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Original Contributions - Originalbeiträge

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A Computational Model of Human Colour Vision for Film Restoration

1. Introduction

Film restoration workflow usually follows the steps of historical research, analogue inspection and restoration, scanning, digital restoration, cataloguing and archiving (Cornwell-Clyne, 1936; Enticknap, 2013). As part of the cultural heritage, films' digitisation, restoration and reproduction must be faithful to the original materials, and additionally to the colouring (e.g. Kinemacolor, Dufaycolor, Technicolor) and projection processes (Fossati, 2018; Plutino, 2020). In this context, film digitisation and restoration is, fundamentally, a simulation, and thanks to the expertise of the film curator and the professionalism of the restorer, people try to reconstruct an image that has been lost over the years. Moreover, a film is not merely a sequence of frames, but a holistic experience, made in a specific cinema, in a defined epoch, and projected with certain projectors equipped with specific lights. This situation is even more complex when working with early cinema films, which were recorded and projected using coloured filters that today are impossible to find, or which were tinted and handed to us in form of negatives or black and white positives. Today, these issues are still a concern and at the centre of many philological debates that attempt to define if the work of the restorer should aim at being faithful to the original materials and condition of projection or aim at a new fruition and valorisation. Different efforts have been made to analyse original film dyes and create databases of film processes, but just few works have been published and there is still a lack of public technical data (Plutino & Rizzi, 2020; Plutino, Barricelli, Casiraghi, & Rizzi, 2021).

In this complex and multidisciplinary context, models of human colour perception could help to restore faded and damaged film frames, especially where a physical–chemical reconstruction is impossible. In fact, the best practices for film restoration suggest retrieving and restoring the film colours being faithful to the original materials, but in most of cases the original appearance is unknown, as well as the original dyes' characteristics (Flückiger, Eva, & Nadine, 2020). Thus, colour restoration through models of colour perception offers a first solution to this problem and the results have been found successful for many applications in film restoration industry (Gschwind & Frey, 1997; Chambah, Besserer, &

Courtellemont, 2001; Chambah, Rizzi, Gatta, Besserer, & Marini, 2003). The approach presented in this work uses the spatial colour algorithms (SCAs), which are a family of algorithms derived from the Retinex model (McCann, 2016), and they simulate some behaviour of the visual system in order to restore and enhance colours/tones in digital images (or digital acquisitions of analogue films).

2. Film Colours and Tones Enhancement

Colour correction and restoration in films are often made manually, because of the lack of references and/or information. Furthermore, the high quality of modern cinema production complicates the situation, because all the film issues are addressed using modern software and hardware, to achieve the best quality possible for the fruition with current visualisation devices, overtaking the technological limits typical of the period in which the film was produced. Consequently, at the current state-of-the-art of film restoration, the retrieval of the original film, in digital version, is impossible without introducing alterations and biases related to the current technologies, and to the subjectivity of the restorer, as it is impossible to reproduce the original colour gamut, gamma and contrast of the original film.

To overcome this limit, we propose an alternative approach: restore the original colour appearance. This method is based on the estimation of the digital image (i.e. the scene) colour appearance, using algorithms that simulate some behaviours of the human visual system (HVS). This family of algorithms, called SCAs (Rizzi & McCann, 2007), simulates the mechanisms of spatial computation, which can be more important than colour fidelity in the evaluation of the final restoration. SCAs are based on the idea that colour appearance does not depend just on the individual electromagnetic stimuli transduced by the retina, but on the overall spatial arrangement of the scene, and thus on the signal elaborated by our brain (McCann, McKee, & McKee, 1976). Colour vision is a complex process, which has extensively been studied, but as of today is still far from being completely understood. Describing the process of vision in few words, we can say that the first step of colour vision take place in retina, where physical colour stimuli are transducted into nervous signals, and sent to the brain. In this context, vision at retinal level is widely studied in many scientific domains, allowing us to model colour vision at a point-wise level by simulating the behaviour of the photoreceptors. Despite this, the subsequent signal elaboration is more complex to model, and starting from the studies made by Hermann von Helmholtz in 1868 and by Hering in 1878, we can no longer consider colour vision just as an individual point-wise signal transduction. Considering the visual pathway, it has been demonstrated in several studies the spatial interactions and, subsequently, the operations of spatial comparisons operated by different structures of the HVS, see the review presented in (McCann, 2017). Consequently, SCAs aim at simulating this spatial behaviour, comparing the pixels of the digital images, as our visual system compares the single stimuli.

Using this approach, the digital image is no longer a transduction of signals in the scene, but a preliminary simulation of the HVS behaviour, and thus the result of the spatial comparison of the pixels.

The improvement provided by this approach generates images that are more similar to the original appearance of the scene, and this is demonstrated also by the removal of eye-ball glare (McCann & Rizzi, 2009) and (Rizzi & McCann, 2009). Glare limits the range of light that reaches the retina (or the imaging system sensor), and it is mainly caused by the light scattering in the eye-bulb (or in the optics). The amount of glare can change depending on the scene, and thus on the amount of environmental light, on the setup and on the acquisition conditions. As a direct consequence, the retinal input can be very different from the observed scene, and what guarantees a vision close to the external input (and not to the retinal one) is our visual spatial computation. Apparent contrast, in fact, is higher when retinal contrast is lower, thanks to the increase of contrast at neural level. This effect is demonstrated by multiple experiments reported in the literature (McCann & Rizzi, 2011; McCann, Vonikakis, & Rizzi, 2017), which show that even if a scene contrast and tones are reduced by glare, the spatial processing at neural level increases the apparent contrast and tones (see Figure 1). The HVS recovers part of the scene-dependent contrast loss caused by optical glare, using spatial neural processing.

Consequently, a scene appearance is the result of the spatial processing along the entire visual pathway as reported by McCann's review (McCann, 2017). Imitating this behaviour, SCAs perform a spatial comparison among the pixels in a scene/image to enhance colours and tones, as our visual system would do in real conditions. This means that SCAs introduce in the domain of image acquisition a simulation of our spatial neural processing performing glare reduction and colour appearance imitation, resulting in a colour and tones redistribution and enhancement.

SCAs are derived from the Retinex model (Land & McCann, 1971; Land, 1977) and in this work we mainly consider some implementations of two Milano-Retinex algorithms (Rizzi & Bonanomi, 2017), automatic colour equalisation (ACE) (Rizzi, Gatta, & Marini , 2003; Plutino et al., 2021) and random spray Retinex (RSR) (Provenzi et al., 2006); and one of the scale-based Retinex algorithms called McCann99 (Funt, Ciurea, & McCann, 2000).

3. Application of Retinex-based Algorithms for Film Restoration

Figure 2 presents an example of image enhancement using three different SCAs: ACE and RSR enhancements have been performed using an implementation

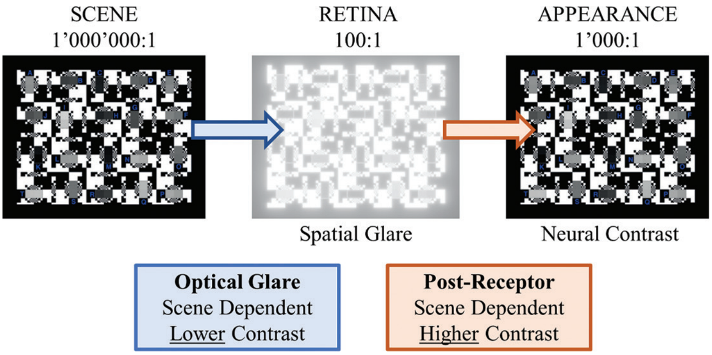

Fig. 1. Illustration of the two scene-dependent spatial processes in HVS. Optical veiling glare reduces the scene contrast range of the image on the retina. Then, the post receptor neural processes use variable contrast response functions depending on scene content. Image reproduced from McCann (2017). HVS, Human visual system.

adopted by Gatta[1], while McCann99 has been implemented using the approach available in Funt et al. (2000)[2]. Based on this example, it is possible to visualise how a photographic or cinematographic image can be restored starting from its original content and by simulating the original scene appearance. Through the employment of different approaches, all the applied algorithms in fact exercise a common function, namely that of removing the yellowish layer on the original input and enhancing colours and tones depending on the scene's spatial content.

The ACE algorithm enhances image colours by comparing every image pixel with every other pixel independently in each RGB channel (Rizzi et al., 2003). Here, a new pixel value is incremented by a nonlinear function (slope parameter) and weighted by the pixels' distance. Slope function is the amplification of the normalised difference between pixel values, and it is the only parameter defined by the user. In other words, the higher the slope is in the ACE algorithm, the higher would the contrast be in the output image, and the user (e.g. the film restorer) can choose to apply the algorithm using the default slope value, or increase/decrease it depending on his/her professional judgment and/or by performing a preliminary test on some reference frames. In the example reported in Figure 2, ACE has been used with a slope of 20 (default parameter in the used implementation).

The RSR is a random-based algorithm of the Milano-Retinex family and, differently from ACE, it compares every pixel in the image with a random spray of pixels belonging to a specific neighbourhood (Provenzi et al., 2006). For example,

[1] Available at: https://mips.di.unimi.it/download.html
[2] Available at: https://www.cs.sfu.ca/~colour/publications/IST-2000/

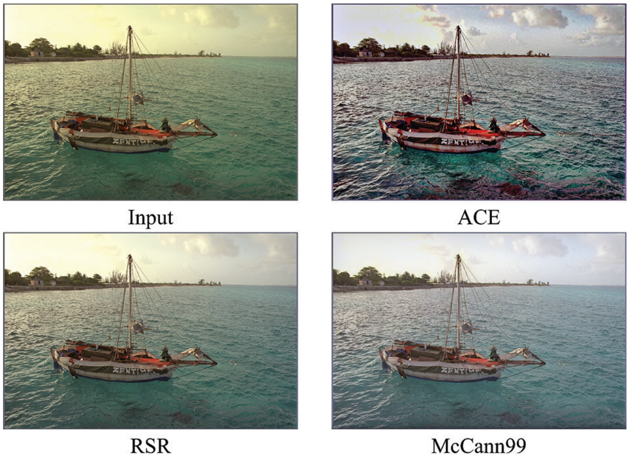

Fig. 2. Enhancements of the image 'KODim06' from the Kodak dataset (Franzen, 2022). On the top left the original input image, top right the image enhanced using ACE (with slope 20), bottom left the image enhanced using RSR and on bottom right the image enhanced using McCann99. ACE, automatic colour equalisation; RSR: random spray Retinex.

in the enhancement reported in Figure 2, every pixel has been compared with 1,000 sprays made of 400 points cast randomly using polar coordinates with uniform sampling. In general, the sprays are denser in the centre.

A different approach is performed by the McCann99 algorithm, which is a multiscale implementation (Funt et al., 2000). Here, the input image is scaled down to the lowest resolution level and at each step of the algorithm the resolution is doubled. At every resolution level the new pixel values are computed by visiting the eight pixels' neighbourhood. Differently from the ACE and RSR, in this algorithm, each visit in the neighbourhood involves a ratio-product-reset operation (Funt et al., 2000). In the McCann99 algorithm, the main parameter is the number of times that a pixel neighbourhood is visited (i.e. the number of iterations). Figure 2 presents an example with 10 iterations.

With the examples reported in this section we do not aim at assessing and making recommendations as to which SCA is better, or as to which could be easily applied to photographic and cinematographic materials; instead, we aim simply at enumerating different approaches (that that we present here with equal preference), and the one actually chosen would depend on the field of application or on the user preference. The main advantage and benefit of the approach of using SCAs is that it is possible to enhance and restore colours and tones in damaged or faded images starting from the pixels' content and by simulating the behaviour of the HVS. This approach could be useful for removing unwanted contrast loss in acquisitions, as a kick-off technique in the restoration workflow, or for full restorations (Barricelli et al., 2020).

4. Conclusion

4.1. Modelling vision can have interesting applications

The domain of photography and cinema restoration is multidisciplinary and often guided by the subjectivity of the restorer or the film curator. Consequently, it is fundamental to expand the research in this field and investigate new approaches to restore and enhance colours/tones objectively.

In this work, we present an alternative approach to the enhancement of photographic and cinematographic colours/tones that is based on the Retinex model of colour appearance. This method aims at restoring images' tones by simulating the original scene appearance, and is made possible primarily by the family of SCAs. These algorithms, in fact, enhance the image tones depending on the pixels' content and spatial arrangement, by simulating the behaviour of the HVS.

Abstract

Even today, film restoration (both photographic and cinematographic) is a challenge, because it involves multidisciplinary competences: from analogue film inspection and conservation to digitisation and image enhancement. In this context, thanks to the high manageability of digital files, the film restoration workflow often follows a digitisation step, which presents many approximations and issues that are often ignored. In this work, we propose an alternative approach to the issues commonly encountered in film restoration (mainly concerning colour and contrast restoration) aiming at restoring the original colour appearance, through models of human colour perception.
Keywords: colour perception, film restoration, HVS, computational modelling.

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