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Original scientific paper

Unveiling Patterns and Colors in Architectural Paintings: An Analysis by K-Means++ Clustering and Color Ratio Analysis

Liang ZHANG, Yiqu ZHANG, Yumeng WEI, Tao ZHANG, Jian ZHANG, Jun XU*

Abstract: This study delves into the intricate world of patterns and colors found in architectural paintings within the illustrious Forbidden City. Through an in-depth analysis, we identified seven distinctive patterns, creating a pattern factor library that showcases five examples for each pattern category. To extract the color schemes of each architectural painting type, we employed the K-Means++ algorithm for secondary clustering. Utilizing both RGB and HSV color space models, we examined scatter diagrams and histograms for three specific architectural color paintings. The results revealed a balanced distribution of warm and cool colors across all three architectural painting types. The prevalent colors observed in the Forbidden City architectural paintings were red, yellow, cyan, and blue, exhibiting low levels of saturation and moderate to high levels of brightness, evoking a serene and luminous ambiance. Through color ratio analysis, we established traditional color names that corresponded to the extracted color values from each painting. Our findings suggest that the colors and patterns within the Forbidden City architectural paintings communicate a profound sense of tranquility and grandeur, aligning with the cultural and artistic values held during the Ming and Qing dynasties.

Keywords: architectural paintings; color ratio analysis; k-means++ clustering algorithm; pattern extraction; the forbidden city

1 INTRODUCTION

Historically and socially significant heritage contributes to the spiritual identity of a nation and facilitates inter-civil exchange [1-4]. This non-renewable resource encapsulates the traditional culture, transmits historical traditions, enhances a nation's self-esteem, and facilitates intercultural communication. Chinese cultural relics represent the tangible legacy of the Chinese national spirit, while subjectively they symbolize their exceptional national spirit. The preservation and restoration of cultural relics contribute not only to gaining relevant insights from history [5, 6] but also to strengthening the sense of spiritual self-confidence and cultural unity in China [7].

Traditional patterns are ubiquitous in clothing, architecture, porcelain, and other decorative arts as they embody a fundamental aspect of traditional Chinese culture. The colored patterns are the soul of ancient architecture, and the aesthetic value of ancient architecture is mainly reflected in the colored pattern [8]. As a vital part of China's intangible cultural heritage, the colored patterns of the Forbidden City's architecture are of immense significance for scientific inquiry. In contrast to patterns used in other dynasties, the architectural color paintings during the Ming and Qing dynasties were exceptionally complex and rigorous. Situated in the heart of Beijing, the Forbidden City is a masterpiece of ancient Chinese palace architecture and represents the epitome of tradition. The edifice is one of the largest and most complete wooden structures globally [9]. A thorough investigation of the architectural colored patterns within the Forbidden City is worthwhile in comprehending the process behind official paintings' creation, potentially yielding more effective means of preserving them.

The advent of digital technology has led to a gradual shift in the preservation and dissemination of historical and cultural heritage, from a 2D static approach to a 3D dynamic approach [10]. According to K. Abduraheem et al., digital technology has the potential to offer crucial support in the preservation, restoration, research, and promotion of cultural heritage [11]. E. Liu et al. have presented an image recognition model for intangible cultural heritage based on CNN and wireless networks [12]. They have constructed a material library for intangible cultural heritage images and enabled the efficient retrieval of educational resources related to national costume images. In this technique, deep learning algorithms are integrated into digital restoration technology.

Commonly used techniques for digital acquisition include 3D laser scanning, close-up photogrammetry, and Python. Digital image processing techniques, such as image noise removal, enhancement, restoration, segmentation, and pattern extraction, are also widely utilized [13]. In the context of image color extraction, statistical analysis methods such as clustering algorithms (e.g., K-Means and DBSCAN algorithms) are commonly employed. Zhao et al. used the K-means clustering method to analyze the color patterns of Yi clothing, and transformed the corresponding color patterns into objective evaluation indicators [14]. Tian et al. used a developed K-means clustering algorithm to classify the surface color of buildings after extracting them from their background environment [15]. Among these algorithms, the K-Means algorithm is widely used due to its high efficiency in clustering large-scale data, although it has certain limitations [16]. The K-Means++ algorithm overcomes the interference of the original algorithm in clustering results by specifying the number of clusters (k) and randomly selecting initial points.

In order to investigate the use of patterns and colors in ancient architectural paintings, the painted drawings of the Forbidden City were extracted and classified by image processing software; the colors in the images were extracted by combining the K-Means++ clustering algorithm; the colors extracted from the painted drawings were analyzed by using two color space models, RGB and HSV, and the K-Means++ clustering algorithm was also used to used to perform secondary clustering to study the proportional distribution of the colors in the painted images. This study provides a reference for exploring the patterns and colors in architectural paintings, and also provides a novel and effective way to preserve and promote traditional cultural heritage.

2 METHODS
2.1 Image Collection and Preprocessing

The material of the architectural painting of the Palace studied in this paper is mainly from several sources: the official high-definition or ultra-high-definition pattern material resources taken by the Palace, the scanned book literature resources and the web image resources collection.

The scanned books that were used in this study include "Chinese Architecture Color Painting Picture", "Forbidden City Architecture Picture Code" and "Chinese Architecture Color Painting Picture Collection". When scanning books, the pages of the books must be in good condition and any pages with torn paper or unclear printing should be discarded immediately. In addition, to avoid the influence of equipment, light, etc. on the results and to keep the overall color uniform and easy to correct later, a uniform standard LED light source is used for scanning.

As a cultural heritage site, the Forbidden City provides a wealth of online resources for its architectural color patterns. Therefore, in the process of collecting images and web resources, this study utilizes Python to develop a web crawler that can automatically extract all picture resources from a designated website. Fig. 1 illustrates the basic workflow of a Python web crawler. When users run the web crawler code, they are asked to specify the content to download and the number of resource pages they wish to crawl. The default setting is 30 images per page.

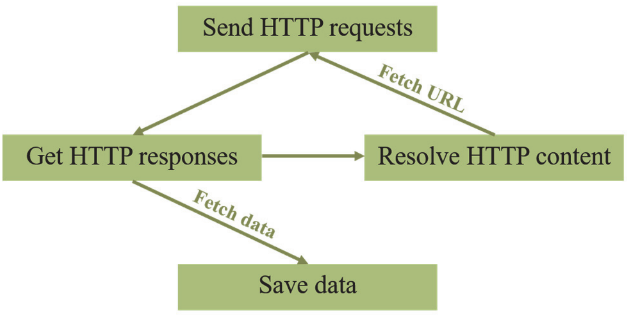

Figure 1 Web picture Python crawler's basic workflow

In order to streamline the extraction of pattern elements, it is necessary to sort all image resources. The architectural paintings of the Forbidden City are divided into three grades, which are arranged according to the level of the grade, namely, Hexi-colored patterns, Xunzi-colored patterns, and Su-style colored patterns, mainly distinguished by the pattern category and the number of gold paste.

Therefore, the images are classified after they are crawled on the web. As shown in Fig. 2, crawled images include Hexi color pictures, Xuanzi color pictures, and Su-style color paintings of the Forbidden City, saved in folders automatically generated on the desktop. A total of 450 images, 150 of each type, were collected.

During the image collection process, various factors may alter the grayscale value of the images and introduce noise that must be reduced before use. Image filtering, which aims to suppress image noise while preserving as much detail as possible, is a commonly used noise reduction technique.

Figure 2 Some crawling images of color paintings: (a) Hexi color paintings; (b) Xuanzi color paintings; (c) Su-style color paintings

The color images of the Forbidden City buildings collected in this study are susceptible to image noise due to various factors such as book wear and tear and photo lighting. To reduce isolated noise and bring the pixel values closer to the true value, the median filter noise reduction principle was applied. This method involves selecting the pixel value and adjacent pixel values in a digital image or sequence of numbers and using the intermediate value as the pixel value of the current pixel point. Eq. (1) was used for this purpose, where $G(x, y)$ represents the pixel point gray value for filtered output, $g(x, y)$ represents the pixel point gray value before filtering, and k represents the set of pixel points during filtering. The median filter is widely used for image noise reduction, and it was applied to the collected images of the Forbidden City in this study. Eq. (1) was used to remove isolated noise and bring the pixel values closer to their true values. This process resulted in clearer images, which were useful for further analysis and research.

$$G_{(x,y)} = Med\left(g_{(x,y)}\right),\ (x,y) \in k \tag{1}$$

In addition, in order to facilitate the subsequent pattern element extraction, all image resources need to be organized first. Firstly, all the images are classified in the initial sieve, and the images that are too blurred and cannot see the pattern are eliminated; secondly, the excess part of each image is cropped and removed to avoid affecting the subsequent color extraction; finally, the Python code is then used to automatically rename the files in each category sequentially. Ultimately, a compilation of 100 images is generated for each of the three categories.

2.2 Pattern Extraction and Vectorization

The architectural colored patterns found within the Forbidden City are known for their intricate designs, detailed specifications, and exceptional craftsmanship. However, due to the vast array of patterns available, a systematic and scientific approach is required to properly categorize each one based on their respective subjects. As depicted in Fig. 3, the patterns have been divided into seven distinct categories: the Dragons and Phoenixes (DP) pattern, the Floral pattern, the Geometric pattern, the Animal pattern, the Auspicious pattern, the Bogu pattern, and the Contour Frame pattern

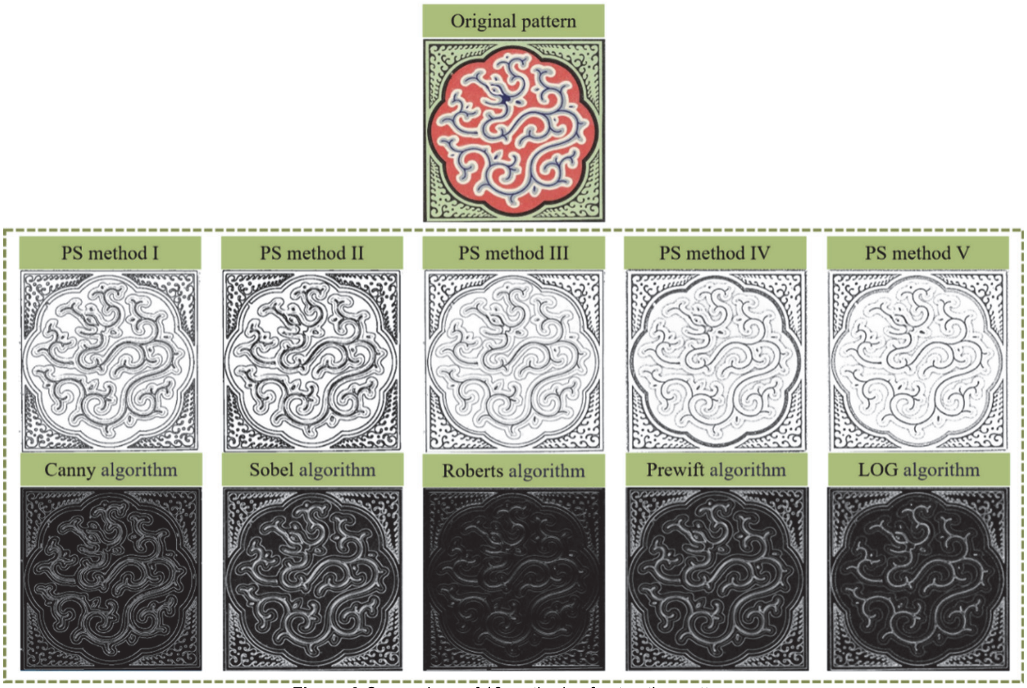

Figure 3 Comparison of 10 methods of extracting pattern

Table 1 Pattern classification of architectural colored patterns

No.	Sorts	Elements
01	DP pattern	Dragon, Phoenix, Kui dragon, Kui phoenix, etc.
02	Floral pattern	Lotus, Gardenia, Reinecklacarnea, Scroll, Ganoderma lucidum, etc.
03	Geometric pattern	Fret, Mosaic, Moire, Wave, etc.
04	Animal pattern	Crane, Bat, Bovine, Lion, Fish, Bird, etc.
05	Auspicious pattern	"卍", Ruyi, Letter, Babao, etc.
06	Bogu pattern	Antique bronzes, Ancient porcelain, Ancient jade ware, etc.
07	Contour frame pattern	Gui line, Lotus-petaled striae, Sword Head Stripe, Bifurcation angle, etc.

This section presents the process of vectorizing pattern information from pre-processed and sorted images of the Forbidden City building. Vectorization involves extracting patterns from images and converting them into vector diagrams, which can be easily preserved and used for subsequent design. Compared to bitmaps, vector diagrams offer several advantages, such as being resolution-independent and allowing for easy editing of individual objects without affecting others. Additionally, vector graph files occupy less storage space, making them easy to store.

Several methods exist for extracting pattern threads, including using image processing software such as Adobe Photoshop (PS) or algorithms for contour recognition and extraction (e.g., Canny, Sobel, Roberts, Prewitt, and LOG). To select a suitable method, this study conducted a pre-experiment involving ten different methods (see Fig. 3) and found that the PS method III and Sobel algorithm yielded superior extraction results. However, due to the particularity of architectural color paintings in the Forbidden City, most of which are treated with gold, the Sobel algorithm was unsuitable for batch processing. Therefore, the PS method was used for extracting colored patterns from the thread.

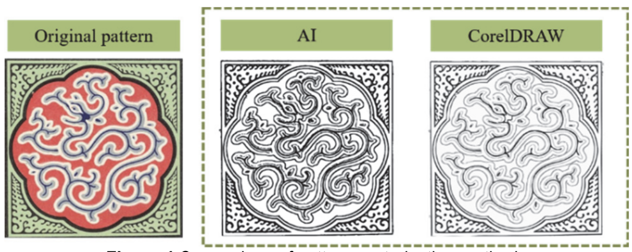

Figure 4 Comparison of pattern vectorization methods

After extracting the pattern line draft, the images were vectorized using the image tracing function of Adobe Illustrator (AI) and CorelDRAW software. Fig. 4 shows renderings of the two methods, where AI image tracing produced smoother and more continuous lines with more detail, but also had more noise. On the other hand, CorelDRAW tracing was noisy and had uneven line weights.

To summarize, this study chose to use PS for extracting the color pattern draft and the PS batch function for quick processing. In the second step, the bitmap was imported into AI for image tracing and conversion into a vector graph. In the third step, the noise was manually removed from the vector diagram, and all lines were smoothed out (as shown in Fig. 5).

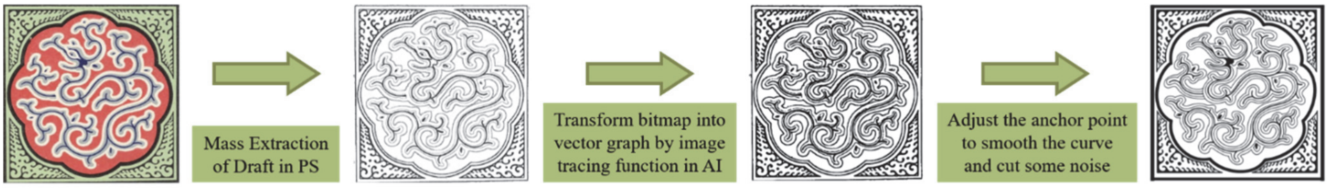

Figure 5 Pattern vector flow diagram

2.3 Color Extraction and Analysis

The K-Means++ algorithm is an enhanced version of the K-Means algorithm [17]. The K-Means++ clustering algorithm in architectural painting uses extracted feature vectors to cluster architectural painting works in order to reveal similarities and patterns in architectural elements, structures or styles. By analyzing the clustering results, researchers and designers can automate the classification and understanding of architectural painting works to support architectural history research, style analysis and design inspiration, and to promote the study and communication of architectural culture.

An analysis of the operation flow of the two algorithms is presented here to comprehend the principles and benefits of the K-Means++ algorithm. As shown in Eq. (2), the cluster analysis uses Euclidean distance to measure the actual distance between two points in m-dimensional space. The samples x_i and y_i are included in Eq. (2).

$$D_{\text{euc}}\left(x_i, y_j\right)=\sqrt{\left(\sum_{k=1}^{m}\left|x_{ik}-x_{jk}\right|\right)^2} \tag{2}$$

Fig. 6 illustrates the operational process of the K-Means++ algorithm. To begin with, a random point is chosen as the initial cluster center from all sample points C_1. In Step 2, each sample point is evaluated for its Euclidean distance $D(x_i)$ from the cluster center, the specific calculation method is shown in Eq. (2). In Step 3, the sample point that is the furthest from the cluster center is selected as the second cluster center based on a probability approach. The next clustering center is selected from the dataset using the probability distribution $P(x_i)$, the calculation of probability $P(x_i)$ is shown in Eq. (3).

$$P\left(x_i\right)=\frac{\left(D\left(x_i\right)\right)^2}{\Sigma\left(D\left(x_i\right)\right)^2} \tag{3}$$

In Step 4, the aforementioned steps are repeated until a total of k clustering centers are identified. In Step 5, the clustering center is determined by calculating the arithmetic mean of the dimensions of all elements in the cluster. Following this, the samples are re-clustered and the revised clustering center is determined. Finally, the third step is repeated until convergence finds the optimal clusters. Although the K-Means++ algorithm appears to have more steps in the diagram, its enhanced selection method for the initial clusters enables the algorithm to identify the clusters more quickly and effectively avoid the algorithm from getting stuck in the local optimum, despite the improvement not being significant.

The five primary colors of traditional Chinese colors are green, red, yellow, white, and black. The common colors used in the architectural paintings of the Forbidden City are these five traditional colors. According to the experimental findings of H. Chang et al. regarding image main color extraction, the *k*-value can extract the main color feature in the 3 to 7 range [18].

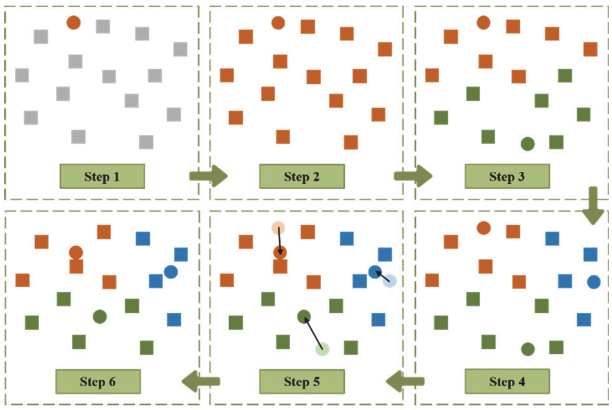

Figure 6 K-Means++ algorithm running step schematic diagram

The image pretreatment of the Forbidden City architectural color painting has been categorized into three types: Hexi color painting, Xuanzi color painting, and Su-style color painting. The K-Means++ algorithm is employed to extract color, and the detailed extraction process is described below:

(1) Determine the number of colors that need to be extracted.
(2) Set up programs to browse every picture in the folder.
(3) Convert the picture from BGR mode to RGB mode.
(4) Convert the data dimension from 3-dimension to 2-dimension in the number of color layers to obtain the picture.
(5) Create clusters and apply K-Means++.
(6) Run the algorithm out of the center point and generate a matrix to prepare for subsequent data visualization.

(7) Save the color image using Open-CV and visualize the extracted color of the picture.
(8) Generate 3D clustering maps.

3 RESULTS AND DISCUSSION

3.1 Results of Pattern Extraction

Based on the aforementioned pattern extraction process, the seven typical patterns of the Forbidden City architectural painting have been processed. The pattern factor library has been obtained, which includes five pattern examples for each type of pattern. Fig. 7 displays the simple pattern factor library.

3.2 Results of Color Extraction

The K-Means++ algorithm is utilized for secondary clustering to extract the color cards of each type of architectural color painting. Fig. 8 displays the main color extraction results.

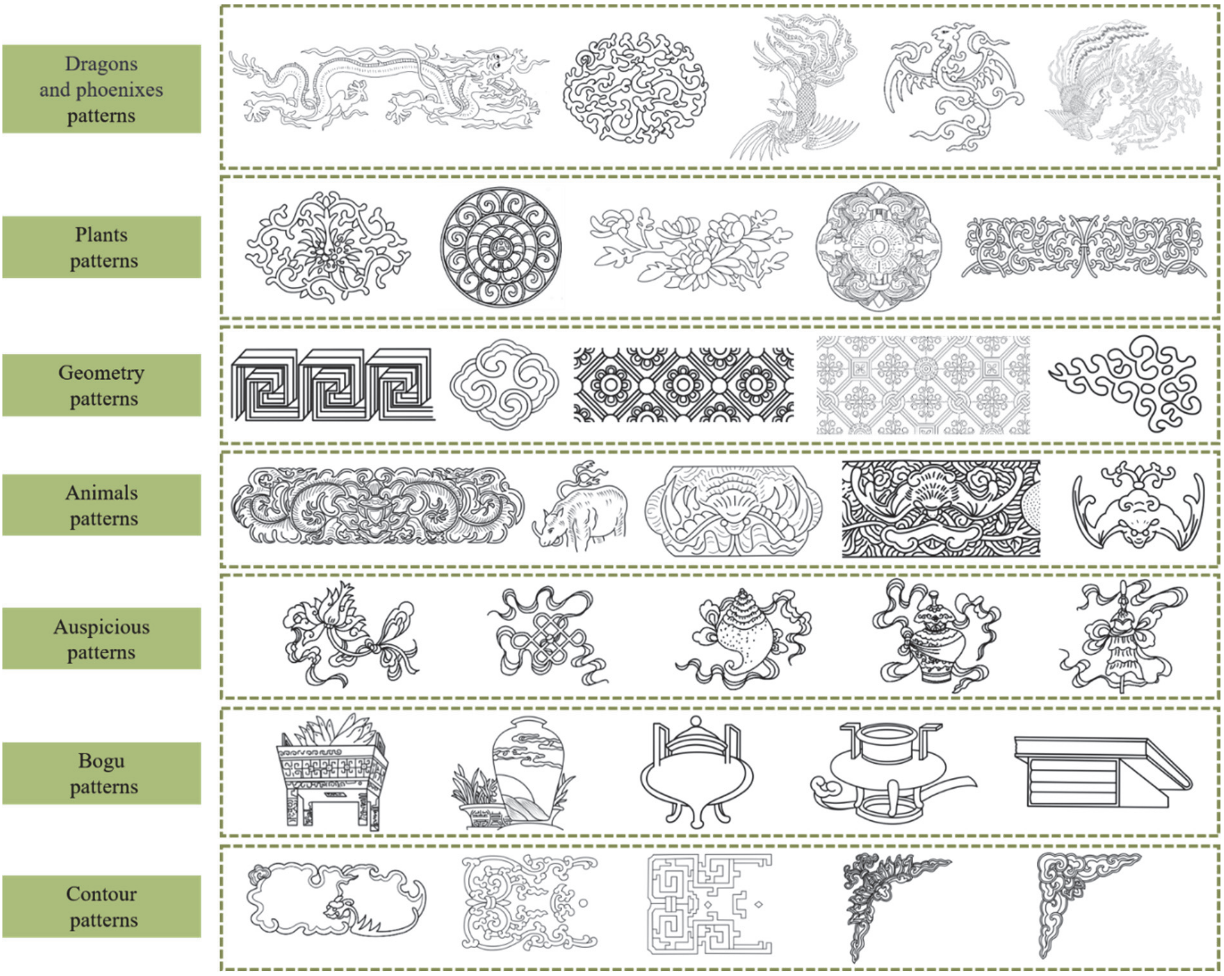

Figure 7 Traditional pattern factor library

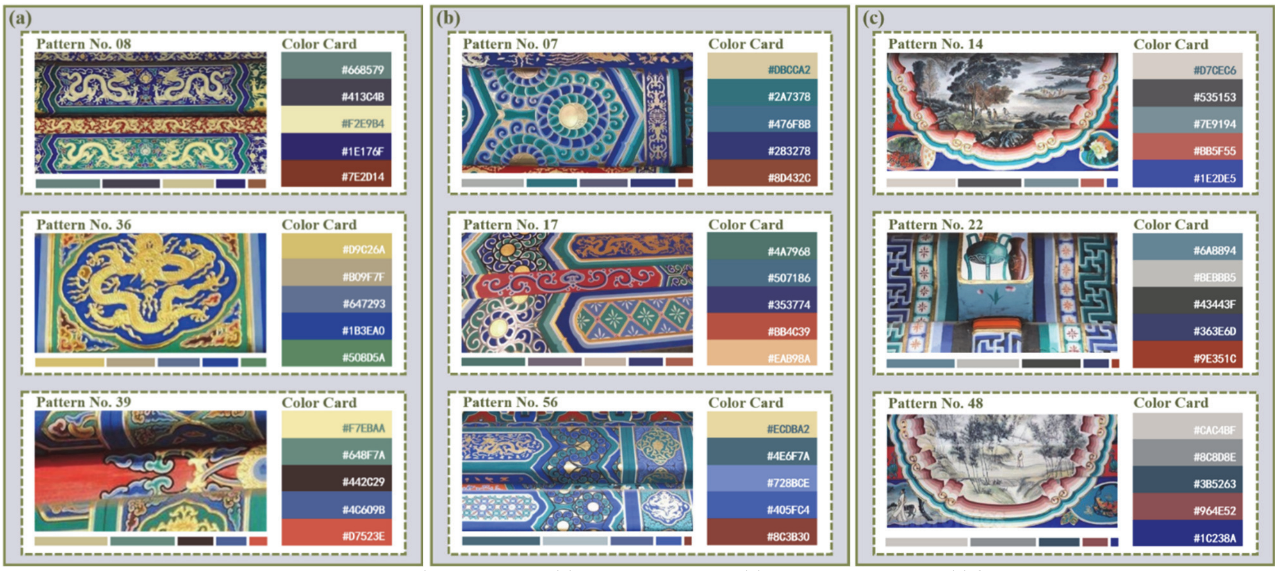

Figure 8 Main color extraction results of color paintings: (a) Hexi color paintings; (b) Xuanzi color paintings; (c) Su-style color paintings

In order to avoid errors in subjective determination of the optimal number of clusters, this paper also combines the contour coefficient method for objective analysis. The contour coefficient is a classical method to determine the optimal number of clusters, and the merit of the clustering effect is evaluated by two factors: the intra-cluster compactness and inter-cluster dispersion of the sample, and the closer the value to 1 indicates the better clustering effect. According to the average contour values of clusters in Fig. 9, the highest value is found when the cluster is 5, which can achieve better classification results compared to other numbers of clusters.

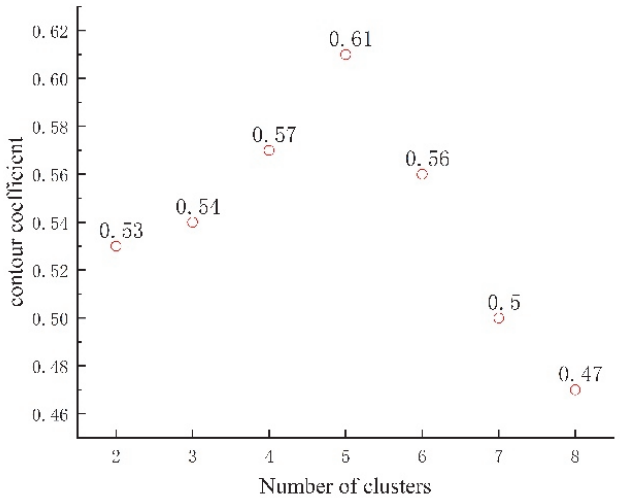

Figure 9 Cluster contour coefficient value

3.3 RGB Color Space Model

RGB and HSV are commonly used color space models in color analysis [19]. RGB directly describes the combination of the intensities of the three primary colors of light (red, green, and blue). The RGB color space visually represents the combination of the three primary colors of light and is therefore widely used in image processing and display. The HSV color space separates color attributes into three components: Hue, Saturation, and Value. HSV space is closer to human perception of color, and it decouples color attributes, making it more intuitive and convenient to adjust color attributes. Hue indicates the type of color (e.g., red, green, blue, etc.), saturation indicates the purity or vividness of the color, and luminance indicates the lightness or darkness of the color. the HSV color space is better for image processing tasks such as color segmentation, color filtering, and image editing.

In this study, the RGB color space model was applied to analyze the scatter diagrams of three types of architectural color paintings. After extracting all image colors using the K-Means++ algorithm, Fig. 9 displays the automatically generated RGB 3D scatter diagrams of Hexi, Xuanzi, and Su-style colored patterns. The 3D color scattering provides an intuitive display of the color characteristics of the Forbidden City architectural color paintings.

Overall, the dispersion distribution of Hexi color paintings is more uniform, with richer and more regular colors. The scattering distribution of Xuanzi color paintings is concentrated, with similar colors, while Su-style color paintings have the most dispersed color usage. The color in the upper left corner of the connection between the 3D coordinate axis coordinates (0, 0, 0) and (255, 255, 255) is mainly cold, while the color in the lower right corner is mainly warm. Warm colors such as yellow, orange, and red bring warm, cheerful feelings, while cold colors such as green, blue, and purple bring serious, calm, and solid feelings.

From Fig. 10, it can be observed that the warm and cold colors of the three types of architectural paintings are evenly distributed. Among them, warm colors have a larger proportion in Hexi color paintings, while cold colors are more frequent in Xuanzi color paintings and more evenly distributed in Su-style color paintings.

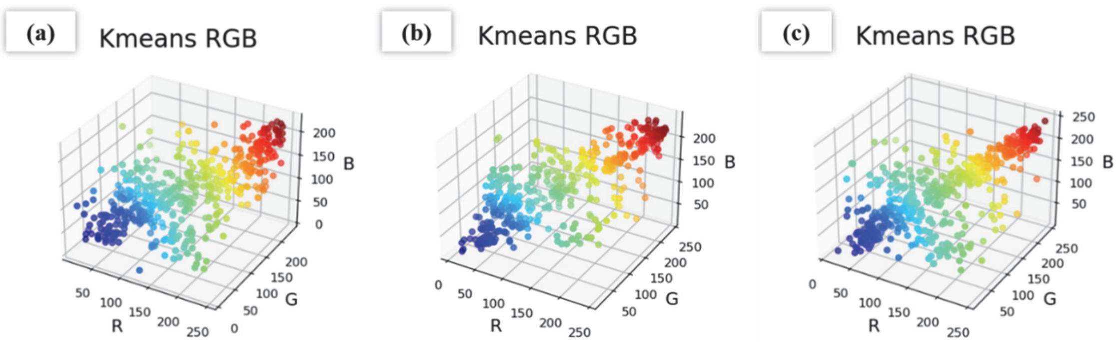

Figure 10 3 types of RGB 3D scatter diagrams: (a) Hexi color paintings; (b) Xuanzi color paintings; (c) Su-style color paintings

3.4 HSV Color Space Model

The HSV color space model was developed by Smith Alvy Ray to enhance the color extraction interface of computer graphics software, based on visual perception. It employs three elements of human eye color perception to identify the color of light. The model is primarily concerned with the main wavelengths of light in the mixed spectrum, representing different hues such as red, orange, green, cyan, blue, purple, and others [20]. The HSV color space model is used to make histograms to analyze the hue (H), saturation (S), and value (V) of the color characteristics of the Forbidden City architectural color paintings. The H ranges from 0° to 360°, S from 0% to 100% (proportional to saturation), and V from 0% (black) to 100% (white), indicating the brightness of the color.

Fig. 11 presents the HSV histogram of Hexi color paintings, revealing that the main colors of the Hexi color paintings are red, orange, yellow, and cyanine. The hues are mainly distributed between 5° to 60° and 210° to 230°. The saturation ranges from 5% to 55%, with the highest point at 25%, primarily low and medium saturation. Highly saturated colors are less, which may be related to the age of weathering in architectural paintings. Brightness is more evenly distributed, mainly between 30% and 85%, with 60% at its highest.

Fig. 12 shows the HSV histogram of the Xuanzi color painting, indicating that the main colors are cyan, cyanine, and blue, with a uniform distribution of red, orange, yellow, yellow-green, and green. The hues are mostly located between 180° and 240° and evenly between 0° and 120°. With the highest saturation at 20%, there are mostly low and medium saturation points, with a range of 0% to 60%. Due to Xuanzi's predominant blue-colored algae, highly saturated colors are less prevalent. The brightness values are mainly distributed from 30% to 80%, with the highest point at 50%, indicating moderate and moderate brightness.

Fig. 13 presents the HSV histogram of Su-style color paintings, showing that the main colors are red, orange, and yellow, with a uniform distribution of turquoise, cyan, blue, and blue lines. The hues are mostly distributed between 350° and 60° and evenly between 140° and 240°. The saturation mainly ranged from 0% to 5%, with the highest point at 5%, representing low saturation. Highly saturated colors are less, which is consistent with the painting technique of Su-style color paintings with black collimation and a gray-white base. The brightness value is mainly distributed between 25% and 90%, with the highest point at 55%, which is the most balanced of the three types of color painting.

After examining the hue, saturation, and brightness of the three types of paintings, it can be observed that the predominant colors in the architectural paintings of the Forbidden City are red, yellow, cyan, and blue. These colors exhibit low levels of saturation, and moderate to high levels of brightness, and impart a serene and luminous appearance to the paintings.

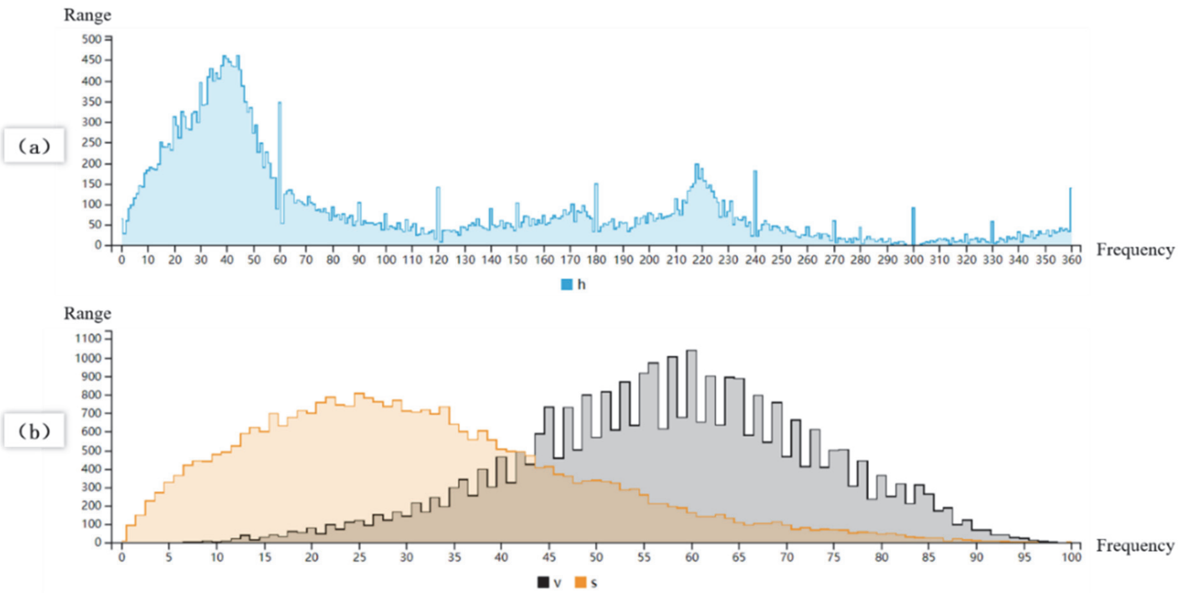

Figure 11 Hexi color painting HSV histogram: (a) Hue histogram; (b) Saturation, value histogram

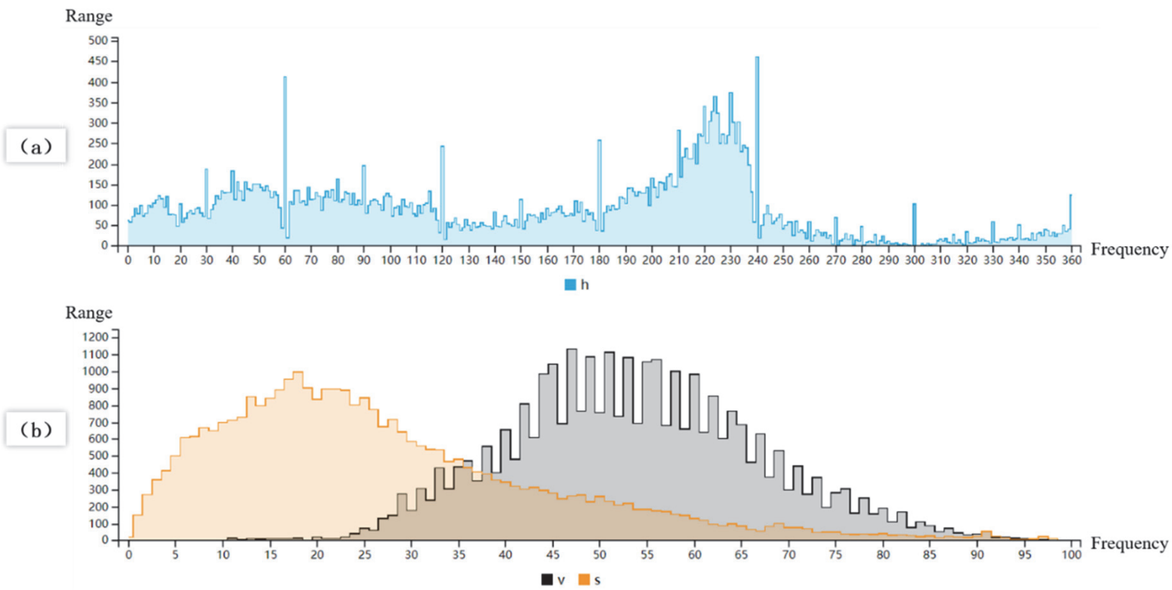

Figure 12 Xuanzi color painting HSV histogram: (a) Hue histogram; (b) Saturation, value histogram

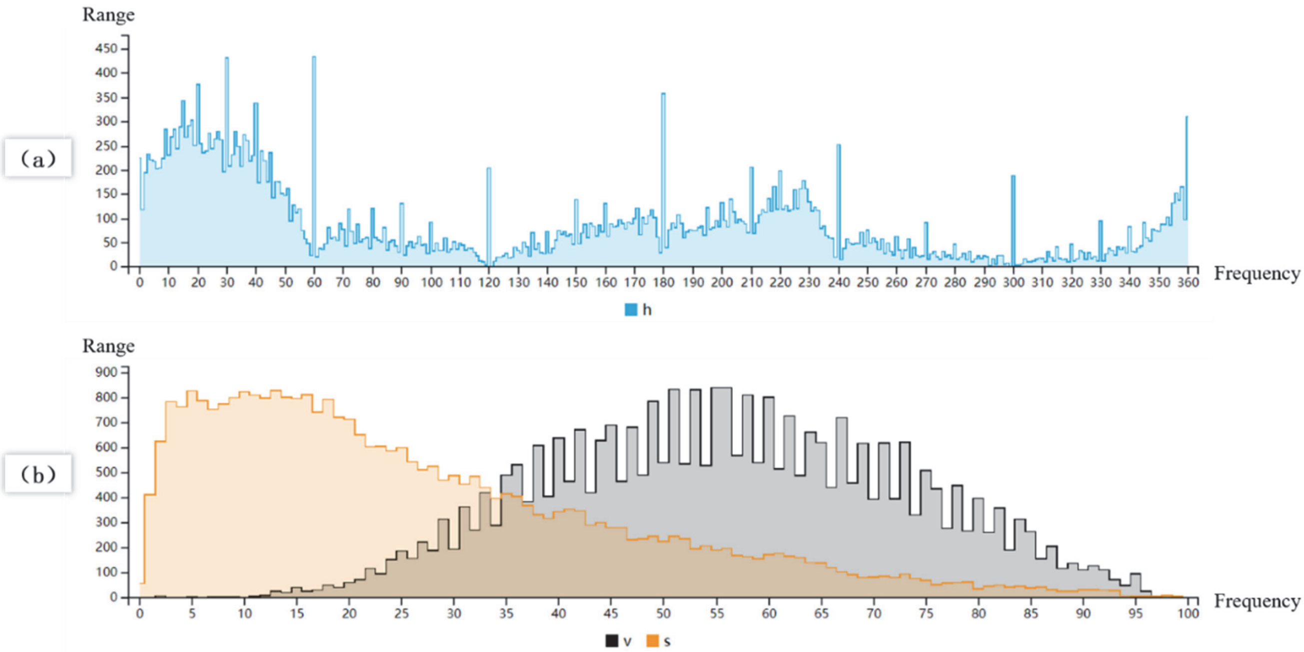

Figure 13 Su-style color painting HSV histogram:(a) Hue histogram; (b) Saturation, value histogram

3.5 Color Ratio Analysis

The color cards obtained from the K-Means++ algorithm were subjected to quadratic clustering to determine the primary colors and their respective proportions for the three types of color paintings, as presented in Tab. 2. The color ratio analysis method allows for the analysis of the proportions of different colors in architectural paintings, helping people to understand the emotions, emphasis and layers of color and to identify the style and expression of architectural works. The steps of the color proportion analysis technique are as follows:

(1) Collect data: Collect images or designs of architectural paintings as the data source for analysis.
(2) Extract color information: Convert the image into a computer processable format and extract the color information from it.
(3) Color classification: The extracted colors are classified and organized. Use k-means++ clustering algorithm to group the colors.
(4) Calculate the proportion: According to the color data obtained by classification, calculate the proportion of each color in the whole architectural painting.
(5) Analyze the results: Analyze the color proportion data obtained from the calculation. Observe the proportion and distribution of different colors to find the main colors, emphasized colors, auxiliary colors, etc.
(6) Interpretation and application: Based on the results of color proportion analysis, interpret and apply.

The color values extracted from each painting were cross-referenced with the traditional Chinese color card (as documented in the "Chinese color traditional color matching illustrated book") to identify the corresponding traditional color names.

From the results of Tab. 2, it can be seen that, in terms of color matching, the overall base color of the Hexi paintings is dominated by lime green, and a large number of leaching powder pasted with gold on the main contour lines of the pattern; the Xuanzi paintings are mostly in blue and lime green, with the lines outlined in gold and ink, and the flower centers of the spinning paintings filled in with gold; and the Su-style paintings are the most colorful, mostly dominated by lime green, and supplemented with intermediate colors such as red, yellow, and violet. Moreover, the three colors are extensively used. Typically, in the creation of the Forbidden City's architectural color patterns, these primary colors are used to establish color contrasts, and the effect is fine-tuned through the use of degeneration techniques to create variations in shades. Finally, these primary colors are utilized in harmony with one another to achieve a coordinated color scheme.

In this study, the motifs in the painted paintings of the Forbidden City are classified into seven categories based on the characteristics of the motifs: Dragons and phoenixes patterns, Plants patterns, Geometry patterns, Animals patterns, Auspicious patterns, Bogu patterns and Contour patterns. The K-Means++ clustering algorithm was used to extract the colors in the painted paintings, and the colors were clustered twice, and finally all the colors were clustered into 5 classes.

Two color space models, RGB and HSV, were used to analyze the colors of three kinds of Forbidden City colored paintings (Hexi-colored patterns, Xunzi-colored patterns, and Su-style colored patterns). The results of the RGB color space model analysis show that warm colors have a larger proportion in Hexi color paintings, while cold colors are more frequent in Xuanzi color paintings and more evenly distributed in Su-style color paintings. The results of the HSV color space model analysis showed that the predominant colors in the architectural paintings of the Forbidden City are red, yellow, cyan, and blue.

Using the color ratio analysis method to obtain the main colors and color proportions in the painted paintings, the results show the color schemes utilized in the three types of architectural color paintings are well-balanced and consistent, with almost identical color usage.

Table 2 The proportion of main colors in the image of the Forbidden City architecture

Sort	Color code	Percent	Patch	Traditional Chinese colors	Examples
Hexi	#D5B81D	30.38%		Shi Huang (Golden Brown)	
	#426A5B	25.75%		Shi Lv (Dark Green Blue)	
	#568AA7	23.46%		Shi Qing (Nice Blue)	
	#334083	11.25%		Qun Qing (Congress Blue)	
	#BC4732	9.17%		Yin Zhu (Fire Engine Red)	
Xuanzi	#3B6561	31.98%		Shi Lv (Dark Green Blue)	
	#69764F	27.24%		You Lv (Cactus)	
	#568FAA	20.57%		Shi Qing (Nice Blue)	
	#384785	13.90%		Qun Qing (Congress Blue)	
	#AF4B4B	6.31%		Yin Zhu (Fire Engine Red)	
Su-style	#5C5B59	39.48%		Mo Can (Fuscous Gary)	
	#A4928A	35.29%		Wan (Beaver)	
	#E2A042	8.65%		Zhe Huang (Deep Saffron)	
	#AF473F	8.57%		Yin Zhu (Fire Engine Red)	
	#3B4AB5	8.00%		Qun Qing (Congress Blue)	

4 CONCLUSIONS

This paper is based on K-Means++ clustering algorithm and color analysis method to analyze the pattern colors of painted paintings of the Forbidden City buildings, which provides some reference for pattern color extraction and analysis of ancient buildings.

The Forbidden City architectural colored patterns material was collected by reviewing data and Python crawler, and the images were preprocessed to build the Forbidden City architectural colored paintings dataset, which was divided into three categories: Hexi-colored patterns, Xunzi-colored patterns, and Su-style colored patterns. There are 100 images in each of these categories of painted paintings. The patterns in the dataset were also classified into seven categories based on the pattern characteristics of the patterns: Dragons and phoenixes patterns, Plants patterns, Geometry patterns, Animals patterns, Auspicious patterns,Bogu patterns and Contour patterns. The K-Means++ clustering algorithm was used to extract the colors of the painted paintings and perform secondary clustering, and finally the colors of the three types of architectural painted paintings were clustered into five classes each. The colors obtained by clustering were analyzed in terms of color space system and color proportion. The results show that in the RGB color space model: warm colors have a larger proportion in Hexi color paintings, while cold colors are more frequent in Xuanzi color paintings and more evenly distributed in Su-style color paintings. In the HSV color space model: the predominant colors in the architectural paintings of the Forbidden City are red, yellow, cyan, and blue. These colors exhibit low levels of saturation, and moderate to high levels of brightness, and impart a serene and luminous appearance to the paintings; the results of the color ratio analysis show that the color scheme used in the three types of architectural color paintings is well balanced and consistent, and the use of colors is almost identical.

The combination of the K-Means++ algorithm and digital restoration technology has provided a novel and effective approach to the preservation and promotion of traditional cultural heritage. The study successfully extracted and restored the patterns and colors of the Forbidden City architectural color paintings. This method can be further applied to other cultural relics and historical artifacts, enabling us to better understand and appreciate the traditional culture and art of our ancestors.

5 REFERENCES

[1] Malik, U. S. (2022). *Enhanced cultural experience based on smart use of 3D digitized cultural heritage artifacts*. Politecnico di Milano, Italy.

[2] Kumar, T. K. G. (2022). Preserving the distributed fragments of cultural heritage: Need for building a sustainable information system in India. *Preservation, Digital Technology & Culture*, *51*(2), 51-61. https://doi.org/10.1515/pdtc-2021-0029

[3] Romphf, J. et al. (2021). Resurrect3D: An open and customizable platform for visualizing and analyzing cultural heritage artifacts. *The 26th International Conference on 3D Web Technology*, 1-7. https://doi.org/10.1145/3485444.3487644

[4] Tarquini, O. et al. (2020). Pigment identification on campana reliefs from the palatine hill and colosseum valley in Rome. *Journal of Cultural Heritage*, *43*, 294-302. https://doi.org/10.1016/j.culher.2019.07.026

[5] Korro Bañuelos, J. et al. (2021). The role of information management for the sustainable conservation of cultural heritage. *Sustainability*, *13*(8), 4325. https://doi.org/10.3390/su13084325

[6] Walsh-Korb, Z. (2022). Sustainability in heritage wood conservation challenges and directions for future research. *Forest*s, *13*(1), 18. https://doi.org/10.3390/f13010018

[7] She W. (2020). Digital object restoration using generalized regression neural network deep learning - Taking Dunhuang mural restoration as an example. *International Journal of Electrical Engineering & Education*. https://doi.org/10.1177/0020720920928549

[8] Lei, Z. et al. (2017). Study on colored pattern pigments of a royal Taoist temple beside the Forbidden City (Beijing, China). *Vibrational Spectroscopy*, *92*, 234-244. https://doi.org/10.1016/j.vibspec.2017.08.005
[9] Fu, P., et al. (2020). Analysis of an ancient architectural painting from the Jiangxue Palace in the Imperial Museum, Beijing, China. *Analytical Letters*, *54*(4), 684-697. https://doi.org/10.1080/00032719.2020.1778014
[10] Liu, K., Lu, S., Zhao, J. et al. (2022). Research on archaeology and digital restoration of costumes in Spring Outing Painting of Madam Guo. *Sustainability*, *14*(19), 12243. https://doi.org/10.3390/su141912243
[11] Abduraheem, K. & Sheri, J. (2022). Significance of Digitization of the Cultural Heritage: In the Context of Museums, Archives, and Libraries. *Handbook of Research on the Role of Libraries, Archives, and Museums in Achieving Civic Engagement and Social Justice in Smart Cities*, 252-263. https://doi.org/10.4018/978-1-7998-8363-0.ch013
[12] Liu, E. et al. (2020). Research on image recognition of intangible cultural heritage based on CNN and wireless network. *EURASIP Journal on Wireless Communications and Networking*, 1-12. https://doi.org/10.1186/s13638-020-01859-2
[13] Omarov, B. S., Altayeva, A. B., & Im Cho, Y. (2015). Exploring image processing and image restoration techniques. *International Journal of Fuzzy Logic and Intelligent Systems*, *15*(3), 172-179. https://doi.org/10.5391/IJFIS.2015.15.3.172
[14] Zhao, L., Wang, Z., Zuo, Y. et al. (2021). Comprehensive Evaluation Method of Ethnic Costume Color Based on K-Means Clustering Method[J]. *Symmetry*, *13*(10), 1-24. https://doi.org/10.3390/sym13101822
[15] Tian, T., Wang, X., & Bai, Y. (2011). The Research of Architectural Color Evaluation Based on Image Processing. *2011 Fourth International Symposium on Computational Intelligence and Design*, *1*, 290-293. https://doi.org/10.1109/ISCID.2011.80
[16] Ikotun, A. M., Ezugwu, A. E., Abualigah, L. et al. (2023). K-means clustering algorithms: A comprehensive review, variants analysis, and advances in the era of big data. *Information Sciences*, *622*, 178-210. https://doi.org/10.1016/j.ins.2022.11.139
[17] Tao, D. & Yang, Z. (2022). Dynamic web page graphic design method for internet big data information system. *Mathematical Problems in Engineering*, 1-10. https://doi.org/10.1155/2022/6753671
[18] Chang, H. et al. (2015). Palette-based photo recoloring. *ACM Transactions on Graphics*, *34*(4), 139-1. https://doi.org/10.1145/2766978
[19] Logvinenko, A. D. (2009). An object-colour space. *Journal of Vision*, *9*(11), 5. https://doi.org/10.1167/9.11.5
[20] Ko, D., Hong, B., & Choi, W. (2019). Probabilistic Caching Based on Maximum Distance Separable Code in a User-Centric Clustered Cache-Aided Wireless Network. *IEEE Transactions on Wireless Communications*, *18*(3), 1792-1804. https://doi.org/10.1109/TWC.2019.2897298

Contact information:

Liang ZHANG
Tiangong University,
Tianjin 300387, China
E-mail: zhangliang@tiangong.edu.cn

Yiqu ZHANG
Tiangong University,
Tianjin 300387, China
E-mail: zhangyiqu_vivi@163.com

Yumeng WEI
Tiangong University,
Tianjin 300387, China
E-mail: 15237165983@163.com

Tao ZHANG
Beijing Institute of Archaeology (Beijing Academy of Cultural Heritage),
Beijing 100032, China
E-mail: zt0922@163.com

Jian ZHANG
Tiangong University,
Tianjin 300387, China
E-mail: 1163976614@qq.com

Jun XU
(Corresponding author)
Tiangong University,
Tianjin 300387, China
E-mail: xujun@tiangong.edu.cn