A numerical inquiry into Multiscale Retinex

Jean-Michel Morel[1], Ana Belén Petro[2], Catalina Sbert[2]

[1]CMLA, ENS Cachan
61, avenue du Président Wilson, Cachan CEDEX, France

[2]Universitat de les Illes Balears
Crta. de Valldemossa km. 7,5, 07122, Illes Balears, Spain
morel@cmla.ens-cachan.fr, anabelen.petro@uib.es
catalina.sbert@uib.es

Résumé – Nous présentons une réflexion numérique sur *Multiscale Retinex*, probablement l'implémentation la plus réussie sous forme *center-surround* de la théorie du Retinex. Bien que cet algorithme apparaisse sous un grand nombre de versions et d'améliorations, une analyse de fond reste à faire pour en proposer des améliorations raisonnées. Nos résultats préliminaires prouvent que dans la plupart des images le logarithme peut être éliminé de l'algorithme *Multiscale Retinex*, (ce qui rend l'algorithme linéaire), que l'appliquer séparément sur les canaux *RGB* ou sur l'intensité est une décision qui dépend de l'image, et que le choix des échelles dépend de l'image.

Abstract – We present a numerical inquiry about Multiscale Retinex, the most successful center-surround implementation of the Retinex theory. Although this algorithm has a great quantity of versions and improvements, a deep analysis of the same does not exist, which is necessary to be able to present well-founded improvements. Some preliminary results show that in most images the logarithm can be eliminated from the Multiscale Retinex algorithm (which makes it linear), that performing Multiscale Retinex in the *RGB* channels or in the intensity channel is an image dependent decision and that the choice of the scales is image size dependent.

1 Introduction

Edwin H. Land's [1] 1964 Retinex theory is the first attempt to give an algorithm simulating the human color visual perception. This theory was further formalized by Land and McCann [2] in 1971. Many Retinex algorithms have been developed ever since. The initial goal of these "color constancy" algorithms is to modify the *RGB* values at each pixel to give an estimate of the physical color independent of the shading.

The interpretations, implementations and improvements of the Retinex algorithm can be categorized ([3], [4]) as center/surround algorithms, path-based algorithms, recursive algorithms and physically-motivated variants. See the review paper [5]. The goal of center/surround algorithms is actually to enhance local image contrast, revealing details in dark or overexposed regions. In this paper, we discuss the most popular exponent of the center/surround algorithms : the Jobson et al. [6] *Multiscale Retinex* algorithm. Even this algorithm has a large list of versions, modifications and improvements (see [7] for a review). Its authors have displayed excellent results in contrast enhancement, dynamic range compression and tonal rendition. Yet, these articles do not explain why does Multiscale Retinex obtain excellent results. They do not attempt at a necessary parameter analysis and reduction. In particular the choice of the right scales is not elucidated. Our numerical inquiry here, based on an online demo, has led to envisage several modifications of the original algorithm. It permits to examine in depth the role of the scales, the necessity of a nonlinear step, and the question of whether channels must be treated independently or not.

2 Multiscale Retinex with Color Restoration

The first algorithm proposed by Jobson et al. ([8]) is Multiscale Retinex (MSR) defined by

$$\mathcal{R}_{MSR_i}(x,y) := \sum_{n=1}^{N} \omega_n (\log(I_i(x,y)) - \log[F_n(x,y) * I_i(x,y)]), \qquad (1)$$

where $\mathcal{R}_{MSR_i}$ is the Multiscale Retinex output, $I_i(x,y)$ is the image distribution in the ith spectral band, $*$ denotes the convolution operation, N is the number of scales, ω_n is the weight associated with the nth scale, and

$$F_n(x,y) = Ke^{-r^2/c_n^2},$$

where c_n is the Gaussian surround space constant associated with the nth scale and K is selected such that

$$\int\int F_n(x,y)dxdy = 1.$$

This operation is performed on each spectral band to produce Land's triplet values specifying color and lightness.

In a posterior paper [6], the authors of Multiscale Retinex proposed an additional post-processing step. Indeed this original MSR can produce a bad color rendition, obtaining grayish images. The modified MSR that results is

$$\mathcal{R}_{MSRCR_i}(x,y) = C_i(x,y)\mathcal{R}_{MSR_i}(x,y)$$

where

$$C_i(x,y) = \beta \left\{ \log[\alpha I_i(x,y)] - \log\left[\sum_{i=1}^{S} I_i(x,y)\right]\right\}.$$

3 Variants of MSRCR Algorithm

As observed in [9], a faithful implementation of the post-processing step of MSRCR is difficult. No reasonable results were obtained with the formula and constants proposed in [6]. To settle this problem, we decided to replace this post-processing, which aim is to stretch the colors, by the simplest available method matching the $\mathcal{R}_{MSR_i}(x,y)$ values to the interval $[0,255]$. This method, "Simplest color balance" is presented in [10].

Taking into account the previous questions, we decided to realize a public demo in IPOL (`http://dev.ipol.im/~lisani/ipol_demo/mps_colormethods/`) with the following modifications in the initial algorithm, to be able to analyze the results :

– Multiscale Retinex in RGB channels or in intensity channel (affix *color* or *gray* in the demo) : MSR is applied to each RGB channel, since the original Retinex performed that way. Yet one can wonder if it is not better to perform an intensity channel modification maintaining the initial color ratios.

– Two new parameters to control the role of the scales : The authors proposed an algorithm with three scales (15, 80, 250), but we propose to consider the scales $w_0 \cdot p^n$, where $n = 0, \ldots, \log_p(dim/w_0)$ with dim the image dimension, w_0 and $p > 1$.

– To displace or to eliminate the logarithm : these two new versions of the algorithm modify the value of $\mathcal{R}_{MSR_i}$ eliminating the logarithm (demo name : *MSRCR_ scales_ nolog*),

$$\mathcal{R}_{MSR_i}(x,y) = \sum_{n=1}^{N} \omega_n (I_i(x,y) - (F_n(x,y) * I_i(x,y))), \quad (2)$$

or moving the logarithm (demo name : *MSRCR_ scales_ logdiff*) :

$$\mathcal{R}_{MSR_i}(x,y) = \sum_{n=1}^{N} \omega_n \log\left(I_i(x,y) - (F_n(x,y) * I_i(x,y))\right) \quad (3)$$

4 Results

4.1 RGB channels *versus* intensity channel

Several authors consider that a better solution can be obtained with a luminance version of MSRCR ([9], [11]) replacing I_i by the single intensity result in Formula (1). Figure 1 illustrates that the choice between the RGB channel and the intensity channel is image dependent. If the original image has a grayish tone, the application of MSRCR in the RGB channels manages to heighten the "hidden" colors (see top of Figure 1). If the original image had a strong color variety, the application of the multiscale Retinex in the RGB channels loses these colors, and yields a greyish image (see bottom of Figure 1).

4.2 Role of the scales

The choice of the opportune "center-surround" scales are discussed by Jobson et al. in several paragraphs of their article [6]. They declared that "experimentation is our only guide in resolving these issues" (in reference to the number of scales to be used and how should be combined), and, they too affirmed that "the choice of the surround space constants does not seem to be critical". Our experimental setup permits to explore the number of scales and their values in MSRCR.

A first observable fact is that the choice of the surround space constants alters the result, and that it is size image dependent. The largest scale is the image size. Therefore, the affirmation of Jobson et al. that a large scale is represented by $c_n > 200$ is true when we consider 400×400 images. For larger images we must consider far larger scales. Figure 2 illustrates this fact. The original image is a large image (2448×3264). The top of Figure 2 shows the results applying a scale of the size proposed by Jobson et al. (c_n=250) and a larger scale (c_n=1000), more adapted to the image size. The result with a small scale obtains a greyish and poorly contrasted image. With a larger scale, proportional to the image size, we obtain more realistic colors and a better enhanced image. Taking this fact into account, we can obtain better results by changing the values of the surround spaces constants. This fact can be observed on the bottom of Figure 2.

In reference to the number of scales, the experimentation has demonstrated that three is the minimum number of scales necessary for acceptable performance, as Jobson et al. had noticed, and that a larger number of scales does not change substantially the result. We can observe in Figure 3 that the values of w_0 have little influence on the perception of details. The smallest w_0 is strong on details. Changing p, the number of scales, does not produce big changes in the image.

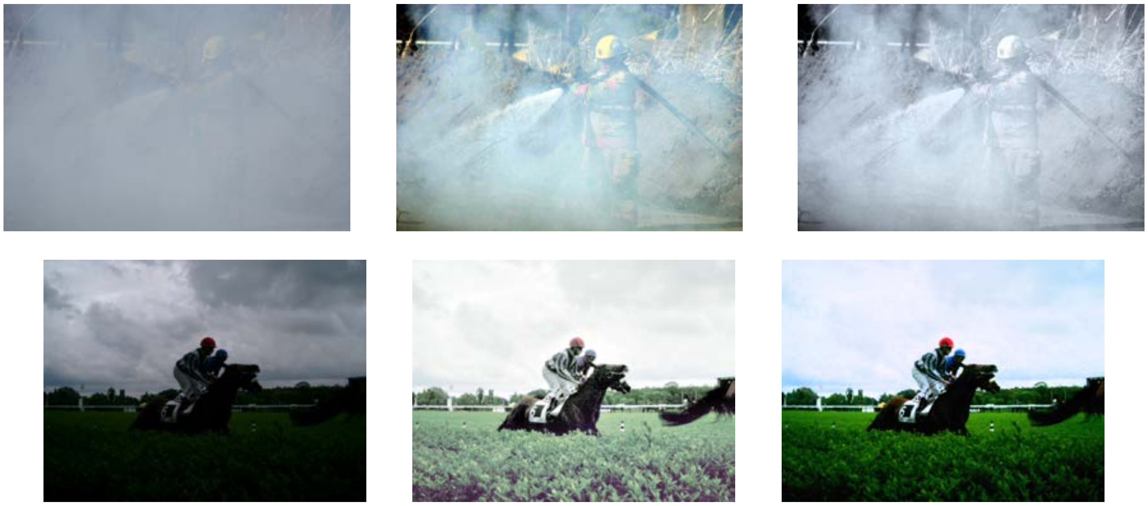

FIGURE 1 – An example of the role of the intensity channel or the RGB channels. Left : Original image. Middle : Result using the RGB channels. Right : Result using the intensity channel.

FIGURE 2 – An example of the role of the scales. Top left : Original image. Top center : Result of Single-Scale Retinex (SCR) with $c_n = 250$. Top right : Result of SCR with $c_n = 1000$. Bottom left : Result of Multi-Scale Retinex with c_0=15, c_1=80 and c_2=250, proposed values in article [6]. Bottom right : Result of Multi-Scale Retinex with c_0=15, c_1=250 and c_2=1000, values adapted to the size of the image.

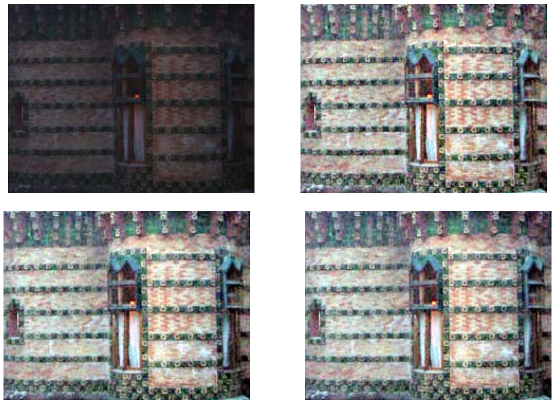

FIGURE 3 – An example of the role of the scales, different results changing the values of w_0 and p. Top left : Original image. Top Right : $w_0 = 2$ and $p = 2$. Bottom left : $w_0 = 16$ and $p = 8$. Bottom Right : Result with original Multiscale Retinex.

4.3 Role of the logarithm

Is the intervention of the logarithm in (1) necessary ? It makes the algorithm into a nonlinear filter. Barnard and Funt ([9]) have commented that global contrast adjustment in MSCRCR is performed via the logarithm. Thus, as we have observed, on images with a good contrast, better results are obtained using the linear filter Formula (2) than using the original MSRCR. Indeed, a contrast enhancement is not necessary, and colors are modified unnecessarily by involving the logarithm. The results moving the position of the logarithm by Formula (3) reinforce the intuition that the logarithm yields a global enhancement. In consequence these results present an excessive enhancement, with excessive detail and therefore an unreal image.

Figure 4 illustrates these facts. If we eliminate the logarithm, we obtain a better result (see bottom left in Figure 4). On the other hand, if we displace as indicated the logarithm we obtain enhanced images, with many details and looking slightly artificial (bottom right in Figure 4).

5 Conclusions

We have presented a initial inquiry about the well-known algorithm MSRCR. In reference to the scales, we conclude that for larger images we must consider far larger scales. In reference to the logarithm, we conclude that the logarithm yields a global enhancement, then it is unnecessary in images with good contrast. Finally, we have observe that the MSRCR applied to the intensity channel is better in images with a good color balance.

Références

[1] E.H. Land, *The Retinex*, American Scientist, Vol. 52, Pag. :247–264, (1964).

[2] E.H. Land and John McCann, *Lightness and Retinex Theory*, Journal of the Optical Society of America, Vol. 61, n. 1, Pag. : 1–11, (1971).

[3] R. Kimmel, M. Elad, D. Shaked, R. Keshet and I. Sobel,*A variational framework for Retinex*, International Journal of Computer Visision, Vol. 52(1), pp. 7-23, (2003).

[4] L. Ling, Z. Yinqing and L. Jingwen, *An investigation of Retinex algorithms for image enhancement*, Journal of Electronics (China), Vol. 24, n. 5, pp. 696-700, (2007).

[5] Jean-Michel Morel, Ana Belén Petro and Catalina Sbert, *A PDE Formalization of the Retinex Theory*, Vol. 19(11), pp. 2825-2837, IEEE Transactions on Image Processing (2010). `DOI:10.1109/TIP.2010.2049239`

[6] Jobson, D.J., Rahman, Z.-U., Woodell, G.A. *A multiscale retinex for bridging the gap between color images and the human observation of scenes*, (1997) IEEE Transactions on Image Processing, 6 (7), pp. 965-976.

[7] Mc Cann John J. and Rizzi A., *The art and science of HDR imaging*, John Wiley & Sons, 2012.

[8] Rahman Z., Jobson D. and Woodell G. *Multiscale Retinex for Color Image Enhancement*, Proc. of the IEEE International Conference on Image Processing, Vol. 3, pp. 1003-1006 (1996).

[9] Barnard K. and Funt B., *Investigation into multiscale retinex*, Colour Imaging : Vision and Technology, pp. 9-17, John Wiley and Sons (1999).

[10] Jean-Michel Morel, Ana Belén Petro and Catalina Sbert, *Simplest Color Balance*, Image Processing on Line (2011), `http://dx.doi.org/10.5201/ipol.2011.llmps-scb`.

[11] L. Meylan and S. Susstrunk, *High dynamic range image rendering with a retinex-based adaptive filter*, IEEE Transactions on Image Processing (2006), 15 (9), pp. 2820-2830.

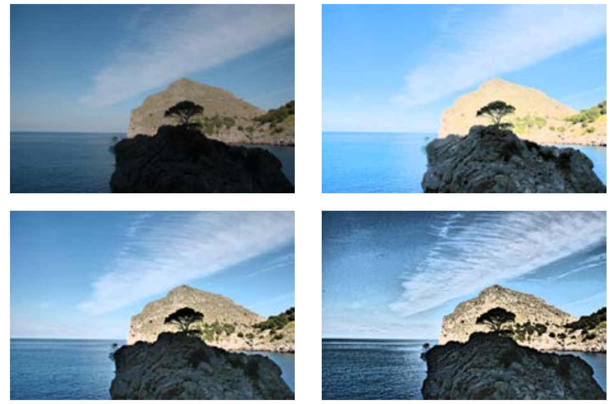

FIGURE 4 – An example of the role of the logarithm. Top Left : Original image. Top Right : Result using the original Multiscale Retinex. Bottom left : Result eliminating the logarithm. Bottom Right : Result moving the logarithm.