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Film and digital media: open issues and novel approaches for digital color film restoration

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Abstract

The problems and issues which can affect color film restoration may involve all the steps of the cinematographic and photographic restoration workflow, from the digitization to the final quality assessment. In this paper, I aim at providing an overview of the main problems which can occur throughout a digital restoration, with particular focus on glare effect, and at offering some novel solutions.

Introduction

Film restoration workflow usually follows the steps of historical research, analog inspection and restoration, scanning, digital restoration, cataloguing and archiving [1]. As part of the cultural heritage, films digitization, restoration and reproduction must be faithful to the original materials, but also to the coloring technique (e.g., Kinemacolor, Dufaycolor, Technicolor) and projection processes. In this context, film restoration is, fundamentally, a simulation, and thanks to the expertise of the film curator and the professionalism of the restorer, people try to reconstruct frames that have been subject to degradation and fading over the years. Moreover, a film is not only a sequence of frames, but it is an experience, made for a specific environment, for the public of a specific epoch, projected with certain instrument equipped with specific lights and/or lenses. This situation is even more complex for early cinema films, which were recorded and projected using colored filters, or which were tinted and now are handed to us in form of black and white negatives and positives.

Today, these issues are still a concern and are at the center of many philological debates that attempt at defining if the work of the restorer should aim at being faithful to the original materials and condition of projection (even if there is a strong lack of references) or should provide new ways of fruition and valorization [2], [3].

In parallel to this situation, film restoration is strongly subject to the influence of the aesthetic of photo and movie production, which requires always more *pleasant* colors, higher resolutions, and higher frame rates. Thus, film restorers should avoid the tendency to act like film colorists and, even in the digitization step, remember to preserve the original film aesthetic in its materials and content.

In this work, I will mainly focus on film digitization and on colors and tones reproduction on the digital intermediate. Here, I aim at underlining some of the limits in digital acquisitions, such as glare (or flare) effect and at providing some preliminary approach to restore end enhance tones and colors. Scope of this work, is also to rise the awareness of the scientific community on the main issues and problems of film digitization, restoration, conservation and preservation, since there is the strong need to provide open source and controlled tools to acquire film frames in an objective, controlled and reproducible way, without leaving his domain in the hands of hardware and software producers or to the subjectivity and competence of the film restorer [4]. Film restoration, as many other scientific domains, must be leaded by scientific and academic research.

Film digitization and restoration: open issues

Today, in many archives and museums are ongoing huge digitization campaign of audiovisual materials, mainly because of the high manageability and usability of the digital intermediate. This support migration could be a great advantage in film historical

Figure 1. *Graphical representation of glare contrast loss in film scanner systems. On the left a representation of the original film, with its characteristic dynamic range. Then a graphical simplification of a general scanning system, where the light which crosses the film is scattered by the lenses before hitting the sensor. Subsequently is reported a representation of the acquired digital image with a reduced dynamic range due to glare, and on the right the differences between the two dynamic ranges.*

research, philology and material sharing, but has prompted different issues regarding the reliability of the digital medium. In the literature, there are many studies focusing on the issues and open problems in color and tones acquisition but concerns mainly biomedical imaging and other scientific domains.

Film scanning is still a less studied step in the digitization workflow, often left in the hands of private companies, and today just a few laboratories have defined scanning protocols and perform in-depth scanning tests. A first solution to overcome acquisition issues is to follow the basic digitization rules and guidelines given at national and international level (e.g., system calibration, use of appropriate formats, use of targets), but in many cases, some errors, like glare, are systematic and unavoidable [5].

Glare is mainly studied in optics and similar fields, and in imaging systems, like film scanners, it can be a major concern. The use of lenses and optics in imaging system, in fact, can cause the scattering of light which crosses them. So, as in the human retina, the image falling on the scanner (or camera) sensor has a reduced contrast if compared to the luminance of the original image. As a consequence, the higher is the dynamic range in the scene, the higher is the overall effect of glare in the darker areas of the acquired image. When performing film acquisitions, this uncontrolled distribution of luminance in the digitized scene could cause contrast loss and a less faithful reproduction of colors and tones on digital intermediates (see Figure 1). In this context, the neglect of glare issue can cause two main effects: first, an unfaithful reproduction of tones in digital intermediates which are often used to make comparisons or as references in philological research and in the restoration workflow, and second, a systematic error in acquisition protocols which lowers the quality of the results.

Today, glare issues are still an open problem in all imaging systems which use lenses and there is the need to furtherly investigate this issue, which cannot be removed using filters or simple systems, because it is scene dependent. In the literature, we can find several works where glare has been measured in digital imaging domain before imaging acquisition [6], [7] and in post-production [8]. Furthermore, some publications in imaging domain try to measure glare in different imaging systems, like micro computed tomography [9], radiographies [10], satellite imaging [11], cameras [12] and hyperspectral imaging [13]. Unfortunately, in film restoration there are few accessible publications relating to this major issue and restoration specialists cannot rely on published and open-source systematic testing and measurements of scanning systems. Thus far, linear scanning systems are the only ones which are not affected by glare, but since them are not diffused in restoration laboratories and archives, glare is still a major concern, especially today that film scanners are introducing HDR technologies or use wet gate systems (i.e., acquisition gate that is submerged in liquid), which could cause bigger glare effect in the output. In fact, the introduction of other optics or *media* crossed by light can only amplify the overall scattering falling on the sensor.

Some preliminary examples and measures of glare have been presented by McCann et al. in [12], who demonstrated that glare can strongly reduce the acquired dynamic range in camera acquisitions and in the subsequent images scanning, but there is the need to further investigate this phenomenon.

As a future work, it could be interesting to systematically analyze all the sources of error using different scanning methods, as well as determine if the use of specific systems like wet gates, or diffuse/collimated light can objectively improve or reduce the quality of the acquisitions. In those contexts, it is fundamental to increase the awareness about this problem in order to improve acquisition protocols, especially in a context where HDR systems are becoming always more prominent [14], [5].

In this work, the focus in mainly on the digital acquisition of film frames, but it is also mandatory to develop the research also on color reconstruction systems. In fact, as described in the Introduction, colors in film are a fascinating subject, mainly because every epoch, Country and Company had its own colorants and coloration techniques [15]. In the last years, different efforts have been made to analyze 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 [4], [16]. The lack of physical information on film dyes and sensitivity makes the reconstruction of different film processes, and therefore their comparison with digital *media*, impossible. Technical film data could be helpful to develop colorimetric reconstruction or dye degradation models to obtain faithful reproductions of cinematographic and photographic film gamuts (i.e., the set of color reproduced by the original film). These solutions could effectively lead to new ways to restore color films and produce references.

SCAs models for color and tones enhancement: a preliminary solution

In the previous Section, an overview of the main issues in color and tones acquisition has been presented. It is clear that, the errors and approximations introduced in the acquisition step, strongly affect the subsequent procedures of color correction and enhancement. Today, the issues in color and tones reproduction from the analog to the digital are corrected manually using image and video editing software, thus are strictly dependent by the expertise of the restorer, who operates as film colorist.

Also in this case, even if image enhancement models and algorithms are widely studied for quite all the imaging domains, from underwater to astronomical imaging, and from medical imaging to biological imaging, the big laboratories of film restoration perform the whole color restoration step manually, and the automatic or unsupervised techniques are used only for specific basic functions, like white balance or histogram equalization. Nevertheless, this approach could provide satisfactory results, when working with images of historical and cultural relevance it is fundamental to provide a solid scientific base to the restoration workflow, to do not incur in errors, approximations and fabrication of history. The implementation of models to restore and correct colors/tones could be a great way to provide a new base to the restoration workflow, together with a cost reduction (both in time and money).

In this Section is presented the use of Spatial Color Algorithms (SCAs), a family of models derived from Retinex, which represent a first approach to the use of mathematical models to restore colors/tones [17]. This family of algorithms has been found to be particularly applicable in film restoration since it enhances image colors according to the spatial distribution of the pixels, imitating the spatial processing of the Human Visual System (HVS). In general, SCAs presents the following characteristics: at first the image is explored through specific paths (e.g., Brownian paths, random sprays, convolution masks) which gives to the algorithms the locality, and second the image is globally scaled (e.g., linearly, using Gray World and/or White Patch assumptions). Thanks to this characteristics SCAs output depend mainly on the local visual characteristic of the input image and, since the algorithms are based on a model of the HVS, the output is basically a reproduction of the original scene appearance [18], [19].

Considering the main acquisition and restoration issues described in the previous Section, the local reconstruction of the original appearance provides a first way to overcome glare effect, since the image tones and contrasts are locally enhanced [5]. In fact, the luminance which arrives on the human retina is reduced by the optical veiling glare; e.g., we can say that for a scene with a luminance of 1,000,000:1, the contrast il lowered until 100:1 on the retina [20]. Nevertheless, when the visual signal is interpreted in the neural process, glare effect is reduced, and the apparent contrast is increased, e.g., considering the previous example a luminance on the retina of 100:1 has an appearance of 1,000:1. This glare reduction is possible thanks to the scene spatial processing operated by our visual system [20], which is simulated by Retinex model and its implementations.

Retinex models and SCAs algorithms have been found successful for many applications in different domains, among which the cinematographic and photographic restoration. In this field Retinex implementations have been used as kick-off technique in the workflow, but also to perform full restoration at reduced costs [21], [22], [23]. See Figure 2 for some examples.

Clearly, the presented models are just a first preliminary solution in a domain which must be further studied. In this context the combination of SCAs with models of dye fading [24] or film color gamut could be of interest for future applications.

Conclusion

In this work the main issues concerning the step of photographic and cinematographic materials digitization have been presented. Image digitization and enhancement are two of the most studies fields in imaging science, but nevertheless this, in film restoration those fundamental practices are left in the hands of the restorers, and there are just few published and open access woks, testing and evaluating the main features of film scanners. A similar trend has been noticed also for image restoration and enhancement techniques, which are fully diffused in many fields, but the majority of the restoration projects and campaigns are done manually, using color grading software.

Aim of this work is to rise the awareness of the scientific community on the main issues of digitization and image enhancement steps, with specific attention to glare effect. This effect in fact in systematic and unavoidable since depend strictly on the input scene. Furthermore, it is really less studies in film restoration field, and in many regulations and guidelines is not even mentioned.

The loss of contrast that glare can cause (as well as other digitization issues and approximations) is redundant during the whole restoration workflow, and even in the image restoration and processing step should be considered. Here, in order to provide a preliminary solution to glare and digitization issues, we propose the use of Retinex-derived models. Those models and their implementations, try to mimic the spatial processing performed by our visual system, to minimize the effect of glare and enhance images colors and tones.

As a future work, it is fundamental to setup a robust and reproducible test to assess the presence of glare in scanners developed specifically for films and further analyze the effect of glare in HDR acquisition and with the use of a wet gate. In addition the combination of Retinex-based algorithms with models of dyes fading and/or specific dyes optical densities curves could provide a better color reconstruction, leading to a more accurate, objective and reproducible color/tones restoration.

Figure 2. *Examples of images from Kodak Lossless True Color Image Suite [28] enhanced using a Retinex-derived algorithm. On the left column the original image, on the left the input enhanced using ACE (Automatic Color Equalization) algorithm [29].*

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