Digital Color Restoration of Faded Motion Pictures

(Term Project Report)

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Abstract- **The objective of our work in this project is to implement the technique proposed in [1] to restore the color of faded color films by using color correction matrices and by enhancing the image contrast by using histogram manipulation techniques. Since photography and motion pictures play an important role in our modem life as document, memory, information carrier, and artistic medium, cinematographic documents represent an important cultural value. It is important to find methods to reconstruct already damaged material and to preserve this heritage in a digital form which allows long term storage. This is possible using powerful multimedia platforms. The digital method is quick, cheap, and does not affect the original. In addition, the restoration of movies requires ideally an automatic procedure in order to keep the human interaction and cost as small as possible. Moreover it is a very universal method.**

I. INTRODUCTION

There are several factors which lead to damaging of films. The bleaching of dyes of color movies with time, the oxidation of fine-distributed silver particles of b/w movies leading to discoloration, the degradation and shrinkage of the film base itself (cellulose acetate / nitrate), storage under non- optimal conditions leading to mechanical wear and abrasion producing dust and scratches are a few of them.

A technique for removal of scratches and temporal discontinuities like dust and fingerprints is proposed in [2]. Restoration of faded color materials by chemicals is impossible because the bleaching of dyes is an irreversible process. Improper processing or environmental influences such as light, chemical agents, heat, humidity and storage, affect images by bleaching the dyes. It is therefore attempted to reconstruct faded color photographs and films by digital image processing.

Usually, a bleached color release print is the only available record of a film, digital color restoration is therefore indispensable. In this report, we first summarize the main steps of the restoration method employed and then compare some of our results on faded images with those in [1].

II. COLOR RESTORATION: Main steps

The processing of the damaged color film is carried out in the following steps- digitization of the film, removal of undesired side absorptions, application of color restoration technique base on the bleaching model chosen for dye fading and image contrast enhancement.

A. Digitization of Film

The first step necessary to allow digital image processing of the available film is its digitization. Digital Film Restoration Systems digitize a film, process it, and then put the images back on the film.

The film is first scanned. This scanned footage is edited and composited on work stations where the restoration techniques are applied on it and then mastered back on film. The restored digital film is stored in the Storage Area Network, from where it is passed to the film recorder which gives us the final restored film. Chromatic calibration at each stage is essential for reliable measurements.

B. Film Scanning

Scanned film frames are used in digital film restoration. There are various motion picture scanners available. Intermittent Film Scanners scan each frame individually whereas Continuous Film Scanners, where the film frames are scanned as the film is continuously moved past the imaging pick up device, are typically evolved from earlier telecine mechanisms, and can act as such at lower resolutions. The imaging system is a CCD (Charge-coupled device) imaging pick-up.

Motion picture film scanners are used in digital filmmaking to scan original film for storage as high-resolution digital intermediate files. There are three layers in a developed negative film- Cyan(C) corresponding to Red light intensity Magenta(M) corresponding to Green light intensity and Yellow(Y) corresponding to Blue light intensity. C, M and Y are referred to as the Emulsion layers.

The scan process determines the part of Red(r), Green (g) and Blue (b) light that would be absorbed by the corresponding layer of the film.

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

where R, G, B correspond to the components emitted by the scanner light source, and R', G', B' correspond to the components measured by the CDD. This can be illustrated as follows:

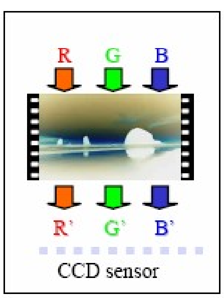

Fig.1: Film Scanning

C. Removal of Side Absorptions

(1) is written supposing that the emulsion layers of the film absorb only their corresponding complementary color (i.e. RGB). In reality, there are some undesirable absorptions, this phenomenon is referred to as Side Absorptions. It arises due to a correlation between the three channels R, G and B.

Cyan layer absorbs a part of green and blue lights along with red light. Magenta layer absorbs green light, blue light and a little bit of red. Yellow layer absorbs blue light, a little bit of green light and an even smaller part of red light.

Side absorptions are emphasized for images having one or two faded layers. Due to the correlation between the three channels, individual RGB channel adjustment is not possible. A correction matrix M is used to remove undesirable absorptions. The proposed structure for the matrix is:

$$\mathbf{M} = \begin{bmatrix} a & e & e \\ c & b & d \\ d & c & b \end{bmatrix}$$

The matrix values are determined keeping the following in mind:

Keep the Red channel as it is, the Cyan layer being the only layer to absorb red light.

Adjust the values of the (g) (b) channels whose corresponding lights have been absorbed by more than one layer. Decrease the value of the (b) channel because it absorbs undesirably Blue light

Add a ratio of the Red and Green channels in order to compensate the absorption of the light by the Cyan and Magenta layers.

These yield:

$$a \approx 1;\ e \approx 0;\ \text{and } a > b > c > d > e \qquad \text{-- (2)}$$

The matrix is applied to every pixel value vector [r g b]' of the original image to obtain the new pixel value vector $[r_A\ g_A\ b_A]'$ of the image with side absorption removed.

$$\mathbf{M} \bullet \begin{bmatrix} r \\ g \\ b \end{bmatrix} = \begin{bmatrix} r_A \\ g_A \\ b_A \end{bmatrix} \quad \text{-- (3)}$$

D. Choice of Bleaching Models

Chromogenic dyes act by absorbing light, as energy, and moving this energy through the bonds in the dye molecule. Dye fade occurs when one or more of the bonds between the atoms in the dye molecule are broken. **T**he resultant chemicals formed during fade may still have some dye effect but not of the intended color. This is noticed as a stain or discoloration within the image.

All movies suffer from color fading with time. There are various reasons for dye fading. High temperature and high relative humidity (RH), air pollution and dirt, light exposure, biological threats such as fungi and insects, residual processing chemicals, base and emulsion deterioration, improper storage and enclosures are some of them.

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).

Yellow, magenta, and cyan are the chromogenic organic dyes used in films. These fade at different rates. Cyan dyes will typically fade more quickly, which will make the image appear too red in color.

It is necessary to develop some models for fading on which we can work to restore the colors of the faded film. Two models have been used in this paper. Both of them model the effects of fading upon the characteristic curves (density versus log exposition) of the intact film. The Offset Bleaching Model (OBM or model b) [2] is a simple curve shift model whereas the Linear Bleaching Model (LBM or model c) [3] is a bleaching model with a curve slope change.

Figure 2 the characteristic curve of the intact film and Figures 3 and 4 model the effects of the fading on the characteristic curve as suggested by the two models.

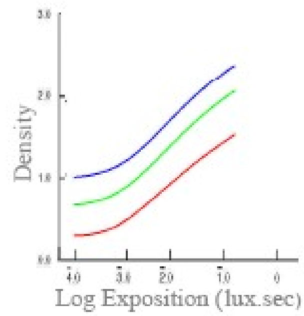

Fig. 2 Characteristic Curve of Intact Film

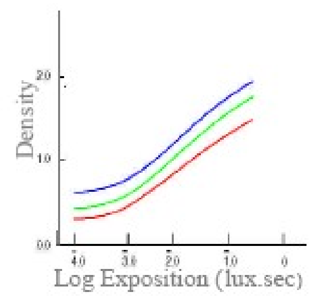

Fig. 3 Offset Bleaching Model (OBM or model b)

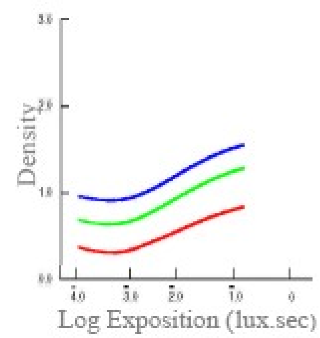

Fig. 4 Linear Bleaching Model (LBM or model c)

E. Color Restoration

As already established, film consists of dye layers that combine to create color images. As film ages, the dyes fade at different rates, resulting in an image with a strong colorcast. The color restoration method used in the reference paper is based on subjective evaluation. The justification is that usually there are no available references to establish what the true colors once were. So, unknown colors of some objects are replaced with their desirable colors. Some key colors like neutral zones, sky color, and flesh color are taken into account in order to easily determine the color cast we want to remove.

An important point to be noted is that all the implemented 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 and color fading.

Using OBM or model b:

Here the fading is assumed to be constant. The adjustment matrix (M) uses the differences between the channels and has the following structure:

$$\mathbf{M} = \begin{bmatrix} 1 & 0 & 0 & a \\ 0 & 1 & 0 & b \\ 0 & 0 & 1 & c \end{bmatrix}$$

As we want to enhance weaker blues and greens while at the same time reducing the overall red colorcast, we get the following conditions on the matrix values:

$$a<0; \quad b>0; \quad c>0 \qquad \text{-- (4)}$$

The matrix operation is as follows:

$$\mathbf{M} \bullet \begin{bmatrix} r_A \\ g_A \\ b_A \\ 1 \end{bmatrix} = \begin{bmatrix} r_R \\ g_R \\ b_R \end{bmatrix} \qquad \text{-- (5)}$$

where r_A, g_A, b_A are the values after removal of side absorption as obtained from (3) and $[r_R, g_R, b_R]'$ is the restored pixel value vector.

Using LBM or model c:

The assumption here is that the fading may be corrected through an affine transform of the bleached color components. The color adjustment matrix has the following structure:

$$\mathbf{M} = \begin{bmatrix} m11 & m12 & m13 & m14 \\ m21 & m22 & m23 & m24 \\ m31 & m32 & m33 & m34 \end{bmatrix} \qquad \text{-- (6)}$$

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.

Defining the following vectors helps in formulating a method to determine the matrix coefficients:

$m_1 = [m_{11}\ m_{12}\ m_{13}\ m_{14}]'$ --(7)
$m_2 = [m_{21}\ m_{22}\ m_{23}\ m_{24}]'$ --(8)
$m_3 = [m_{31}\ m_{32}\ m_{33}\ m_{34}]'$ --(9)

Consider n target color zones and the following vectors for the corresponding restored target zones:

$r' = [r_1\ r_2 \ldots\ldots r_n]'$ --(10)
$g' = [g_1\ g_2 \ldots\ldots g_n]'$ --(11)
$b' = [b_1\ b_2 \ldots\ldots b_n]'$ --(12)

The coefficients are determined such as to minimize the difference between the converted colors and the desired colors using the least-squares method. Specifying more target color zones leads to a better restoration.

Defining the matrix O of the average color values of the i^{th} target color of a faded image as:

$$\mathbf{O} = \begin{bmatrix} r1 & g1 & b1 & 1 \\ r2 & g2 & b2 & 1 \\ . & . & . & . \\ rn & gn & bn & 1 \end{bmatrix} \qquad \text{-- (13)}$$

The least squares approach gives the following results:

$m_1 = (O^tO)^{-1} O^t r'$ --(14)
$m_2 = (O^tO)^{-1} O^t g'$ --(15)
$m_3 = (O^tO)^{-1} O^t b'$ --(16)

This model gives better results than OBM if enough target colors are available and the setting of target colors is correct.

F. Image Contrast Enhancement

Correcting only the color balance still does not correct the color deficiency appropriately in cases when the dye loss has occurred in one or two film layers. In such cases, the contrast of the obtained image is low after the scanning and the adjustment processes (balancing and removal of side absorptions).

The color contrast must be enhanced. The various methods used in the reference paper to enhance dynamic range are histogram equalization [3], histogram stretching [4], and histogram bi-equalization.

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. The histogram equalization technique was chosen to be implemented in the paper because it enhances both brightness and contrast of the restored color image.

III. RESULTS

We chose to work on the same image as the reference paper in order to be able to compare the results.

Fig. 5 Original Picture with an overall Red cast

A. Side Absorption Removal Results:

Fig 6 and 7 are the results after the removal of side absorptions in the reference paper and our result respectively.

Fig. 6 After Side Absorption Removal
(Reference Paper)

Fig. 7 After Side Absorption Removal
(Our result)

The adjustment matrix of (3) which we have used for removal of side absorption is:

$$M = \begin{bmatrix} 1 & 0 & 0 \\ 0.12 & 0.6 & 0.1 \\ 0.1 & 0.12 & 0.6 \end{bmatrix}$$

Code: Side Absorption Removal

```
function a = sideab(x,m)
%x is the original image
%m is the adjustment matrix

[u,v,z]=size(x)

for i = 1:1:u
    for j = 1:1:v

old  = [x(i,j,1);x(i,j,2);x(i,j,3)];
dold = double(old);
new = m*dold;
         if new(1)>=255
            new(1)=255;
         end
        if new(2)>=255
            new(2)=255;
        end
        if new(3)>=255
            new(3)=255;
        end
b(i,j,1)=new(1);
b(i,j,2)=new(2);
b(i,j,3)=new(3);
    end
end

imwrite(b/255,'sideab_removal.bmp');
```

B. Color restoration results:

Using OBM or model b:

The adjustment matrix of (5) is obtained as follows:

```
M = [1 0 0 -81.3
     0 1 0  45
     0 0 1  35.8]
```

The results are displayed in figures 8 and 9.

Fig.8. Color adjustment Result – model b **(Reference Paper)**

Fig. 9 Color adjustment Result- model b **(Our Result)**

```
Code: Color Restoration using
Offset Bleaching Model(model b)

function x = obm(sideab)
%sideab is the image obtained
after side absorption removal
g = sideab;
[u,v,w]=size(g);
sumcolr=sum(g(:,:,1));
sumr=sum(sumcolr(1,:));
ar=sumr/(u*v);
sumcolg=sum(g(:,:,2));
sumg=sum(sumcolg(1,:));
ag = sumg/(u*v);
sumcolb=sum(g(:,:,3));
sumb=sum(sumcolb(1,:));
ab = sumb/(u*v);

m = [1 0 0 125-ar; 0 1 0 125-ag;
0 0 1 125-ab ];

for i = 1:1:u
    for j = 1:1:v
        old = [g(i,j,1 )
;g(i,j,2);g(i,j,3);1];
        dold = double(old);
        new = m*dold;
        b(i,j,1)=new(1);
        b(i,j,2)=new(2);
        b(i,j,3)=new(3);
    end
end
imwrite(b/255,'modelb.bmp');
```

Using LBM or model c:

The adjustment Matrix of (6) for this model, using 4 target colors and least squares estimation approach is found to be:

```
M =[1.9652 0.2638 -0.5660 -170
    0.1199 0.5068  0.3983  85.7240
   -0.0422 0.1986  0.9200  89.8005]
```

Fig 10 and Fig 11 display the results of applying the color adjustment matrix on the side absorptions removed image.

Fig 10 Color adjustment Result – model c Using 4 target colors **(Reference Paper)**

Fig. 11 Color Adjustment results- model c Using 4 target Colors **(Our Result)**

```
Code: Color Restoration using
```

```
Linear Bleaching Model(model c)

function b= modelcnew(x,o,prime)
%sideab is the image obtained
after side absorption removal
%o is the matrix as defined in(13)
%prime is the matrix defined by
r', g' and b' in (10),(11) and
(12)
[u,v,z]=size(x)
on = inv(o'*o)*o';
m=on*prime;
m=m'
for i = 1:1:u
    for j = 1:1:v

old =
[x(i,j,1);x(i,j,2);x(i,j,3);1];
        dold = double(old);
        %size(old)
        new = m*dold;
         if new(1)>=255
            new(1)=255;
         end
        if new(2)>=255
            new(2)=255;
        end
        if new(3)>=255
            new(3)=255;
        end
        b(i,j,1)=new(1);

        b(i,j,2)=new(2);

        b(i,j,3)=new(3);
    end
end
imwrite(b/255,'modelc.bmp');
end
```

C. Contrast Enhancement Results:

We used Histogram Stretching and Histogram Equalization on the restored images for contrast enhancement. The results obtained were similar to those in the reference paper.

Fig 12 Contrast Enhancement by Histogram Stretching **(Reference Paper)**

Fig 13 Contrast Enhancement by Histogram Stretching **(Our Result)**

Fig 14 Contrast Enhancement by Histogram Equalization **(Reference Paper)**

Fig 15 Contrast Enhancement by Histogram Equalization **(Our Result)**

```
Code: Histogram Stretching

function image = hist_st(I)

I = double(I);
layers=size(I,3);

for i=1:1:layers

    minp=min(min(I(:,:,i)))
    maxp=max(max(I(:,:,i)))
    a=(I(:,:,i)-minp);
    b=(maxp-minp);
    I(:,:,i)=(a/b)*255;
    minp=min(min(I(:,:,i)))
    maxp=max(max(I(:,:,i)))
    imhist(I(:,:,i)/255)
end
figure
imshow(I/255)
imwrite(I/255,'hist_st.bmp');
image=I;
end
```

```
Code: Histogram Equalization
_
function image = hist_eq(I)

h1 = histeq(I(:,:,1));
h2 = histeq(I(:,:,2));
h3 = histeq(I(:,:,3));
eq(:,:,1)=h1;

eq(:,:,2)=h22;
eq(:,:,3)=h33;
imwrite(eq,'hist_eq.bmp');
imshow(eq)

end
```

We also applied histogram equalization on the original image, the result of which was good. It is surprising to note that a single operation on the original image resulted in an image which had contrast and color restoration comparable to those obtained by applying side absorption removal and color restoration using the bleaching models.

Fig 16: Result obtained upon applying Histogram equalization on the Original Image

IV. CONCLUSION

We have successfully implemented the methods given in the reference paper for digital color restoration of faded motion pictures. We first removed the side absorptions caused by digitization using an adjustment matrix. The image colors were balanced using a color correction matrix. We found the correction matrices by using two different models for dye fading. We have also enhanced the image contrast by using the histogram manipulation techniques, namely Histogram Equalization and Histogram Stretching, mentioned in the paper.

The results obtained, upon comparison with the given results, proved satisfactory, thereby verifying the correctness of our implementation of the methods.

References:

[1] M. Chambah, B. Besserer, *Digital Color Restoration of Faded Motion pictures,* CGIP Conf. Proc., CGIP2000, Saint-Etienne, France, 338 342.

[2] L. Rosenthaler, A. Wittmann, A. Günzl, Gschwind, *Restoration of old movie films by digital image processing*, IMAGECOM'96, Bordeaux, France, 1996.

[3] R. C. Gonzalez, R. E. Woods, *Digital image processing,* Addison-Wesley publishing company, September 1993.

[4]http://www.ph.tn.tudelft.nl/Courses/FIP/noframes/fip-istogram.html