DIGITAL COLOR RESTORATION OF FADED MOTION PICTURES

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ABSTRACT

The cinematographic documents recorded on chemical support represent a significant cultural heritage. These films, however, are often very damaged. Using powerful multimedia platforms, motion pictures can be digitized at a high resolution, processed and reproduced, thus allowing a digital restoration of old films. We present in this paper a technique to restore faded color films. This method consists first in removing the side absorptions introduced by the scanning process, then adjust the image colors using correction matrices and enhance the image contrast using histogram manipulation techniques.

Keywords: *Digital film restoration, color correction, color adjustment matrix, contrast enhancement, histogram processing.*

1. INTRODUCTION

Several damages (due to improper manipulation, storage under less than optimal conditions,…) affect all categories of films even the new ones. Traditional restoration uses mechanical and photochemical means, these techniques however cannot correct all kinds of defects, especially the bleaching of faded color movies which is irreversible. Usually, a bleached color release print is the only available record of a film, digital color restoration is therefore indispensable. In this paper, we present the main steps of our restoration method and some of the results obtained on faded images.

2. THE DIGITAL FILM RESTORATION SYSTEM

A typical digital film restoration system [3], illustrated on figure 1, digitizes a film, processes it, then puts the images back on the film. 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 described in the following.

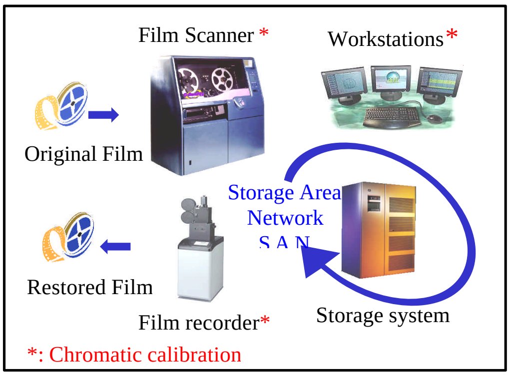

FIG. 1: Digital restoration system

3. 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.

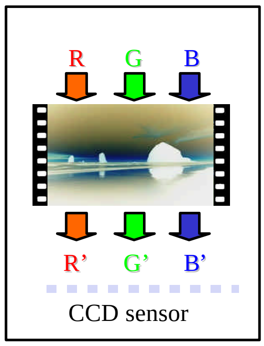

FIG. 2: Film scanning process

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:

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

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 monochromatic.

4. 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.

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 outline that the side absorptions are emphasized for images having one or two faded layers.

In order to remove undesirable absorptions, 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 :

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

We applied our matrix on a picture taken from an old movie with an overall red cast (see figure 3). After the removal of undesirable correlations, the red cast is more prominent. 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).

5. DYE FADING

As they become old, all movies 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 some models of fading upon the characteristic curves [4] (density according to exposition). Model *b* is a bleaching model with a curve shift [2], model *c* is a bleaching model with a curve slope change [8].

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

TAB.1: Side absorptions

FIG. 3: ❶ Original picture with an overall red cast
❷ After side absorptions removal

6. COLOR RESTORATION

Some methods [5] [12] rely on accelerated fading tests in order 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 neutral zones, sky color, flesh color,… are taken into account in order to easily determine the color cast we want to remove.

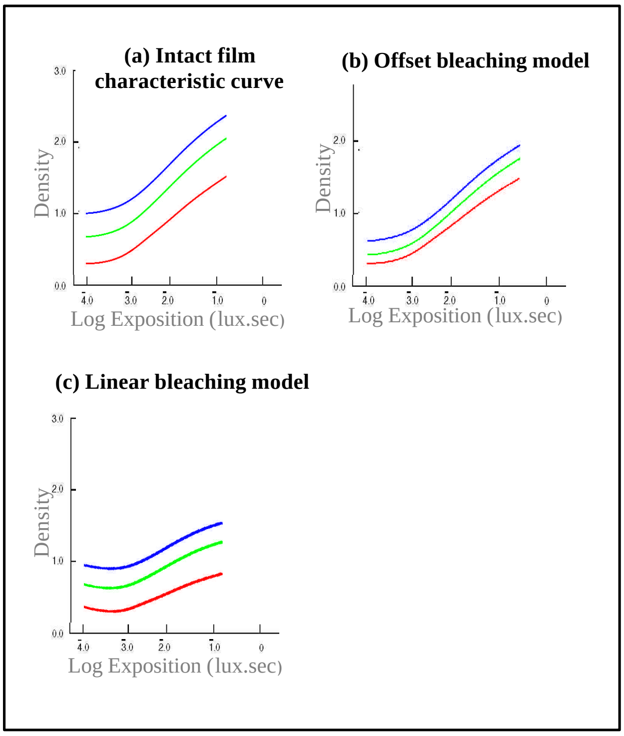

FIG. 4: Bleaching models

If we suppose that the fading is constant (model *b*), the adjustment matrix uses the differences between the channels. The adjustment matrix is as follows:

$$\mathbf{M} \bullet \begin{bmatrix} r_A \\ g_A \\ b_A \\ 1 \end{bmatrix} = \begin{bmatrix} r_R \\ g_R \\ b_R \end{bmatrix}$$

$$\text{where } \mathbf{M} = \begin{bmatrix} 1 & 0 & 0 & a \\ 0 & 1 & 0 & b \\ 0 & 0 & 1 & c \end{bmatrix} \quad a<0,\ b>0,\ c>0$$

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. For a better restoration, more colors should be used to calculate the matrix coefficients. The coefficients are determined such as to minimize the difference between the converted colors and the desired colors using the least-squares method [1]. Thus more colors and tones are taken into account to reduce errors due to inappropriate target color definition. Figure 5 illustrates target color zones specification. The adjustment matrix M is as follows:

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

with $\mathbf{r'} = \mathbf{O} \bullet \mathbf{m_1}$ $\quad \mathbf{g'} = \mathbf{O} \bullet \mathbf{m_2}$ $\quad \mathbf{b'} = \mathbf{O} \bullet \mathbf{m_3}$

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

$$\mathbf{r'} = \begin{bmatrix} r'_1 \\ r'_2 \\ . \\ r'_n \end{bmatrix},\ \mathbf{g'} = \begin{bmatrix} g'_1 \\ g'_2 \\ . \\ g'_n \end{bmatrix},\ \mathbf{b'} = \begin{bmatrix} b'_1 \\ b'_2 \\ . \\ b'_n \end{bmatrix},\ \mathbf{O} = \begin{bmatrix} r_1 & g_1 & b_1 & 1 \\ r_2 & g_2 & b_2 & 1 \\ . & . & . & . \\ r_n & g_n & b_n & 1 \end{bmatrix}$$

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} corresponding restored target zone.
The least squares method estimation leads to:

$$\mathbf{m_1} = (\mathbf{O}^t\mathbf{O})^{-1}\,\mathbf{O}^t\,\mathbf{r'}$$
$$\mathbf{m_2} = (\mathbf{O}^t\mathbf{O})^{-1}\,\mathbf{O}^t\,\mathbf{g'}$$
$$\mathbf{m_3} = (\mathbf{O}^t\mathbf{O})^{-1}\,\mathbf{O}^t\,\mathbf{b'}$$

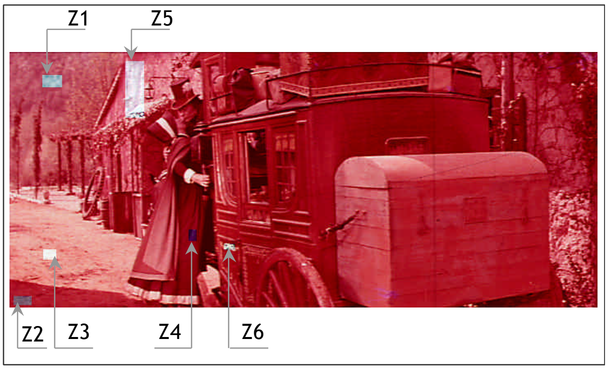

FIG. 5: Target color zones definition

The first restoration method based on an offset bleaching model is simpler (it uses less target colors) than the second one and gives acceptable results. However, the use of a linear bleaching model leads to better results if enough target colors are available and also if the setting of target colors is correct. The improvement of the latter 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 the corresponding adjustment matrices can be combined with the previous side absorptions matrix to achieve the final color fading correction. So, only one operation is needed to correct color defects (side absorptions, color fading,...). Figure 6 illustrates the obtained results.

Note: This method is applicable on films that have kept a significant quantity of color dyes, so that the colors can be restored.

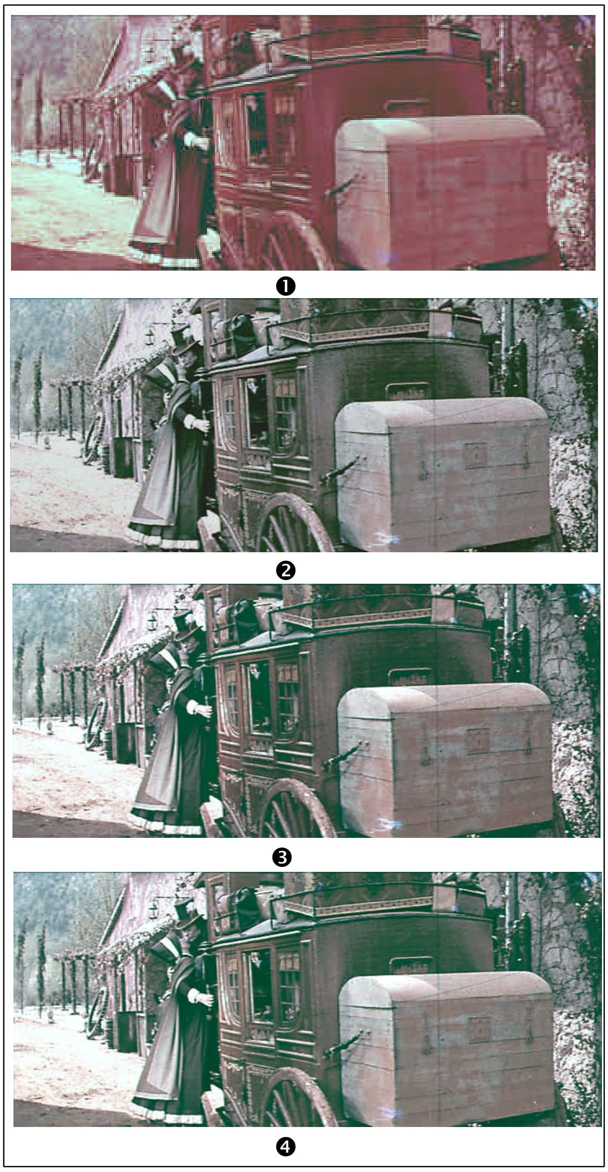

FIG. 6: Color adjustment results: ❶ by color channels shift ❷ by linear method using four target colors ❸ using five target colors ❹ using six target colors.

7. IMAGE CONTRAST ENHANCEMENT

In many 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 7.

If only the color balance were corrected, the color deficiency would still not be completely corrected. The color contrast must be enhanced [8].

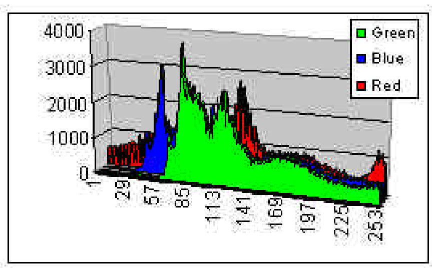

FIG. 7: Histogram of a restored image

We use various methods to enhance dynamic range: histogram stretching, histogram equalization [7], color rotation matrix [11] and histogram bi-equalization [10]. 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 an histogram equalization technique because it enhances both brightness and contrast of the restored color image.

8. 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, the image color channels are balanced using another correction matrix. Finally, the contrast is enhanced in order to improve the visual quality.

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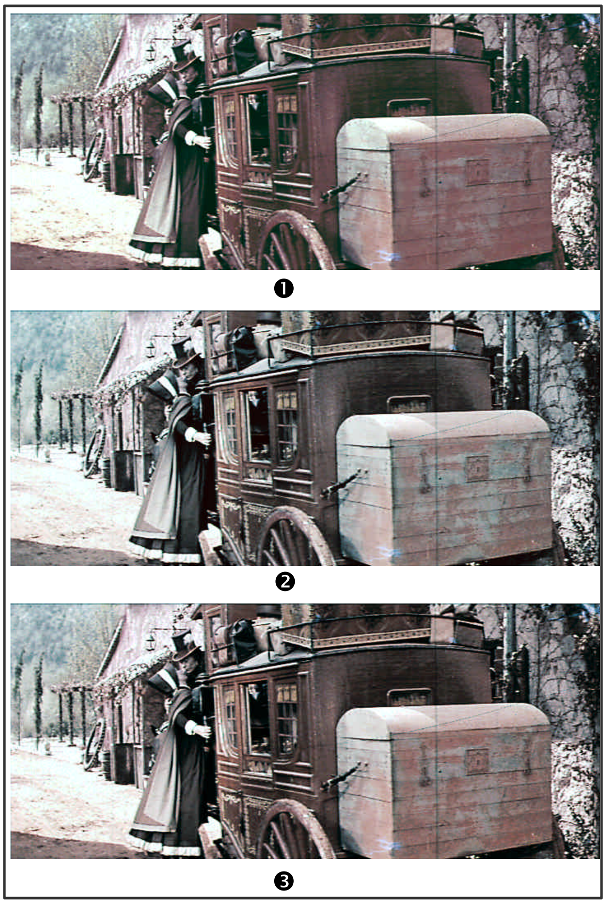

FIG. 8: Contrast enhancement ❶ by histogram stretching ❷ by histogram equalization ❸ by histogram bi-equalization

9. REFERENCES

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