# Digital Restoration of Faded Color Images by Subjective Method

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Restoration of faded color images using digital technology has become widely accepted as a very effective and practical method. Restoration can be done if the bleach matrix is known, but usually it is not known. We applied two methods based on subjective judgment to restore old faded color prints. The first method uses a conversion matrix with matrix coefficients that are determined using a known color or desirable color. The second method restores the image by trial and error by judging the resulting image. For the first method, it is important to use many colors to calculate the matrix coefficients. For the second method, it is better to adjust the range of the three color signal first. Both methods give acceptable results. The second method is easier and faster than the first method, but first method has the possibility of giving better results because it can compensate fading that occurs when the fading of one color dye layer is effected by the density of other color dye layers. This type of fading happens in the case of light fading.

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## Introduction

In step with recent advances in computer performances, the treatment and preservation of digital images is becoming an increasingly popular application. Although color images stored as digital data do not fade, most images in existence are traditional dye-based images that tend to fade over time. In the past, the faded images of old photographs, for example, were restored using photographic processing techniques.[1] The use of digital image processing techniques, however, has made such restoration much easier and more flexible.

Restoration can be done if the bleach matrix which represents the relation of the density of each CMY dye image before and after fading, is known.[2] Knowing the scanner characteristics that output the RGB signal scanning CMY dye images is also necessary. The usual process for restoration based on the bleach matrix is as follows. The scanned RGB signal of the faded photograph is converted to CMY dye density using a matrix. The matrix represents the characteristics of spectral sensitivity of the scanner and spectral reflectance or transmittance of the dyes used. Then the CMY dye density image of the faded image is converted to the dye density image before fading using an inverse matrix of the bleach matrix. The dye density image is converted to the RGB signal using the matrix again. From accelerated test results, it was shown that these restoration processes will work well with a linear matrix except in cases of heavy bleaching.[2]

Normally the bleach matrix is not known, because it depends on the type of film, printing paper, and storing conditions such as temperature, humidity, and light strength of each image. Spectral characteristics of dyes are not known as well as the bleach matrix, so restoration based on subjective judgment was investigated.

## Restoration Method Based on Subjective Judgment

We applied two methods based on subjective judgment to restore old faded color prints.

**Target Color Method.** This method uses matrix conversion to restore color like the bleach matrix method. Using a linear-type matrix, the restored image data R, G, and B can be written as a function of faded image data R', G', and B'.

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} \begin{pmatrix} m_{00} & m_{01} & m_{02} & m_{03} \\ m_{10} & m_{11} & m_{12} & m_{13} \\ m_{20} & m_{21} & m_{22} & m_{23} \end{pmatrix} \begin{pmatrix} R' \\ G' \\ B' \\ 1 \end{pmatrix}. \quad (1)$$

We tried to determine these matrix coefficients using a known color (we call this a target color). Because a $3 \times 4$ matrix contains 12 unknown coefficients and one color consists of three data, which are R, G, and B, at least four target colors are necessary to determine 12 unknown coefficients.

It is well known that we judge the quality of a color image based on the memory color that we have of some object being a certain color. As skin color is a very important color, it should be selected as a target color when human face or body is included. As its hue is almost constantly independent of its lightness and racial differences,[3] it is easy to set the color value after restoration.

The brightest color and the darkest color (white and black, if included) should also be selected. Sky or grass are also suitable target colors.

Of course we cannot know exactly the original color of faded photography, so unknown data can be desirable colors that we perceive the object to be. If we cannot imagine desirable colors for at least four objects in a faded photograph, this method cannot be applied.

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Let $r_1'$, $g_1'$, $b_1'$ be the color value of the first target color of a faded image, and $r_1$, $g_1$, $b_1$ be the color value of the first target color after restoration. Then chose in the same way the color value of the second target color and so on. If we put four sets of target color together,

$$\left.\begin{aligned} r_1 &= m_{00}\, r_1' + m_{01} g_1' + m_{02} b_1' + m_{03} \\ r_2 &= m_{00}\, r_2' + m_{01} g_2' + m_{02} b_2' + m_{03} \\ r_3 &= m_{00}\, r_3' + m_{01} g_3' + m_{02} b_3' + m_{03} \\ r_4 &= m_{00}\, r_4' + m_{01} g_4' + m_{02} b_4' + m_{03} \end{aligned}\right\}. \tag{2}$$

By solving these simultaneous equations, the coefficient of the first row ($m_{00}$ to $m_{03}$) can be obtained. Then, the coefficients of the second and third rows can be obtained in the same way. When using more than four target colors, coefficients should be determined using the least-square method to minimize the error of converted color from desired color.

If a nonlinear correction is necessary, conversion using a $3 \times 10$ or $3 \times 11$ matrix is possible. This is expressed as:

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} m_{00}\, m_{01} m_{02} m_{03} m_{04} m_{05} m_{06} m_{07} m_{08} m_{09} m_{10} \\ m_{10}\, m_{11} m_{12} m_{13} m_{14} m_{15} m_{16} m_{17} m_{18} m_{19} m_{110} \\ m_{20}\, m_{21} m_{22} m_{23} m_{24} m_{25} m_{26} m_{27} m_{28} m_{29} m_{210} \end{pmatrix} \tag{3}$$
$$\bullet \left( R\ G\ B\ R^2\ G^2\ B^2\ RG\ GB\ BR\ RGB\ 1 \right)^T$$

To obtain the coefficient of this matrix, more than eleven target colors are necessary.

Based on this experiment, the number of target colors should be larger than four even in a $3 \times 4$ matrix as described later. When four colors are used, the selected color value is converted to the desired color value. But if its setting is not completely correct, the other colors cannot be converted into the correct colors, and the reproduced image will not be good. If many colors are used to calculate the matrix coefficient, as the coefficient is determined to minimize the difference between the converted colors and desired colors using the least-squares method, the color that is produced will not be very different even if some wrong setting is included.

A nonlinear correction based on Eq. 3 could not be done successfully in this experiment. It has too many variables compared to the data we can enter. This method would become useful only when there is plentiful knowledge of the color to be reproduced.

**Manual Retouching Method.** This method restores the color by trial and error using a color correction function incorporated in photo-retouching software such as Photoshop.

There are many ways to change color. By changing the tone curve for three (RGB) signals, it is possible to change the color image very much without a masking operation. But usually, it is difficult to know how it should be changed to get the desired result. Therefore, changing colors is usually done using the modes that are easy to predict the result of, such as color saturation, hue, color balance, lightness, etc. If restoration needs a masking operation, it should be done by matrix conversion, which is realized in a target color method.

At first, we tried to restore a faded image using the method to change hue or saturation, but could not get good results. From the analysis of the histogram for each color signal, we found a way to first adjust the color signal range for three color signals, then change the color.

## Experimental

Three old photographic prints, all of them belonging to the Thai Royal Palace were used as samples. They all seem to have been displayed in panels and suffered from light fading.

The scanner used to scan the images was ARCUSII manufactured by Agfa-Gevaert AG. Image processing was conducted using several Macintosh computers. Manual restoration was done using Photoshop for Macintosh. Output prints were obtained using a dye sublimation thermal printer.

## Manual Retouching Method

**First Sample.** The first sample is shown in Fig. 1 (a). It had become reddish-yellow. Seemingly, the cyan dye had been mainly bleached. A histogram of the scanned data is shown in Fig. 2. It is realized that the dark (small) region of the red signal is lost. This means the bleaching of cyan dye. Suppose that the red signal (R) is composed only from the density of cyan dye (C) and the logarithm of absorbance in the red region is proportional to the density of cyan dye for the simplicity and both are normalized to 1. Then

$$R = 1 - C. \tag{4}$$

If the maximum of C becomes $\alpha$ (a decimal between 0 and 1) because of bleaching, R becomes distributed between (1 to 1 - $\alpha$) instead of (1 to 0). This is why the loss of the dark (small) region of the red signal means the bleaching of cyan dye. Therefore, expanding the range of the red signal from (1 to 1 - $\alpha$) to (1 to 0) corresponds to the restoration of the bleaching of cyan dye if the bleach matrix is composed only from diagonal components. But usually these assumptions are not fulfilled. The red signal is composed not only from cyan dye density but also from magenta dye density. If the bleaching of the magenta dye is not so great as the cyan dye, the previous expansion is not enough to compensate for the bleaching of the cyan dye. This effect was pointed out by R. Gechwind and F. Frey (see Fig. 2 and 4 in Ref. 1). The fact that this operation is not enough to restore the color become apparent by seeing the results.

The first sample seems to contain both a white and black region. In the white region, the RGB signal should be 255. The darkening of the green and blue signal can be seen in Fig. 2. This seems to come perhaps from the coloring of the base paper toward magenta and yellow. Expanding the brightest value of the green and blue signal to 255 corresponds to eliminating the coloring. So the brightest value of the three color signals was changed to 255, and the darkest value of the three color signals was changed to 0 because it seems to contain both a white and black region. This function is incorporated in Photoshop as a level adjustment under the color correction menu. The result of this signal range adjustment is shown in Fig. 1(b). Though the color became neutral, its saturation was quite low. This is because the compensation for bleaching by expanding the signal range is not enough.

The color was then corrected using a hue (H), saturation (S), and lightness (L) correction. The H, S, and L were set to 34 deg, +50%, and -8%, respectively. The result is shown in Fig. 1(c). As this process was a subjective one based on trial and error, another tester may have better


**Figure 1.** Results of color conversion for the first sample: (a) original photograph, (b) after RGB signal range adjustment, (c) after restoration by manual method, (d) after matrix conversion using four target colors, and (e) after matrix conversion using eleven target colors.

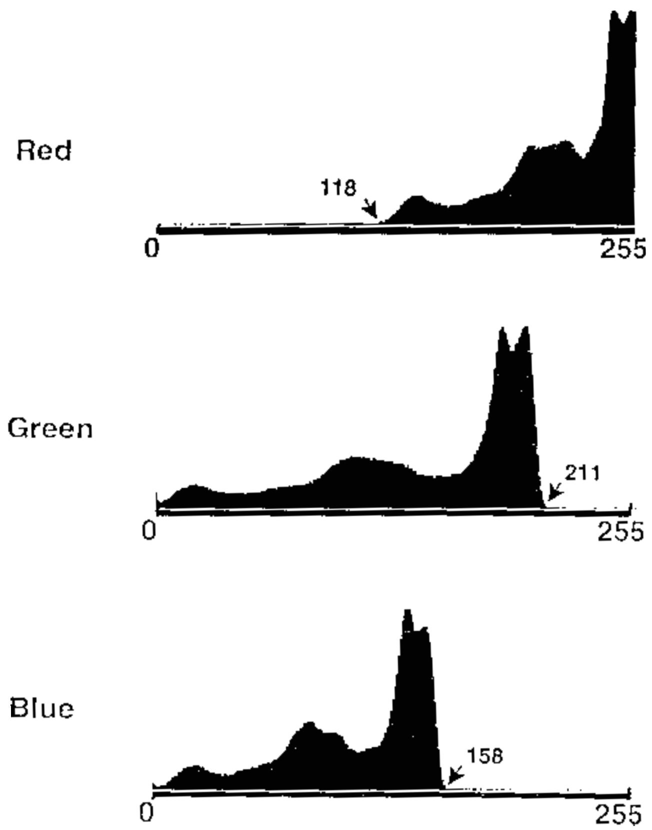


**Figure 2.** Histogram of the first sample.

results. Although the resulting image was really not bright enough, we think the level of brightness was acceptable. Many stains appear after restoration, which must be removed by another method if necessary, such as a brush tool available in Photoshop.

**Second Sample.** The second sample is shown in Fig. 3(a). It had become predominantly magenta. Seemingly, the cyan and yellow dye had been bleached.

A histogram of the scanned data is shown in Fig. 4. This histogram indicates that the coloring, like the first sample, also exists. The green data had possibly been lost in the shadow area, which meant that scanning again by changing input conditions would be necessary.

At first, the range of RGB signals was expanded from 0 to 255 because this photograph also seemed to include both a white and black region. The resulting image is still predominantly magenta. When the G signal was expanded to distribute from 27 to 255, the color balance of the resulting image became better, as is shown in Fig. 3(b).

After this correction, the color was corrected using the color balance correction function. The color C-R was represented at +20%, M-G at +90%, and Y-B at -20%, respectively. In the C-R correction, a positive value indicates a shift to the red side, and a negative value indicates a shift to the cyan side. This operation involves bending the tone curve of the red signal to the upper or lower side. Next, color saturation was increased by 50%.

The result is shown in Fig. 3(c). False contours appeared in the face in the resulting image. This meant that a finer resolution for tone level was necessary during the original scanning in this case. Moreover, green color noise appeared in the darker area, seemingly the result of scanning conditions (a lack of green information in the shadows).

**Third Sample.** The third sample is one that had become predominantly yellow as is shown in Fig. 5(a). A histogram of the scanned data is shown in Fig. 6. This histogram indicates that, as the black level was located nearly in the same position for three different color signals, the cause of the change in color was not bleaching but rather the result of the colored base material. This meant that it might be sufficient to simply adjust the color range as is shown in Fig. 5(b). Moreover, a slight color change or tone curve modification could be added, if necessary.

### Target Color Method

**First Sample.** In the image produced after the RGB signal range adjustment, the color of the king's decorative belt seemed to be red. At first, the assumed flesh color, this belt color, and black and white were used as the target colors. The assumed values were set for each target color, which were determined by seeing color on monitor. The image converted through matrix transformation using the coefficient thus calculated was reddish, though the red color of the belt was clear, as is shown in Fig. 1(d).

Then the number of target colors was increased by adding the bright and dark areas of the skin, lip, military uniform, wall, and red, pink, and yellow flowers. Thus eleven colors were used to calculate the matrix. The color value of these target colors are shown in Table I. The resulting image is shown in Fig. 1(e). It seems to be better than the manually restored image, especially in terms of color brightness. The values of the matrix are shown below.

| | | | |
|---|---|---|---|
| –0.016 | –1.277 | 3.385 | –0.026 |
| –2.426 | 1.982 | 1.156 | 1.075 |
| –4.048 | –0.514 | 5.912 | 1.768 |

It is curious that red data could be reconstructed using primarily blue data. This seems to have been possible because the fading type was a light fading, and the bleaching of the blue color (yellow dye) was very affected by the red color (cyan dye). Because this photo had been displayed in a frame, the color of the area under the frame had become purple after restoration. Stains also appeared after the restoration. It must be noted that this set of coefficients is valid only for this scanning data. A different matrix must be calculated again even for the same original if the scanning condition is different.

**Second Sample**. From the image that was produced after the RGB signal range adjustment, the queen's decorative belt appeared to be green. Thereafter, this belt color, the dark and light flesh color, the dark and light lip color, and black and white were used as the target colors. The image converted through the matrix transformation using the coefficients thus calculated is shown in Fig. 3(d). It was noisy, though the color brightness was better than in the manually restored image. The matrix is shown below.

| | | | |
|---|---|---|---|
| 1.044 | –0.133 | 0.540 | –0.222 |
| –2.057 | 1.304 | 2.845 | 0.484 |
| –1.390 | 1.149 | 2.212 | 0.251 |

### Conclusion

To restore faded color images, two methods were examined, When manual restoration is used, it is recommended to first correct the range of the color data based on histograms.


(a) (b)

(c) (d)

**Figure 3.** Results of color conversion for the second sample: (a) original photograph, (b) after RGB signal range adjustment, (c) after restoration by manual method, and (d) after matrix conversion.

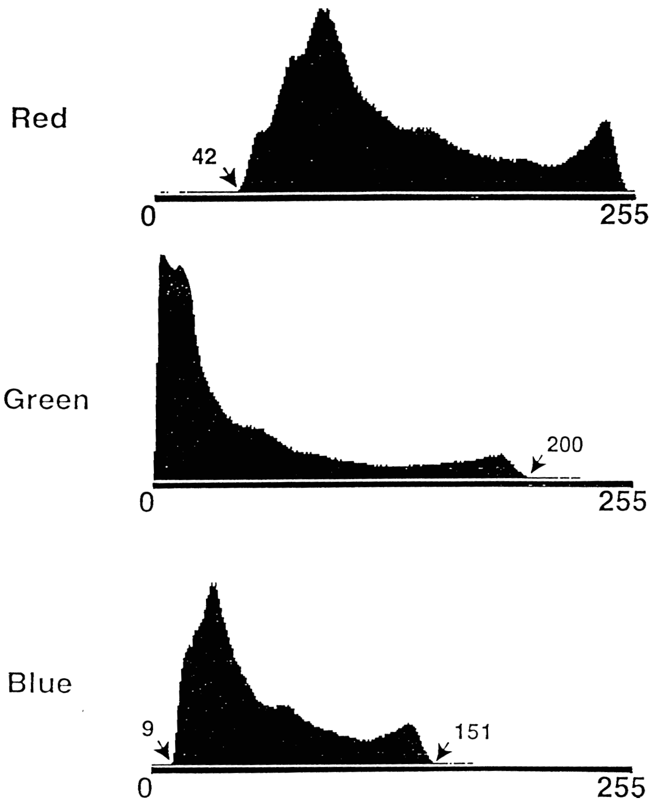


**Figure 4.** Histogram of the second sample.

**TABLE I. Color Value for the First Sample to Calculate Matrix Coefficients**

| Target color | Faded original color | | | Target color value | | |
|---|---|---|---|---|---|---|
| | r' | g' | b' | r | g | b |
| Skin (bright) | 249 | 184 | 139 | 235 | 190 | 170 |
| Skin (dark) | 225 | 136 | 107 | 180 | 145 | 120 |
| Lip | 215 | 105 | 91 | 140 | 70 | 60 |
| Decorative belt | 210 | 95 | 85 | 190 | 40 | 60 |
| Military suite | 224 | 143 | 104 | 150 | 135 | 80 |
| Wall | 243 | 128 | 133 | 210 | 200 | 170 |
| Flower (red) | 200 | 85 | 75 | 120 | 40 | 30 |
| Flower (pink) | 228 | 156 | 112 | 190 | 160 | 130 |
| Flower (yellow) | 234 | 170 | 125 | 170 | 170 | 100 |
| Black (shadow) | 118 | 5 | 5 | 5 | 5 | 5 |
| White (dress) | 254 | 202 | 151 | 245 | 240 | 230 |

Then, images can be converted by correcting the color balance, color saturation, etc.

Correction through matrix conversion has the possibility to give complete reproduction of the original image if the setting of the target color is correct. In this experiment, it gave better color brightness, although its procedure is more complex than manual restoration. A combination of both methods is possible. The value of target color can be modified to give the desired result.

Scanning conditions are very important to retain sufficient information after restoration. The digitizing tone resolution must be high enough, since tone resolution decreases at every step of the process. Furthermore, when an image is excessively faded, 8 bits for each color is not sufficient during original scanning because false contours appear.


(a)


(b)

**Figure 5.** Results of color conversion for the third sample: (a) original photograph, and (b) after RGB signal range adjustment.

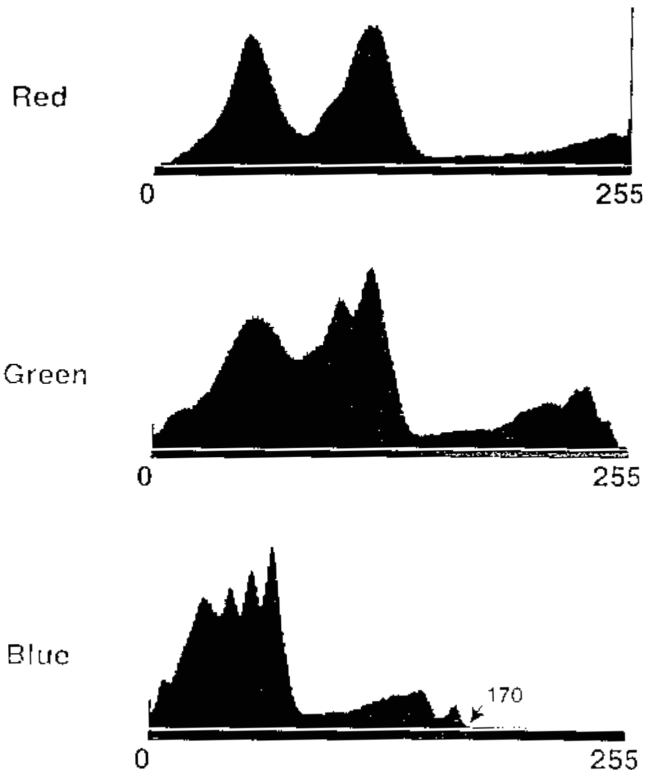


**Figure 6.** Histogram of the third sample.

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