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Analysis and Application of Yi Embroidery Color Characteristics Based on K-Means Clustering

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***Abstract*—Yi embroidery is one of the outstanding intangible cultural heritages of the Yi people, serving as a vital conduit for the transmission of Yi culture and a testament to the integration of Chinese national cultures. The colors in Yi embroidery reflect deep cultural meanings and possess significant cultural value. This study employs the K-Means clustering algorithm for the extraction and analysis of color characteristics in Yi embroidery, and uses graph theory to construct a network model of representative Yi embroidery colors, creating a data visualization engine for Yi embroidery color coordination. The results demonstrate that the characteristic colors extracted via the K-Means clustering algorithm are highly representative, and the color network model developed in this study provides objective and clear color matching relationships. The findings aim to assist in the modern design transformation of Yi embroidery and promote the innovative development of the cultural industry.**

Keywords—Yi Embroidery; Color Characteristics; K-Means Clustering Algorithm; Color Extraction; Design Application

Ⅰ.INTRODUCTION

Yi embroidery is a prominent symbol of the Yi ethnic folk culture, serving as a crucial conduit for Yi cultural heritage and a shining gem within the Chinese cultural treasury[1], often described as "the art on the fingertips". Color, as the most direct medium of perception and the language of vision, vividly reflects the distinct personality traits of different ethnic groups[2]. Yi embroidery is characterized by its strong color contrasts and bright, vibrant hues, which possess significant decorative and aesthetic value, unique symbolic meanings, and artistic value, embodying the simple and genuine cultural traits of the Yi people. The development of the Yi embroidery industry is still in its nascent stages, lacking modern transformational ideas and directions, with Yi embroidery techniques still anchored in traditional production technologies and aesthetic styles, and lacking adaptability to modern life, resulting in high production costs and low efficiency. Therefore, studying its color characteristics and matching patterns, and integrating them with modern design methods, is crucial for promoting the popularization and everyday use of Yi embroidery craft, playing a significant role in facilitating the modern transformation of Yi embroidery and protecting and promoting the ethnic intangible cultural heritage industry.

Current research on Yi embroidery colors primarily focuses on summarizing and analyzing the stylistic features of these colors. For instance, Shengting Liu and others have provided a basic description and analysis of the main colors used in Yi ethnic garments, their symbolic meanings, and the related ethnic psychology [3]. Pu He has summarized the color philosophy and origins of Yi embroidery, specifically analyzing the color characteristics of Yi floral waist embroidery [4]. With the advancement of computer technology, the study of Yi embroidery colors has integrated with digital techniques. For example, Yatong Zhu and others have used the PCCS color system as a standard, combined with the color cultural characteristics of Yi women's clothing, to summarize their color features and expression techniques, thereby constructing a color spectrum[5].

A review of literature related to ethnic colors reveals that the K-Means clustering algorithm holds distinct advantages in managing big data, and it is extensively applied in image color processing. For instance, Pinghua Xu and his team employed the K-Means algorithm to cluster the colors in ethnic garments, extracting principal colors for each ethnic group and visually displaying the distribution of these color characteristics. This method provides a reliable means for analyzing the color formation mechanisms in minority ethnic clothing[6]. With the advancement of intelligent algorithms, some researchers have combined these technologies to extract characteristic ethnic colors and construct color network models. This approach visually presents the color matching relationships derived from multiple images[7]. For example, Jing Jia utilized image analysis techniques to build a color network for She ethnic clothing, visually demonstrating its color characteristics and compositions[8]. Similarly, Mei Yang extracted characteristic colors from Dunhuang murals, using graph theory to develop color network models based on the co-occurrence relationships among these colors, forming both primary and secondary color network models[9].

In summary, existing academic research provides a rich foundation and methodological references for the quantitative analysis of Yi embroidery colors. Some studies focus on the historical culture, cultural symbolism, and ethnic psychology associated with Yi embroidery colors, while others aim to establish datasets for Yi embroidery colors. However, current research lacks a more systematic approach to extracting color characteristics and constructing color matching systems, and there is a deficiency in systematic studies oriented towards modern design transformation.

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This study utilizes the K-Means clustering algorithm to perform multiple cluster analyses on Yi embroidery image samples, extracting characteristic colors, establishing color mapping relationships, and developing a Yi embroidery color matching engine, which is then validated through design practice. The proposed approach effectively addresses the gaps in existing research by providing a systematic study of Yi embroidery colors, aiding in the modern design transformation of Yi embroidery, promoting the popularization and everyday use of Yi embroidery colors, and driving the development of the cultural industry.

II .METHODS

To extract characteristic colors from Yi embroidery, the first step is to collect Yi embroidery images and establish a sample set. After selecting and preprocessing the collected image samples, the optimal k-value is determined, and the K-Means clustering algorithm is applied multiple times to extract representative characteristic colors. Subsequently, these characteristic colors are used to train a color network model to establish color combinations and mapping relationships. Finally, the color network model is utilized to guide the development of a Yi embroidery color matching engine, which is then applied in design practice (Fig.1).

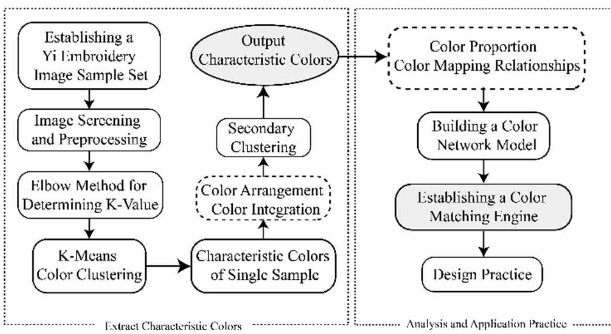

Fig. 1: Yi Embroidery Color Extraction Analysis Process

A. *Collection of Yi Embroidery Color Samples*

This study collects and selects Yi embroidery images digitally by gathering existing Yi embroidery books[10-11], newspapers, and academic papers, amassing a total of 429 images. Firstly, the images are uniformly scanned and color-corrected using an IT8.7/2 color card to eliminate lighting and equipment effects, ensuring accurate and uniform colors for further processing. Secondly, a preliminary screening of 429 samples is conducted to exclude those affected by lighting, brightness, or severe damage. Finally, the samples are imported into Adobe Photoshop 2022 to remove background interference, establishing a dataset of 232 Yi embroidery images. Some samples are shown in Fig. 2.

Fig. 2: Selected Samples of Yi Embroidery Images

B. *Yi Embroidery Color Extraction*

The K-Means clustering algorithm is a widely used unsupervised learning method that clusters pixels in images to identify the most predominant colors. The fundamental concept of the K-Means algorithm involves initially dividing the data space randomly into a predefined number of clusters, k. For each point in the dataset, it is assigned to the nearest centroid based on the Euclidean distance between the point and each centroid. The centroids of each cluster are then iteratively recalculated and updated based on the points assigned to each cluster. This process continues until the results of successive iterations are essentially identical, at which point the algorithm has met its criteria and the clustering is complete[12].

In the process of image color clustering using the K-Means clustering algorithm, the specific steps are as follows:

Extract the pixel data from the image, representing the color of each pixel as a tuple of RGB (Red, Green, Blue) values;

Randomly select k colors from the color data to serve as initial centroids;

Calculate the distance from each pixel in the image to the k centroids, and assign each pixel to the nearest centroid. The distance, denoted as D, is calculated as shown in (1):

$$D = \sqrt{(p_r - q_r)^2 + \left(p_g - q_g\right)^2 + (p_b - q_b)^2} \tag{1}$$

In the formula, $p= (p_r, p_g, p_b)$ and $q=(q_r, q_g, q_b)$represent the RGB color values of the pixel and the centroid, respectively;

Once all pixels have been assigned to a category, the new centroid for each category is determined by calculating the average of all pixels within that category, is calculated as shown in (2):

$$\mu = \left(\frac{1}{|S|}\sum_{x\in S} x_r , \frac{1}{|S|}\sum_{x\in S} x_g , \frac{1}{|S|}\sum_{x\in S} x_b\right) \tag{2}$$

In the formula, S represents the set of all pixels assigned to the current centroid, and $|S|$is the number of elements in the set. x_r, x_g and x_b respectively represent the red, green, and blue color components of each pixel in the category;

Continue to repeat the above steps iteratively, optimizing until the termination condition is met. This condition is fulfilled when each centroid's color can represent a primary color in the image, and the classification of all pixels accurately describes the color distribution of the image.

C. *Yi Embroidery Color Matching Engine*

This study employs graph theory to analyze the color network model, aiming to elucidate the relationships between colors to facilitate the creation of a data visualization-based color matching engine. Graph theory, based on classical mathematical theories, represents relationships using nodes (representing colors) and edges (representing connections between these colors). By constructing a color network model using graph theory, it becomes possible to effectively analyze the frequency of color combinations, as well as visual or perceptual similarities. In the color network, each node represents a specific color, and the weight of the edges reflects their co-occurrence frequency.

The specific steps for constructing the color network model using graph theory methods are as follows:

Collect data related to color combinations and create an undirected weighted graph, where nodes represent different colors and edges represent the relationships between these colors.

Calculate Degree Centrality, which is one of the most fundamental centrality metrics in network analysis. It measures the importance of a node within the network, is calculated as shown in (3):

$$C_D(v) = \frac{\deg(v)}{N-1} \tag{3}$$

In the formula, ， $\deg(v)$ represents the degree of node v (i.e., the number of edges directly connected to v), and N is the total number of nodes in the graph;

Calculate Betweenness Centrality, which measures the frequency with which a node appears on the shortest paths between all pairs of nodes in a network. This metric is used to identify bridge nodes within the network, as shown in formula (4):

$$C_B(v) = \sum_{s \neq v \neq t} \frac{\sigma_{st}(v)}{\sigma_{st}} \tag{4}$$

In this formula, σst represents the number of shortest paths from s to t, and $\sigma_{st}(v)$ is the number of these paths that pass through v;

Conduct community detection, specifically through modularity optimization. Modularity Q is a metric used to assess the quality of a network division, as shown in formula (5):

$$Q = \frac{1}{2m} \sum_{i,j} \left[A_{ij} - \frac{k_i k_j}{2m} \right] \delta(c_i, c_j) \tag{5}$$

In the formula, Aij represents the elements of the adjacency matrix, indicating whether i and j are connected. k_i and k_j are the degrees of nodes i and j respectively, and m is the total number of edges in the graph. δ is the Kronecker delta function, and c_i and c_j are the community labels of the nodes. This helps identify clusters within the color network, i.e., common color combination relationships.

Through the steps described above, graph theory methods can be systematically applied to analyze the color network model, obtain the relationships between colors, and establish a color matching engine.

D. Practical Application Design of Yi Embroidery Colors

To ensure the modern design transformation of Yi embroidery and to foster innovation in the cultural industry, this study will undertake practical design experiments on characteristic Yi embroidery patterns. Utilizing a Yi embroidery color matching engine for color design, the resulting patterns will be applied to cultural and creative products. This application in cultural creativity aims to preserve the distinctive colors of Yi embroidery, facilitating cultural transmission. It promotes the innovative application of Yi embroidery color design in contemporary society and drives the modern transformation of ethnic handicrafts.

III.RESULTS

A. Color Clustering Analysis Process

The characteristic colors of Yi embroidery are derived from representative colors extracted from individual Yi embroidery images. Due to the rich and contrasting colors in Yi embroidery, two rounds of color clustering are necessary. Initially, color clustering is performed on a single sample to extract primary colors. Subsequently, a secondary clustering analysis is conducted on the colors obtained from the first clustering to extract the most representative characteristic colors.

To extract the main colors from a single Yi embroidery sample, it is essential to determine the optimal number of clusters for that sample, which can be achieved using the Elbow Method. The Elbow Method involves varying the number of clusters K and calculating the Sum of Squared Errors (SSE) for each K. The point where the rate of decrease in SSE abruptly slows is known as the "elbow." The optimal K value for a single sample usually lies near this elbow, and selecting a K value to the left of the elbow ensures that the clustering results are sufficiently distinct without being overly complex. For instance, in the analysis of the "Png210" sample, the elbow graph indicates that at k = 7, the decline in SSE becomes noticeably more gradual, suggesting that this number of clusters achieves a better clustering effect compared to other numbers.

Fig. 3: Original Image of the Png210 Sample

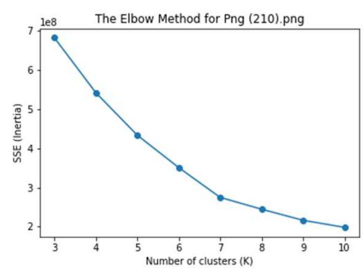

Fig.4: Elbow Analysis Graph for the Png210 Sample

Correspondingly, this method is applied to determine the optimal number of clusters for each Yi embroidery sample image. The 232 Yi embroidery samples are divided into five categories (with cluster values of 4, 5, 6, 7, and 8), and grouped for initial clustering analysis to obtain the characteristic colors of individual samples.

B. Analysis of Color Feature Extraction Results

Through K-Means clustering analysis, the optimal number of clusters for each of the 232 sample images was used to extract colors, resulting in a total of 1400 cluster results and their color proportions. These results were analyzed to determine the main colors and characteristics of individual samples. Taking Fig. 3 as an example, the optimal cluster value was set to 7 (k=7) based on the Elbow Method analysis. The initial clustering analysis provided a color palette and the color proportions for the Yi embroidery sample, facilitating subsequent data processing and analysis, as shown in Table Ⅰ.

TABLE I. COLOR EXTRACTION RESULTS AND COLOR QUANTIZATION INFORMATION

Cluster value	Sample	Color card	RGB-Color proportion/%
7			

The number of colors obtained from the initial clustering is still substantial, necessitating a second clustering to obtain the most representative characteristic colors. The K-Means clustering algorithm is applied to the 1400 color values from the initial clustering, converting them into the HSV color space. These colors are then classified and sorted based on their hue to create the initial color library for Yi embroidery image color extraction (Fig. 5).

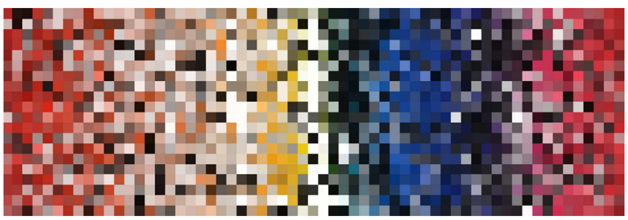

Fig.5: Initial Color Library Extracted from Yi Embroidery Image Clustering (Partial)

The 1400 color values were subjected to a second clustering analysis, ultimately resulting in 20 representative characteristic colors of Yi embroidery. These characteristic colors and their corresponding color cards were sorted and numbered based on their hue, as shown in Table Ⅱ.

C. *Yi Embroidery Color Matching Engine*

By using the K-Means algorithm to extract characteristic colors of Yi embroidery, the aim is to provide designers and related professionals with color options, obtaining the co-occurrence frequency and color proportions of Yi embroidery's characteristic colors. This ensures that the color characteristics of Yi embroidery are maintained during design transformation. Additionally, the visual color matching engine allows professionals to intuitively make color choices and apply these in their designs.

This phase of the research is divided into two main parts.

TABLE II. COLOR INFORMATION AFTER SECONDARY CLUSTERING

Number -ing	Color card	RGB	HSV	Color proportion/%
01		122,37,36	H:0.7, S:70.49%, V:47.84%	2.93
02		174,50,44	H:2.77°, S:74.71% V:68.24%	8.07
03		198,67,76	H:355.88° S:66.16% V:77.65%	4.07
04		207,124,117	H:4.67° S:43.48% V:81.18%	2.57
05		171,95,82	H:8.76° S:52.05% V:67.06%	3.50
06		73,53,52	H:2.86° S:28.77% V:28.63%	4.43
07		113,83,77	H:10.00° S:31.86% V:44.31%	4.00
08		195,166,157	H:14.21° S:19.49% V:76.47%	6.14
09		170,144,134	H:16.67° S:21.18% V:66.67%	5.29
10		212,192,181	H:21.29° S:14.62% V:83.14%	6.14
11		229,219,210	H:28.42° S:8.30% V:89.80%	4.71
12		216,166,94	H:35.41° S:56.48% V:84.71%	1.50
13		220,163,44	H:40.57° S:80.00% V:86.27%	1.86
14		253,253,252	H:60.00° S:0.40% V:99.22%	13.29
15		81,116,167	H:215.58° S:51.50% V:65.49%	1.57
16		29,59,124	H:221.05° S:76.61% V:48.63%	5.50
17		77,85,107	H:224.00° S:28.04% V:41.96%	3.36
18		36,38,51	H:232.00° S:29.41% V:20.00%	7.14
19		23,20,22	H:320.00° S:13.04% V:9.02%	9.86
20		127,123,124	H:345.00° S:3.15% V:49.80%	3.93

The first part focuses on constructing the characteristic color relationships of Yi embroidery. This study uses graph to analyze and record the co-occurrence frequencies of Yi embroidery characteristic colors, generating a color relationship network. The programming language Python, along with its Matplotlib library, is used for visualization, with a co-occurrence threshold set at 10%. The results are shown in Fig. 6. Larger nodes indicate a higher frequency of that color among all colors. Connections between colors are displayed only when their co-occurrence exceeds the threshold, and thicker lines represent higher co-occurrence frequencies.

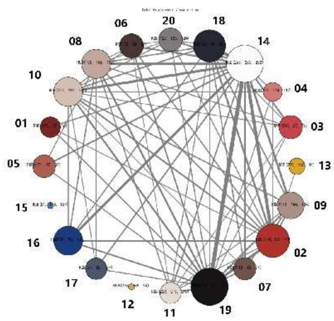

Fig. 6: Network Model of Yi Embroidery Characteristic Colors

From the color combination connections in the color network model, it is evident that Yi embroidery features rich and vibrant colors. Notably, colors such as 02, 14, 16, and 19 have a significantly higher co-occurrence frequency, representing characteristic colors found in many Yi embroidery pieces. Designers often need to determine color combinations based on different design requirements. As an example, this study uses color 02 as the main color and pairs it with 4 auxiliary colors, showing the top 9 five-color combination schemes in Fig. 7.

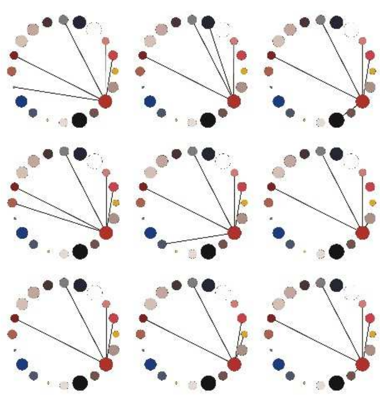

Fig. 7: Top 9 Five-Color Combination Schemes with Color 02 as the Main Color

The second part involves establishing a data visualization color matching engine. Based on the color network relationships obtained in the first part, users can select a primary color and receive the corresponding auxiliary color values through the matching engine system. The final Yi embroidery color matching engine system is presented through a graphical user interface, as shown in Fig. 8.

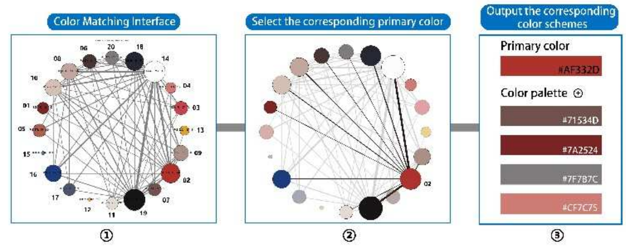

Fig. 8: Color Matching Engine Graphical User Interface Design

In the original interface at ①, users can select their desired primary color, which will result in related auxiliary colors being displayed as shown in ②. In step ②, by selecting the intended primary color, users can obtain its color information and matching color palette. By clicking the plus sign next to "Matching Color Palette," users can add new color schemes.

D. Practical Application Design of Yi Embroidery Colors

Selecting a modern-style diamond pattern from Yi embroidery as the main motif, the design is drawn using Adobe Illustrator 2022 and color-coordinated using the Yi embroidery color matching engine, as shown in Fig. 9. In the color matching engine, color 02 is chosen as the main color, and the given color scheme is used for color matching. This is then applied to actual product design, as depicted in Fig. 10.

The main focus of this paper is to demonstrate the design practice of integrating the Yi embroidery color matching engine with pattern design in cultural and creative design. In fact, the Yi embroidery color matching engine can not only be applied to cultural and creative design but can also be extended to various design fields related to the Yi embroidery cultural industry and various aspects of Yi embroidery color research.

Fig. 9: Yi Embroidery Pattern Design

Fig.10: Product Application Design

Ⅳ.DISCUSSION

This study combines color clustering results, HSV color features, and the color network model to determine the color characteristics of Yi embroidery. The analysis reveals that Yi embroidery primarily uses colors such as red, yellow, cyan, pink, and brown, which generally belong to mid-to-high brightness and mid-to-high saturation categories, and are often used as primary colors. Yi embroidery rarely employs low-saturation and low-brightness colors, which are mostly used as auxiliary colors in color combinations. Overall, warm tones are more frequently used, with hues concentrated in the red-yellow and cyan spectrums, and there is a noticeable contrast between hues. In terms of color combinations, Yi embroidery often uses analogous colors and complementary colors. Analogous color combinations involve the organic combination of hues that are close in color but differ in brightness, creating a rich sense of layering. Complementary color combinations use one or more sets of complementary colors to create strong contrast in Yi embroidery patterns, highlighting the main motifs.

This study advances the methodology of existing research on the color characteristics of Yi embroidery. It utilizes the K-Means algorithm to extract Yi embroidery's color features and employs graph theory to construct a Yi embroidery color network model, yielding more objective data on color characteristics and combinations. Additionally, this research further enhances the application by incorporating graphical user interface design to build a data visualization-based Yi embroidery color matching engine, which is then applied in design practice.

In summary, the main contributions of this study are twofold. Firstly, it employs scientific methods to objectively and effectively extract and analyze the color characteristics and color combination relationships of Yi embroidery, providing detailed color data for relevant professionals. Secondly, it establishes a Yi embroidery color matching engine, offering a practical tool for color matching to professionals, thereby enhancing the efficiency of design transformation in Yi embroidery.

This study has certain limitations. Firstly, it focuses solely on color characteristics, excluding Yi embroidery patterns. Secondly, due to the difficulty in collecting physical samples, the research relied mainly on existing book records. Future research should include pattern analysis and expand sample collection to enhance the study of Yi embroidery's modern transformation.

Ⅴ.CONCLUSION

This study uses the K-Means clustering algorithm to extract characteristic colors of Yi embroidery and combines graph theory to develop a color network model, ultimately establishing a data visualization-based Yi embroidery color matching engine. This effectively presents the color characteristics and styles of Yi embroidery, providing numerous color matching schemes for professionals and offering theoretical and practical tools for the modern design transformation of Yi embroidery.

Additionally, the theoretical framework of this study can be extended to the preservation and transformation of ethnic cultural heritage. Integrating algorithms in the study of ethnic craft colors can parameterize color preferences and imagery, offering data references for the development of ethnic crafts. It also provides detailed color data for contemporary practitioners, accelerating the design transformation of ethnic crafts and ensuring the protection, preservation, and development of ethnic cultural heritage in a globalized, market-driven context.

In conclusion, this study successfully demonstrates the value of combining scientific methodologies with cultural industry practices, providing methodological references for the modern transformation of Yi embroidery and other ethnic crafts.

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