Dunhuang Decorative Pattern Digital Intelligent Enhancement Algorithm

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Abstract: Dunhuang Grottoes Art attracts attention from the world. The famous Mogao Grottoes, Yulin Grottoes, and Thousand-Buddha Grottoes not only have valuable artistic treasures such as murals, colorful sculptures, and architecture, but also have rich decorative pattern arts to be studied. However, due to the protection policy for Dunhuang murals and the limited research technology, the study of Dunhuang decorative designs has been greatly hindered. Therefore, this paper proposes a digital intelligent enhancement algorithm for Dunhuang decorative patterns study. Through image restoration and color enhancement processing of Dunhuang decorative pattern photographs, the decorative patterns are restored to the greatest degree, and scientific research is conducted on this. This not only can fully study the value of decorative patterns, but also can protect the Millennium murals in Dunhuang Caves well.

Keyword: Dunhuang Grottoes, decorative patterns, digitization, image restoration, color enhancement

1. Introduction

Dunhuang decorative patterns are interspersed among murals, colorful plastics and architecture, and play an auxiliary role in Dunhuang art. Only a small number of scholars at home and abroad who study Dunhuang or Dunhuang art pay attention to the study of Dunhuang patterns[1]. Through modern people's constant repair and consolidation, it has been found that these decorative patterns not only reflect the artistic characteristics of different historical periods, but also have very strong applicability in the present. The content of Dunhuang decorative patterns is very rich. After thousand years of development, each decorative pattern has different styling characteristics, color applications, patterns, and combinations of patterns that all reflect the era characteristic. After the millennium-developed Dunhuang decorative designs are rich in content, the humanities, history, religion, science and technology, and artistic expression methods contained in the patterns are worth studying[2]. Therefore, the work of sorting, researching, and re-designing Dunhuang decorative patterns needs to be more researchers involved. The current research issues are also faced with various aspects. For example, the Dunhuang Grottoes as a world cultural heritage receives visitors from all over the world all the year round. The gas they breathe and the activities in the caves all cause irreparable damage to the murals of the millennium, and thus they are facing the grotto art. Considering the protection, some of the special caves will be protected by taking turns to be open or not open to the outside world, and the time for the
viewers to enter the cave will be limited. Only 15 minutes will make it difficult to study in depth. After more than a thousand years of experience in Dunhuang patterns, a large number of exquisite murals have fallen off and swelled, showing problems such as crisp alkalis, empty drums, and armor. Therefore, how to use modern digital methods to restore a large number of vague and indistinct decorative patterns. Organizing patterns for more scholars to research and re-design applications, and more effective protection and dissemination of Dunhuang decorative patterns is a modern proposition that is worthy of study.

2. Image enhancement algorithm

The image enhancement algorithm improves the visibility of the scene by enhancing the contrast of the image. The most commonly used methods for image enhancement are histogram equalization, wavelet transform, and methods based on the retinal cortex theory. The image enhancement method based on the Retinex theory was first proposed by E. Land et al. in 1971 [3]. Retinex is an abbreviation of Retinex and Cortex, which indicates that the theory is based on the human visual system.

![Figure 1. The retinex schematic.](image)

Figure 1 shows that the scene image seen by the observer is actually a combination of incident and reflected light images. Therefore, each point in the image can be expressed as this formula.

\[ S(x, y) = R(x, y)L(x, y) \]  

(1)

In the formula, \( S(x, y) \) is the original image, that is, the fuzzy image that needs to be processed; \( R(x, y) \) is the reflection image, which is controlled by the reflection condition of the surface of the object and contains the real details of the image; \( L(x, y) \) is the luminance image, which is the incident light, the size of the incident light. Reflects the dynamic range that the image pixel can represent.

At present, the most widely used is the Single Scale Retinex (SSR) algorithm [4], Multiple Scale Retinex (MSR) algorithm [5], Multiple Scale Retinex color restore (MSRCR) algorithm [6]. The Retinex-based approach uses a logarithmic function and a Gaussian wrap function to enhance the visually weaker region. Compared to other commonly used image enhancement algorithms, the processed image has higher local contrast and less color distortion. However, because this algorithm involves the value of standard deviation of the Gauss function, if the value is too small, the visual effect of the enhanced image is not true. Even though MSR and MSRCR solve this problem by using different standard deviations, the problem still exists. Among them, the MSRCR algorithm recovers the color by using the non-linear function of the chromaticity of the original image, so as to compensate for the missing color information in the MSR algorithm, instead of restoring the true color of the image. Therefore, the color compensation of the MSRCR algorithm violates the theory of color constancy in a sense [7].

Meylan [8] used the center/neighborhood Retinex model as the core of the adaptive filtering method, according to the edge of the image adaptively changing the shape of the filter, thereby effectively eliminating the image of the halo phenomenon.
Petro et al. [9] proposed the Multiscale Retinex with Chromaticity preservation (MSRCP) algorithm with color retention, which is an improved MSRCR algorithm. MSRCP only executes on the luma channel, instead of performing an algorithm on each channel of R, G, and B, and then calculates the scaling factor to recover the true color of the image. In most cases, the image processed by the MSRCP algorithm has better enhancement.

Liu et al. [10] proposed an improved MSRCR low-visibility aeronautical image enhancement method to design an MSRCR with three or more scales. Based on mathematical analysis and derivation, an accurate balance of image contrast and color plausibility was proposed. In addition, the histogram truncation technique was introduced as a post-processing to remap the multi-scale Retinex to the dynamic range of the display. The image enhancement effect after processing is good.

Tang et al. [11] proposed an improved Retinex image enhancement algorithm based on steered filtering. In the HSI color space, the algorithm replaces the Gaussian filter with steerable filtering to obtain detailed information at different fine scales. Enhances high frequency information in different frequency bands. Then, guided filtering is used to extract certain low-frequency information in the logarithmic domain, and then the enhanced high-frequency information and low-frequency information are combined to obtain a joint image. Finally, the joint image is stretched to enhance the contrast of the image. Compared with the existing image enhancement methods, the images obtained in this way can effectively avoid the loss of halo effect and details.

This paper proposes a joint algorithm based on HSI color space model and color enhancement and image restoration based on fuzzy theory. The joint algorithm converts the image from RGB model to HSI model. In the fuzzy domain, WLS filtering is applied to the components of HSI space. Instead of the Soft Matting method, the transmission rate is refined, and then image enhancement is performed through the improved adaptive fuzzy logic to obtain an image of the enhanced image of Dunhuang decorative pattern.

3. Pal-King algorithm
This paper will implement the basic content of fuzzy set theory through Pal-King algorithm [12]. The algorithm proposed by Pal and King transforms an image into a fuzzy matrix through a transformation function. Then, it uses the fuzzy set theory to perform enhancement processing on the degradation in the fuzzy domain. Finally, the inverse transformation of the fuzzy domain yields the result. The process of the algorithm is as figure 2:

![Figure 2. Image enhancement steps based on fuzzy set theory.](image)

(1). Image fuzzy feature extraction.
The degraded image needs to be transformed from the spatial domain to the fuzzy domain. The expression is as follows:

\[
\mu_{mn} = G(g_{mn}) = \left[1 + \frac{g_{\text{max}} - g_{mn}}{F_d} \right]^{-F_e}
\]

(2)

In the formula \(F_e\) and \(F_d\) are exponential and reciprocal transform coefficients respectively. The size of \(F_e\) and \(F_d\) determines the degree of fuzziness on the fuzzy feature plane. The scope of \(F_e\) is \([1,3]\) and the scope of \(F_d\) is \([0.5(g_{\text{max}} - g_{\text{min}}), 2(g_{\text{max}} - g_{\text{min}})]\). \(g_{\text{max}}\) is the largest gray value in the image; \(g_{\text{min}}\) is the gray value of the current pixel. When \(\mu_{mn} = \mu_c = G(g_c) = 0.5\), and \(g_c\) is called the crossing point. And the selection of transition points is usually acquired by a priori knowledge at present.

(2). Membership function value correction.
The regression function of the fuzzy enhancement operator is used to correct the membership
function. The expression is as follows:

\[
T(\mu_{mn}) = \begin{cases} 
2(\mu_{mn})^2 & 0 \leq \mu_{mn} \leq 0.5 \\
1-2(1-\mu_{mn})^2 & 0.5 \leq \mu_{mn} \leq 1 
\end{cases}
\]

(3)

Fuzzy domain enhancement mainly depends on the value of \( \mu_{mn} \) which is increased or reduced fuzzy enhancement operator, reducing the fuzziness of \( G \). The fuzzy enhancement operator produces another fuzzy set on the fuzzy set \( G \).

\[
\mu'_{mn} = T^{(r)}(\mu_{mn}) = T(T^{(r-1)}(\mu_{mn})) \quad r = 1, 2, \ldots, \infty
\]

(4)

In the formula, \( T^{(r)} \) is a multiple call to \( T \). And When \( r \to \infty \), \( T^{(r)} \) produces a non 0 or 1 two value image. In order to ensure the integrity of image details and fuzzy image enhancement, according to different enhancement targets and image features, the average \( r \) value is 1, 2 or 3.

(3). Inverse transform of fuzzy domain.

The new gray level \( g_{mn}' \) is generated by inverse transformation, and then the data is transformed from the fuzzy domain to the spatial domain of the image. The following expressions are as follows:

\[
g_{mn}' = G^{-1}(\mu_{mn}') = g_{mn} - F_d[(\mu_{mn}')^{-1} - 1]
\]

(5)

The following figure shows the fuzzy enhanced image:

![Figure 3. The fuzzy enhanced image.](image)

4. The color space

The color space is also called a color model. The commonly used color models are: RGB model, CMY model, CMYK model, HSI model, NTSC model, and YCbCr model. There are still many current color models because the fields involved in color science are very extensive [13].

4.1 The RGB model

The RGB model is based on the Cartesian coordinate system mainly composed of the three primary colors of red, green and blue. This model as shown in figure 4.
$R, G, and B$ are located on three corners of a rectangular coordinate system. In figure 3, the diagonal from black to white in the cube model is the gray level. The image represented by the RGB color model is composed of three component images, each of which represents a component image. The RGB model focuses on hardware and is commonly used in color monitors and a large part of color video cameras.

4.2 The HSI model
The RGB color model works very well for hardware processing. In addition, the RGB model meets the human eye's keen recognition of the red, green, and blue primary colors. However, the RGB model cannot explain human visually understood colors well. The proportion of each primary color given the three primary colors cannot describe the color of a chair. In general, people use hue, saturation and brightness to describe a colored object. Therefore, the HSI color model is produced by American colorist H. A. Munseu proposed in 1915. It describes color by hue ($H$), saturation ($S$), and brightness ($I$). Hue represents a color attribute, usually a solid color; saturation shows the intensity of white light diluting a solid color; brightness is subjective and in fact it is unmeasurable. It portrays the concept of colorless strength, and it is one of the important factors that characterize color perception[13].

4.3 RGB and HSI space conversion
An RGB space image is converted into an HSI model. The expression of each RGB pixel component is as follows:

$$H(R,G,B) = \begin{cases} \theta, & B \leq G \\ 360 - \theta, & B > G \end{cases}$$

In the formula,

$$\theta = \arccos \left( \frac{1}{2} \left[ (R-G) + (R-B) \right] \right) \left[ (R-G)^2 + (R-B)(G-B) \right]^{1/2}$$

And the component $S$ can be obtained by the following formula:

$$S(R,G,B) = 1 - \frac{3}{(R+G+B)} \left[ \min(R,G,B) \right]$$

The component $I$ can be obtained by the following formula:
In the formula, the RGB and HSI components are normalized to the interval [0,1].

From HSI model to RGB model conversion, the formula that can be used depends on the value of H. The formula is as follows:

When $H \in [0^\circ, 120^\circ)$:

\[
R = I \left[1 + \frac{S \cos H}{\cos(60^\circ - H)}\right]
\]

(10)

\[
G = 3I - (R + B)
\]

(11)

\[
B = I(1 - S)
\]

(12)

When $H \in [120^\circ, 240^\circ)$:

\[
R = I(1 - S)
\]

(13)

\[
G = I \left[1 + \frac{S \cos(H - 120^\circ)}{\cos(180^\circ - H)}\right]
\]

(14)

\[
B = 3I - (R + G)
\]

(15)

When $H \in [240^\circ, 360^\circ)$:

\[
R = 3I - (G + B)
\]

(16)

\[
G = I(1 - S)
\]

(17)

\[
B = I \left[1 + \frac{S \cos(H - 240^\circ)}{\cos(360^\circ - H)}\right]
\]

(18)

5. Joint algorithm for color enhancement and image restoration

Combining dark-color prior and WLS filtering theory in the fuzzy domain to perform color enhancement on images in the HSI space model. The color image enhances the essence of the enhancement of its luminance component, while the hue and saturation do not change. Therefore, this article will mainly operate on components $I$. The algorithm is as follows:

1. First, extracting the component R,G,B from the input original image. And according to the formula (6),(8),(9) transfer to the HIS space to obtain the component $H,S,I$.

2. The dark color image is extracted from the component $I$ and refined by WLS filtering.

3. Transform images from spatial domain to fuzzy domain for feature extraction.

4. The selection of transit points in the Pal-King algorithm is based on prior knowledge and is random, because different thresholds have a greater influence on the effect of image enhancement. Therefore, this paper adopts the OTSU (Maximum Class Variance Method) algorithm to search adaptively. The optimal threshold value of the image to be processed is used as the value of the transition point in the blur enhancement process. Next, the membership function value is corrected by the regression call of the fuzzy enhancement operator.

5. Perform inverse transformation to convert the HSI space image to RGB space image to obtain the enhanced image of decorative pattern.

6. Experiment and result analysis

The algorithm in this paper is simulated on matlab platform. In this paper, the image enhancement algorithm used in this paper is compared with the original image according to these evaluation indexes include the image contrast, information entropy, average brightness, histogram correlation coefficient
and algorithm running time. And the results are shown in table 1.

**Table 1.** Comparison of original and enhanced image parameters

| Image     | Contrast | Information Entropy | Average Brightness | Histogram Correlation Coefficient | Running Time /s |
|-----------|----------|---------------------|--------------------|-----------------------------------|-----------------|
| Original  | 260.69   | 7.54                | 140.81             | —                                 | —               |
| Enhanced  | 1049.50  | 7.65                | 133.08             | 0.8037                            | 2.79            |

Figure 5 and figure 6 show the experimental results of this paper’s algorithm as well as the channel histograms for the two sets of images. In the histogram, red indicates $R$ channels, and green indicates $G$ channels, blue indicates the $B$ channel.

![Image enhancement](image1.png)

**Figure 5.** Image enhancement.

![Channel histograms](image2.png)

**Figure 6.** Comparing graphs and channel histograms after the original graph and algorithm in this chapter are processed.

The local contrast of the image processed by this algorithm is moderately enhanced, the restored image is clearer, the color reproduction is higher, the image is natural, and it is more in line with the visual perception of human eyes. As can be seen from the table, this algorithm enhances the contrast of the original image, improves the information entropy of the image, which is suitable for human eyes observation, and the correlation coefficient between the processed image and the original image histogram reaches 0.8037. It shows a high degree of similarity. And it reduces the time complexity and has strong robustness.

7. **Conclusion**

This paper mainly introduces the joint algorithm of image restoration and color enhancement based on Pal-King algorithm and HSI color space model. In the fuzzy domain, WLS filtering is used to replace the component of HSI space. The Soft Matting method refines the transmittance and then enhances the image through fuzzy logic. The OTSU algorithm is used to adaptively obtain the optimal threshold of the image to be processed. Finally, the Dunhuang decorative pattern experiment results obtained after the enhancement show that the algorithm complexity of this chapter is more complex. Low, brightly
restored image, better detailing, better visual experience, and stronger robustness. Therefore, an intelligent enhancement algorithm based on image enhancement has provided us with a good solution for the study and investigation of Dunhuang decorative patterns.

Reference

[1] Zhao, J., Department, F. A., & Academy, D. (2017). The heart of a craftsman passed down——mr.duan wenjie's copying,research and inheritance of dunhuang mural art. Dunhuang Research.

[2] Yao, J. (2009). Secular characteristic of the dunhuang decorative pattern art. Art & Design

[3] Land E H, Mccann J J. Lightness and Retinex Theory[J]. Josa, 1971, 61(1): 1–11.

[4] Jobson D J, Rahman Z U. Properties and performance of a center/surround retinex[J]. IEEE Transactions on Image Processing, 1997, 6(3): 451–462.

[5] Rahman Z, Jobson D J. Multi-scale retinex for color image enhancement[J]. Proceedings of 3rd IEEE International Conference on Image Processing, 1996, 3:

[6] Jobson D J, Rahman Z U. A multiscale retinex for bridging the gap between color images and the human observation of scenes[J]. IEEE Transactions on Image Processing, 1997, 6(7): 965–976.

[7] Barnard K, Funt B. Investigations into Multi-Scale Retinex[J]. Colour Imaging: Vision and Technology, 1999: 9–17.

[8] Meylan L, Süsstrunk S. High dynamic range image rendering with a Retinex-based adaptive filter[J]. IEEE Transactions on image processing, 2006, 15(9): 2820–2830.

[9] Petro A B, Sbert C. Multiscale Retinex[J]. Image Processing On Line, 2014, 4: 71–88.

[10] Liu C, Cheng I. Enhancement of low visibility aerial images using histogram truncation and an explicit Retinex representation for balancing contrast and color consistency[J]. ISPRS Journal of Photogrammetry and Remote Sensing, International Society for Photogrammetry and Remote Sensing, Inc. (ISPRS), 2017, 128: 16–26.

[11] Tang S, Dong M. Color image enhancement based on retinex theory with guided filter[C]//Proceedings of the 29th Chinese Control and Decision Conference, CCDC 2017. 2017: 5676–5680.

[12] Pal S K, King R A. On Edge Detection of X-Ray Images Using Fuzzy Sets[J]. IEEE Transactions on Pattern Analysis and Machine Intelligence, IEEE Computer Society, 1983, 5(1): 69–77.

[13] Gonzalez, Rafael C, & Woods, Richard E. (1987). Digital image processing. Prentice Hall International, 28(4), 484 - 486.