Tuning Retinex for HDR Images Visualization

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Abstract

In some cases, consumer devices (monitors, printers, cameras, etc) do not allow us to capture or reproduce the full range of luminance information of a synthetic or real scene. Many techniques have been proposed in the last years, that address the tone mapping problem (i.e. the conversion from real luminance values into available ranges) trying to simulate some mechanisms of the Human Visual System, but few of these take into account the color constancy problem, i.e. the ability to discount color cast induced by illuminant. In this paper we present some experiments on high dynamic range images, modifying a Retinex implementation, the Brownian Retinex algorithm (characterized by the construction of Brownian random paths in the image), to solve the tone mapping and the color constancy problem at the same time. We also try to better simulate the process of scene observation, considering the eye movements called *saccades* and simulating them by applying different statistical distributions to random paths construction. Moreover, we propose an alternative technique to compute Retinex ratios on the paths, based on the assumption that vision can be considered a kind of sampling process.

Introduction

In several cases, the full range of luminance information of a synthetic or real scene is not compatible with the supported ranges of normal consumer devices like monitors or printers. In fact, a standard display has a maximum range of supported luminance of two order of magnitude, while in the real world we can find up to five or six order of magnitude ranges (e.g. sun and shadows at midday on a beach or on a snowy ground).

On the other side, modern computer graphics algorithms can calculate with great accuracy the light-material interaction in a synthetic scene, giving as results luminance values very close to a real scene; furthermore, recent methods[2] allow us to obtain actual extended ranges of radiance values of a real scene taking several photographs at increasing exposure intervals.

In the last years, the increasing simplicity to obtain this kind of data has brought to a great interest in algorithms[4] that try to simulate Human Visual System (HVS) mechanisms, converting luminance values into limited ranges of commercial media (this is called the *tone mapping* or *tone reproduction* problem), and consequently it has originated a great diffusion of a new kind of images, the so-called High Dynamic Range (HDR) images, that allow us to store the complete luminance of the scene.

However, few of the operators proposed so far take into account the problem of the color shift induced by light sources, which gives rise to pictures whose colors are different to those we expect to see observing the real scene. This problem is due to the fact that HVS is able to adjust the chromatic appearance of the scene under varying light sources, while a camera or an image synthesis software are not. In fact, in synthetic image generation usually color is computed following the tristimulus model, therefore the resulting colors have the same characteristics of a photograph taken using a film non calibrated for the given light source. In digital photography, color images are acquired on the three bands of the camera sensor, it is therefore evident that this method has the same limitations of traditional photography, in particular the absence of color adaptation mechanisms.

On the contrary, in real life, if we observe a scene under different light conditions, illuminated for instance by a tungsten lamp or by the sunlight through a window, we do not perceive any important color difference. This human ability to compensate for varying light conditions is called *color constancy*.

HVS mechanisms are very interesting since they are able to adapt automatically to any lighting situation, without requiring any knowledge about object reflectances or spectral light composition. Their robustness mainly derives from the locality of the adaptation mechanisms.[10]

HVS does not perform any spectral estimation. From HVS point of view, color constancy means preserving the appearance of the scene under every kind of illuminant. Consequently adaptation has not to be exact or complete[11] and no illuminant can be preferred to any other to judge this adjustment.

Using a model of HVS perception is an effective way to obtain simultaneously a natural mapping of the luminance and a color correction. A well-known model of color perception that explains HVS color constancy is the *Retinex* theory,[7,8] introduced by Edwin Land and John McCann.

The Retinex Theory

The Retinex theory assumes that color perception is the result of complex comparisons among different visual areas. The input to this processing is the stimulus of the retina cones, and the processing is completed in the higher cortical visual area of the brain. A quantity exists, named "lightness", that is associated to every object of a scene, and that does not change with illumination conditions or object location; this quantity is perceived by the HVS independently from the light flux that impinges the eye. The magnitude of the perceived signal is relative and what gives us the sensation of lightness or color is the relative lightness of the area compared to the rest of the scene. This is the basic idea of Retinex, which calculates relative ratios across the image in order to recompute each perceived value. This is done independently on the three retinal-cortical systems, each processing the low, middle and high frequency of the visible spectrum.

Land and McCann discussed[7] how this computation can be simulated. They came to the conclusion that a couple of excitatory and inhibitory neurons in a chain can account for the reset mechanism required by the search for the lightest area (i.e. the white).

The basic Retinex algorithm is applied separately on the three chromatic channels of a digital image. For each channel, every pixel is recomputed "exploring" the image with a certain number N of paths.

For each color plane, the relative lightness *R(i)* of a pixel at position *i* is computed as the mean value of relative lightnesses *r{i,j}* computed along the N paths starting from points *j* and ending in point *i* (see Figure 1):

$$R(i) = \frac{\sum_{k=1}^{N} r(i, j_k)}{N} \tag{1}$$

with

$$r(i, j_k) = \sum_{x \in path} \delta \cdot log \frac{I_{x+1}}{I_x} \tag{2}$$

and

$$\delta = \begin{cases} 1 & if \ \left| \log \frac{I_{x+1}}{I_x} \right| \succ threshold \\ 0 & otherwise \end{cases} \tag{3}$$

In the previous equations *I* is the value of the pixel at location *x* in each chromatic channel.

The threshold plays the role of reducing non-uniform illumination, since it eliminates low lightness ratios.

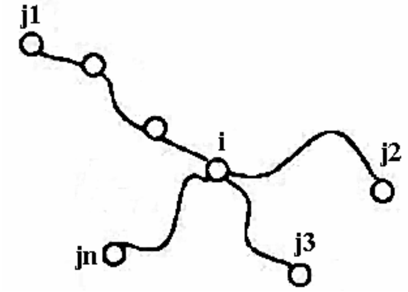


Figure 1. Paths for the computation of the average relative lightness.

Finally, during a path computation, a reset mechanism is adopted so that if a brighter area is found, the cumulated relative lightness is clamped to the maximum value. This forces the computation to restart from the brightest area, considering it as a white reference.

Different implementations of Retinex have been developed so far.[12] These algorithms differ in the way the image is explored, in the use of the threshold and on the proposal of a multiscale approach. The latter aspect has been introduced mainly to reduce the high computational cost of the basic algorithm.

The research described in this paper is based on a Retinex implementation called Brownian Retinex,[9] characterized by the construction of Brownian random paths (see Figure 2) in the image, inspired by the distribution of receptive field centroids in cortical area V4,[17] responsible for color vision in complex scenes.

The approximation method used to construct the random paths is the well-known mid-point displacement recursive algorithm,[14] that displaces randomly the middle point of a segment and applies recursively the same method on the new two generated segments.

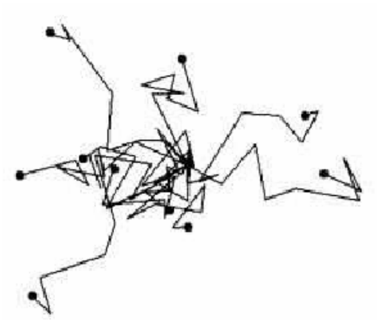


Figure 2. Example of 10 Brownian paths.

Experiments on HDR Images

We tested a modified version of Brownian Retinex on HDR images to perform, at the same time, both tone mapping and color recovery.

We have improved the algorithm trying to better simulate the process of scene observation. In particular we recall that observation is composed by a sequence of two different stages: the movement of the eye, called *saccade*, shifting the gaze direction from a point to another, and a short interval between two *saccades*, called *fixation*. Information on the scene observed is taken only during fixations; no information is acquired during saccades.[3,5,6,15,16]

The saccades movements are mainly due to the high concentration of cones (and thus to the high visual acuity) in the 2-5 degrees area of the retina, centered in the gaze direction, called *fovea.* Therefore human eyes must move to compensate the drop in both resolution and color sensing in the most part of retina outside the fovea.

The analysis of eye movements is a complex topic: saccades are in many cases automatic and unconscious, guided only by the lack of resolution outside the fovea, but they can also be voluntary, often affected by various elements, e.g. the context of the scene observed[16] (the eye moves in different ways if we are looking to a panorama instead of a room or a face, because different is the kind of information and features that must be analyzed).

Saccades could also be generated by a sudden visual stimulus, like a rapid light impulse or a moving feature in the scene, or they could be guided by specific intentions or decisions of the viewer,[3] as the research in the scene of a particular object or the reading of a text; in some cases, even the past experience and the attitude of the viewer influences the eye movements.[16] Relevant are also the effects of memory and recognition: the second time we look at a room our eyes move differently compared to the first time. Thus, eye movements present both conscious and unconscious aspects; in this paper we mainly consider low-level, automatic, unconscious aspects.

What we can notice is that, due to these aspects, eye scan-paths[15] present an alternation between different types of saccades: quick jumps among largely spaced points and shorter shifts. Visually this alternation consists in a sequence of some segments that lie almost on the same line, that suddenly changes direction (see Figure 3). This is more evident in areas where the movements are made in unconscious and automatic way (e.g. those circled in Figure 3), not driven by some points of attention; this makes the eyes converge voluntary and near these points the scan-path appears more crumbled.

Ignoring the complex components that influence voluntary saccades, whose computational simulation is still an open problem, we tried to construct random paths with both the characteristics described above (quick jumps and shorter shifts) in a uniform way across the image, and whose appearance resembles those that can be observed in many eye scan-paths, as the one circled in Figure 3.

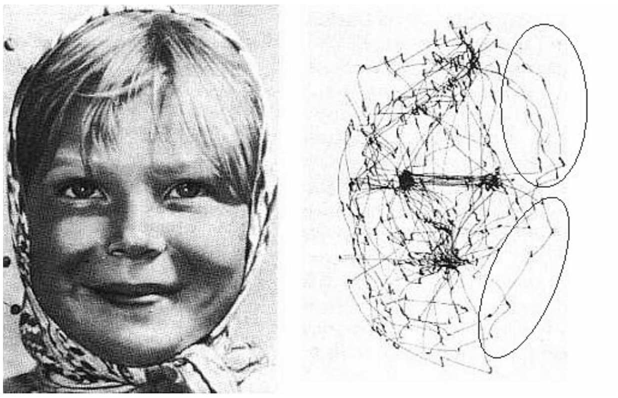


Figure 3. An example of eye scan-path[15]: in the ovals the path structure we have tried to simulate.

We would like to recall that our approach does not intent to exactly simulate eyes movements, but only to take inspiration from them in order to develop an efficient exploration of the image. To this aim, we have made some experiments focusing our attention on the random distribution of the mid-point displacement algorithm, that rules the position of the points of the paths in the image, and therefore their final shape.

We considered uniform and Gaussian distributions, as discussed in the next subsections. Moreover, we propose an alternative technique to compute Retinex ratios on the generated paths.

Applying Uniform Distribution

We have modified the Brownian paths computation by calculating random shifts using uniform distribution: resulting paths are very crumbled, largely spaced across the image, with long jumps from one point to another, similar to the first saccades type cited above, like paths marked with circles in Figure 4.

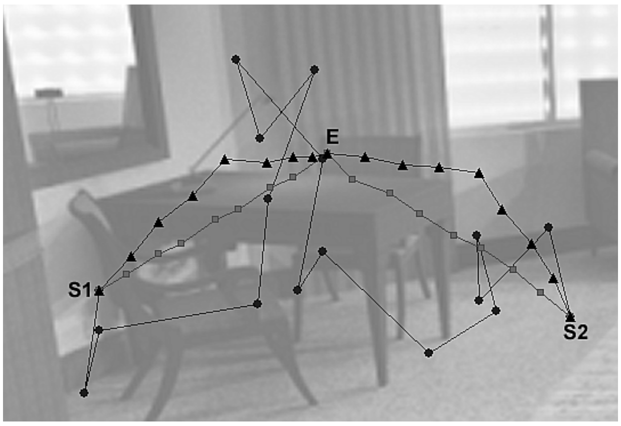


Figure 4. An example of paths (from point S1 and S2 to point E), constructed applying uniform distribution (lines with circles), Gaussian distribution (lines with squares), and both distributions together (lines with triangles).

Applying to HDR images the modified Retinex algorithm, with paths constructed only with uniform distribution, we observed a good color recovery effect in all the situations, but with poor rendition in dark areas (see images *(a)* in Figures 6 and 7).

Applying Gaussian Distribution

Trying to simulate the other saccades type, the shorter shifts, we needed a random distribution that gives as results little displacements for the middle points of the segments in the various levels of recursion of the paths construction algorithm.

Our choice was to use Gaussian distribution in the algorithm instead of the uniform, because the obtained Gaussian paths are almost straight, presenting much smaller shifts, exactly the effect of this kind of movement (see the paths marked with squares in Figure 4).

Applying the Retinex algorithm with paths constructed only with Gaussian distribution we have obtained brighter and more detailed images, but, in most cases, with halos and artefacts, due to both the Retinex reset mechanism and the strong Gaussian paths directionality (see images (*b)* in Figures 6 and 7).

Applying Both Distributions Together

In the third experiment we have tried to simulate the two movements together. To this aim we used the uniform distribution at the first level of recursion of the mid-point displacement algorithm, and the Gaussian distribution at the other levels, generating paths that exhibit the characteristics of both the saccades types considered (see the paths marked with triangles in Figure 4). In particular these paths resemble those indicated in Figure 3.

The images filtered using the Retinex algorithm with paths constructed using this new technique have the same brightness of those filtered only with gaussian paths, but with halos and artefacts removed in most images (as the image *(c)* in Figure 6).

Undesired artefacts are still present in some images (e.g. the image *(c)* in Figure 7) in which bright light sources of reduced dimensions cause the presence of small areas with high local contrast that lead to a relevant reverse gradient effect.

A New Proposal to Compute Retinex Ratios

The results obtained with the experiments exposed above are promising, but not completely satisfactory. The enhancement in the overall brightness of the output images obtained using both distributions instead of uniform distribution only can be improved.

Thus, we focused our attention on *how* the paths are used to compute Retinex ratios. In fact, the basic Brownian Retinex uses the Bresenham algorithm[1] to determine all the pixels along a path segment. Equations 1, 2 and 3 are then applied on all the pixels involved by a path, as shown in the top half of Figure 5.

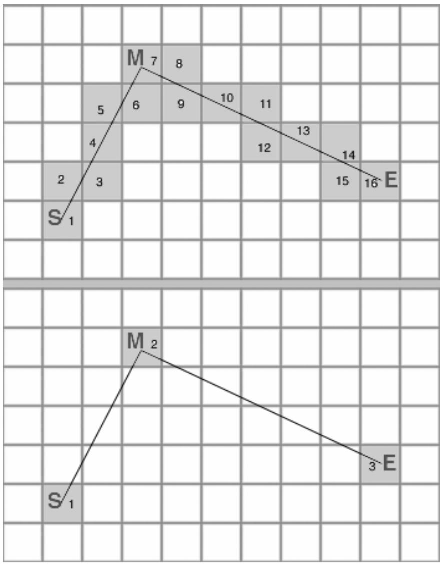


Figure 5. Schemes of Bresenham algorithm (top) and of the proposed method (bottom). In the first case Retinex algorithm is applied on all the marked pixels, in the second case it is applied only on the line terminal points.

In the saccades analogy, this could be as considering the eye capturing information from *all* the points on a path, but this is not what happens: information is captured only during the fixations. Thus vision can be considered a kind of *sampling process* of the information of the observed scene.

Consequently, we decided to simulate this sampling process computing the Retinex ratios only on the terminal points of each segment chain (see bottom half of Figure 5), without scan converting each path segment.

The obtained results are satisfying: the images are pleasant and appear natural, with a relevant enhancement of their overall brightness. Also color recovery is enhanced, one example is the sky in image *(d)* of Figure 6; it can be noticed that halos and artifacts still present in some previous results are now completely eliminated, like in image *(d)* of Figure 7.

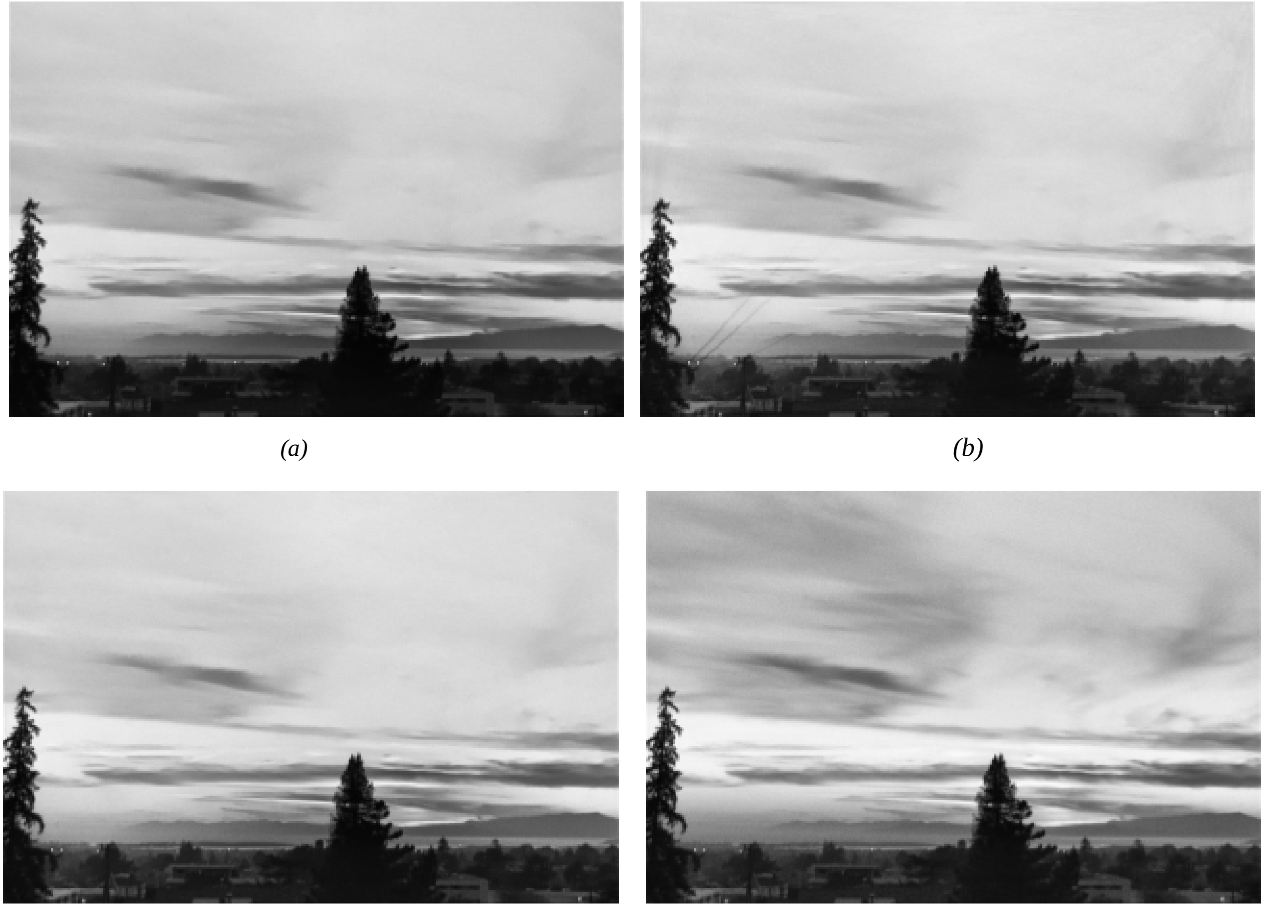
Conclusions

In this paper we have presented some experiments on HDR images, modifying a Retinex implementation, the Brownian Retinex algorithm,[9] to solve the tone mapping and the color constancy problem at the same time.

We took inspiration from the eyes movements called saccades in order to develop an efficient exploration of the image, applying uniform and Gaussian distributions to random paths construction. Moreover, we have proposed an alternative technique to compute Retinex ratios on the paths, based on the assumption that vision can be considered a kind of sampling process: scene information is not acquired during eyes movements, but only between subsequent saccades.

In absence of quantitative measures of the HVS adjustment in observing complex scenes, the naturalness of the final image can be a possible criterion for evaluating the HDR displaying process. In our opinion the final results obtained from HDR images representing synthetic and real scenes appear natural and pleasant, with a satisfactory color recovery effect. Other results and comparisons (without gamma correction) between the various experiments are available at the web address http://eidomatica.dico.unimi.it/eng/research/TnRet.html.

Presently we are testing the use of a new contrast measure[13] in order to control the level of recursion in the construction of the paths. This idea is based on the fact that human eyes acquire the information in relation to the contents, and consequently to the contrast, of the observed scene.



(a) *(b)*

(c) *(d)*

*Figure 6. Images filtered with paths constructed applying uniform distribution (a), Gaussian distribution (b) and both distributions together (c). Retinex ratios are applied to the pixels determined by the Bresenham algorithm. In image (d) the ratios are applied instead only to the terminal points of each path. See the evident artefacts in image (b), and how they are eliminated in image (c). Also, see the improvement in the color rendition of the sky and of the clouds between images (c) and (d). The images are no gamma corrected. Original HDR image by Paul Debevec (*http://www.debevec.org/*).*

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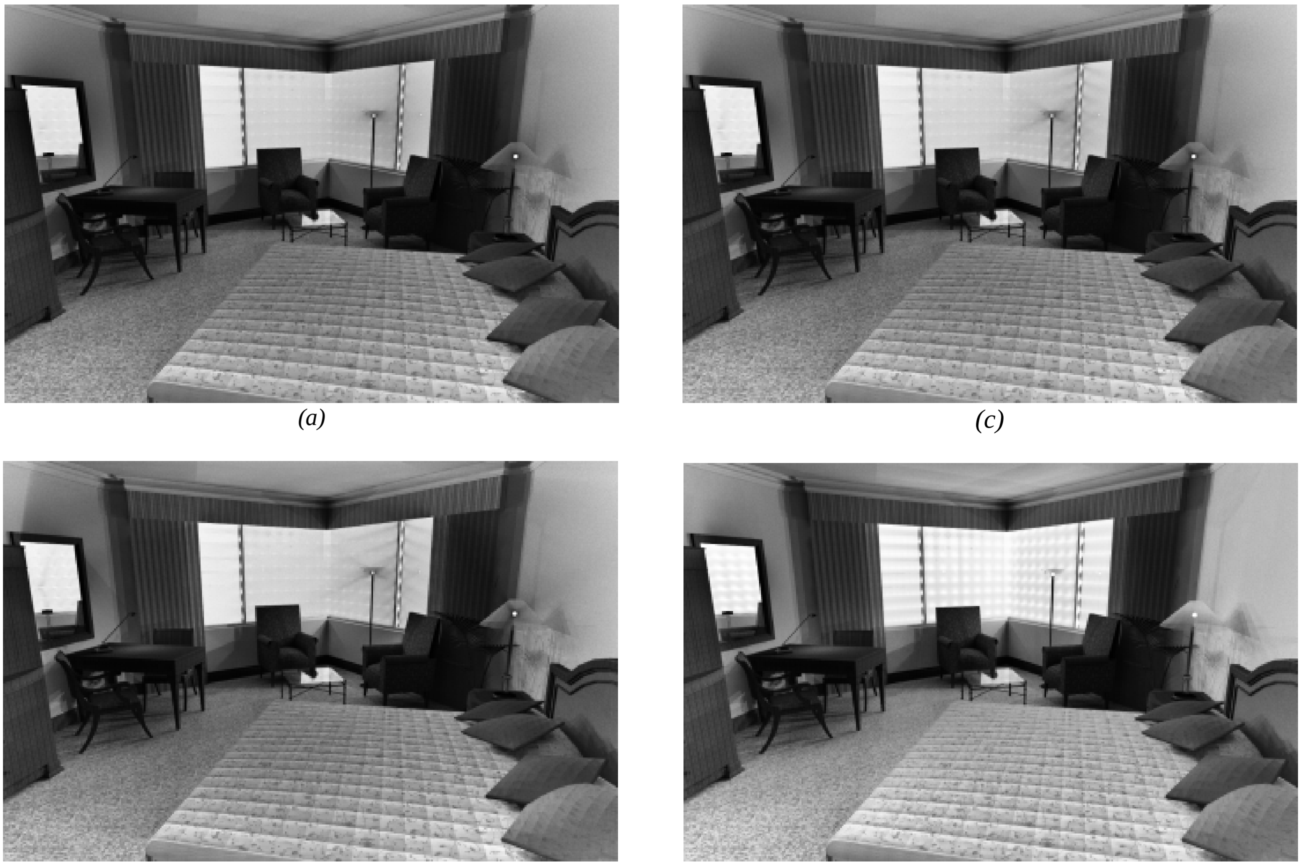

(a) *(c)*

(b) *(d)*

Figure 7. Images filtered with paths constructed applying uniform distribution (a), Gaussian distribution (b) and both distributions together (c). Retinex ratios are applied to the pixels determined by the Bresenham algorithm. In image (d) the ratios are applied instead only to the terminal points of each path. See the evident halos in image (a) and the artefacts in image (b) around the light sources. In image (c) we notice only an attenuation of the undesidered features, still present and relevant.In image (d) artefacts are completely eliminated; the image is brighter and more detailed (see the window and the mirror on the left). The images are no gamma corrected. Original HDR image by Simon Crone.

Biographies

Davide Gadia (gadia@dico.unimi.it) took the Degree in Computer Science at University of Milano in 2003, and now he is a Ph.D. student in Computer Science. Actually he is participating at the research project “Computational Simulation of Colors Appereance”. His research fields are Computer Vision and Computer Graphics.

Daniele Marini (daniele.marini@unimi.it) is an Associate professor, he graduated in Physics in 1972; since 1978 his research at the Department of Information Sciences of the Università di Milano encompasses several areas of graphics and image processing, with specific reference to visual simulation, realistic visualization, classification, image recognition and compression. In Italy he pioneered the image synthesis: he contributed to the foundation of the journal PIXEL and he was one of the founders of the Aicographics association.

In 1982 he created Eidos, the first Italian company specialized in the advanced image processing till 1988. Since 1997 he is member of the National University Council. In 1998 he was appointed supervisor and coordinator of the initiatives on multimedia at Triennale di Milano. He published more than 140 papers as well as three books. Presently, he is teaching Computer Graphics and Image Processing for the Graduation Programs on Informatics at the Università degli Studi di Milano.

Alessandro Rizzi (rizzi@dti.unimi.it) took the degree in Computer Science at University of Milano and received a PhD in Information Engineering at University of Brescia (Italy). He taught Information Systems and Computer Graphics at University of Brescia and at Politecnico di Milano. Now he is assistant professor at University of Milano teaching Multimedia and Human-Computer Interaction. Since 1990 he is researching in the field of digital imaging and vision. His main research topic is the use of color information in computer vision with particular attention to color adaptation mechanisms.