Software Application of the New Algorithm for Restoration of Faded Photographs and Maps in Geology

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This paper presents a software application of a new method for color restoration of faded images and maps. This method is composed of two steps. The first step is to enable the recovery of the brightest point and the darkest. The second step lets build chart of integrated average luminance in (R, G, B) space. This is different from the usual chart built for each color channel separately. The algorithm focuses on adjusting the points with the average luminance and especially the point almost gray. The algorithm is programmed as a part of the data-tool software package. The data-tool software package comprises of two parts: Part I for restoration of aged photos; and Part II specifically for maps. The data-tool software is programmed in the C language, integrated with the support of a few tools in Matlap. A set of the old faded maps at the Geological Museum of Vietnam is selected to test the performance of the proposed color restoration method. The time needed to process images is shorted by utilizing parallel computing tools.

Keywords: balancing method, color restoration, linear bleaching model, data-tool, geology

Introduction

Restoring lost data is an important problem in many areas, such as science, technology, economics, and other areas of human social life. The restoration of lost data is complicated, requiring the use of different scientific methods. In the framework of this article, the author is only limited mention a method for recovering color photos and maps were aging.

Color photos and color film reflect the actual world more exact than black and white images and black and white movies. However, due to the characteristics of materials and manufacturing technology, color materials less durable than black and white materials, the most common is the discoloration and deterioration contrast. After a storage time of about 10 years, the images are often blurred and color imbalance, causing image quality feels very much impaired. The imaging element in black and white film is pure silver particles, very sustainable for the chemical reaction. The imaging element in the color film is the organic dye particles, biodegradability in hot and humid conditions or long lighting. So black and white movies and black and white images are less affected by temperature and humidity of the environment than the color film and color images. Furthermore, the decay rate of the different colors is also uneven leading to an imbalance of color, which rapidly reduces image quality.

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Since the mid-1990s, thanks to the rapid development of digital and digitized image devices, people began to study methods of recovering faded color image with digital image processing technique. However, the results are still limited. The modern restoration system for trading still requires human intervention at many stages and has a very high cost (e.g., the Da Vinchi Systems were offered for around two million pound). Therefore, the study for new effective method is still ongoing.

The main objective of this paper is to build processes and signal processing data-tool software package to recover the data and imaging quality of maps and photographs in the field of geology. The data-tool software package comprises of two parts: Part I for restoration of aged photos; and Part II specifically for maps. The data-tool software package allows researchers, administrators of data storage, and students to restore lost data including photos and maps in the Center of Data Storage, Hanoi University of Mining and Geology. The data-tool software is programmed in the C language, integrated with the support of a few tools in Matlap. The software is effective and stable, compatible with personal computers with normal configuration on Windows XP2 or higher.

The paper is organized as follows. Section 2 presents fundamental mathematical models of discoloration and the basic methods of restoring color. Section 3 describes the mathematical model of new color restoration method. Section 4 presents the software application results. Finally, some conclusions have been made in section 5.

Models and Methods of Restoring Color

In general, the restoration method of faded color image includes the following steps:
• Establish a mathematical model describing the process of film faded with time, temperature, humidity, and the intensity of light impact on image materials;
• Construction of algorithms, allowing redefined original color density, based on the measurements of color density and the parameters of the bleaching equation.

Mathematical Model of Discoloration

To be able to use the digital processing technique for the retrieval of the missing color components from old faded images, one needs to build mathematical model that describes the color density of the film layers, which contains all the main factors affecting the discoloration, such as storage time, temperature, humidity storage environment, and the intensity of light impact on the image materials. Since the late 1990s, based on experiments on different types of color film in various storage conditions, Gschwind, Frey, and Rosenthaler (1995) had built a model, which quite accurately describes the process of fading color film and color photographic paper types. This model has been tested and widely accepted.

Denoting r', g', and b'—luminance of pixels (i, j) of the image faded and r, g, and b—the initial luminance (which must be determined) of that pixels. A valuable model for fading can be described by the following linear bleach equation:

$$\begin{pmatrix} r' \\ g' \\ b' \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \begin{pmatrix} r \\ g \\ b \end{pmatrix} + \begin{pmatrix} a_{41} \\ a_{42} \\ a_{43} \end{pmatrix} \tag{1}$$

where $\{a_{ij}\}$—the elements of the bleach matrix A.

The Methods of Restoring Color

Generally, the methods of restoring color have been proposed are based on equation (1), or based on the Retinex theory (Land, 1977) on the mechanism of visual perception of color.

Method Based on Linear Bleaching Model

Gschwind, Frey, and Rosenthaler (1995) had identified the parameters $\{a_{ij}\}$ in equation (1) for a variety of popular films in different conditions and duration of storage. However, the actual conditions of Vietnam are often not known exactly what types of film as well as time and conditions to preserve them. Therefore, the above parameters are only for reference.

From equation (1), to determine the 12 parameters $\{a_{ij}\}$, it is necessary to know the initial luminance (r, g, and b) at least four pixels. As usual, there is no information about the original image, so the identification of four pixels is very difficult. In *Restoration of Faded Color Digital Motion Pictures*, Chambah and Besserer (2000) had proposed method to estimate the value of four pixels original, based on the familiar color usually appears in the image, such as skin color characters, foliage color, color blue, etc.

The Balancing Methods

The color balancing methods are proposed in order to correct the color deviation, when photos are taken in non-standard lighting conditions. These methods are based on the properties of color perception of the visual. Usually, people do not identify the colors in dark areas of photos. These areas are recognized as the gray area. Moreover, in the photo quality standards, the average luminance of the color channels is usually equal. Analogously, the brightest area in the image is perceived as white. Therefore, the method of color balance, usually divided into two types: the method of gray areas (Grey World Method) and white areas methods (Max White Method).

• Grey World: This method assumes the average luminance of the color channels R, G, and B in the image is equal. Denoting the average luminance of the color channels R, G, and B, respectively, mR, mG, and mB. And suppose that the average brightness of G channel is constant. Then the coefficients of R and B channels by channel G will be determined as follows:

$$a_R = mG\,/\,mR$$
$$a_B = mG\,/\,mB$$

• Max White: Max White method assumes that the brightest point in the three R, G, and B channels is reaching the maximum value and by (2^n, 2^n, and 2^n), where n is the number of bits representing a transmission channel (normally, $n = 8$, $n = 16$). Magnification of the channels will be determined as follows:

$$a_R = 2^n\,/\,R_{Max}$$
$$a_G = 2^n\,/\,G_{Max}$$
$$a_B = 2^n\,/\,B_{Max}$$

Based on two main ideas presented above, recently, many color balancing methods have been proposed (Lam, 2005; Ahmed, 2009).

New Model of Restoring Color

An Algorithm for Color Restoration of Old Images and Film (Pham & Nguyen, 2010) proposed a new color restoration approach for equation (1). The main idea of this approach can be described as follows.

Let—$X' = (r', g', b')^T \in R^3$ pixels measured; $X = (r, g, b)^T \in R^3$—the original pixels (not discolored);

Bleaching matrix size (3 x 3):

$$A = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix}$$

$b = (b_1, b_2, b_3)^T$—vector indicating the aging film substrate.

The bleaching model takes the following form:

$$x' = Ax + b \tag{2}$$

Then determine 12 parameters a_{ij}, b_j, and the original value x can be calculated by the following equation (3):

$$x = A^{-1}(x - b) \tag{3}$$

New construction method is performed in two steps:

Step 1. Consider a special form of equation (2) as follows:

$$x' = \begin{pmatrix} a_{11} & 0 & 0 \\ 0 & a_{22} & 0 \\ 0 & 0 & a_{33} \end{pmatrix} x^{(1)} = \begin{pmatrix} b_1 \\ b_2 \\ b_3 \end{pmatrix} \tag{4}$$

Since the coefficients outside the main diagonal of the matrix A are usually very small compared to the elements on the main diagonal, so equation (4) can be considered as model approximation of equation (1). Determine the value of two pixels of the image to find $x^{(1)}$, and then define the parameters of equation (4). Similarly, in the Max White technique, choose the brightest point [for a value (255, 255, 255)] and the darkest point [for a value (0, 0, 0)] of image x'.

Step 1 allows recovering quite accurate color in bright and the darkest parts of the image. At the same time, the main diagonal elements of A help restore the amplitude of the contrast on the color channels R, G, and B separately. However, in areas where the average luminance and especially, in the area near the gray, there will be the color cast.

Step 2 is to build up the chart of integrated average luminance in (R, G, B) space which allows eliminating the color cast.

Unlike normal brightness chart (histogram) is built on each separate color channels, chart of integrated average luminance is built in space (R, G, B) as shown in Figure 1.

Without the loss of generality, assume that the first image is digitized 24 bit (eight bits per color channel). For each pixel $x = (r, g, b) \in I$, the point x is almost gray pixels if:

$$(\max\{r, g, b\}—\min\{r, g, b\}) \leq S_{\min}$$

Proposed algorithm mainly focuses on adjusting the points with the average luminance and especially the almost gray points.

At plane $[R, G, B]$ (Figure 1). The Descarte coordinates of the vertices R, G, and B are $R = (384, 0, 0)$; $G = (0, 384, 0)$; $B = (0, 0, 384)$. Calling O_p is the barycenter of the triangle RGB, then Descarte coordinates of O_p are:

$$\vec{O}_P = (128, 128, 128) \tag{5}$$

Barycenter coordinates of O_p in the plane $[R, G, B]$ are:

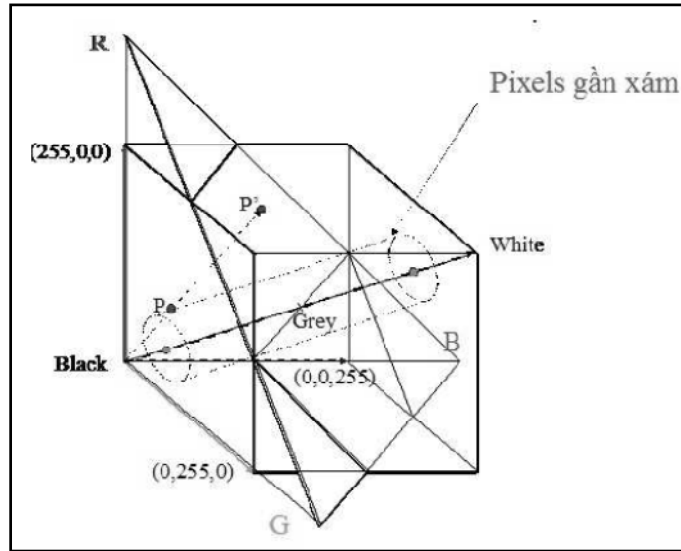$$O_P = \frac{1}{3}R + \frac{1}{3}G + \frac{1}{3}B \tag{6}$$

Figure 1. Color space (*R, G, B*).

Denoting $\lambda = \left\| \vec{O}_P \right\|$, then the projection of the point $x = (r, g, b)$ on the plane $[R, G, B]$ can be represented by the formula:

$$\vec{x}' = \vec{x}\frac{\lambda}{\left(\vec{x}, \vec{O}_{p0}\right)} \quad \text{with} \quad \vec{O}_{p0} = \frac{\vec{O}_p}{\lambda} \tag{7}$$

Let $x = (r, g, b) \in [R, G, B]$ be the representative of x in orthogonal coordinate systems. Let $M = r + b + g$, then representation of x in barycenter coordinates on $[R, G, B]$ will be defined by the following:

$$x = \rho R + \gamma G + \beta B, \text{ with } \rho = \frac{r}{M}, \gamma = \frac{g}{M}, \beta = \frac{b}{M}$$

Constructing the chart of the triangle *RGB* (Figure 2) to consider the barycenter coordinate system in the plane $[R, G, B]$. For a given integer N, the interval $[0, 1]$ is divided into 2^N equal segment by the dividing point:
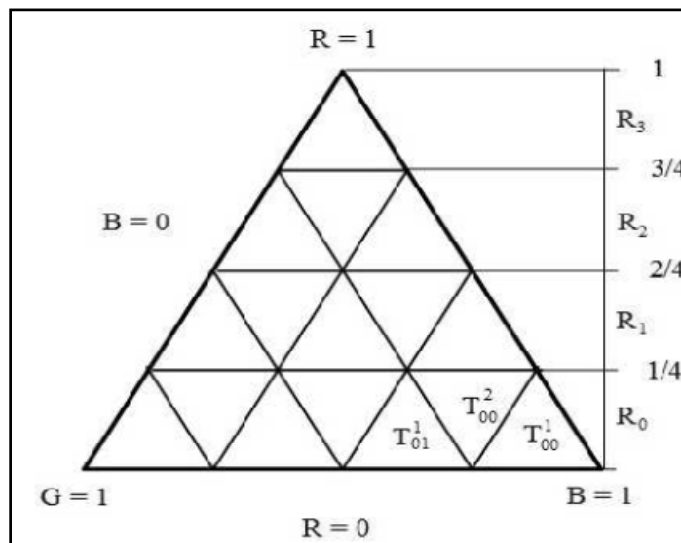

Figure 2. Partition RGB triangle with $N = 2$.

$$n_0 = 0, \; n_1 = \frac{1}{2^N}, ..., \; n_i = \frac{i}{2^N}, ..., \; n_{2^N} = 1$$

Then in the barycenter coordinate system (Figure 3), the point x will belong to the plane $[R, G, B]$ if and only if $x = (\rho, \gamma, \beta); \; \rho + \gamma + \beta = 1$.
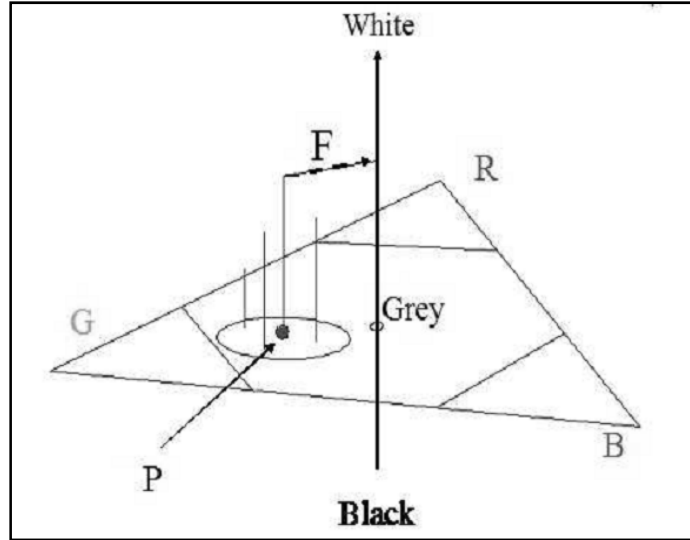

Figure 3. Color cast vector.

So the segments:

$$R_0 = \left[0, \frac{1}{2^N} \right); \; R_1 = \left[\frac{1}{2^N}, \frac{2}{2^N} \right); ...; \; R_{2^N - 1} = \left[\frac{2^N - 1}{2^N}, 1 \right]$$

are similar segments for the G and B.

The point $(\rho, \gamma, \beta) = (n_i, n_j, 1 - (n_i + n_j))$, with $i, j = 0, 1, ..., 2N, \; n_i + n_j \le 1$. Determine a partition of the equilateral triangles in RGB.

Denoting $\beta_{ij} \triangleq 1 - (n_i + n_j)$ such that $(n_i + n_j \le 1)$. Let $i, j = 0, 1, ..., 2^N - 1$ such that $(n_i + n_j \le 1)$, then the rhombus defined by four points $(n_i, n_j, \beta_{i,j}), \; (n_{i+1}, n_j, \beta_{i+1,j}), \; (n_i, n_{j+1}, \beta_{i,j+1}), \; (n_{i+1}, n_{j+1}, \beta_{i+1,j+1})$, or in other words, the rhombus is determined by four edges $\rho = n_i; \; \gamma = n_j; \; \rho = n_{i+1};$ and $\gamma = n_{j+1}$ which contains two equilateral triangles dividing by $\beta = \beta_{i,j+1} = \beta_{i+1,j}$, denoting $T_{i,j}^1$, the class Type I of the triangle which has the coordinates satisfying $\rho + \gamma + \beta < 1$. The triangles with $\rho + \gamma + \beta \ge 1$ called Type II and denoted by $T_{i,j}^2$. There also have some other rhombus determined as above but with only triangles of Type I in the triangles RGB along line $B = 0$. Therefore, the triangle RGB is partitioned into triangles $T_{i,j}^1$ and $T_{i,j}^2$.

To make the pixels have average brightness it falls into each equilateral triangle of above partition, a matrix of counter point $A[i, j], \; i, j = 1, 2, ..., 2^N + 1$ can be built. This matrix consists of $(2^N + 1) \times (2^N + 1)$ elements. Number of pixels falls into the triangle $T_{i,j}^1$ inscribed in the element $A[i + 1, j + 1]$ and number of pixels falls into the triangle $T_{i,j}^2$ inscribed in the element $A[(2^N + 1) - j, (2^N + 1) - i]$, which symmetrizes across the diagonal line.

The next step is to determine the histogram. First, calculating the barycenter of the equilateral triangle of partition triangle RGB.

Setting $\triangle = \dfrac{1}{3.2^N}$ (i.e. 1/3 of each small piece of $1/2^N$).

For triangle Type I with the coordinates of the edge $\rho = n_i, \gamma = n_j, \beta = n_k$, the formula $n_i + n_j + n_k < 1,$ can be got, and the barycenter coordinates are determined by:

$$\rho_c^1 = \frac{i}{2^N} + \triangle; \gamma_c^1 = \frac{j}{2^N} + \triangle; \beta_c^1 = \frac{k}{2^N} + \triangle \tag{8}$$

With the triangle Type II, by $T_{i,j}^2$, $n_i + n_j + n_k \geq 1$ barycenter coordinates will be:

$$\rho_c^2 = \frac{i}{2^N} + 2\triangle; \gamma_c^2 = \frac{j}{2^N} + 2\triangle; \beta_c^2 = \frac{k}{2^N} + 2\triangle \tag{9}$$

Then the barycenter of the histogram is determined by the formula:

$$P = \frac{1}{M} \underset{i,j}{\Sigma} \left(x_{ij}^1 c_{ij}^1 + x_{ij}^2 c_{ij}^2 \right) \tag{10}$$

where:

x_{ij}^1 —the number of pixels falls into triangles T_{ij}^2; x_{ij}^2 —the number of pixels falls into triangles T_{ij}^2;

$C_{ij}^1 = (\rho_c^1, \gamma_c^1, \beta_c^1)$ —the barycenter of the triangle Type I; T_{ij}^1; $C_{ij}^1 = (\rho_c^1, \gamma_c^1, \beta_c^1)$ —the barycenter of the triangle Type II; and T_{ij}^2, $M = \underset{ij}{\Sigma} \left(x_{ij}^1 + x_{ij}^2 \right)$ —cumulative number of pixels in the histogram.

The barycenter coordinates of the histogram and the barycenter of *RGB* triangle show color cast vector (see Figure 4):

$$\vec{F} = P - \left(\frac{1}{3}, \frac{1}{3}, \frac{1}{3} \right) \tag{11}$$

With color cast vector $\vec{F} = (F_R, F_G, F_B)$, the author uses the technique of "gamma correction" to adjust the color values of the pixels of $x^{(1)}$, with gamma values are defined as follows for each color:

$$\gamma R = \frac{\ln(0,5 - F_R)}{\ln(0,5)}; \gamma G = \frac{\ln(0,5 - F_G)}{\ln(0,5)}; \gamma B = \frac{\ln(0,5 - F_B)}{\ln(0,5)}.$$

The above equations (5)-(11) help us to find the approximation $x^{(2)}$. The results are a new approximation $x^{(2)}$ which is better than the original image. The image $x^{(2)}$ is used to determine the entire 12 parameters of the equation (1). Then to use the equation (3) to restore color to the whole of the video images needed restoration.

Application Results

Data-Tool Software Package

The above mentioned algorithm is applied to restore photos and map that are too old and blurry. The algorithm is programmed as a part of the data-tool software package.

The data-tool software package comprises of two parts: Part I for restoration of aged photos; and Part II specifically for maps.

The data-tool software package allows researchers, administrators of data storage, and students to restore

lost data including photos and maps in the Center of Data Storage, Hanoi University of Mining and Geology.

The data-tool software package has also been used to restore photos and maps at the Viet Nam Museum of Geology. Some images of it are shown below in Figures 4, 5, 6, and 7.

The data-tool software is programmed in the C language, integrated with the support of a few tools in Matlap. The software is effective and stable, compatible with personal computers with normal configuration on Windows XP2 or higher.
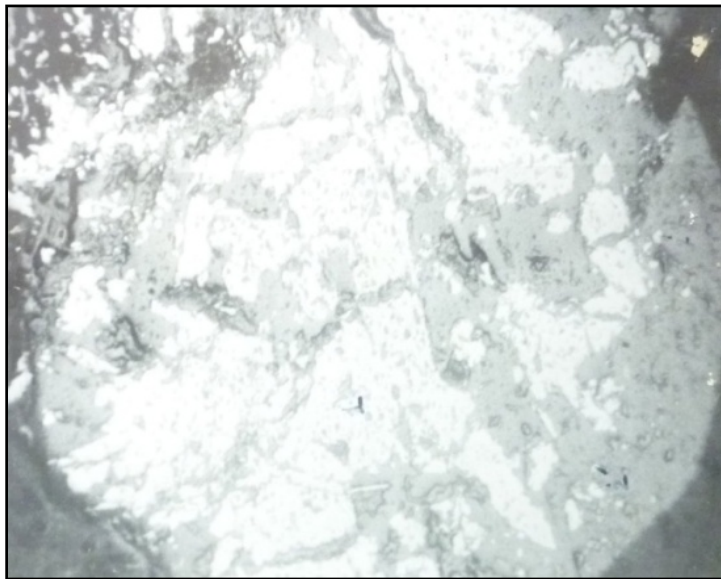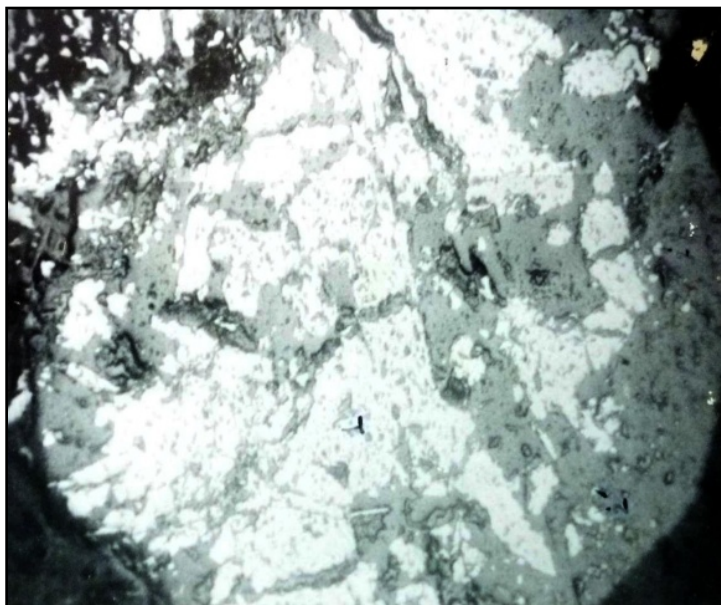

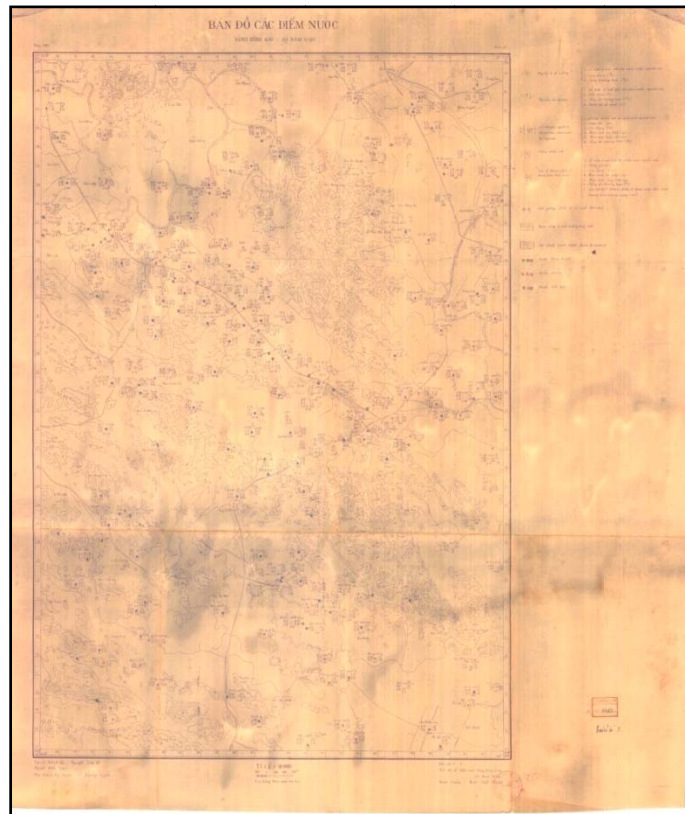*Figure 4.* Original picture.

Figure 5. After restoration.

Figure 6. Map with the water point blurry, blurry due to weather conditions.
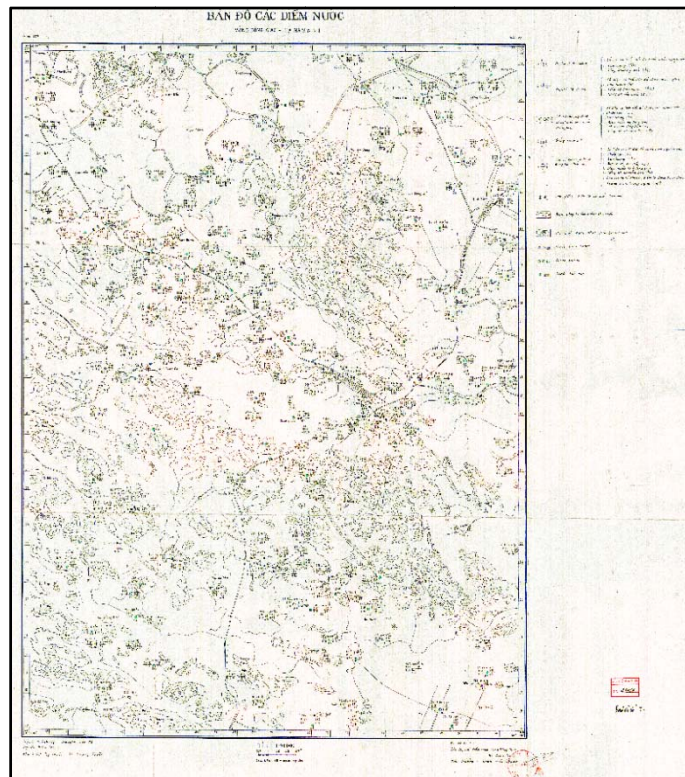

Figure 7. Map after being restored.

Functions of the Data-Tool Software Package

• Input data: old image files that are blurry, faded, and torn at corners, in such formats as *.jpg; *.bmp; *.png; or *.tif.

   • The processing moduls include:

   - Moduls to read data and present output data;

   - Moduls to handle and filter noises for images;

   - Moduls to separate images into layers to process;

   - Moduls morphology interpolation of images;

   - Moduls to restore the surface of images;

   - Moduls to restore the color of images;

   - Moduls to balance colors of images;

   - Modul of the main program.

   • Output data: The processed products are saved in *.pdf and could be viewed on computers or printed.

Conclusion

The research can be summarized in the following points:

• The above mentioned algorithm is programmed as a part of the data-tool software package.

• Build data-tool software that fully integrates all tools to restore aged and faded images and maps.

• Experiment on photo and map samples at the Viet Nam Museum of Geology.

From the samples to restore images and geological maps at Viet Nam Museum of Geology, the following points can be concluded:

   • The photos and maps after restoration show clear improvement.

   • The time needed to process images is shorted by utilizing parallel computing tools.

   • Spliting images with morphology interpolation tools show effective layering, simplify computing, and increase effectiveness in computation.

   • With regards to the restoration of the image surface with continuous projection onto a closed convex set, between the frequency domain and the space domain, the algorithm performs fast, normally with no more than 10 iterations. The reason is the restoring process is carried out around the area of lost data instead of the whole image. As a result, the algorithm is effective for photos in which lost data are adjacent and stretching pixel.

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