Approach to Automate Digital Restoration of Faded Color Films

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Abstract

Bleaching is a serious threat to all color films. Since the bleaching phenomenon is irreversible, photochemical restoration of faded prints is not possible. Digital film restoration is therefore indispensable.

We present in this paper some advances in automating the color restoration process, especially with regard to the selection of the points of interest that allow the correction of the whole image. This selection is based on a principal components analysis of the image. We present also some methods to recover the hue of some parts of the image

Introduction

The motion pictures represent an important cultural heritage. As films age, their chromatic layers fade away. Usually, a bleached color release print is the only available record of a film, hence the incontestability of digital color restoration.

The work that preceded this article focused on the capabilities and the steps of digital color film restoration.[1-3] It provided experimental evidence for restoration of an entire image or an entire sequence by only correcting the color of some zones. The quality of a restoration depends on the selection of these zones (called target color zones). After an overview of our previous work, we present a new method for selecting the target color zones based on a principal components analysis (PCA) of the color image. We report the results of our experiments and we present also some methods to recover the hue of some parts of the image.

Overview of Our Digital Restoration Method of Faded Films

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”. The color channels of this “reference image” are balanced using a fading correction matrix (We considered different bleaching models and we demonstrated that a linear bleaching behavior was the closest to reality).

Since we work on images without references, the fading correction matrix is determined by the choice of some particular zones in the reference image by the expert (figure 2). These zones may be memory color[14,15] zones (called also key colors) like achromatic zones, sky color, flesh color, foliage,… By determining the target colors of these zones (the colors they should “normally” have), we determine the color correction matrix that will be used to correct the whole image (the zones must be at least four to resolve our linear system).

After the fading correction step, the “reference image” contrast is enhanced in order to improve the visual quality. Finally, the same processing is propagated over the whole sequence.

As we have seen, the selection of the zones and the definition of their target colors, play an important role in the visual quality of the restoration. In fact these zones must be selected in quite different areas and they should be of different colors and luminance. We present in the following sections a new method for selecting these zones based on a principal components analysis PCA of the reference image.

PCA of a Color Image

First, let us give a short reminder about a PCA of a color image. Since this technique is adequately explained elsewhere,[11] we include here only some principles, to motivate and simplify the explanation of the following sections.

PCA is used in statistics to decorrelate data, while some works focussed on image spectral data,[8,12,16] our data here are represented by the three (RGB) color channels of the image. A common way to find the principal components (PCs) of an image is by calculating the eigen vectors of the correlation matrix between the three channels. These vectors give the directions in which the RGB cloud is stretched most. The projection of the data (RGB cloud) on the eigen vectors are the principal components. This decorrelating projection of the zero mean RGB data is done by means of the matrix **T**:

$$\boldsymbol{T} = [\boldsymbol{e}_1, \boldsymbol{e}_2, \boldsymbol{e}_3]^T$$

where $\mathbf{e}_i$ are the eigen vectors.

The corresponding eigen values give an indication of the amount of information the respective PCs represent. PCs corresponding to large eigen values, represent much information in the data set.

One of the advantages of PCA is the reduction of dimensionality by keeping only the important PCs. Another advantage of this method is the dependency of transformation upon the intrinsic characteristics of the image.

Data Representation using PCA

The RGB channels are usually very correlated (especially for faded images). In fact, the first two PCs represent more than 99% of the data. We will only take into account the first two PCs. On one hand, we do not have an important loss of information, on the other hand, plotting PC1 (first PC) and PC2 (second PC) gives us a 2D diagram easy to interpret and use.

Besides, Ohta[10] showed that PCA splits color information into three PCs: the first principal component represents the luminance, while the remaining two components represent the chrominance information, like the human visual system in a sense.[4]

$$\begin{array}{cccc} & \mathbf{e}_1 & \mathbf{e}_2 & \mathbf{e}_3 \\ \mathbf{T} = & \multicolumn{3}{c}{\begin{bmatrix} 0.42 & -0.87 & -0.26 \\ 0.63 & 0.07 & 0.78 \\ 0.66 & 0.49 & -0.58 \end{bmatrix}} \end{array}$$

To underline the usefulness of such a diagram, let us consider the image of figure 1. The transformation matrix to PCs space is as follows (matrix of the eigen vectors)

The eigen values are : $\lambda1$=5.9 103, $\lambda2$=49.4, $\lambda3$=7.5. We notice that the first two PCs represent nearly 99,9% of the information. The diagram illustrating data projection on the PC1 PC2 plane is showed on figure 4.

As PCA is done on a zero mean image, the point (0,0) on the diagram is the mean of the image, which equals to $\mathbf{m}=[91, 66, 72]^T$ for this image.

By looking at the matrix **T**, we verify that PC1 represents the luminance of the image, with a little more importance given to the green and blue channels ($PC1=0.42*R+0.63*G+0.66*B$). This means that the shadows will be plotted on the left side of the PC1 axis, while the highlights will be on the right side.

As for PC2 axis, it separates blue color from red color, in other words it represents the B-R axis (B,G have positive coefficients, R negative coefficient), the green coefficient being too small. In fact, points with predominant red will have a negative PC2 value and will be at the bottom of the PC2 axis, whereas points with predominant blue color will have a positive PC2 value and will be plotted therefore at the top of the PC2 axis.

Let us notice here that since we work on a zero mean image the predominance of a color is relative to its mean. That is to say, the point $\mathbf{x} = [110, 104, 124]^T$ for instance, will be considered as having a dominant blue color since after subtracting the mean **m** from the image we get: $\mathbf{x}–\mathbf{m} = [19, 38, 52]^T$. This fact is very important, especially when we work on images having an overall color cast. In fact, zones that had a more or less saturated color (greater than the mean of the concerned channel) before image fading, can still emerge on the diagram, since even on the bleached image these zones still have a greater value than the mean (which decreases as the image fades). The PC diagram is dependent upon the characteristics of the image (mean, PCs,…), this is one of the most important advantages of using PCA.

As example, we selected a zone from the top of the 2D PC diagram (figure 5a), we show on figure 6a the corresponding points to that zone. They belong to the sky (blue zone). The zone selected on figure 5b corresponds to flesh tones and some shades of red (flags) as illustrated on the figure 6b. This diagram is a powerful tool to divide the image pixels up, according to their color and luminance.

Zones Selection

In this section we will use the 2D PC diagram to find the criteria (number, distribution,…) to select the target zones needed for the color restoration step. In Refs. 2 and 3 we suggested to the expert to select zones of different colors and of different brightness levels, but it is not easy for the user to distinguish between the colors of a bleached image. It is also hard to know the number of the zones to be selected. Moreover, if the result of the color correction were not satisfying, it was difficult to say if it was due to the unsuitability of the selected zones or rather to the unsuitability of the target colors given to these zones.

In short, the selection of these zones is a tedious task even for a trained user. That is why, we will look here for some criteria that enables us to automate this process of selection as much as possible.

Experiments

For these experiments, we will consider the image shown on figure 1. To concentrate totally on the zone selection process and avoid problems related to unsuitable target colors specification, we will consider an image restored by our method described in [3] using five target zones (the target colors were determined by an expert). This image will provide us with the right target colors (figure 3).

We tried different zone selection layouts, one of the most intuitive layouts is to consider four zones (it is the minimum number to solve our linear system [2]) scattered as far as possible on the axis of the PC diagram, we considered also different numbers (4, 5, 6) of zones. We considered some random layouts and also a worst case layout: a layout where the zones are close to each other. Figure 7 illustrates some of the different layouts taken into account during these experiments. The results are judged according to their visual quality.[13]

Experimental Results

One of the conclusions that we found out, is that there is no need to have more than four zones, if these zones are "well selected". In fact the restoration yielded with 6 zones is not better than the restoration obtained with 4 zones, unless these zones are well scattered . The second conclusion is that there is no ideal layout, but the selection should obey one simple rule: the zones should be placed at different spots to cover as much as possible of brightness levels and of different colors. In other words, zones towards the extremes of the PCs axis, the zones in opposite directions being roughly parallel to these axis (figure 7.d, 7.e). This is an important result, since it leaves enough freedom to the user to select the zones that he recognizes most (memory colors,…). Figure 8 illustrates and comments the results obtained for each layout of figure 7.

We carried out another series of tests on other faded images, coming from different films, and having different color casts (figure 10 shows one of these images). These new series of tests led to the same conclusions. Figure 11 shows a "good" layout giving the result illustrated on figure 12.

As a conclusion, the usage of this new method will allow several enhancements: the system will be able to guide the user in selecting the zones. The user selects the zones that he is able to recognize and the system can suggest to the user which zones are likely to give the best restoration, and can suggest to the user some other zones of the image to have a "decent" restoration. Hence, selecting the zones will be much easier and much faster and is no longer a major concern for the user. This technique could be used for other linear color mapping purposes (between images taken under different illuminants for instance). It is much simpler (only 4 zones for mapping, RGB color space, speediness,…) than existing color mapping methods[7] and more powerful than methods done independently of image characteristics and based upon a single color mapping.

Recovery of the Hues of Some Zones

Now, the only problem left, is to help the user in determining the target colors of the zones. Especially, the zones that before fading were showing a kind of saturated colors, those that we find toward the extremities of the PC2 axis at all brightness levels. If we take advantage of the fact that these zones have a greater value than the mean of the channel, it would be possible to amplify the right channels to recover the original hue and remove the color cast. We will employ some techniques that we have modified in this purpose.

Non Linear Local Correction Techniques

This kind of techniques was originally designed to smooth the contrast and enhance the exposition images [9]. Our usage of these techniques, on the contrary, aims at amplifying the differences between the levels of the channels. It consists in a variable power function as follows:

$$O = 255 \times \left(\frac{I}{255}\right)^{\left(i^{\left(\frac{m-I}{m}\right)}\right)}$$

$$O = 255 \times \left(\frac{I}{255}\right)^{\left(i^{\left(\frac{m-I}{m}\right)}\right)}$$

where I is the pixel input value, O is the output value, I $\geq$ 2.

This means that the pixels having a greater value than the mean of the channel will yield an exponent less than 1 and hence the output value will be amplified with regard to input value. Pixels having a value less than the mean will be more lessened. Zones located at the extremes of the PC2 axis will recover some of their hue whereas the cast will be stronger in the rest of the image. Figures 13.a, 13.c illustrate the results obtained on two different images. Some zones recover their hue: the sky, the dresses, in figure 13.a, the foliage, the ground in figure 13.c. Of course, this method recovers the hue, nevertheless, the user have to adjust the saturation and the luminance of the zones.

Color Rotation

This is a global technique[6] used generally for enhancing the highlights of an image by rotating the white of the image (assumed to be the mean of the image) into the desired white.

Our local technique aims to change the color of the zones having a greater value than the mean, and lessen their color cast. To do so, we consider a rotation of the pixels of the image with an angle θ, which is the angle formed by the mean vector and the current pixel RGB vector. The rotation is done with respect to the origin of the RGB cube. If the pixel values are greater than the mean, the angle is positive and the values are thus increased. The matrix of the 3D rotation can be found in Ref. 6.

As shown on figures 13.b, 13.d, this technique permits to recover the hue of some zones that had originally pure colors such as the sky, the dresses, the flags,… in image 13.b the foliage, the pink roof, the ground, in image 13.d. The user have only to readjust the luminance and the saturation of these zones.

Remarks

Although skillful operators are used to calibrate film colors, these techniques can help them a lot in defining the target colors. Consequently, they allow to save a lot of time and minimize the human intervention increasing hence productivity.[15] With regard to specification of colors that are not recovered by these techniques, the user can count on an intuitive color specification palette with some presets like achromatic zones, memory colors[5,14] etc… to correct other zones if he wishes.

Conclusion

We presented in this paper a new method for selecting the zones of interest (target zones) that determine the parameters of the correction matrix to be applied to a faded image. This method automates this formerly tedious and time consuming step.

It is based on a PCA of the image, one of its most important advantages is that is takes into account the characteristics of the image being processed.

We presented also some local enhancement techniques permitting to recover the hue of some zones, and which are of great help to the user.

These methods come within the framework of our digital film restoration automation project.

One of the future prospects of this work is a combination between this technique and our automatic fading correction methods.[17]

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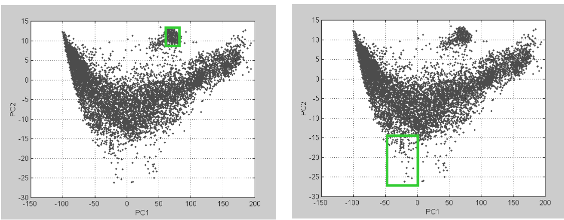
Biography

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 imaging. He is a member of the IS&T society.

Figure 1. Faded image to restore

Figure 2. Target zones definition

Figure 3. Target image used for target zones definition



(a) (b)

Figure 5. Selection of some points of the diagram

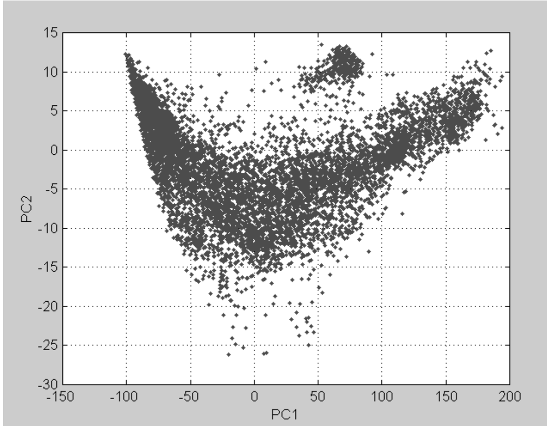
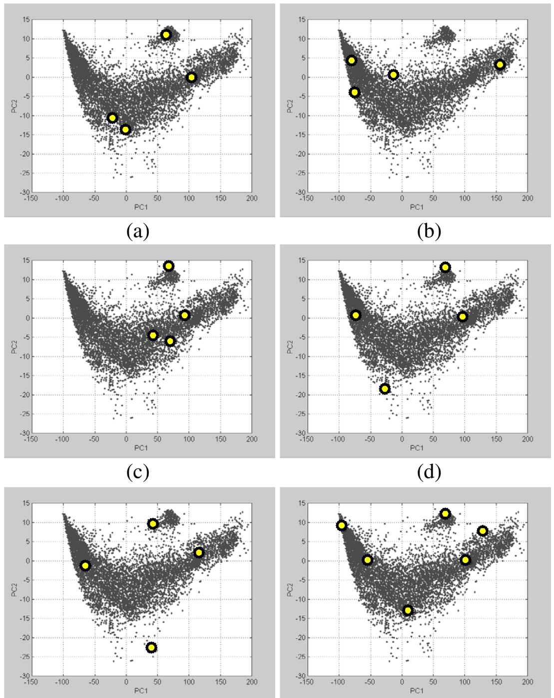


Figure 4. 2D PC diagram of the faded image in fig. 1

Figure 6. Points corresponding to the selections in fig.5



(a) (b) (c) (d) (e) (f)

Figure 7. Some layouts considered in our experiments. The selected zones appear as yellow spots on the diagram

(a): The specified zones recovered their color. The achromatic shadows are distorted because they are not represented

(b)

(c)

(b) : There is a terrible lack of colors since no colorful zones were selected. (c): Totally distorted colors due to the vicinity of the zones (worst case).

(d): Good correction due to the good scattering of the zones (fig. 7.d, 7.e) . It is visually identical to the target image. It is also the result obtained with 6 zones (fig 7.f)

Figure 8. Restoration using target zones of fig. 7.

Figure 9. Zones corresponding to layout in figure 7.d: sky, flesh (colorful midtones), ground (shadow), wall (highlight)

Figure 10. Faded image

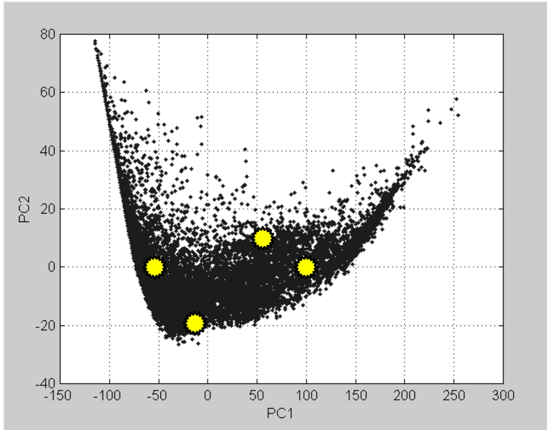


Figure 11. 2D PC diagram of original image, the yellow spots represent one well scattered layout.

Figure 12. Restoration result using target zones of fig.11. It is visually identical to the target image (we did not include it here, since it is the same).

(a)

(b)

(c)

(d)

Figure 13. (a) (c) : Recovery of some zones hues by a non linear correction. (b) (d): Recovery of some zones hues by a color rotation technique.