

Digital Restoration of Faded Color Movies: A Four-Step Method

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Abstract

The motion picture is not only a theatrical art but also a vivid record of past life. Unfortunately, almost all color films made since 1953 are subject to fading that can be arrested only by storing prints at very low temperatures. The photochemical restoration of faded motion prints is impossible. Nowadays, the improvement of computer power let us expect digital restoration of motion pictures at acceptable rates.

We present in this paper a semi-automatic technique to restore faded color image sequences which is an extension of our previous work. This method consists first in removing the side absorptions introduced by the scanning process, then choose a "reference image" from the sequence, adjust its colors and contrast then propagate the performed correction to the whole image sequence.

Introduction

All kinds of films even the new ones are subject to damages. Usually, a bleached color release print is the only available record of a film, digital color restoration is therefore indispensable since the film bleaching is irreversible.

In this paper, we describe our four-step restoration technique which consists in choosing a "reference image" from the sequence after removing the side absorptions from the high resolution scanned images. Three bleaching models, four color balancing methods and three histogram manipulation techniques are involved in order to adjust the "reference image" colors. The method giving the best visual result is finally applied to the whole sequence.

Before presenting our restoration method and some of the obtained results, we give a brief outline of the digital film restoration system, and the film digitization process.

The Digital Film Restoration System

A typical digital film restoration system,[3] illustrated on figure 1, digitizes a film, processes it, then puts the processed images back on a new film support. This system can be used for all post-production processes like special effects. The whole system must be chromatically calibrated to ensure reliable measurements. The main steps providing as automated processing as possible are as follows:

Figure 1. The digital film restoration system

Film Scanning

A developed negative film is made up of three layers: Cyan, Magenta and Yellow corresponding respectively to Red, Green and Blue light intensities.

The film scanning[9] is often applied on a negative and yields a positive image. The scan process determines the part of Red (r), Green (g) and Blue (b) light that would be absorbed respectively by the Cyan, Magenta and Yellow layer of the film:

$$r = R - R' \qquad g = G - G' \qquad b = B - B' \qquad (1)$$

where R, G, B correspond to the components emitted by the scanner light source, and R', G', B' the components measured by the CDD.

Note: We checked out the system to make sure that the scanner illuminants are as monochromatic as possible.

Side Absorptions

The previous formulas (in the latter section) suppose that the emulsion layers (CMY) of the film absorb only their corresponding complementary color (i.e. RGB). But, actually, there are some undesirable absorptions. In fact, the cyan layer does not absorb only red light but also a part of green and blue lights.[6] The magenta layer absorbs green light, blue light and a little bit of red. As for the yellow layer, it absorbs blue light, a little bit of green light and a tiny bit of red light. Table 1 outlines the absorptions of the various layers.

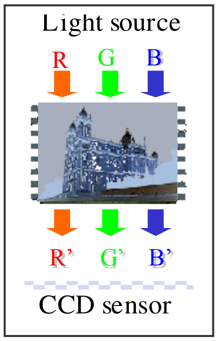


Figure 2. Film scanning process

The side absorptions phenomenon is a correlation between the three channels R, G and B. So, no individual RGB channel adjustment is possible. That is why it is interesting to use a correction matrix. Let us underline that the side absorptions are emphasized for images having one or two faded layers.

In order to remove undesirable correlations, we should keep the Red (r) channel as it is, the Cyan (C) layer being the only layer to absorb red light and adjust the values of the (g) (b) channels whose corresponding lights have been absorbed by more than one layer. More precisely we decrease the value of the (b) channel because it absorbs -undesirably Blue (B) light and we add a ratio of the Red (r) and Green (g) channels in order to compensate the absorption of the light by the Cyan (C) and Magenta (M) layers.

Therefore, our adjustment matrix takes the following form:

$$\begin{bmatrix} a & e & e \\ c & b & d \\ d & c & b \end{bmatrix} \bullet \begin{bmatrix} r \\ g \\ b \end{bmatrix} = \begin{bmatrix} r_A \\ g_A \\ b_A \end{bmatrix} \qquad a \approx 1, e \approx 0, e < d < c < b < a \quad (2)$$

We applied our matrix on a picture taken from an old movie with an overall red cast. After the removal of undesirable correlations, the red cast is prominent (see figure 3). This comes from the fact that the Blue (b) and Green (g) channels of the original image contain a side absorption of the Red channel (r).

Note: The side absorptions removal is an essential step before processing the images. It should be considered as part of the scanning process which aims at having a digital image as close as possible to the original one.

Original picture with an overall red cast

After side absorptions removal

Figure 3. Side absorptions removal

Table 1: The absorptions of the film layers

Emulsion	Blue Light	Green Light	Red Light
Cyan	**	***	****
Magenta	***	****	*
Yellow	****	*	*

Dye Fading

Old films are subject to color fading (whose causes may be several and difficult to be identified). The fading of one or two layers leads to an image with an overall color cast (which is the complementary color(s) of the undamaged layer(s)). In our image (the one with an overall red cast), the cyan did not become more saturated over time, instead, the magenta and yellow dyes faded away.

Figure 4 illustrates the effects of three models of fading upon the characteristic curves[4] (density according to exposition). The model *b* is a bleaching model with a curve shift,[2] the model *c* is a bleaching model with a curve slope change,[8] the model *d* is a non linear bleaching model.

Color Restoration

Some methods[5,12] rely on accelerated fading tests to establish correction parameters by comparing the intact and the artificially faded image. Our method is based on subjective evaluation. Since we work on faded images without references, we cannot know exactly their original colors, so unknown colors of some objects are replaced with their "desirable" colors. Some key colors[1] like achromatic zones, sky color, flesh color,… are taken into account in order to easily determine the color cast we want to remove.

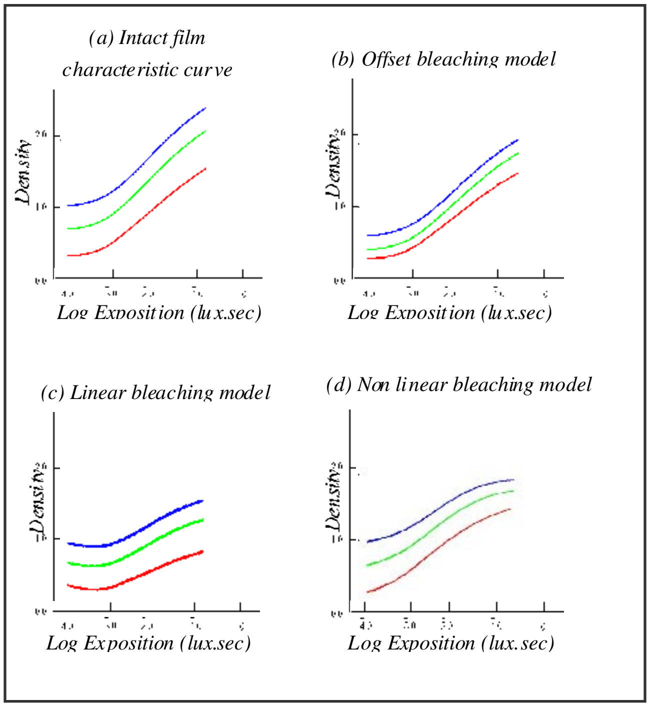


Figure 4. Bleaching models

The Selection of a "Reference Image"

To restore an image sequence, there is no need to check the algorithms on all the images. Indeed, a much simpler strategy could be used. It consists in first, choosing a "reference image", adjust its colors then apply the same processing to the remaining images. The reference image should be a sufficiently significant frame of the sequence, i.e. an image with the most prominent features of the sequence. The "reference image" should also include as many objects of well known color (key color) as possible. This reference image selection step is illustrated on figure 9.

Color Adjustment of the "Reference Image"

To adjust the colors of our image we rely on three main bleaching models (in order to model different fading behaviors) illustrated on figure 4, the model giving the best visual result will be chosen. If we suppose that the fading is constant (model *b*), the adjustment matrix takes the following form:

$$\begin{bmatrix} r_A \\ g_A \\ b_A \\ 1 \end{bmatrix} \bullet \boldsymbol{M} = \begin{bmatrix} r_R \\ g_R \\ b_R \end{bmatrix} \quad \text{where } \boldsymbol{M} = \begin{bmatrix} 1 & 0 & 0 & a \\ 0 & 1 & 0 & b \\ 0 & 0 & 1 & c \end{bmatrix} \quad a<0,\ b>0,\ c>0 \qquad (3)$$

which simply consists in adding an offset to each current color component. Thus, only three parameters (offsets) have to be estimated.

If we consider that the fading may be corrected through an affine transform of the bleached color components (bleaching model *c*), at least four target colors are necessary to determine the twelve unknown coefficients of the adjustment matrix.

Figure 5. Target color zones definition

Those target color zones must be of quite different colors and tones (highlights, shadows, and mid-tones) in order to reliably represent the characteristic curve. Otherwise, some tones of the image would be poorly or even not corrected. Furthermore, for a better restoration, more target colors have to be used to estimate the matrix coefficients. The coefficients are determined so as to minimize the difference between the converted colors and the desired colors using a least-squares scheme.[1] Thus more colors and tones are taken into account to alleviate errors due to inappropriate target color definition. Figure 5 illustrates target color zones specification. The adjustment matrix M is as follows:

$$\boldsymbol{M} = \begin{bmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \end{bmatrix}$$

with $\boldsymbol{r'} = \boldsymbol{O} \bullet \boldsymbol{m_1} \quad \boldsymbol{g'} = \boldsymbol{O} \bullet \boldsymbol{m_2} \quad \boldsymbol{b'} = \boldsymbol{O} \bullet \boldsymbol{m}$

$$\text{where } \boldsymbol{m_1} = \begin{bmatrix} m_{11} \\ m_{12} \\ m_{13} \\ m_{14} \end{bmatrix}, \ \boldsymbol{m_2} = \begin{bmatrix} m_{21} \\ m_{22} \\ m_{23} \\ m_{24} \end{bmatrix}, \ \boldsymbol{m_3} = \begin{bmatrix} m_{31} \\ m_{32} \\ m_{33} \\ m_{34} \end{bmatrix},$$

$$\boldsymbol{r'} = \begin{bmatrix} r'_1 \\ r'_2 \\ . \\ r'_n \end{bmatrix}, \ \boldsymbol{g'} = \begin{bmatrix} g'_1 \\ g'_2 \\ . \\ g'_n \end{bmatrix}, \ \boldsymbol{b'} = \begin{bmatrix} b'_1 \\ b'_2 \\ . \\ b'_n \end{bmatrix}, \ \boldsymbol{O} = \begin{bmatrix} r'_1 & g_1 & b_1 & 1 \\ r'_2 & g_2 & b_2 & 1 \\ . & . & . & . \\ r'_n & g_n & b_n & 1 \end{bmatrix} \qquad (4)$$

where r_i, g_i, b_i represent the average color values of the i^{th} target color of a faded image and r_i', g_i', b_i' the color values of the i^{th} target zone of the restoration.

The least squares method estimation leads to:

$$\begin{aligned} \boldsymbol{m_1} &= (\boldsymbol{O'O})^{-1}\boldsymbol{O'r'} \\ \boldsymbol{m_2} &= (\boldsymbol{O'O})^{-1}\boldsymbol{O'g'} \\ \boldsymbol{m_3} &= (\boldsymbol{O'O})^{-1}\boldsymbol{O'b'} \end{aligned} \qquad (5)$$

If we consider that the fading is non-linear, eleven target colors are necessary to determine the 33 unknown coefficients. However the determination of such numerous target zones without errors is a difficult issue. Furthermore, it is well known that non-linear methods enhance the noise of the image and this phenomenon was confirmed by our experiments.

The simplest method is the first one, which uses less target colors than the latter and gives acceptable results. The second method gives better results if enough target colors are available (generally in a sequence of images we can find a “reference image” with at least four reliable target colors). The improvement of this method, using a least squares estimation provides the best results if more than four target colors are available. The use of six target colors seems to be a good compromise between resulting visual quality and the number of target zones. All these methods are linear and their adjustment matrices can be combined with the previous side absorptions matrix to achieve the final color fading reduction. So, only one operation is needed to correct color defects (side absorptions, color fading,...). Figure 7 illustrates the obtained results.

Note: This method is only applicable on films that have kept a significant quantity of color dyes, otherwise the bleaching would be poorly reduced.

Let us notice that the method described in [5][12] is also linear. The main advantage of our method is the use of a reference image to speed up the fading correction process, and the experimentation of different bleaching models. Let us emphasize that our investigation, unlike other existing methods,[5,12] has been entirely carried out on old films.

Image Contrast Enhancement

In most cases, the dye loss occurs in one or two film layers. After the scanning and the adjustment processes (balancing and removal of side absorptions), the contrast of the obtained image is low as illustrated by figure 6.

If only the color balance were corrected, the color deficiency would still not be fully corrected. The color contrast must be enhanced for a better visual effect.[8]

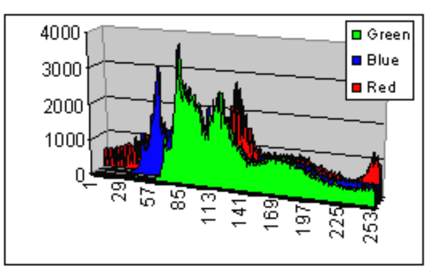


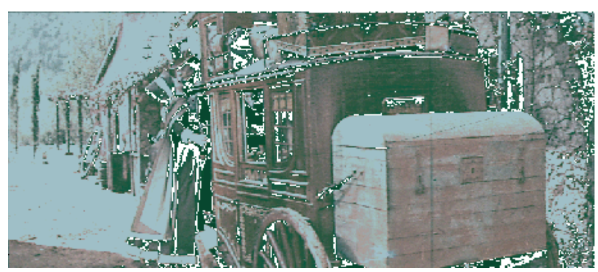
Figure 6. Histogram of a restored image

Original image

After side absorptions removal

Color adjustment by color channels shift

By linear method using four target colors



By linear method using six target colors

Figure 7. Color adjustment results

We use various methods to enhance dynamic range: histogram stretching, histogram equalization,[7] color rotation matrix,[11] histogram bi-equalization[10] using always the same “reference image”.

Figure 8 shows the obtained results. Histogram stretching techniques give acceptable results, they maximize the dynamic range, but they keep the global shape of the histogram. Histogram equalization gives better results since it redistributes the histogram data which corrects the remaining color unbalance. Histogram bi-equalization preserves the mean brightness of the image while it performs contrast enhancement. We chose histogram equalization because it enhances both the brightness and the contrast of the color restored image.

Contrast enhancement by histogram stretching

By histogram equalization

By histogram bi-equalization

Figure 8. Contrast enhancement results

The Restoration of the Whole Image Sequence

The remaining images of the sequence are batch processed using the designed color fading correction technique. When the "reference image" is well chosen the bleaching correction gives good results for the sequence. And even if for some images (especially the farthest one from the "reference image") the correction appears less better in some zones, it is recommended to not modify the correction process, because that would also change the color of other objects which are common to other images. This would result in very unpleasant dissimilarities when the sequence would be entirely played. Those minor zones are much less noticeable than the changes of an object color over the sequence. Moreover those little defects (generally present in one tone) might disappear after enhancing the dynamic range of the image.

Conclusion

We have developed a method for digital color restoration of old faded movies. First, the film is digitized with a film scanner, then the side absorptions caused by the digitization are removed using an adjustment matrix. In a second step, we choose from the sequence a "reference image", whose color channels are balanced using another correction matrix. The "reference image" contrast is enhanced in order to improve the visual quality. Finally, the same processing is propagated over the whole sequence.

References

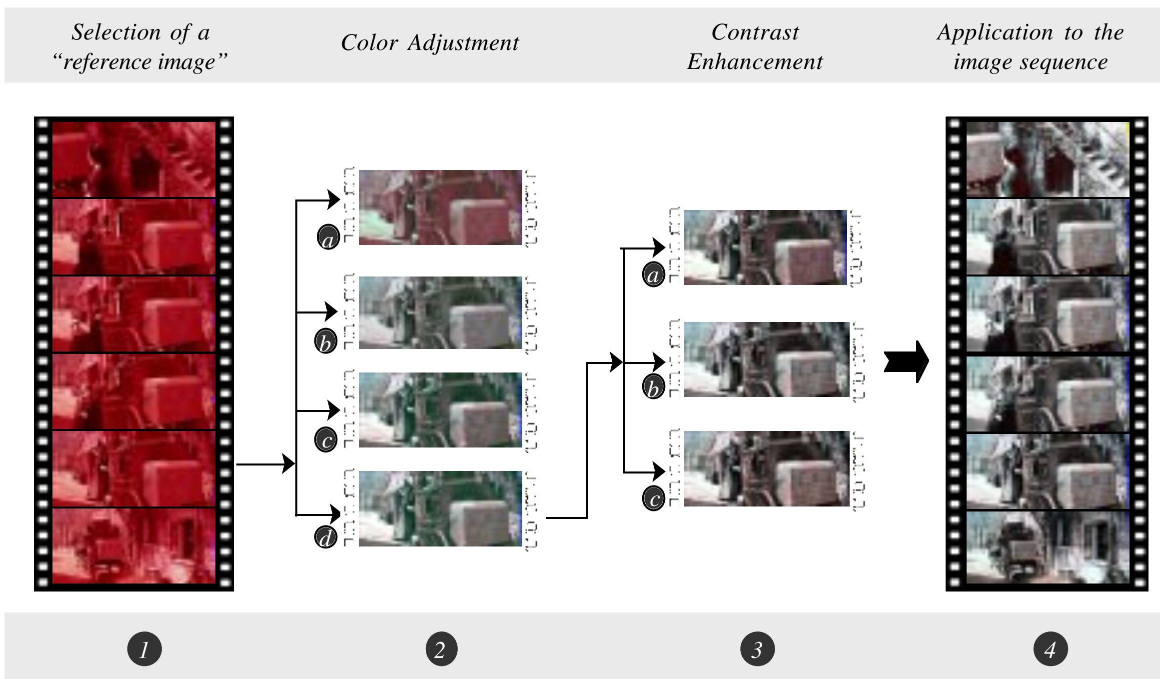
1. Y. Ando, A. Hansuebsai, K. Khatong, Digital restoration of faded color images by subjective method, The Journal of Imaging Science and Technology, Vol. 41, pg. 259. (1997).
2. M. Chambah, Analyse de données colorimétriques et de textures d'images digitalisées haute résolution. Application au traitement et à la restauration de films cinématographiques, Technical report L3i, France, RT-1999-10-001. (1999).
3. CST, La restauration numérique des films cinématographiques. CST (Commission Supérieure Technique de l'Image et du Son) report. (1997).
4. Eastman Kodak, Eastman Kodak's student filmmaker's handbook, Kodak publication N° H-19. (1996).
5. F. Frey, R. Gschwind, Mathematical bleaching models for photographic three-color materials, IS&T's 46th Annual conference, Boston, USA, (1993).
6. P. Glafkidès, Chimie et physique photographique, Paul Montel, Publications photo-cinéma. (1976).
7. R. C. Gonzalez, R. E. Woods, Digital image processing, Addison-Wesley publishing company. (1993).
8. C. Bradley Hunt, Corrective reproduction of faded color motion picture prints, SMPTE Journal (Society of Motion Picture and Television Engineers), Bd 90, N° 7, pg. 591. (1981).
9. G. Kennel, Digital film scanning and recording : The technology and practice, SMPTE Journal (Society of Motion Picture and Television Engineers), pg. 174. (1994).
10. Y. T. Kim, Quantized Bi-Histogram equalization, ICASSP'97, Vol. 4, pg. 2797, (1997).
11. K. M. Kim, C. S. Lee, C. H. Lee, Y. H. Ha, Color image enhancement by highlight-preserving vector transformation and nonlinear mapping, IEEE International conference on image processing ICIP'98, Chicago, Illinois, USA. (1998).
12. L. Rosenthaler, A. Wittmann , A. Günzl, R.Gschwind, Restoration of old movie films by digital image processing, IMAGECOM'96, Bordeaux, France. (1996).

Acknowledgements

We'd like to thank *Centrimage* Company, the *CNC* and the *Conseil Régional Poitou-Charentes* for supporting our work.

Biography

Majed Chambah has a computer science engineer degree, he received his Computer Vision and Image Processing MSc degree in 1998 from Université de Nice Sophia Antipolis in France. He worked at Lucent Technologies and he is currently studying for his PhD. His current research interests are digital movie restoration and color image processing. He is a member of the IS&T.



(1) Selection of a "reference image" (2) Color Adjustment: (a) by color channels shift (b) using four target zones (c) using five target zones (d) using six target zones. (3) Contrast enhancement of the chosen image (a) by histogram shift (b) by histogram equalization (c) by histogram bi-equalization. (4) Application of the chosen color adjustment and contrast enhancement techniques to the whole sequence.

Figure 9. Steps of color restoration of an image sequence