RESTORATION OF FADED COLOR FILMS USING DIGITAL IMAGE PROCESSING

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ABSTRACT

Only in the last 20 years it has been possible to restore historically valuable films using digital image processing. In the past few years this has been also possible for educational institutions. Nowadays most typical faults such as scratches, dirt and flickering can be restored on the digital side, though only in very few cases semi or fully automatically. This paper deals with a fairly new topic of digital film restoration - the color restoration. The first color movies evolved in the 1950s. Due to aging the characteristics of the film material changed which resulted in miscolorings. A possible attempt to restore these types of faults is shown and a developed method for color restoration is introduced.

1 INTRODUCTION

In the 1950s the era of color films started. A couple of years before attempts to shoot color photos had been undertaken successfully. As with many technologies the first color films bared something which had a very negative effect on the quality throughout time. The colors faded while aging because the film components which form the colors using subtractive color mixing deteriorated. This was not noticeable at first but in the early 70s the first faded colors appeared. Faded colors are defined as the loss of color density in at least one layer. A density loss of about 10% and more is perceivable.

Pictures and photos with faded colors mostly receive a more intense color portion depending on the film material used. For instance pictures which were taken on material using the Kodak-chrome method mostly have a more intense red portion. In other variants they can appear as yellow highlights or even blue shadows.

Influenced by this fact quite a few film makers stopped producing color movies and switched back to black and white film. In the early 80s, Martin Scorsese started a campaign addressing this problem. The result of this campaign was that organizations started supporting the film preservation, especially of color film. For many years people involved in mechanical film restoration had tried to produce a photo chemical solution to restore the original color from old color motion picture negatives without noticeable success until now [1]. Therefore mechanical means of restoring this kind of faults are no longer being researched.

2 COLOR FILM

In contrary to black and while films, the color film consists of 3 different layers instead of only one. Color films are based on the method of subtractive color mixing with the three base colors: cyan, magenta and yellow. Subtractive color mixing makes it possible to reproduce all possible colors [2]. In order to restore the original color of a film the densities of each layer have to be known. Densities can be categorized into two different types: the integral density and the analytical density. The integral density is the measurable density of a color film. These measurable yellow, magenta and cyan density curves in dependency to the wavelength are shown in fig 1. The non-overlapping parts of the curves are referred to as main densities whereas the overlapping parts are called tributary densities. It can hereby be seen that densities influence each other in this part making the distinguishing between single color densities more difficult.

The analytic densities are the peaks of each respective density curve to be seen in fig. 1. For Kodak-chrome based file the value for the wavelength of the yellow peak is around 450 nm, of the magenta peak around 550 nm and for the cyan peak around 650 nm. In the faded picture these original values are naturally no longer measurable and have to be provided by the producer of the photo material. A table with the analytical density values of Kodak-chrome color film [3] is given in tab. 1. There the density values for D_C, D_M and D_Y for every peak of the density curves are given. In order to calculate the integral densities the transmissions, which is the amount of passing light, have to be measured using a densitometer. This apparatus is able to measure transmissions at any part of the picture in wavelengths between 380 and 730 nm. A description of the densitometer is given in the following section.

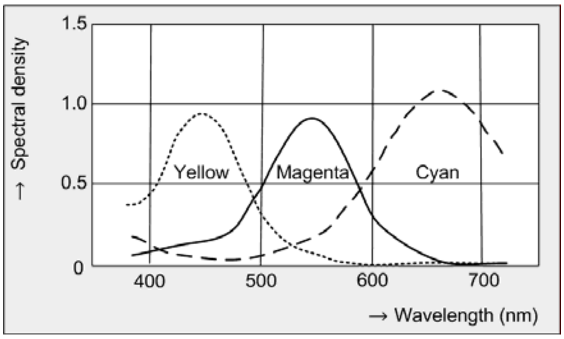

Fig. 1: *Density Curves of Color Layers*

$D_X(\lambda)$	λ =650 nm	λ =552 nm	λ =458 nm
D_C	0,8761	0,1528	0,0978
D_M	0,0930	0,7708	0,2546
D_Y	0,0309	0,0764	0,6485

Tab. 1: *Analytical Densities*

3 METHOD USED

The method of color restoration is shown in fig. 2. In this procedure an image with faded colors has to be obtained and must be available in digital form (1). This can be done with a film scanner or for single frames with an ordinary flatbed scanner. The film material is also needed in order to measure the densities (2) using a densitometer. Alternatively it is also possible to use densities provided by the producer as shown in tab. 1. This however requires the knowledge of which material was used. Using these obtained values potentiates the calculation of the, in the further restoration process needed original densities (3). With the original calculated densities the original color values can be restored (5).

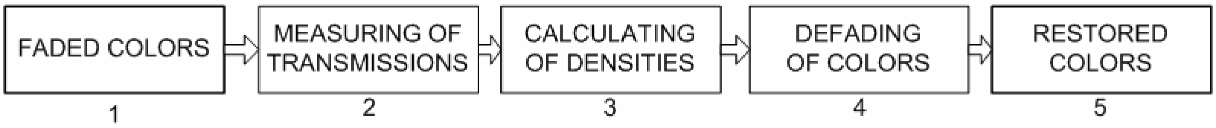

Fig. 2: *Restoration Method*

4 DEFADING

Defading describes the process of retrieving the original integral color densities and reconstructing the original color values hence called defading. These densities can either be measured using the densitometer or calculated from the faded picture.

In order to defade discolored pictures it is necessary to determine all densities and all transmissions of the single color portions cyan, magenta and yellow. The densities can be won out of the transmissions which were measured using the densitometer. The transmission through the film material is the ratio between outgoing luminous flux ϕ and incoming luminous flux ϕ_0. Mathematically the transmission τ is dependant on the wavelength λ of the incoming luminous flux and is described as:

$$\tau(\lambda) = \frac{\phi}{\phi_0} \tag{1}$$

The values at the lower boundary of about 0 refer to nearly complete darkness. In the contrary complete transparency would have values going to 1. These transmissions apply to every layer or an entire transmission.

After [4] the transmissions of a color film multiply to an entire transmission:

$$\tau(\lambda) = \tau_C(\lambda) \cdot \tau_M(\lambda) \cdot \tau_Y(\lambda) \tag{2}$$

The variables τ_C, τ_M and τ_Y are the transmissions for the layers forming cyan, magenta and yellow respectively.

After [5] the transmissions can be transformed to an in film techniques commonly used value, the optical density D as follows:

$$D = \lg\left(\frac{\phi_0}{\phi}\right) = -\lg(\tau) \tag{3}$$

The optical density can take values from 0 to approximately 4, where 0 is complete transparency and 4 is nearly complete opacity.

The entire density of a color film can be calculated by adding the single densities of the color layers. It is also known as the earlier described integral density:

$$D(\lambda) = D_C(\lambda) + D_M(\lambda) + D_Y(\lambda) \tag{4}$$

The analytical densities however have to be provided as described earlier and shown as an example in tab. 1.

After the integral densities have been obtained using the earlier described densitometer the retrieval of defading values can be done.

The analytical densities are standardized using Eq. 5-7. The index *n* stands hereby for normalized and the variable *col* stands for the chosen color red, green or blue and yellow.

$$Dn_C(col) = \frac{D_C(col)}{D(col)} \quad (5), \qquad Dn_M(col) = \frac{D_M(col)}{D(col)} \quad (6), \qquad Dn_Y(col) = \frac{D_Y(col)}{D(col)} \quad (7)$$

Written as a matrix this appears as follows:

$$\begin{pmatrix} D(R) \\ D(G) \\ D(B) \end{pmatrix} = \begin{pmatrix} Dn_C(R) & Dn_M(R) & Dn_Y(R) \\ Dn_C(G) & Dn_M(G) & Dn_Y(G) \\ Dn_C(B) & Dn_M(B) & Dn_Y(B) \end{pmatrix} \cdot \begin{pmatrix} d_C \\ d_M \\ d_Y \end{pmatrix} \quad (8)$$

The gray equivalent densities of the faded picture are a measure for color concentration. Therefore it is possible to express changes mathematically. After [6] the gray equivalent densities of the faded picture can be calculated as follows:

$$\begin{pmatrix} d_{faded\_C} \\ d_{faded\_M} \\ d_{faded\_Y} \end{pmatrix} = \begin{pmatrix} Dn_C(R) & Dn_M(R) & Dn_Y(R) \\ Dn_C(G) & Dn_M(G) & Dn_Y(G) \\ Dn_C(B) & Dn_M(B) & Dn_Y(B) \end{pmatrix}^{-1} \cdot \begin{pmatrix} D_{faded}(R) \\ D_{faded}(G) \\ D_{faded}(B) \end{pmatrix} \quad (9)$$

Also the gray equivalent densities of the original densities have to be calculated:

$$\begin{pmatrix} d_{orig\_C} \\ d_{orig\_M} \\ d_{orig\_Y} \end{pmatrix} = \begin{pmatrix} Dn_C(R) & Dn_M(R) & Dn_Y(R) \\ Dn_C(G) & Dn_M(G) & Dn_Y(G) \\ Dn_C(B) & Dn_M(B) & Dn_Y(B) \end{pmatrix}^{-1} \cdot \begin{pmatrix} D_{orig}(R) \\ D_{orig}(G) \\ D_{orig}(B) \end{pmatrix} \quad (10)$$

After that it is possible to calculate fading factors of each color:

$$a_C = \frac{d_{faded\_C}}{d_{orig\_C}} \quad (11), \quad a_M = \frac{d_{faded\_M}}{d_{orig\_M}} \quad (12), \quad a_Y = \frac{d_{faded\_Y}}{d_{orig\_Y}} \quad (13)$$

The fading factors range from nearly 0, which means complete fading, to 1 which means no fading at all.

With the knowledge of the fading factors it is now possible to retrieve the original values for every layer R, G and B of the image.

5 EXPERIMENTS AND RESULTS

In order to accomplish the experiments of color restoration some special hardware equipment was used. The densitometer, described in section 3 was used in order to obtain the integral densities. In general the densitometer is used to analyse at least one frame of a movie to obtain the actual integral densities. In order to scan a single frame for color restoration just a simple desktop scanner is needed. For a whole movie a professional film scanner like the one used, FDL 90 from Philips BTS [7] is naturally more advisable.

The calculations and restoration of single frames was carried out using MatLab 6.5 from the MathWorks Inc. The developed application allowed one to enter required densities and reconstruct the original colors of a faded picture as mathematically described in section 3. An example for an image with faded colors and restored image can be seen in Fig. 3 and Fig. 4.

Fig. 3: *Picture with Faded Colors*

Fig. 4: *Picture with Restored Colors*

6 CONCLUSIONS AND FUTURE WORK

The method shown in collaboration with the developed MatLab application restores faded pictures in an adequate way. As long as the analytical densities are known and the integral densities are measured correctly with the densitometer. Future work will include various method of automatically detecting the densities out of the image information. This can be done when there is a homogenous area which can be assigned to a definite color. A method to obtain these parameters from the picture information was described in [8]. However, that method is very static and failed under certain circumstances. It also has to be analyzed whether there is a huge difference between detecting the densities using the picture or using a densitometer to measure these physically.

ACKNOWLEDGEMENTS

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