the orientation notion with the parameter $\theta$ and a normalization of their model at the reference point so that the value of the CSF relating to the reference frequency will be equal to 1. Thus, the analytical expression of this model is as follows:

$$CSFR(f,\theta) = \frac{\left(a(\theta) + \frac{f}{f_p(\theta)}\right) \exp^{-\left(\frac{f}{f_p(\theta)}\right)^{c(\theta)}}}{\left(a(\theta) + \frac{f_{ref}}{f_p(\theta)}\right) \exp^{-\left(\frac{f_{ref}}{f_p(\theta)}\right)^{c(\theta)}}}, \qquad (5)$$

where $f$ is the test frequency in cycle per degree (cpd) and $\theta$ the angle in degree. *a*($\theta$) and *c*($\theta$) influence the curve slope respectively for low and high frequencies for the $\theta$ orientation. $f_p(\theta)$ and $f_{ref}$ are respectively the peak position of the CSF for the $\theta$ angle and the selected reference frequency.

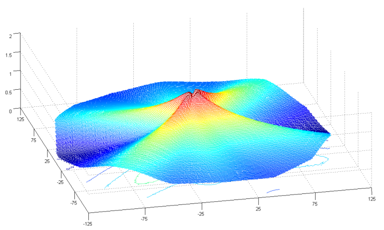

*Figure 6. Black-White anisotropic rCSF*

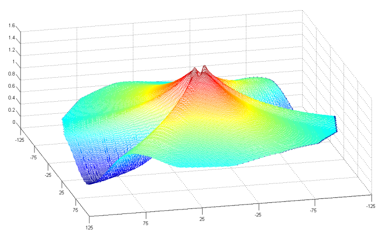

*Figure 7. Red-Green anisotropic rCSF*

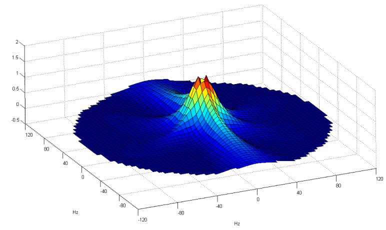

*Figure 8. Blue-Yellow anisotropic rCSF*

## Perceptual color difference metric

### Our approach

The introduced CSF is constructed by matching, this means that it is based on the subjective comparison concept. This leads directly to the definition of a perceptual color difference metric.

This is a metric belongs to the full-reference family of metrics meaning that the original image is used in comparison with the impaired one.

The image is firstly separated in an opponent representation using the AC1C2 color space. Because of the definition of the CSF, each channel is filtered in the Fourier domain. Back to the spatial domain, the color space of the image is changed to the L*a*b* space. The process is run on the original image and its impaired copy. The $\Delta E_{2000}$[8] is then computed to obtain the perceptual color difference error image.

The figure 9 summarizes the described process.

The reason to use the $\Delta E_{2000}$ metric is that the $\Delta E_{2000}$ is particularly adapted to the evaluation of natural images. It includes the $\Delta E_{94}$ coefficients for natural images with the addition of a weighting factor.

### Experimentation

In this section, we present the experiments performed in order to demonstrate the efficiency of the proposed model. To do that, we have used 40 images representing landscapes, natural images, portrait, . . . and selected 6 compression formats (H264, HDPhoto, JPEG2000, JPEG2000 with visual optimisations, JPEG and JPEG QM) and 4 bit-rates (0.3bpp, 0.5bpp, 1bpp and 1.3bpp).

In a first time, a psychophysical campaign is purchased. For an image and a bit-rate, the original image is dispayed in the center of the screen with its 6 impaired copies around, placed in a random order (double-blind conditions). The task of the observers is to classify, in order of preference (from the worst to the nicest), the impaired copies. The figure 10 shows a snapshot of the test.

In a second time, the same test is done by our metric and 4 others ($\Delta E_{2000}$, MSE, SSIM and VDP). In the case of the metrics, the mean errors of the compressed copies, in comparison with the original one, are used to classify the coders.

The aim of the experimentation is to study the correlation between the results of the observers, with the Mean Opinion Score (MOS), and the ones from the metrics. And, by extension, we wanted to rank the objective metrics and saw where our is placed.

As the results are from a classification task, the Spearman correlation is chosen. The table gathers those correlations.

As the bit-rate increases, the correlation factor of most of the metrics decreases . This phenomenon can be explained by the fact that it was harder for the observers to classify images. Especialy for 1bpp and 1.3bppp : the answers were often made randomly.


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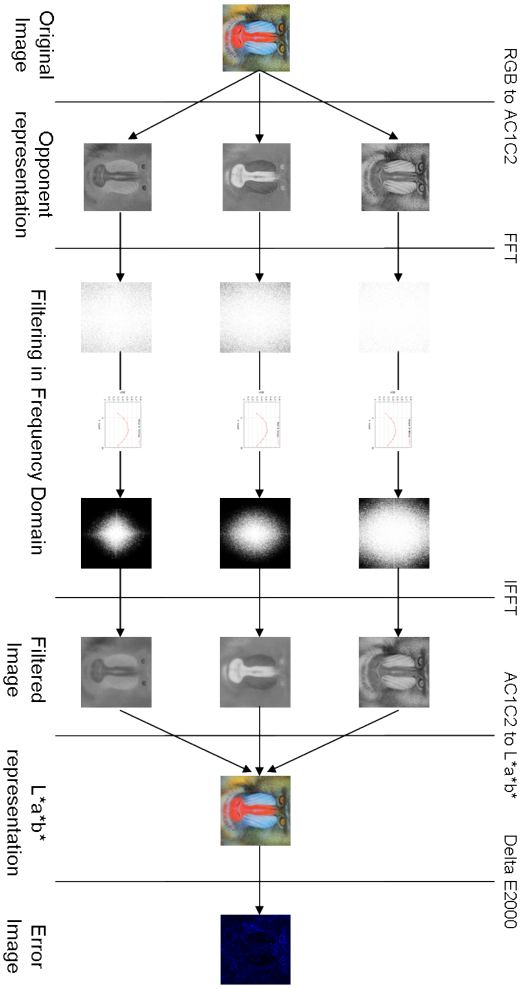


***Figure 9.*** *flowchart of the proposed model*

If we only focus on the 0.3bpp and 0.5bpp bit-rates, we can see that our model is well correlated with the MOS.

As it was said in the proccess description, the $\Delta E_{2000}$ is used to compute the error between the images but the correlation of our metric with the MOS is better than its. This means that the choice of pre-proccessing images with our rCSF is revelant.

## Conclusions

In this work, we have presented a perceptual color difference metric including a new approach for the construction of anisotropic spatio-chromatic CSF to model a part of the human visual system properties. The novelty of the construction lies in the estimation of the perception threshold (discrimination threshold) instead of the detection threshold used intensively in literature and which is well adapted for fidelity estimation.

The obtained results are very encouraging and shows a promising way to estimate the fidelity of color image tools. This study has been based on both objective and subjective evaluation procedures allowing to take into account the human perception in the loop.

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***Figure 10.*** *Disposition of the images during the psychophysics tests*

| | $\Delta E_{2000}$ | MSE | SSIM |
|---|---|---|---|
| 0.3 bpp | 0,687887 | 0,668048 | 0,712495 |
| 0.5 bpp | 0,443006 | 0,377217 | 0,621980 |
| 1.0 bpp | 0,047184 | 0,053220 | 0,244834 |
| 1.3 bpp | 0,134434 | 0,094394 | 0,313768 |
| | VDP | Our Metric | |
| 0.3 bpp | 0,509152 | 0,725227 | |
| 0.5 bpp | 0,374701 | 0,531600 | |
| 1.0 bpp | 0,175727 | 0,061240 | |
| 1.3 bpp | 0,181679 | 0,043668 | |

**Correlation with MOS for each bit-rate**

## Author Biography

*Vincent ROSSELLI received his BS in computer science from the University of Poitiers (2006) and is actully in PhD in signal proccessing at the University of Poitiers. He is working on the European project EDCine. His research focus on the study and the modelisation of the HVS to enhanced the quality and resolve some problems due to the JPEG2000 compression.*