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Simulating Aging and Reverse-Aging Phenomena of Traditional Chinese Paintings

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Conventional image processing techniques are often too unsophisticated in their approaches to simulating the effects of aging and restoration of paintings. Current processing approaches fail to consider factors such as storage conditions, the status of pigments and surface materials, as well as historical trends in color selection and utilization. By neglecting these issues, realistic image manipulation of painted art is too often unsuccessful, both in terms of simulating weathering and age on contemporary works, and in attempting to restore or remove these same effects from older pieces.

This paper proposes a knowledge-based approach to simulate and remove the effects of aging in traditional Chinese paintings. A database of information related to degrees of color fade over time is constructed by collecting, categorizing, and analyzing the images of paintings from different eras. In addition, relationships among color distribution histograms, the different subjects being depicted, the year or dynasty the painting was created, and the properties of different pigments are also tracked.

A commonly used motif in traditional Chinese paintings is to intentionally leave areas blank. These untouched areas provide a useful clue for our prototype system to separate the aging influence of pigment colors from any surface coloration. The diffusion of colors across boundaries is also handled by using a vector field. After accounting for the color of blank areas and color diffusion, several image processing techniques are applied to further enhance image quality.

By using our prototype system, both aging and reverse-aging processes can be simulated. Initial study results show that this approach has great potential in simulating aging effects on images of traditional Chinese paintings.

Keywords: traditional Chinese paintings, web-mining, color analysis, color simulation, color mapping.

1. Introduction

As time passes, traditional Chinese paintings often fall victim to physical and chemical changes. Attempts to preserve these works usually consists of cleaning surface dust, filling in pigments in missing areas, patching missing pieces with glue, and replacing surface materials such as paper, canvas, and silk. These efforts help restore physical changes to a certain degree, but are unable solve problems related to the chemical changes which cause colors to fade.

For digital images of traditional Chinese paintings, the aging problem becomes further complicated and difficult to simulate. In general, conventional image processing methods only consider limited information obtained from a single image source. Therefore, it is very difficult to realistically simulate aging and reverse-aging effects by simply using conventional image processing methods.

Previous approaches to manipulating images of traditional Chinese paintings have not focused on the variation of pigments. One approach [1] adds saturation to the colors based on the hue of the background in order to reduce the effects of age and color fade. Another method [2] focuses on color restoration techniques for faded photos and paintings. Still another technique [3] implements virtual restoration of ancient Chinese paintings using color contrast enhancement and lacuna texture synthesis in an attempt to eliminate stains and cracks. While all of these approaches can alter an image of a painting to appear new, they cannot effectively simulate the aging process across different dynasties and lack the detailed knowledge-based approach proposed by our system. To achieve this goal, we used various online resources to collect a large number of images of traditional Chinese paintings from different years and eras. Before analyzing the overall color distribution of the paintings, we converted these images from their RGB values to a spectral histogram. In order to construct a knowledge base of colors, it is very important to understand the properties of pigments in traditional Chinese paintings. Until the end of the Qing dynasty (A.C. 1875), the raw materials used in traditional paintings could be divided into mineral pigments and plant pigments. The former includes white powder (白粉), cinnabar (朱砂), vermillion (朱膘), ochre (赭石), azurite (石青) and malachite (石綠), while the latter includes rouge (胭脂), gamboge (藤黃) and cyanine (花青) (Table 1). Changes to these pigments over time are tabulated using heuristic formulas capable of creating precise variations of color.

1	2	3	4	5	6	7	8	9
White powder	Cinnabar	Vermillion	Ochre	Malachite	Azurite	Rouge	Gamboge	Cyanine

Table 1: Colors of pigments used in traditional Chinese painting

The rest of this paper is organized as follows. Section II details steps for implementation. Section III shows comparisons and results. Section IV gives our conclusions and potential future research directions.

2. Implementation

The approach outlined in this paper focuses on the pigment fading process and simulates the changes of color on traditional Chinese paintings. The majority of the source images used originating from a website [4] containing images from the National Palace Museum. The images collected ranged from the Song Dynasty (A.C.960) through the early Republic of China era,

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with the painting in each image classified into a 100-year time period, as well as by subject. In order to provide an adequate sample pool, we collected over six hundred images of separate traditional paintings.

Traditional Chinese painting differs from traditional western oil painting in that it often leaves bare large areas of the support medium, such as paper, cloth, and other materials herein referred to by the more general term canvas. This emphasis on empty space is a key component of artistic expression in traditional Chinese painting. This format leaves large areas of the painting the same color of the canvas. Therefore, our system implements a GUI, or graphical user interface, whereby the canvas color can by manually excluded from color analysis. Following Brian Smits's RGB conversion algorithm [5], pixels are converted from RGB to spectrum color space with wavelength values of additive primary colors (RGB) and subtractive primary colors (CMY) in nanometer units. The basic process is shown in pseudo code form in Figure 1. Our method uses MATLAB to draw the distribution pattern of a one-dimensional color space for each painting.

```
Spectrum RGBToSpectrum(red,green,blue)
  Spectrum ret = 0;
  if(red ≤ green && red ≤ blue)
    ret += red * whiteSpectrum;
    if(green ≤ blue)
      ret += (green - red) * cyanSpectrum;
      ret += (blue - green) * blueSpectrum;
    else
      ret += (blue - red) * cyanSpectrum;
      ret += (green - blue) * greenSpectrum;
  else if(green ≤ red && green ≤ blue)
    ⋮
  else      // blue ≤ red && blue ≤ green
    ⋮
The other two cases are similar.
```

Fig. 1: RGB conversion pseudo code.

Color distributions are analyzed images starting from the Song Dynasty to the early period of the Republic of China. We first picked landscape paintings from each dynasty and removed their canvas colors as shown in Figure 5. Figure 5(a) shows a painting from the Song Dynasty entitled "Sitting beside the Stream Alone" (960-1031). Figure 5(b) shows a painting from the Yuan Dynasty called "Illustrating Rain and Shine over Spring Mountain" (1299). Figure 5(c) is from the Ming Dynasty, named "Picture Scroll of Spring Mountain" (1501-1583). Figure 5(d) from the Qing Dynasty is entitled "Colored Mountain and Water" (1644-1728), and Figure 5(e) is from the early Republic of China period, called "Mountain and Water" (1948-now). The left sides of the figures show the original paintings, with results after removal of the canvas colors displayed on the right. These results are then processed by the steps outlined above and MATLAB creates color distributions as shown in Figure 6. Figures 6(a) to 6(e) show the color distributions of the right side of Figure 5, and Figure 6(f) combines these into one graph. As shown in Figure 6, colors tend to change from red to blue. Possible causes for this may be that Lateritic minerals were used as pigments earlier and cyan-blue minerals were incorporated later, or there might be a tendency for pigments to fade into red as time goes by. Additionally, the histograms of landscape paintings tend towards blue and green, while paintings of female subjects tend towards pink, and histograms of paintings with flowers and birds tend to be somewhat neutral.

To average the color of a selected area, 5 by 5 pixel square is used. However, the color of the canvas in older paintings causes the selected color to be more yellow. Techniques mentioned in related literature shows that painters will spread vitriol glue on the canvas for pigments to attach to before creating the painting. The glue is usually mixed with something like gamboge, and the backgrounds of traditional Chinese paintings usually tend to be yellow. Our approach uses the Beer-Lambert law to solve this problem, as shown in Equation (1).

$$I = I_0 .\ e^{-\alpha_a . l} \qquad (1)$$

The strength of light, I, is the strength of light incident, I_0, multiplied by the exponential function e, with an exponent of a negative absorption coefficient, α^a, multiplied by the thickness of the medium, l. The selected colors are applied to this algorithm to fix this problem in the CMY color space, with the result as shown in Equation (2).

$$\begin{aligned} C_0 &= C_I - C_B .\ e^{-k1 .\ saturation_{CI}} \\ M_0 &= M_I - M_B .\ e^{-k2 .\ saturation_{M}} \\ Y_0 &= Y_I - Y_B .\ e^{-k3 .\ saturation_{YI}} \end{aligned} \qquad (2)$$

The CMY color space is described as subtractive primary colors consisting of cyan, magenta and yellow. The original selected color, C_I, M_I and Y_I, are regarded as the strength of light incident. To reduce the influence of the background color, the selected color subtracts the background color after being calculated. Its values are the original background color, C_B, M_B and Y_B, multiplied by the exponential function e, whose exponents are negative absorption coefficients multiplied by the thicknesses of the pigment medium. The principle of light refraction when passing through pigment mediums is used in this equation. Their absorption coefficients were obtained from association rule mining approach, as discussed below, and their thickness of medium is replaced by the saturation of the original selected color which regard as the medium of light. The result is displayed in a graphical form as illustrated in Figure 2.

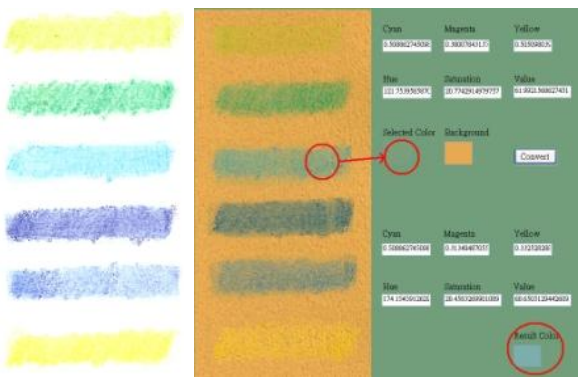

Fig. 2: The GUI which experiment Equation (2).

Support=10%, confidence=70%		
ID	pigments & dynasty	HSV
5	pigment=cyanine dynasty=Ming 9 => Saturation=15 9	conf:(1)
287	pigment=cyanine dynasty=Republic of China period 6 => Saturation=55 5	conf:(0.83)
52	pigment=cyanine dynasty=Song 9 => color=yellow 7	conf:(0.78)
16	pigment=cyanine dynasty=Qing 9 => color=indigo 9	conf:(1)
30	pigment=cyanine dynasty=Republic of China period 6 => color =indigo 6	conf:(1)
407	pigment=malachite dynasty=Song 9 => Hue=90 7	conf:(0.78)
408	pigment=malachite dynasty=Qing 9 => Hue=150 7	conf:(0.78)

Table 2. Parts of the strong association rules.

Name	Color	Data size	Average. color	Original color	The number of the difference	Usage
White powder		9			18.6%	Paint snow, white flowers or birds.
Cinnabar		9			8.9%	Depict flowers, birds or clothing.
Vermillion		9			11.2%	Illustrate flowers, birds, furniture and clothing.
Ochre		18			8.3%	Paint stone, tree trunks, old branches and leaves.
Malachite		9			19.5%	Represent stone, tree and moss.
Azurite		9			38.4%	Draw leaves and stone.
Rouge		15			6.1%	Illustrate flowers and make-up.
Gamboge		9			14.4%	Draw flowers and leaves.
Cyanine		9			31.0%	Illustrate stones, sky, streams, flowers, grass and clothing.

Table 3: Shows the names of the main pigments and their colors and usages, and compare the color of scans and the color after being averaged over many images from the internet.

Data mining was applied to generate the pigments fading rules. Data mining is the process of discovering new, implicit and significant patterns from large data sets, and it's a new technology among the knowledge discovery in databases process. This research adopts association rule [6] which is an important method in data mining and applies its Apriori algorithm [7-8]. With Apriori algorithm, how pigments and dynasties affect the hue, saturation and brightness value (HSV) was discovered. Association rule mining appeared to analyze the market basket in 1990s. It observed the hidden relationships between those purchasing items and found the consuming habit of those customers in the transaction database. An example shows below.

To calculate the appropriate absorption coefficients, we apply the association rule mining process. The association rules represent the relationships of the interested items or attribute values in the form "A $\Rightarrow$ B". It can be roughly interpreted as the likelihood of B's appearance when A already existed. The quality of each rule is determined by two probability measurements shown below.

$$support(A \Rightarrow B) = P(A \cap B)$$

$$confidence(A \Rightarrow B) = P(B \mid A)$$

We usually set threshold values to trim off low quality rules from a potentially huge set of possible combinations. This approach adjusted the *minimum confidence* to 0.7 and the *minimum support* to 0.01 in the database contained 336 pixels about pigments fading information. Parts of the strong association rules were listed in Table 2. The example of ID=407 shows below.

pigment=malachite dynasty=Song 9 =>Hue=90 7 conf:(0.78)

This rule means that with the confidence 78%, when the pigment is malachite and the dynasty is the Song Dynasty, the data entry will have 90 as its hue value. (The 9 and 7 here indicates the ids of corresponding attribute values). According to all of mining rules, we conclude that the absorption coefficients of Equation (2) with k1=1.825, k2=1.85 and k3=1.875 properly matches the trend from our underlying database.

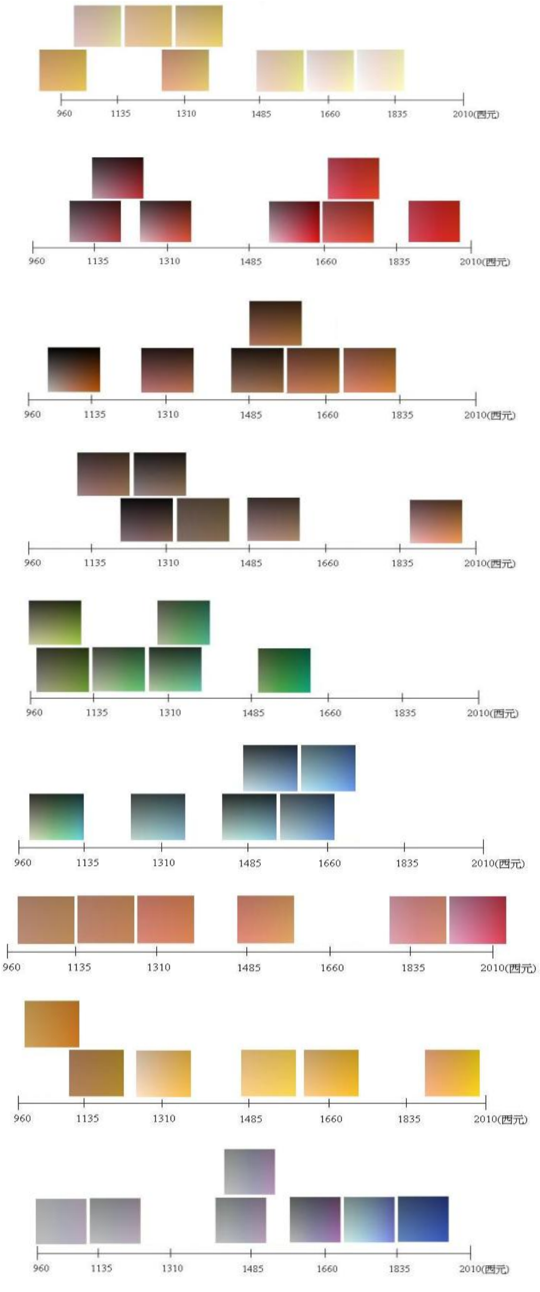

Fig. 3: The faded pigments table through Song Dynasty to Republic of China' paintings. From the top to the button and the left to right are the changes of White powder, Cinnabar, Vermillion, Ochre, Malachite, Azurite, Rouge, Gamboge and Cyanine.

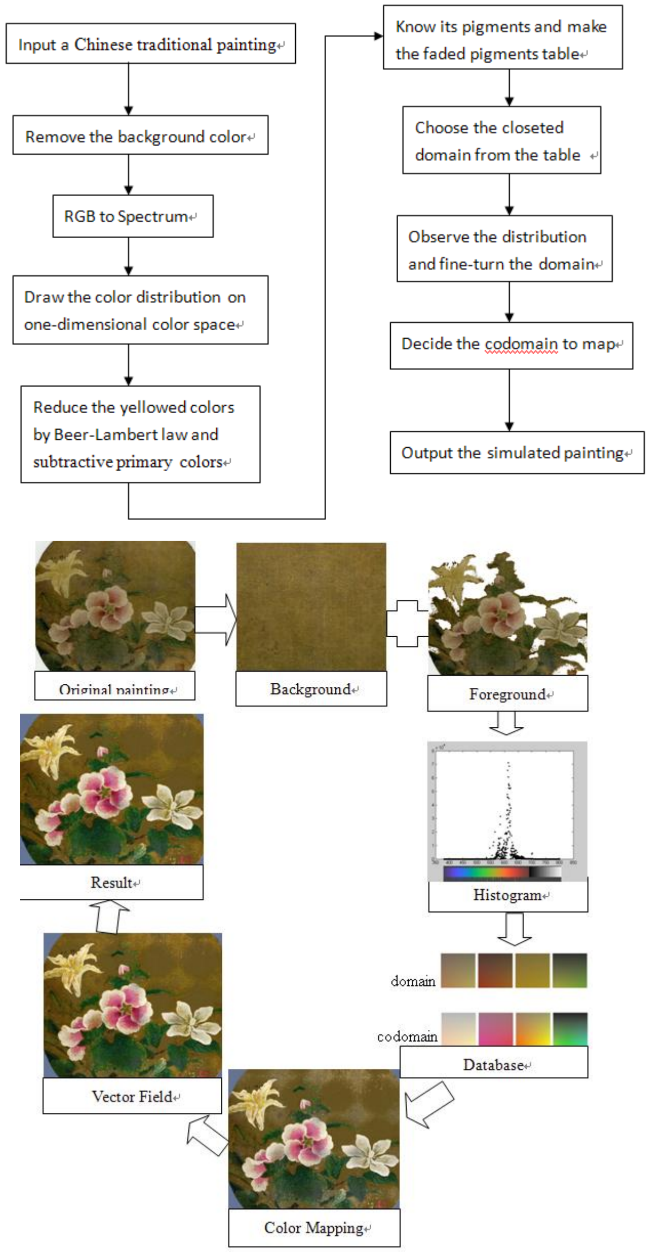

Fig. 4: Flow diagram

Mineral pigments tend to fade slower than plant pigments used in traditional paintings. Table 3 shows the names of the main pigments and their colors and usages. There are two kinds of the white powder: gefen and lead powder. Because the paintings sampled were in different states of preservation, different degrees of pigment fade were selected according to dynasties and subject matter in which a pigment appears, from the Song Dynasty to the early Republic of China era. The results were sorted into a faded pigment table as shown in Figure 3. It should be noted that the paintings were run through Equation (2) before being added to the table. However, if the equation resulted in errors for pigments made from white powder, gamboge or rouge, the equation was not applied.

To use the faded pigment table for a painting, the user chooses the closest degree of faded pigment for the domain by the color and dynasty of the given painting, and observes its color distribution to decide the degree of fine-tuning for the pigments. If one pigment has more distribution, its hue range is adjusted to wide, and its ranges of brightness value and saturation are set to narrow. If one pigment has a lower distribution, its range of hue is set to narrow, and its ranges of value and saturation are adjusted to wide. Next, after deciding these ranges, the user manually clicks the x and y coordinates of pigments in the painting to ensure that there are no errors. Then a co-domain is determined by choosing which degree of fade we want to simulate on the table, and the domain will map to the co-domain, making the painting appear newer or older. From this process we can achieve the goal of simulating the faded colors of traditional Chinese paintings.

Our approach also applies some image processing techniques. To simulate restoration of traditional paintings, edge detection is used to enhance the borders of the painting. The background is then smoothed through the GUI, and a vector field is applied to the whole painting to avoid any discontinuous rendering. For the opposite effect of simulating the effects of aging on newer paintings, image-based rendering is used to combine the painting with noise chosen from older paintings. This process can be expressed in the flow diagram shown in Figure 4.

3. Result

Because this approach is based on such a wide range of web-mined images, the sizes of the paintings differ from one another, and their resolutions are generally low. There are also distortions which can appear on the images after processing, like those shown in Figure 7, which shows a painting from the Song Dynasty called “Cherry and Yellow Sparrow”, measuring 514×534 pixels. On the left is the original painting; to its right is the failed simulated result which mapped colors to those common in the early Republic of China era. Due to the low resolution of the image, the colors become discontinuous after being processed. Therefore, the source objects have been changed into scans of higher resolution paintings from traditional Chinese painting albums. However, the images of paintings collected from websites are still reliable. This approach experimented on each pigment from one painting to compare the color of scans and the color after being averaged over many images. The differences between them are indicated in Table 3. Because the backgrounds tend to be yellow, there are more differences related to pigments using azurite and cyanine. Equation (2) can solve this problem. As the GUI depends on manual input, the user should know some information about traditional painting techniques and related pigment changes. This combination of user familiarity with the subject material and data-driven technical application further enhances the precision of our approach.

Some final results are illustrated in Figure 9. Figure 9(a) shows a painting from the Ming Dynasty called “The Volume of Imitating the Ancient”, while Figure 9(b) shows a painting from the Qing Dynasty called “The Volume of Ladies”, and Figure 9(c) is a painting from the Song Dynasty called “The Antithesis between the Summer Flowers and Grass”. On the left are the original paintings; in the middle are the results after processing with PhotoImpact; and to the right are the results of our approach by mapping the colors of each painting to those from the early Republic of China era. By comparing these two methods, contrast, brightness and saturation are adjusted to appear newer, as shown in the middle of Figure 9. This approach made the colors of the paintings appear richer, brighter and more saturated. Common image processing software lacks the database of faded pigments provided by our faded pigment table. Our approach introduces a new method to more accurately simulate different states of traditional Chinese paintings.

The images in Figure 8 illustrate a painting from the Qing Dynasty called “A Cluster of Four-Color Flowers”. On the left is the original painting; to its right is our approach’s result, simulating colors mapped to those of the Song Dynasty. The colors become more faded, darker and have a lower saturation than those on the left, and the background appears much rougher, as well. Additionally, the domains we chose are not included the blended colors of pigments, like grass-green and purple.

4. Conclusion

This approach proposes a technique to analyze the faded pigments of traditional Chinese paintings across several dynasties, and to simulate the colors of these paintings with different degrees of faded colors based on heuristic formulas and an extensive database of samples. The pigments of traditional Chinese paintings have become much more diverse since the Song Dynasty. Changes in chemical compositions influence color and fading progress, especially after the introduction of western-created pigments came into use in the Qing Dynasty (1875). Therefore, the painting samples from the later Republic of China era are not adopted, and modern pigments in traditional Chinese paintings are not simulated, because the colors of pigments and their components differ greatly from those used in the past.

Our research leaves open the possibility of future work. Additional information regarding traditional Chinese paintings, such as the pigments used and the way artists painted would further enhance our knowledge base. The initial low resolution samples used for the faded pigment table could be replaced by samples of higher resolution. Experts in traditional Chinese paintings could be consulted as to whether the simulated results created by our system are reasonable or not. We therefore welcome any advice and recommendations for later approaches.

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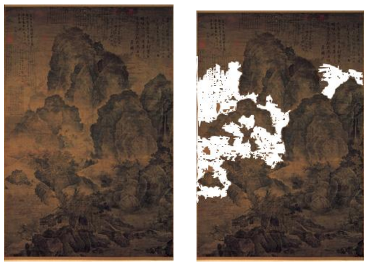


Fig. 5: (a) Shows a painting from the Song Dynasty entitled “Sitting beside the Stream Alone” (960-1031).

Fig. 5: (b) Shows a painting from the Yuan Dynasty called “Illustrating Rain and Shine over Spring Mountain” (1299).

Fig. 5: (c) is from the Ming Dynasty, named “Picture Scroll of Spring Mountain” (1501-1583).

Fig. 5: (d) from the Qing Dynasty is entitled “Colored Mountain and Water”(1644-1728).

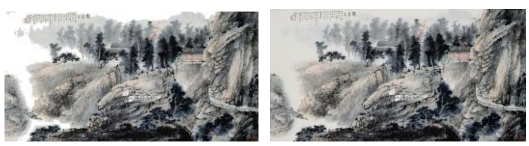
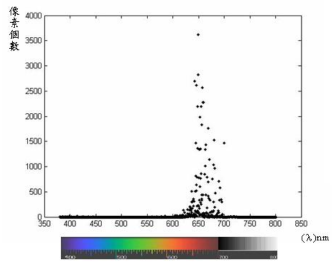
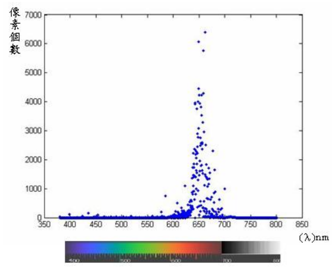


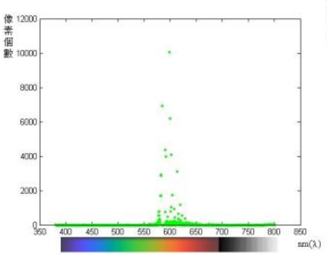
Fig. 5: (e) is from the early Republic of China period, called “Mountain and Water”(1948-now).



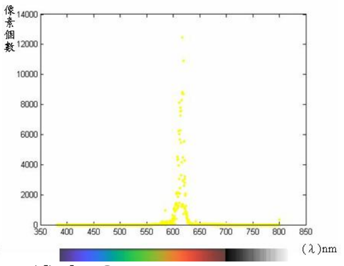
(a) the Song Dynasty



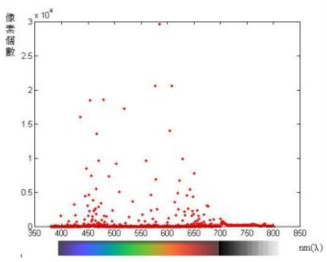
(b) the Yuan Dynasty



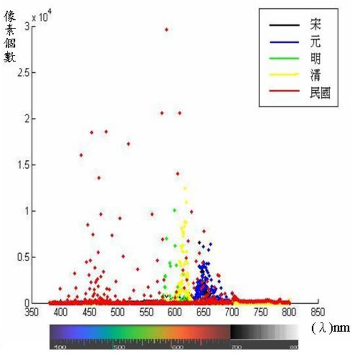
(c) the Ming Dynasty



(d) the Qing Dynasty



(e) the early Republic of China period



(f) the combination

Fig. 6: From (a) to (e) show the color distributions of the right side of Fig. 5, and (f) combines these into one graph.

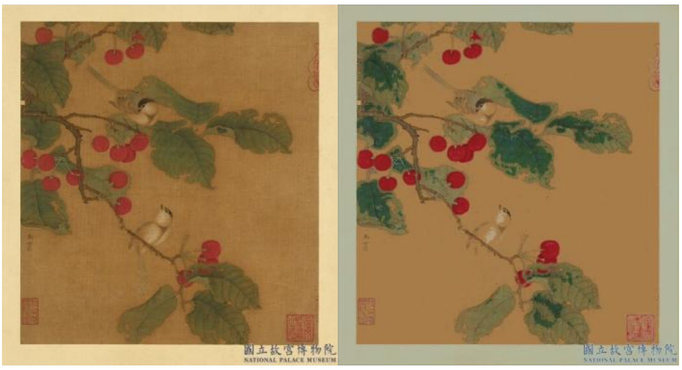
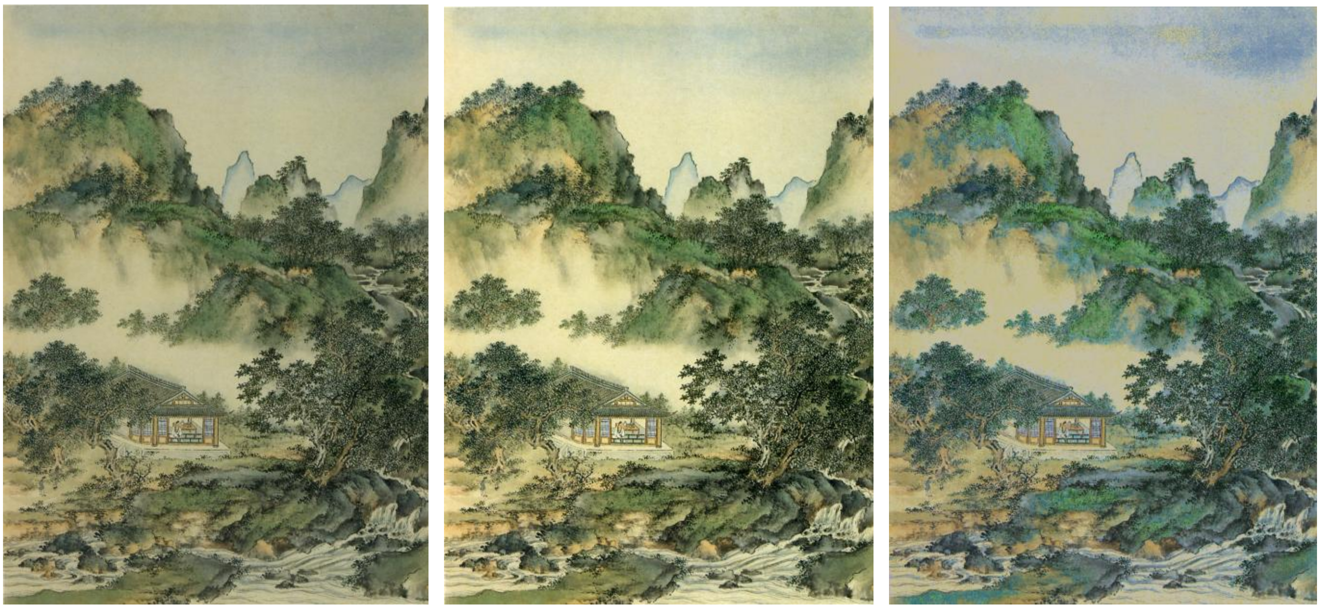


Fig. 7: Shows a painting from the Song Dynasty called "Cherry and Yellow Sparrow", measuring 514×534 pixels. On the left is the original painting; to its right is the failed simulated result which mapped colors to those common in the early Republic of China era.

Fig. 8: Illustrate a painting from the Qing Dynasty called "A Cluster of Four-Color Flowers". On the top is the original painting; to its foot is our approach's result, simulating colors mapped to those of the Song Dynasty.



(a)

(b)

(c)

Fig. 9: (a) shows a painting from the Ming Dynasty called "The Volume of Imitating the Ancient", while (b) shows a painting from the Qing Dynasty called "The Volume of Ladies", and (c) is a painting from the Song Dynasty called "The Antithesis between the Summer Flowers and Grass". On the left are the original paintings; in the middle are the results after processing with PhotoImpact; and to the right are the results of our approach by mapping the colors of each painting to those from the early Republic of China era.