Colorized Chinese Ink-and-Wash Painting by Region Growing in Segmented Marked Sub-images

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Abstract

This work presents an effective method to colorize the Chinese ink-and-wash paintings. The Chinese ink-and-wash paintings are first digitized into the images. The user can impose the initial colors on the image freely to become the segmented-marked image. Using image sub-sampling to down-scale the segmented-marked image as the sub-image, the image colorization is then implemented on the sub-image. Since the number of image sub-sampling process is very flexible, the proper number will efficiently accelerate the colorization procedure and take fewer computing time. In addition, the colorization procedure is utilized to refine the boundary between the different colors in the up-scaled colorized sub-image. The lowpass filter is applied on the last colorized image in order to present the soft-gradual tone in the ink-and-wash paintings, such as, water-flowing, smog, cloud, waterfall, and shadow etc. Simulation results have compared the image quality and the computing time for Levin's and the proposed methods. Both two methods result in similar quality colorized images. However without the cost function involved, the proposed method needs 1/15 to 2/3 times the computing time of Levin's method.

1. Introduction

With the rapid progress of electronic technology, it brings several convenient, comfortable and entertaining products into our human life. For the visual products, the digital camera is more popular than the analog one recently. Especially, the colorful digitized image becomes the mainstream; the monochrome (black-and-white) photograph in the photo marketplace seems to decline. For TV shows and movies, people would rather find great performance in the colorful video than the black and white monochrome ones. Furthermore, the similar case occurs in the communication accessory. People tend to have mobile phone with the million-pixel colorful screen, the monochrome screen is no longer popular. Consequently, color is preferred in the modern life.

There are various color-based research topics, such as color enhancement, segmentation, clustering, illuminations-invariant, and image colorization etc. For image colorization, its goal is to impose the self-defined chromaticities on the proper pixels of the target image. Recently, the various approaches are presented to efficiently implement the image and video colorization. Welsh et al. [1] describe a semiautomatic method, adopts the neighborhood matching approach, to colorize a target grayscale image from the specified source color image. They match the luminance and texture information between source and target images, and then transfer the chromatics of the source image to target one.

Levin et al. [2, 3] propose to add colors to the monochrome images and movies. They use a quadratic cost function to solve the optimization problem for the image colorization. In their opinion, the neighboring pixels with the similar intensities in the target image will correspond to the similar colors. Qiu et al. suggest the linear neighborhood embedding method [4] to transmit the monochrome pixels to the chrominance ones, this method utilizes the linearly constrained quadratic optimization problem similar to [2]. Reinhard et al. develop a technique [5], which adopts *lαβ* color space to decrease the color correlation and uses the statistical analysis, and it transfers the colors of the specified source color image to another one.

The rest of this paper is organized as follows: Section 2 introduces the proposed method. Next, Section 3 presents the experimental results. Conclusions are finally drawn in Section 4.

2. Proposed Algorithm

The colorization method for Chinese ink-and-wash paintings is constructed by various phases, which include color conversion, initial color drawing, image scaling, image colorization, boundary refinement and post-processing. Each phase will be described thoroughly in the following. The block diagram of the proposed method is shown in Figure 1.

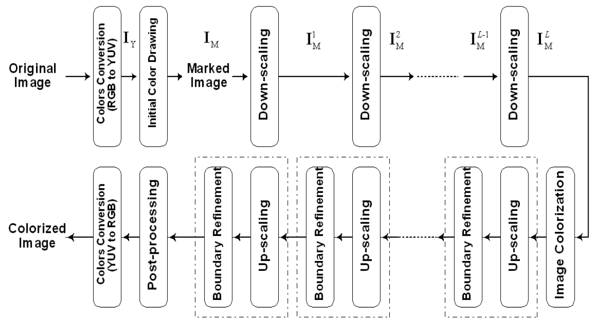
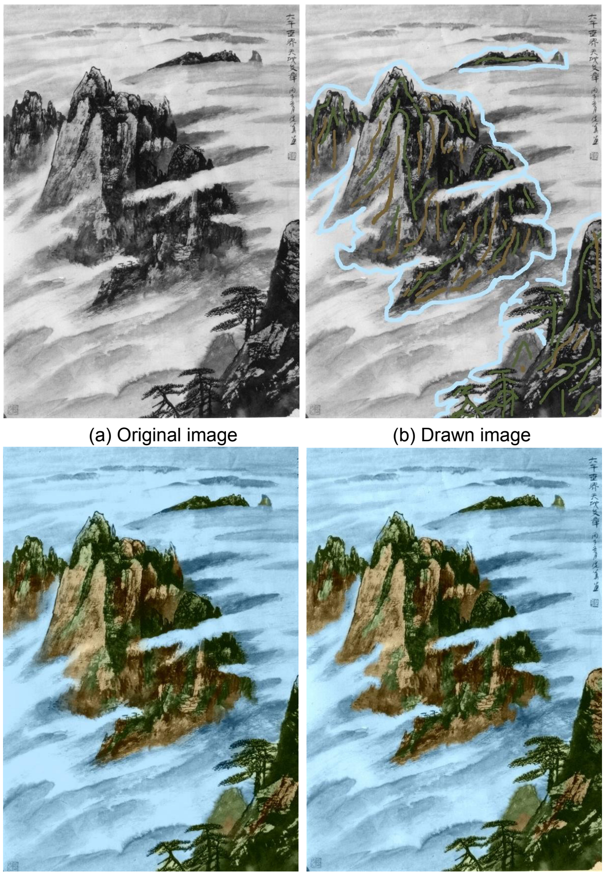


Figure 1 Block diagram of the proposed image colorization algorithm

2.1 Color Conversion

Most of the ancient Chinese ink-and-wash paintings are digitized as the image with higher resolution; therefore, the color conversion is useful to extract the luminance component from the color image. Additionally, the image colorization actually performs on the luminance, and the chromaticities are spread and duplicated to the neighbor ones. The final colorized results are one luminance and two chromatic components, and the color conversion is implemented again to inverse transform those components to the RGB tri-chromatic colors.

The RGB components of original image **I** is transformed to YUV colorspace. The relation of forward color conversion is,



(a) Original image (b) Drawn image

(c) Levin's result (d) Our result

Figure 2 Colorization of the ink-and-wash painting is derived from [6]. (a) Original grayscale image with size 600×840, (b) segmented-marked color image, (c) Levin's result (5886.91 second), and (d) our result (441.92 second).

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.274 & -0.322 \\ 0.212 & -0.523 & 0.311 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}, \quad (1)$$

where R, G and B denote the red, green and blue color components, respectively. The Y component is the luminance value of a color, and the other chromaticities are U and V. After accomplishing the image colorization, the color conversion will be applied again on the colorized image. The backward color conversion is described as below,

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & 0.956 & 0.621 \\ 1 & -0.272 & -0.647 \\ 1 & -1.106 & 1.703 \end{bmatrix} \begin{bmatrix} Y \\ U \\ V \end{bmatrix}. \quad (2)$$

2.2 Initial Color Drawing

The luminance image $\mathbf{I}_\mathrm{Y}$ is an 8-bit gray level image. The user can impose the initial colors on this image, and the resultant image is called as segmented-marked color image $\mathbf{I}_\mathrm{M}$, which is composed of luminance image and two chromatic images $\mathbf{I}_\mathrm{U}$ and $\mathbf{I}_\mathrm{V}$. Those chromatic components derive from the initial colors. For example, Figures 2(a)-(b) show the original luminance image and segmented-marked color image, respectively.

2.3 Image Scaling

The segmented-marked image is down-scaled subsequently. Let the size of segmented-marked image be $H \times W$, it is down-scaled with L levels and then the sub-image $\mathbf{I}_\mathrm{M}^L$ is calculated as,

$$\mathbf{I}_\mathrm{Y}^L(i,j) = \frac{1}{4}\sum_{x=0}^{1}\sum_{y=0}^{1}\mathbf{I}_\mathrm{Y}^{L-1}(2i+x, 2j+y), \text{ and} \quad (3)$$

$$\mathbf{I}_\mathrm{M}^L(i,j) = \begin{cases} \mathbf{I}_\mathrm{M}^{L-1}(2i+1, 2j+1), & \text{if } (2i+1, 2j+1)\text{-th pixel is a color pixel;} \\ \mathbf{I}_\mathrm{M}^{L-1}(2i, 2j+1), & \text{if } (2i, 2j+1)\text{-th pixel is a color pixel;} \\ \mathbf{I}_\mathrm{M}^{L-1}(2i+1, 2j), & \text{if } (2i+1, 2j)\text{-th pixel is a color pixel;} \\ \mathbf{I}_\mathrm{M}^{L-1}(2i, 2j), & \text{otherwise.} \end{cases}, \quad (4)$$

where $\mathbf{I}_\mathrm{M}^L(i,j)$ is the (i,j)-th color value of $\mathbf{I}_\mathrm{M}^L$, and $\mathbf{I}_\mathrm{Y}^L(i,j)$ is the (i,j)-th luminance value of $\mathbf{I}_\mathrm{Y}^L$. As L=0, $\mathbf{I}_\mathrm{M}^0$ and $\mathbf{I}_\mathrm{Y}^0$ are the segmented-marked color image $\mathbf{I}_\mathrm{M}$ and luminance image $\mathbf{I}_\mathrm{Y}$, respectively. The sub-image size is $\lceil H/2^L \rceil \times \lceil W/2^L \rceil$. The symbol $\lceil s \rceil$ is a ceil function in which it takes the nearest integer that is larger than or equal to s.

After accomplishing image colorization on the sub-image $\mathbf{I}_\mathrm{M}^L$, the colorized image $\hat{\mathbf{I}}_\mathrm{M}^L$ is up-scaled to $\mathbf{I}_\mathrm{M}^{L-1}$ as below,

$$\mathbf{I}_\mathrm{M}^{L-1}(2i+x, 2j+y) = \begin{cases} \mathbf{I}_\mathrm{M}^{L-1}(2i+x, 2j+y), & \text{if } (2i+x, 2j+y)\text{-th pixel is a color pixel;} \\ \hat{\mathbf{I}}_\mathrm{M}^L(i,j), & \text{otherwise.} \end{cases} \quad (5)$$

and $x, y \in \{0,1\}$.

2.4 Image Colorization

Region growing is used to implement the image colorization, its function is to propagate the initial colors to the neighbor uncolored pixels. Therefore, the area of uncolored pixels adjoined the colorized ones in $\mathbf{I}_\mathrm{M}^L$ is defined as,

$$\mathbf{J}_{\bar{\mathrm{C}}}^L = \left(\mathbf{J}_\mathrm{C}^L \oplus \mathbf{B}\right) - \mathbf{J}_\mathrm{C}^L, \quad (6)$$

where both of $\mathbf{J}_\mathrm{C}^L$ and $\mathbf{J}_{\bar{\mathrm{C}}}^L$ are binary images which mark the colorized and uncolored pixels in $\mathbf{I}_\mathrm{M}^L$, respectively. $\mathbf{B}$ is the structure element of 3×3 unitary matrix, and the symbol '⊕' denotes the morphological dilate-operation. As $\mathbf{J}_{\bar{\mathrm{C}}}^L(i,j) = 1$, it means that the (i, j)-th pixel is an uncolored pixel.

To cluster the same colorized pixels in the $(2N+1)\times(2N+1)$ window, the center of the window is the uncolored pixel $p(i, j)$. Then, the average luminance (AL) of each cluster is formulated as,

$$AL_k(i,j) = \frac{1}{M}\sum_{x=-N}^{+N}\sum_{\substack{y=-N \\ \forall p(i+x, j+y)\in \mathbf{C}_k}}^{+N} \mathbf{I}_\mathrm{Y}^L(i+x, j+y), \quad (7)$$

where $\mathbf{C}_k$ denotes the k-th cluster of the colorized pixels with the same chromaticities U and V, and M is the total number of colorized pixels in $\mathbf{C}_k$. Measuring the distance between the luminance $\mathbf{I}_\mathrm{Y}^L(i,j)$ and average luminance $AL_k(i,j)$, the minimum distance is found which corresponds to the cluster $\mathbf{C}_l$. If the minimum distance is smaller than threshold τ, the U- and V- chromaticities of $\mathbf{C}_l$ ($U_{\mathbf{C}_l}$ and $V_{\mathbf{C}_l}$) will be duplicated to the uncolored pixel $p(i,j)$.In Figure 3, the uncolored pixel $p(2,2)$ adjoins three clusters ($\mathbf{C}_1$, $\mathbf{C}_2$ and $\mathbf{C}_3$), and the average luminance values of these clusters are,

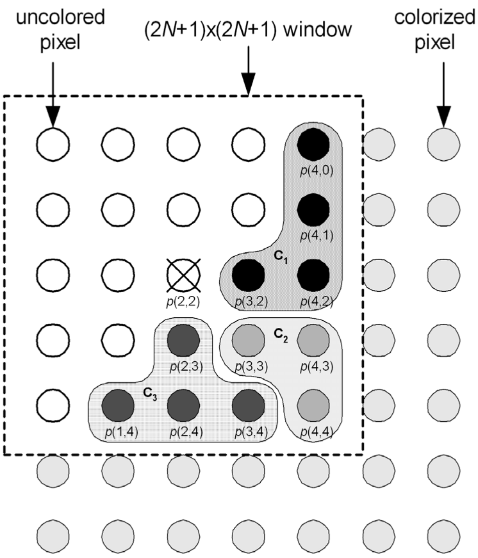


Figure 3 An example describes the region growing. If $\mathbf{I}_Y^L(2,2)$ is close to AL2(2,2) and the minimum distance is smaller than threshold, p(2,2) will be duplicated the U- and V- chromaticities of C2.

$$\begin{aligned} AL_1(2,2) &= \tfrac{1}{4}\left\{\mathbf{I}_Y^L(4,0)+\mathbf{I}_Y^L(4,1)+\mathbf{I}_Y^L(3,2)+\mathbf{I}_Y^L(4,2)\right\}, \\ AL_2(2,2) &= \tfrac{1}{3}\left\{\mathbf{I}_Y^L(3,3)+\mathbf{I}_Y^L(4,3)+\mathbf{I}_Y^L(4,4)\right\}, \\ AL_3(2,2) &= \tfrac{1}{4}\left\{\mathbf{I}_Y^L(2,3)+\mathbf{I}_Y^L(1,4)+\mathbf{I}_Y^L(2,4)+\mathbf{I}_Y^L(3,4)\right\}. \end{aligned} \quad (8)$$

For instance, if $\mathbf{I}_Y^L(2,2)$ is close to $AL_2(2,2)$ and the minimum distance is smaller than threshold τ, $p(2,2)$ will be imposed the chromaticities of $\mathbf{C}_2$.

It is possible that the region growing may be stagnant. To solve this problem, increasing the threshold with stepsize $\Delta\tau$ ($\tau \leftarrow \tau+\Delta\tau$) until the region growing process works. Into the next level segmented-marked sub-image, the threshold is reset to the initial one.

2.5 Boundary Refinement

Subsequently, the colorized image $\hat{\mathbf{I}}_M^L$ is up-scaled to $\mathbf{I}_M^{L-1}$ by Eq.(5). Since the marked image is down-scaled to the sub-image, and the boundary is smoothened. The colors can easily cross the boundary during the colorization procedure, which is called the color-crossing phenomenon. For this reason, the pixels in the boundary between the different colors will be reset to uncolored pixels and will be reprocessed again by the image colorization for the up-scaled image $\mathbf{I}_M^{L-1}$.

2.6 Post-processing

The Chinese ink-and-wash painting not only shows the strong contrast between the object and the background, but also it can express the soft-gradual tone, e.g. water-flowing, smog, cloud, waterfall, and shadow etc. For the soft-gradual tone representation, the lowpass filter with 9×9 window is adopted at the last phase of our method. The filter performs on both U and V- chromaticities of the colorized image $\hat{\mathbf{I}}_M^0$, it smoothes the color sharpness between the boundary of the different colors. Finally, the YUV tri-chromatic colors of $\hat{\mathbf{I}}_M^0$ are transformed back to RGB by Eq.(2).

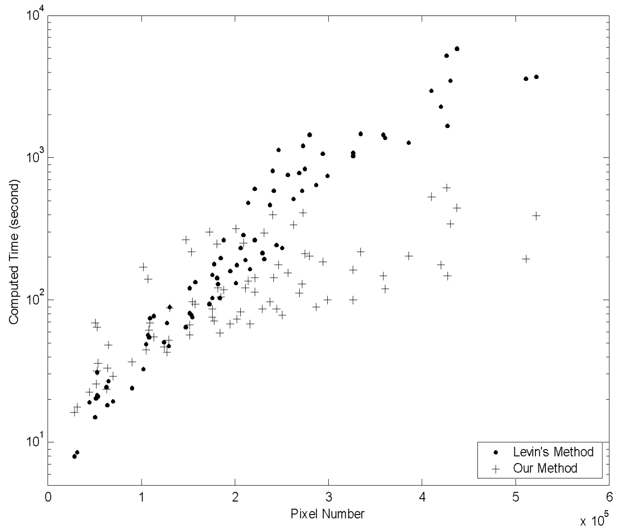


Figure 4 The computing times of 80 colorized images by Levin's and proposed methods.

Table 1 Computing Times of 8 Samples for Levin's and Proposed Methods

		Pixel Number							
		49008	99341	147712	184543	216095	251821	305506	433101
Time (sec)	Levin's Method (a)	18.80	46.83	85.85	156.41	280.67	613.31	1103.24	3156.37
	Proposed Method (b)	34.04	70.30	127.06	127.15	137.60	171.66	183.02	316.75
	Time Difference (a-b)	-15.24	-23.47	-41.21	29.27	143.07	441.65	920.22	2839.62

3. Experimental Results

3.1. Levin's vs. Proposed Methods

The parameters are set as L=1, τ=8 and $\Delta\tau$=32 in the following two experiments. For the first experiment, the image colorization of Levin's [2, 3] and the proposed methods are implemented on 80 Chinese ink-and-wash paintings. The image sizes are very diverse, the smallest image size is 151×240 pixels and the largest one is 4323×250 pixels. Figure 4 illustrates the computing times of those images by the two methods. The horizontal and vertical axes of Figure 4 represent the total pixel number and the computing time, respectively. In Table 1, it lists the comparisons of 8 samples with the proposed and Levin's method. Since the proposed method doesn't involve the time consuming cost optimization, consequently, it is faster than Levin's method for the large-size image. The time difference is positive means that Levin's method need take more computing time than ours. For example, the test image of size 600×840 takes 5886.91 second and 441.92 second to be colorized using Levin's and our methods, and the resultant images are shown in Figures 2(c)-(d), respectively. The proposed algorithm needs about 1/15 to 2/3 times the computing time of Levin's method.

The second experiment is the image quality of the colorized image. Initially, the original color images are extracted the luminance component, which is imposed the specified colors to be segmented-marked image. Subsequently, Levin's and proposed methods are implemented on those segmented-marked images. Thirty color images are tested in

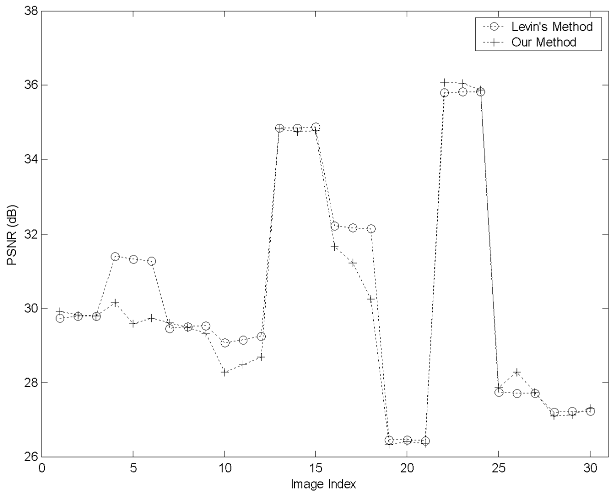


Figure 5 PSNR values of 30 colorized images by Levin's and proposed methods.

Table 2 Comparisons of Levin's and proposed methods

	Levin's Method	Proposed Method
Computing Time (Unit)	1	1/15~2/3
Hierarchical Level	No	Yes
Colorspace	YUV	YUV
Cost Optimization	Yes	No
Average PSNR (dB)	30.40	30.29
Applications	Image/Video	Image/Painting

Table 3 Details of five Chinese ink-and-wash paintings

Figure No.	Name	Author	Dynasty	Image Size	Computed Time	Ref.
2	Unknown	Unknown	Recent	600×840	441.92	[6]
6	Flower volumes	Jinnong	Qing	427×640	248.65	[7]
7	Unknown	Unknown	Recent	600×846	528.28	[6]
8	A beauty plays the flute	Dan-Xu Fei	Qing	341×504	110.08	[8]
9	Three peonies	Shouping Yun	Qing	546×350	177.39	[9]

this experiment. Figure 5 shows PSNR values between colorized and original images. The average PSNR values of Levin's and proposed methods are 30.40dB and 30.29dB, respectively; those two methods get the similar image quality results, and the major comparisons between them are listed in Table 2. Both two methods are implemented on MATLAB software on 2.40GHz Pentium-4 CPU with 256 megabyte RAM.

3.2. Colorized Chinese Ink-and-Wash Paintings

Five Chinese ink-and-wash paintings are colorized using the proposed method, and the details of these images are summarized in Table 3. Figure 6(a) shows the black-and-white ink-and-wash painting of the 'flower volumes' with size 427×640. The colorized image is shown in Figure 6(b) and takes 248.56 second. The rest of three ink-and-wash paintings shown in Figures 7(a)-9(a) are originally colorful. To embed the colors on those originally color paintings, the final results

(a) Original image (b) Colorized image

Figure 6 Colorization of 'Flower volumes' is derived from [7]. (a) Original image with size 427×640, (b) resultant colorized image (248.56 second).

(a) Original image (b) Colorized image

Figure 7 Colorization of the ink-and-wash painting is derived from [6]. (a) Original image with size 600×846, (b) resultant colorized image (528.28 second).

(a) Original image (b) Colorized image

Figure 8 'A beauty plays the flute' is derived from [8]. (a) Original image with size 341×504, (b) resultant colorized image (110.08 second).

(a) Original image

(b) Colorized image

Figure 9 'Three peonies' is derived from [9]. (a) Original image with size 546×350, (b) resultant colorized image with the interchange of the flowers' colors (177.39 second).

are shown in Figures 7(b)-9(b), and take 528.28, 110.08 and 177.39 seconds, respectively.

4. Conclusions

This paper presents an effective method to colorize Chinese ink-and-wash paintings. The advantages of the proposed method are simple, efficient and fast to colorize the image. To compare the computing time and image quality for Levin's and the proposed method, the colorized image qualities of both two methods are very similar. However, for computing time, the proposed method without cost optimization is faster than Levin's one, it needs 1/15 to 2/3 times the computing time of Levin's method.

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