A Modified Algorithm for Perceived Contrast Measure in Digital Images

Alessandro Rizzi[1], Gabriele Simone[2], Roberto Cordone[1];
1: Dip. Tecnologie dell'Informazione - University of Milano; Via Bramante, 65 - 26013 Crema (CR) - Italy
2: Gjøvik University College, Gjøvik

Abstract

In this paper, we propose an algorithm for the measure of local and global contrast in digital images. It applies locally, at various sub-sampled levels, a simplified computation of local contrast based on DOG and finally it recombines all the values to obtain a global measure. The proposed method comes from the modification of a previous algorithm with a different local measure of contrast and with a parameterized way to recombine color channels. As new approach we propose the idea of recombining the channels following measures taken from the image itself. Preliminary tests and results are presented and discussed.

Introduction

Since the first studies on contrast in images, it has emerged how arduous it could be to give a definition of contrast and, moreover, how subjective and related to the observation task or observer experience this definition could turn out to be. For this reason, the first approaches to this topic have confined themselves to study the phenomenon from rather limited points of view, operating in controlled situations and under very restrictive conditions, the so-called "void conditions". After this very first experiments more complex measures have been devised, but a measure of contrast in images is still not clearly defined.

Several measures have been proposed so far [1-5]. The classic approaches consist of global measures and for this reason they result inadequate in most of the cases. In fact, the study of contrast in an image at a global level provides only a measure related on the maximum global difference in lightness and in some cases chromaticity. The response of the human visual system depends much less on the absolute luminance than on the relation of its local variations.

A very first measure of global contrast, in the case of sinusoids or other periodic patterns of symmetrical deviations ranging from $L_{\max}$ to $L_{\min}$, is *Michelson contrast* [1]:

$$C^M = \frac{L_{\max} - L_{\min}}{L_{\max} + L_{\min}}$$

Michelson's definition is not suitable for natural images because one or two points of extreme brightness or darkness can determine the contrast of the whole image.

To overcome the limits of global measures, alternative measures have been developed in the 90's, among them Tadmor and Tolhurst [3].

Tadmor and Tolhurst's analysis of contrast [3] is based on the D.O.G. (Difference Of Gaussian) model, adapted to natural images. In the conventional model, the spatial sensitivity in the center of receptive-fields (central component) is described by a bi-dimensional Gaussian:

$$Center(x,y) = \exp\left[-\left(\frac{x}{r_c}\right)^2 - \left(\frac{y}{r_c}\right)^2\right]$$

where radius r_c represents the distance beyond which the sensitivity decreases below 1/e with respect to the peak level. The surround component is represented by another Gaussian curve, with a larger radius, r_s :

$$Surround(x,y) = 0.85\left(\frac{r_c}{r_s}\right)^2 \exp\left[-\left(\frac{x}{r_s}\right)^2 - \left(\frac{y}{r_s}\right)^2\right]$$

When the central point of the receptive-field is placed in (x,y), the output of the central component is calculated as:

$$R_c(x,y) = \sum_i \sum_j Centre(i-x,j-y)\ Picture(i,j)$$

where Picture(*i,j*) is image pixel at position (i,j), while the output of the surround component is:

$$R_s(x,y) = \sum_i \sum_j Surround(i-x,j-y)\ Picture(i,j)$$

The conventional DOG model assumes that the response of a neuron depends uniquely on the local luminance difference between the center and the surround.

Tadmor and Tolhurst propose the following three criteria for the measure of contrast:

$$C1(x,y) = \frac{R_c(x,y) - R_s(x,y)}{R_c(x,y)}$$

$$C2(x,y) = \frac{R_c(x,y) - R_s(x,y)}{R_s(x,y)}$$

$$C3(x,y) = \frac{R_c(x,y) - R_s(x,y)}{R_c(x,y) + R_s(x,y)}$$

One of the authors has recently developed a very simple algorithm for local contrast measure. This algorithm [5], indicated with RAMMG, subsamples the image to various levels in the CIEL*a*b* colorspace. The undersampling is simplified halving the image without pre-filtering. This produces a set l of subsampled images $P^{(l)}$, one for each level. Then, local contrast is calculated by taking the average difference between the channel value (e.g. luminance) $P^{(l)}_i$ of each pixel i and the surrounding 8 pixels j (which form subset $N8(i)$), thus obtaining a contrast map of each level l.

$$C^{RAMMG} = \frac{1}{\#liv}\sum_{l}\left[\frac{1}{m^{(l)}n^{(l)}}\sum_{i}\left(\sum_{j\in N8(i)}\frac{P^{(l)}{}_i - P^{(l)}{}_j}{8}\right)\right]$$

where $m^{(l)}$ and $n^{(l)}$ are the numbers of rows and columns on level l.

A recombination of the averages for each level results in the final overall measure. Its steps are described in Figure 1.

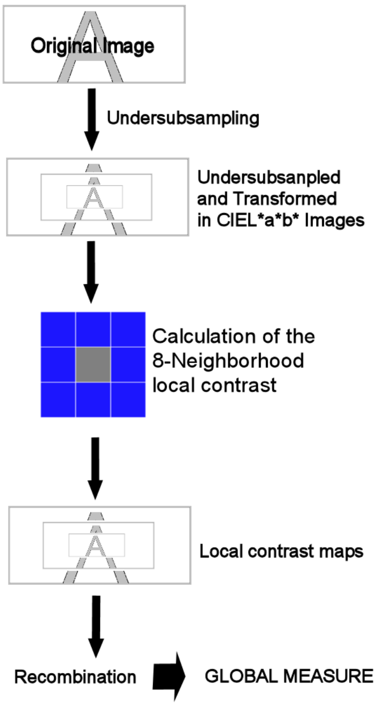

Figure 1. *RAMMG algorithm steps*

The proposed measure

We have combined *Rizzi et al*'s multilevel approach [5] with *Tadmor and Tolhurst*'s evaluation of a color stimulus [3]. The steps of the algorithm are described in Figure 2.

First, we compute all sub-sampled images creating a pyramidal image structure starting from the given image. Then, we execute a neighborhood contrast calculation for every pixel in each level using DOGs on the lightness and on the chromatic channels separately.

After this step, we extract the averages for each level, which will later contribute to the final measure, reported in the following formula:

$$RSC_c = \frac{1}{\#liv}\sum_{l}\left[\frac{1}{m^{(l)}n^{(l)}}\sum_{i} DOG^{(l)}(i)\right] \qquad (1)$$

where c is the channel on which is applied and

$$DOG = C_3 = \frac{R_c(x,y) - R_s(x,y)}{R_c(x,y) + R_s(x,y)} \qquad (2)$$

In order to consider also isoluminant color contrast configurations, we use also chromaticity channels of the CIEL*a*b* space, weighted differently than L^*. The final measure can be expressed by the formula:

$$RSC = \alpha \cdot RSC_{L^*} + \beta \cdot RSC_{a^*} + \gamma \cdot RSC_{b^*} \qquad (3)$$

The attempt is to investigate mainly two directions: first checking whether the use of DOGs on the multilevel pyramid yields a better performance in considering more extended edges and gradients in the image and, second, whether the use of the chromatic channels in the computation of the perceived contrast leads to more accurate measures.

As in RAMMG, pyramid levels are averaged and a single measure of contrast is produced at the end. This make the measure suitable for the use as a trigger on image dependent algorithms, but at the same time lose the ability to distinguish among various type of images that usually originate different contrast perceptions: e.g. geometric vs natural images.

In these preliminary tests, the averages of all the levels are averaged again among them, with uniform weights. In the authors' opinion some frequency channel could account more than others to the final perceived contrast and should therefore be assigned a stronger weight. We don't want to address this topic in the present paper. However the reader can use the presented approach keeping in a vector all the results for each level separately and develop a vectorial contrast comparison technique. This will be the subject of future developments.

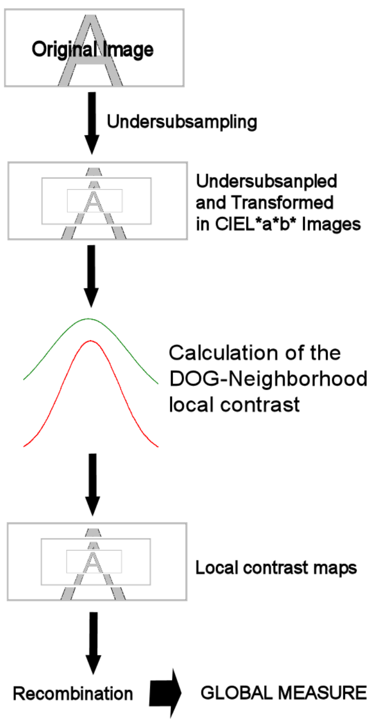

Figure 2. *RSC algorithm steps*

The computational complexity of algorithm RSC is the same as RAMMG [5]:

$$\Theta(N \log N)$$

where N is the number of pixels, but with a slightly heavier multiplication constant due to the DOGs instead of the neighbor difference computation.

Parameters

RSC parameters are the following: ColorSpace, Channels, γ, r_c r_s .

Here we briefly discuss each one:

- ColorSpace: The measure of contrast can be computed under CIEL*a*b* or CIEL*u*v* space. All tests reported in this paper have been computed on CIEL*a*b*.
- Channels: It's possible to decide to evaluate contrast only on L* channel, or on all of three channels.
- α β γ: the importance that we want to give to each channel in contrast calculation (see formula 3).
- r_c: It expresses the width of the center Gaussian component.
- r_s: It expresses the width of the surround component. r_s must be always greater than r_c .

This is only a preliminary proposal, thus a complete discussion of the parameters is missing. However, preliminary tests with users have been carried out to evaluate their behavior.

Tests and Results

The test set is the same presented in [6], composed of 15 different images, representing different characteristics.

17 observers were asked to rate the contrast in the 15 images. 9 of the observers were experts, i.e. had experience in color science, image processing, photography or similar and 8 non-experts had no or little experience in these fields. All observers were recruited from Gjøvik University College, both students and employees. Observers rated contrast from 1 to 100, where 1 was the lowest contrast and 100 maximum contrast. The observers were told to rate the contrast as they comprehended contrast, i.e. no definition of contrast was made by the researchers before starting the experiment. All observers had normal or corrected to normal vision. Each image was shown for 40 seconds with a surrounding black screen, and the observers stated the perceived contrast within this time-limit. The experiment was carried out on a calibrated CRT monitor, LaCIE electron 22 blue II, in a gray room. The observers were seated at approximately 80 cm [7] from the monitor, and the lights were dimmed and measured to approximately 17 lux.

Several outputs with different parameters $\alpha, \beta, \gamma, r_c, r_s$ have been generated for the test set. In Table 1 we show all RSC configurations adopted and the Pearson correlation with the subjective tests. Further details about psychophysical experiments together with comparisons have been presented in [6].

Pearson correlation			
$\alpha-\beta-\gamma-r_c-r_s$	All observer	Expert	Non Expert
1-0-0-1-2	0.51	0.46	0.42
1-0-0-1-3	0.49	0.41	0.44
1-0-0-2-3	0.49	0.56	0.26
1-0-0-2-4	0.50	0.53	0.31
1-0-0-3-4	0.42	0.55	0.14
0.5-0.25-0.25-1-2	0.18	0.38	-0.11
0.5-0.25-0.25-1-3	0.22	0.2	0.18
0.5-0.25-0.25-2-3	-0.13	-0.49	-0.34
0.5-0.25-0.25-2-4	-0.3	-0.048	-0.51
0.5-0.25-0.25-3-4	0.16	0.15	0.12
0.33-0.33-0.33-1-2	0.15	0.34	-0.12
0.33-0.33-0.33-1-3	0.21	0.19	0.17
0.33-0.33-0.33-2-3	-0.35	-0.15	-0.49
0.33-0.33-0.33-2-4	-0.31	-0.053	-0.51
0.33-0.33-0.33-3-4	0.15	0.13	0.11
Michelson-1-2	0.38	0.53	0.096
std-1-2	0.71	0.69	0.52
std-1-3	0.66	0.47	0.68
std-1-4	0.051	0.017	0.075
std-2-3	0.36	0.42	0.17
std-2-4	0.29	0.38	0.081
std-3-4	0.64	0.55	0.55
std-3-5	0.38	0.53	0.096
Poisson-1-2	-0.051	-0.099	0.022
Kurtosis-1-2	0.27	0.39	0.04

As we can see from Table 1 contrast has been measured on *L** channel only ($\alpha = 1, \beta = 0, \gamma = 0$), on *L*a*b** with equal weightings ($\alpha = 0.33, \beta = 0.33, \gamma = 0.33$), on *L*a*b** with greater weighting for lightness and equal for chromatic channels ($\alpha = 0.5, \beta = 0.25, \gamma = 0.25$).

Furthermore it has been measured on *L*a*b** weighting channels with different deviation index measured on the image itself: standard deviation (std), Poisson, Kurtosis. In this case the measures on the image have been calculated for each channel separately and used as weight for the contrast measure among channels.

In general r_c has been set between 1 and 3 and r_s between 2 and 5.

The goodness of each output has been evaluated with the Pearson correlation coefficient which reflects the degree of linear relationship between two variables (in this case the measure of contrast provided by RCS and the subjective measure provided by the observers). The correlation coefficient ranges from +1 to -1, indicating at the extremes a perfect positive and negative linear relationship.

Best results are obtained using small values of radius and weighting channels with the standard deviation of the image. Standard deviation seems to be an interesting feature to weight channels contribution to perceived contrast.

Conclusions and perspectives

A new proposal for the measure of contrast in digital images has been presented. We have combined *Rizzi et al*'s multilevel approach [5] with *Tadmor and Tolhurst*'s evaluation of a color stimulus [3]. It applies locally, at various sub-sampled levels, a computation of local contrast based on DOG and finally it recombines all the values to obtain a global measure.

DOGs have been chosen to investigate if they have a better performance in considering more extended edges and gradients in the image. According to preliminary tests the advantage of this approach is not evident.

A more interesting direction of investigation is the way achromatic and chromatic channels are recombined for the final measure. In fact, recombining the channels following measures taken from the image itself, seems to be a promising technique. In this way the contrast measure adjust itself according to the image to measure. However, more accurate tests are required to better understand this mechanism.

Pyramid levels are averaged and only one number of contrast is produced at the end. In these preliminary tests, the averages of all the levels are averaged again among them, with uniform weights. In the authors' opinion some frequency channel could account more than others to the final perceived contrast. Using the measures at the different levels and developing a contrast vectorial comparison technique will be the subject of future developments.

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Author Biography

Alessandro Rizzi

He took degree in Computer Science at University of Milano and PhD in Information Engineering at University of Brescia. Now he is assistant professor, and senior research fellow at the Department of Information Technologies at University of Milano. Since 1990 he is researching in the field of digital imaging and vision. His main research topic is color information with particular attention to color perception mechanisms. He is the coordinator of the Italian Color Group.

Gabriele Simone

He received his Bachelor in Information Technology in 2005, and his Master in Information Science and Technology in 2007 both at University of Milan - Department of Information Technology, Italy.

Actually he's a PhD student at Gjøvik University College, Norway.

Since 2004 he has been working and researching in the field of digital imaging and color science. His main research topic is contrast measure and tone mapping algorithm in HDR images.

Roberto Cordone

He took degree in Electronic Engineering at Politecnico di Milano and received PhD in Computer and Control Science at Politecnico di Milano .

Now he is assistant professor, teaching Algorithm Design and Analysis and Decision Support Methods and Models at the Department of Information Technologies at University of Milano.

His main research topics are computational complexity, combinatorial optimization, mathematical programming. He is fellow of the Italian Operational Research Society (AIRO).