COLOUR CONSTANCY AND OPTICAL ILLUSIONS: A COMPUTER SIMULATION WITH RETINEX THEORY

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ABSTRACT

Traditional colour models do not give satisfactory justification of human ability to perceive colours with different illumination conditions, both in terms of spectral and intensity distribution, and do not solve colour constancy problem. In this paper we present results of a computer simulation of the Retinex Theory that allows to solve various problem in colour constancy, both during image acquisition and reproduction. Main results are: the possibility of balancing colours independently from source light spectral composition, of equalising luminance, of emulating human compensation ability in non uniform illumination, and the emulation of some known colour illusion effects. *

1. Introduction

A critical problem in colour Image Analysis and Synthesis is the accurate reproduction of colour signal. The colours reflected in a scene change accordingly to change of illumination conditions. A uniform colour surface illuminated by a non uniform intensity source reflects irregular intensities as well. The spectral composition of reflected light is influenced by the spectral composition of the light source. The physical laws that rule these effects are based on electromagnetic theory and can be approximated by computational methods based on the tristimulus colour model. This same colour model is used in photorealistic image synthesis to correct the luminance response in the three colour frequencies with approximated human sensitivity curves [3,5].

The importance of constant colour detection can be easily experienced in colour photography: by varying the illumination of a scene from sun or daylight to lower temperature light sources, e.g. the same scene has an orange dominant colour when artificial lights are used for a picture shot. Colour variations due to irregularly illuminated areas can be only partly attenuated by applying equalisation techniques. All these methods and techniques can solve the problems of uniform illumination or colour constancy one at a time. So does not exist a reliable and scientifically well founded method that emulates what human vision system performs continuously and in real time.

Such problem, known as Colour Constancy Problem, can be considered as an inverse problem [4]: to identify the reflectivities of a surface, given the light emission spectral distribution, photoreceptor sensitivity and photoreceptor response. Unfortunately in many practical situations the light emission spectral distribution is not known a priori.

Another open problem is how and why human perception is relatively non sensitive to limited variations in illumination conditions. Moreover human ability of colour correction has some drawbacks: well known are many optical illusions that arise in particular colour configurations. A typical illusion, usually taught in design schools, arises observing a configuration of two small paper square of the same colour placed in

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the middle of two other larger papers of different colour: the internal squares appear of very different colour. An accurate classification of such illusions has been proposed by Itten and Albers [1,6].

2. The Retinex Model

Many efforts have been devoted to a comprehension of colour perception, and it is of particular interest the theory of Retinex, due to Edwin Land [7,8,9], who assumes that colour perception depends strictly on the neural structure of human vision system. Land experienced that human colour perception is not based on absolute sensitivity to spectral radiant flux from a reflecting surface. The experience is based on a colour display, a patchwork of coloured papers of different size, illuminated with three independent and controllable light sources whose spectral composition is around 670, 540 and 450 nanometers. The relative intensities of the sources are adjusted so that the light flux from an area of a given colour is the same as that from an area of a different colour, in both cases the observer perceives the proper colour sensation for the two different colour areas.

This experiment, that has been repeated with success by others, drives Land to the hypothesis that colour perception depends on "lightness", i.e. a psycho-physiological property that, in turn, depends on the physical relative reflectivity of the coloured areas. Land and McCann [7] proposed a computational model based on the calculation of relative reflectance of coloured 'Mondrian' patches as the mean value of relative reflectance computed along a number N of random paths to that patch:

$$R^{\lambda}(i) = \frac{\sum_{j=1}^{N} R^{\lambda}(i,j)}{N} \quad \text{where:} \tag{1}$$

$R^{\lambda}(i,j) = \sum_{k} \delta \log \frac{I_{K+1}}{I_k}$ is the reflectance of a coloured patch i relative to a patch j,

and: $\delta \log \frac{I_{K+1}}{I_k} = \begin{cases} \log \frac{I_{K+1}}{I_k} & \text{if } \left| \log \frac{I_{K+1}}{I_k} \right| > \text{threshold} \\ 0 & \text{if } \left| \log \frac{I_{K+1}}{I_k} \right| < \text{threshold} \end{cases}$

These computations are to be executed for the three fundamental frequencies corresponding to red, green and blue colours, following the theory of the spectral main sensitivities of human cones. This algorithm depends on the randomness and number of paths that are chosen for the computation of the relative reflectance, moreover to the level of the threshold that makes less relevant low reflectance ratios, that correspond to smooth change in colour due to non uniform illumination. The basic Land algorithm moreover has a reset mechanism which, during a path computation, if a lighter area is found the cumulated relative reflectance is forced to 0, making the average computation to restart form this area. The effect of the reset mechanism is to consider as white reference value the lightest area of an image.

Retinex theory has been explored and tested only with artificial images (so called Mondrian colour patches) and has given contradictory results [2,10,11]. An RGB image can be analysed by the Retinex algorithm producing another RGB image whose colours are corrected by simulating the Retinex model of the human visual process.

3. A Retinex Algorithm Implementation

We have implemented a version of Retinex algorithm and applied it to a variety of images, not only to the original Mondrian like coloured patches. The algorithm examines an image pixel by pixel, computing the relative reflectance as in (1). It works separately on each main colour components R,G and B.

We have implemented two method for the generation of random paths: a first one based on a random number generator required at least 200 paths for each pixel to obtain good quality results. A more accurate and efficient result has been obtained adopting Brownian motion simulation to generate paths so that the algorithm becomes an approximation to a stochastic integral. In this case about 40 paths can produce results comparable to the former random path generation method. A path reduction or a better image quality can also be obtained by framing the input image with a white area, as artists and graphics designers do to present their works. Our Retinex algorithm can be used as a filter to balance colours and to equalise input image, with better results then traditional histogram equalisation methods. We have applied Retinex filter to a set of Albers-Itten illusive patterns; the resulting images exhibit an aspect close to the perceived one, as shown in fig. 1. Our experience gives evidence that Retinex theory can be used to improve image equalisation, colour correction and constancy against varying light characteristics and white balancing. Moreover the simulation of optical illusions suggests to consider Retinex colour perception model as a good candidate to simulation of human perception process.

4. References

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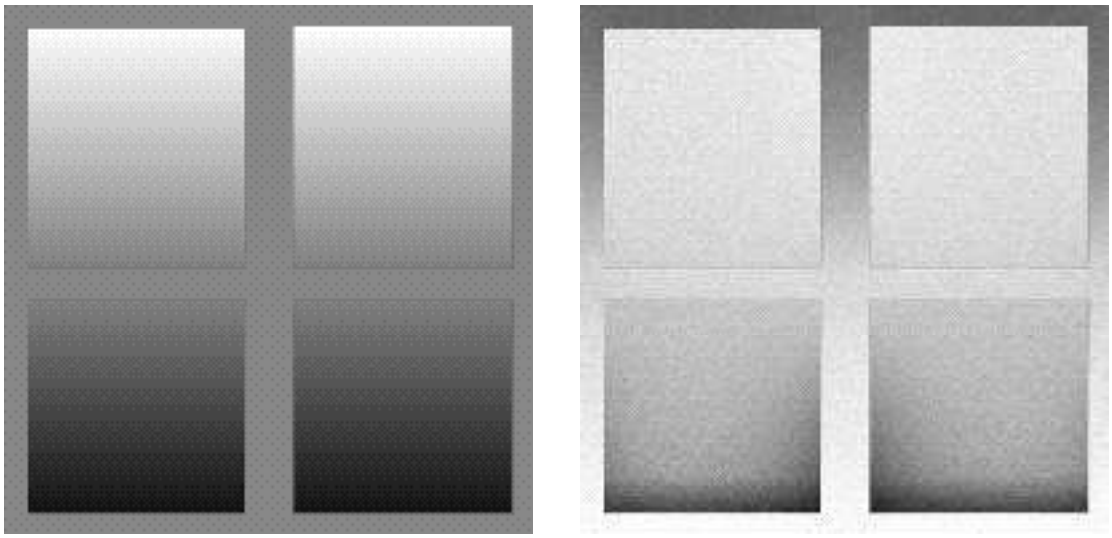

Fig. 1 - In the left picture the grey cross and border appears of non constant value; the Retinex image on the right exhibits the apparent grey scale (Albers cit.)

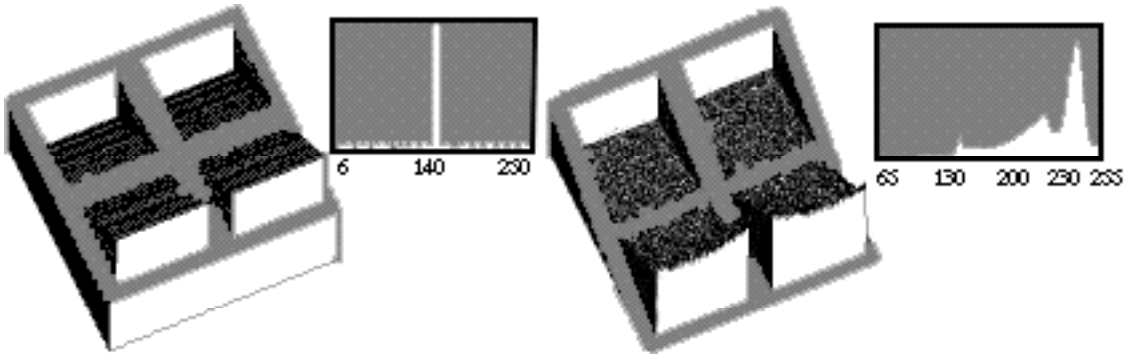

Fig. 2 - 3D Plot and histogram of original image (left) and Retinex filtered image (right)