Research on the Color Characteristics of Yanchuan Cloth Appliqué Painting Based on the Munsell-Spencer Color Harmony Theory

Yuqing Wu[1*], Ying Guan[2], Ruoyu Wang[3]

[1]CSSC Jiujiang Marine Equipment Group, Jiujiang, China
[2]School of Design and Art, Shaanxi University of Science and Technology, Xi'an, China
[3]Academy of Fine Arts, Baoji University of Arts and Sciences, Xi'an, China
**Corresponding Author. Email: 948969304@qq.com*

Abstract: Innovative upgrading based on inherent elements is key to the dynamic inheritance of fabric-based intangible cultural heritage (ICH). Color, as the most intuitive embodiment of aesthetic perception, serves both as an entry point for studying traditional folk textiles and as an opportunity for their expansion and enhancement. This study focuses on the color characteristics of Yanchuan cloth appliqué painting. Based on the Munsell-Spencer (M-S) color harmony theory and using the FCM soft clustering algorithm, the study clusters sample colors and constructs a color set to accurately extract color characteristics of the appliqué paintings. Through a second round of clustering, 11 representative colors and 55 color combination schemes were identified. The Berlyne's aesthetic measure evaluation model and the color network model were then used to quantitatively analyze the aesthetic and harmony values of these combinations. By applying the M-S color harmony theory to the realm of traditional textile colors, this study transforms the emotional color semantics of Yanchuan cloth appliqué into scientifically quantified data. The overall color relationships in these artworks are generally harmonious, though a few combinations exhibit lower aesthetic values. These findings are corroborated by traditional folk color-matching proverbs, affirming the theory's applicability in traditional textile color research. Consequently, this paper proposes color optimization strategies that hold practical significance for the inheritance and development of Yanchuan cloth appliqué painting, offering valuable insights for the innovation and revitalization of textile-based ICH.

Keywords: Yanchuan cloth appliqué painting, color harmony, color characteristics, quantitative analysis, optimization strategy

1. Introduction

With the implementation of relevant policies, the cultural industry has witnessed rapid development. Fabric-based items account for a significant portion of intangible cultural heritage (ICH). Among the 383 items listed in the First Batch of the National Catalogue for the Revitalization of Traditional Craftsmanship, 104 are related to textiles [1]. Scholars have proposed strategies such as building an ecological circle for textile ICH [2], leveraging the garment industry chain [3], and promoting the academic and market-oriented development of ICH [4] to support the inheritance and advancement

of fabric-related heritage. While establishing a favorable external environment system has proven effective in supporting ICH, its essence lies in a people-centered approach and dynamic evolution. Continuous innovation and upgrading are essential for sustainable development.

Yanchuan cloth appliqué painting, also known as cloth collage painting, features rich symbolic patterns and vibrant, distinctive colors. As early as the Zhou dynasty, the Zhouli (Rites of Zhou) recorded practices akin to collage techniques, such as "engraving and painting feathers of pheasants" and officials in charge of managing feather materials in accordance with seasonal hunting regulations, indicating that collage-like craftsmanship was already popular at that time and may be considered the origin of cloth appliqué. The color usage in cloth appliqué paintings is bold and unrestrained, with vivid and magnificent hues that encapsulate the aesthetic values of local folk color culture. Among all forms of aesthetic experience, color aesthetics is the most accessible and widely appreciated [5], making it an effective lens through which to examine the aesthetics of traditional folk textiles and identify opportunities for their development and modernization. Current academic research on the color schemes of Yanchuan cloth appliqué is predominantly based on perceptual analysis [6], with a lack of solid theoretical foundation and scientific, data-driven support. The Munsell-Spencer (M-S) color harmony theory originated from Japan's urban color planning [7], aiming to determine the harmony and aesthetic quality of color combinations by analyzing relationships between hues, saturation, and brightness. The theory is now widely used in fields such as urban architecture [8,9], plant landscape color planning [10], and product color matching [11,12], yet its application in the realm of traditional folk textile colors remains limited.

This study applies the M-S color harmony theory to investigate the color characteristics of Yanchuan cloth appliqué painting. By employing color clustering techniques to identify characteristic textile colors and analyzing their attributes, the study uses established formulas to determine whether color combinations are harmonious and aesthetically pleasing, ultimately providing targeted suggestions for optimization. This approach not only deepens the understanding of the color aesthetics of Yanchuan cloth appliqué but also offers new perspectives for the dynamic transmission and innovative development of fabric-based ICH, while contributing to the advancement of digital solutions in this domain.

2. Munsell-Spencer color harmony theory

Color harmony refers to the orderly, coordinated, and aesthetically pleasing combination of two or more colors. Harmonious color combinations evoke a sense of comfort and visual delight. The Munsell-Spencer (M-S) color harmony theory operationalizes the perceptual evaluation of color by quantifying the relationships among hue, saturation (chroma), and brightness (value), thereby transforming subjective perceptions into rational, data-driven analysis. The theory defines specific difference thresholds for hue, brightness, and saturation between two colors, and classifies their relationship into five zones: the same-tone harmony zone, the first ambiguous zone, the analogous harmony zone, the second ambiguous zone, and the contrast harmony zone [13,14].

The same-tone harmony zone refers to color pairs with negligible differences in hue, saturation, and brightness—essentially highly similar colors that appear nearly identical to the human eye. The first ambiguous zone includes color pairs with a hue difference of 0–7, a brightness difference of less than 0.5, and a saturation difference of less than 3. These colors are not exactly the same, but difficult to distinguish, often resulting in a subtle harmony. The analogous harmony zone encompasses colors with a hue difference of 7–12, a brightness difference of 0.5–1.5, and a saturation difference of 3–5. These colors are similar yet distinguishable, and when used together, can enhance visual appeal. The second ambiguous zone covers color combinations with a hue difference of 12–28, a brightness difference of 1.5–2.5, and a saturation difference of 5–7. These colors are neither similar nor strongly contrasting, and tend to produce lower aesthetic value. The contrast harmony zone includes color

pairs with a hue difference of 28–50, a brightness difference greater than 2.5, and a saturation difference greater than 7. These distinctly contrasting colors, when used skillfully, can significantly enhance visual interest and aesthetic impact [13]. A diagram illustrating the distribution of these M-S color relationship zones is shown in Figure 1.

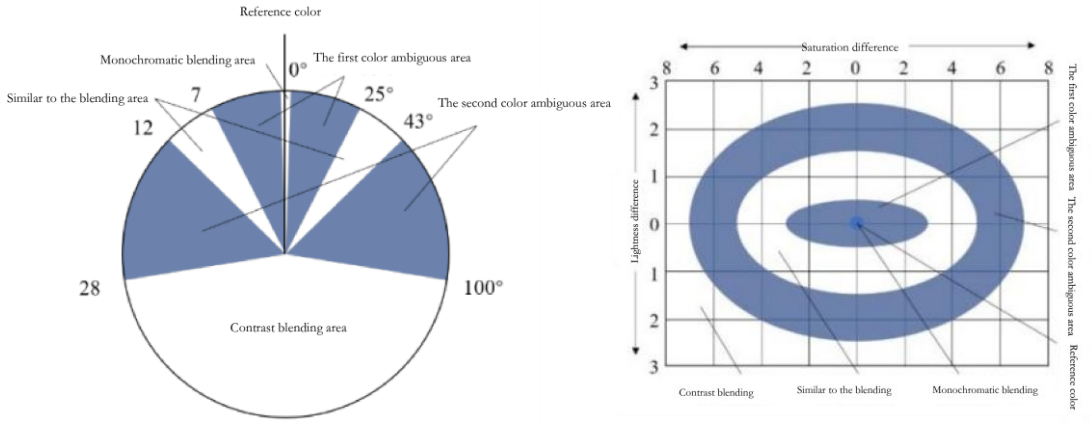


Figure 1: M-Spencer color attributes interval distribution diagram

3. Construction of the color set of Yanchuan cloth appliqué painting

3.1. Overview of Yanchuan cloth appliqué painting

Yanchuan cloth appliqué painting originated from the everyday needlework of rural women in Yanchuan, northern Shaanxi, who mended worn clothing. Located deep in northern Shaanxi on the eastern Loess Plateau along the Yellow River, Yanchuan is geographically remote, with poor transportation and a monotonous natural environment. In response, women creatively and skillfully transformed leftover fabric scraps into decorative and durable patchwork by cutting them into special shapes and stitching them into vivid patterns. These embellishments not only adorned their lives but also enriched their inner worlds. As living standards and craftsmanship improved, these practical fabric patches evolved into decorative works of art. Drawing inspiration from traditional folk papercutting and embroidery, they became what is now known as Yanchuan cloth appliqué painting. Characterized by rustic themes, full compositions, and vivid, brilliant colors, these paintings are praised as “accumulating colors into Buddha forms, worshipped day and night” [15]. They represent the aesthetic sensibility and cultural wisdom of the Yanchuan people, embodying deep-rooted folk traditions.

The word "堆" (duī) means "to accumulate," while "彩" (cǎi) refers to "color," vividly capturing the essence of this art form: the cutting, layering, and composition of fabrics in different colors. One of the most prominent features of cloth appliqué painting is that the viewer perceives the color before the form. The selection and combination of colors not only exhibit an ordered beauty but also carry symbolic meaning. As the second attribute of any object, color relies heavily on sensory perception [16]. It is a vital medium for experiencing and understanding the core of cultural expression, and plays a key role in revitalizing and sustaining Yanchuan cloth appliqué painting in contemporary times.

(a)Geographic location (b)Real-time shooting of the cloth appliqué production process

Figure 2: Yanchuan geographical location diagram, the production of Yanchuan cloth heap painting

3.2. Extraction of characteristic colors and construction of the color set

The samples used in this study were obtained through three main channels: official downloads, scanned illustrations from books, and field photography. These samples were then classified into five categories: (a) worship and belief, (b) love and marriage, (c) labor and activity, (d) zodiac animals, and (e) nature and plants. All images were captured from a vertical angle in a photography studio with stable lighting to ensure realism and clarity. Images were further adjusted and color-corrected to guarantee data accuracy. Ultimately, 25 high-quality images were selected as representative samples. Selected examples are shown in Figure 3.

(a) Worship and belief (b) Love and marriage (c) Zodiac animals (d) Labor and activity (e) Nature and plants

Figure 3: Yanchuan cloth dui painted part of the sample image

3.2.1. Color extraction procedure

The color extraction process involved six steps: 1) Preprocessing of sample images: To eliminate the influence of background colors, image backgrounds were converted to black (R:0, G:0, B:0), and categorized separately during the experiment. 2)Determination of target color regions: All visible colors in the sample images were considered extractable. 3) Color clustering of images: The Fuzzy C-Means (FCM) clustering algorithm—a key soft clustering technique in digital image color processing—was applied. FCM is particularly suitable for classifying items with complex features and vague boundaries, such as the emotionally charged and semantically ambiguous colors in Yanchuan cloth appliqué paintings. The algorithm clustered colors in the images and output the cluster centers. 4) Calculation of color proportions: The area occupied by each extracted color was measured to determine its proportion. 5) Construction of the color set: All 25 samples were processed using the above workflow, resulting in 163 distinct colors and the creation of a comprehensive color set for cloth appliqué paintings. 6) Identification of characteristic colors: A second round of clustering was applied to the color set, from which 11 representative (characteristic) colors were extracted. The overall procedure is illustrated in Figure 4.

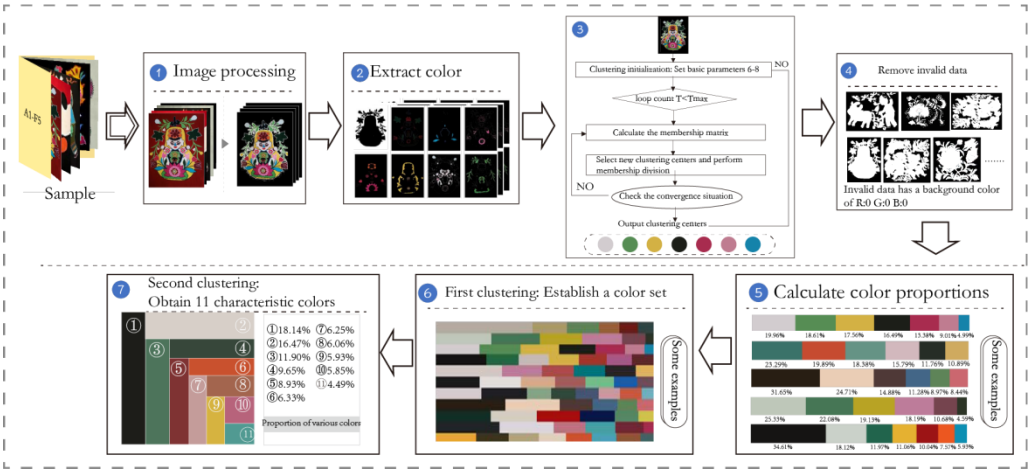


Figure 4: Experimental flow chart

3.2.2. Color extraction process and results

Each sample of Yanchuan cloth appliqué painting typically contains 6 to 8 distinct colors. The initial number of color categories for clustering was therefore set between 6 and 8 to maximize the grouping of similar colors while preserving key distinguishing hues. Once the clustering results met the convergence criteria, the extracted RGB values and corresponding pixel counts were recorded, and the proportion of each color was calculated. The final output included 163 colors from the 25 sample images, forming a comprehensive color dataset (see Figure 5).

Figure 5: Characteristic color collection of cloth pile painting

4. Color analysis of Yanchuan cloth appliqué painting

4.1. Color characteristics of cloth appliqué painting

The sample images were processed in the RGB color mode using MATLAB. However, the HSB (also known as HSV) color space, which better reflects color relationships and aligns more closely with human visual perception, was used for analysis. Therefore, the representative color set was converted from RGB to HSB. The HSB color system classifies colors by hue into six categories: red, yellow, green, cyan, blue, and purple. Starting at 0°, hues rotate clockwise: red spans 0°–30°, yellow spans 30°–90° [17], and so on. Based on the distribution of hues in the color dataset, descriptive statistical analysis was performed on hue, saturation, and brightness attributes.

a) Hue: In the samples related to worship and belief as well as love and marriage, red hues accounted for 47.7% of the total colors. Red symbolizes auspiciousness and enthusiasm, conveying a joyful and celebratory atmosphere. In labor and activity samples, red and yellow hues together made up 75% of the colors, evoking scenes of fieldwork and autumn harvests. In nature and plant samples,

green hues appeared 7 times—the highest among all five categories—eliciting a sense of natural beauty.

b) Saturation and Brightness: Over 60% of the colors in the dataset had medium to high saturation, while over 80% had medium to high brightness. The colors are bright and vivid, consistent with the overall color tone of northern Shaanxi folk culture and reflecting the region's monotonous natural environment, where people often favor vibrant colors to enrich their emotional lives.

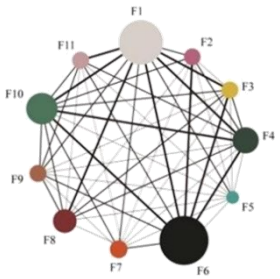
In summary, color distribution patterns vary widely within the same thematic category, strongly correlating with the cultural meanings conveyed by the samples. Creators prefer using medium to high brightness and saturation hues—especially reds, yellows, and greens—while cooler colors such as blue and purple appear less frequently.

4.2. Construction of the color network model

The initial clustering of the representative color set contained many similar hues. Therefore, a second round of clustering was conducted. When the classification number C converged to 11, the clustering result was found to be optimal, maximizing the preservation of representative colors while effectively grouping similar tones. Ultimately, 11 symbolic representative colors (denoted F1 to F11) of Yanchuan cloth appliqué painting were identified.

The color network model presents and explores the pairing relationships and usage patterns of color combinations in a visualized form. In this model, the 11 representative colors are represented by circular nodes of different sizes based on their proportions. Each of the 163 extracted colors corresponds to one of the representative nodes. Connecting lines between nodes indicate pairing relationships observed with a certain frequency. When the connections form a closed loop, they represent a complete color pairing scheme. The thickness of the lines indicates the frequency of the pairing. See Table 1 below:

Table 1: Color network model

Color Network Model	Node	HSB Values			Proportion (%)	Node	HSB Values			Proportion (%)
		H	S	B			H	S	B	
	F1	28	7	84	16.47	F7	14	77	79	6.33
	F2	343	46	72	5.85	F8	0	60	49	8.93
	F3	46	70	84	5.93	F9	16	52	64	6.06
	F4	131	23	28	9.65	F10	142	34	45	11.90
	F5	173	47	60	4.49	F11	3	21	77	6.25
	F6	60	14	11	18.14					

4.3. Birkhoff's aesthetic measure model

Birkhoff's aesthetic measure model offers an objective means of assessing the aesthetic appeal of color combinations. This model was applied to evaluate the beauty (aesthetic harmony) of the color pairings to ensure that combinations retained local traditional characteristics while also meeting modern design aesthetics. The formula [18] is:

$$M = O/C$$

Where $M$is the aesthetic measure (beauty value);$O$is the order factor;$C$is the complexity factor. A beauty value$M$below 0.5 indicates low aesthetic appeal, and the combination should be avoided. A

value of 0.5 or above suggests a harmonious and aesthetically pleasing combination—the higher the value, the more harmonious the pairing. The order factor O is the sum of order components for hue contrast (O_h), brightness contrast (O_b) and saturation contrast (O_s) based on intervals between the paired colors [19]. The complexity factor C is calculated based on the number of color pairs and how many exhibit differences in hue, brightness, or saturation. The formula is: $C = Cm + Ch + Cs + Cb$.

Table 2: Order factor value

Order Factor	Same Hue Harmony	First Ambiguity	Second Ambiguity	Analogous Harmony	Contrast Harmony	Explanation
O_h	1.5	0	0.65	1.1	1.7	Determined by hue intervals
O_s	-1.3	-1	-0.20	3.7	0.7	Determined by saturation gap
O_b	0.8	0	0	0.4	0.1	Determined by brightness gap

4.4. Quantitative results and analysis

By pairing all 11 representative colors, a total of 55 unique color combinations were generated. For each pair, the differences in hue, brightness, and saturation were calculated to determine the complexity factor C,Based on the distribution map of color attribute intervals (see Figure 1), the corresponding region was identified, and the related order factor values O (from Table 2) were assigned. Using the formula $M = O/C$, the beauty value M of each color combination was calculated. The complete results are shown in Figure 10.

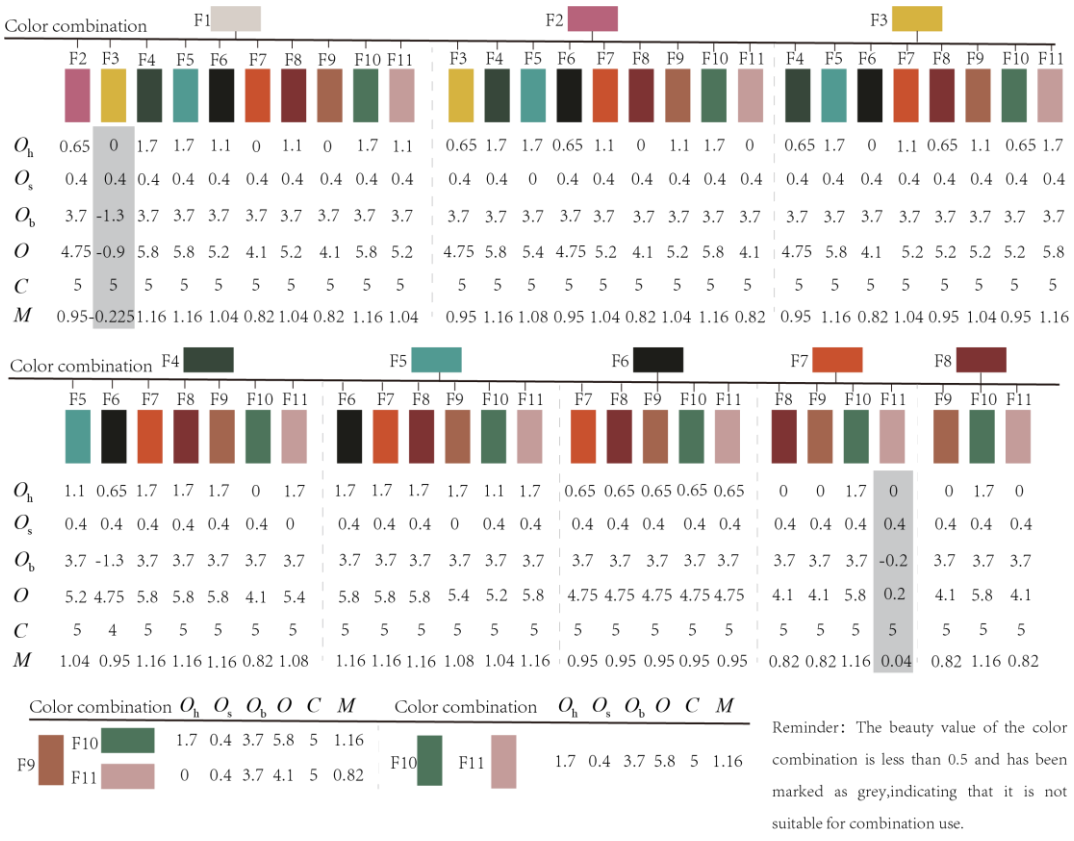


Figure 6: Color harmony degree and aesthetic value calculation

4.4.1. Aesthetic value of color combinations

The analysis of the aesthetic value M for the 55 color combinations shows that two combinations—F1 (H:28 S:07 B:84) with F3 (H:46 S:70 B:84), and F7 (H:14 S:77 B:79) with F11 (H:3 S:21 B:77)—have M <0.5 , indicating that these color pairs exhibit low aesthetic harmony and are not suitable for use in combination. The remaining 53 combinations have $M \geqslant 0.5$ values greater than or equal to 0.5, suggesting that the color relationships among the 11 representative colors obtained through secondary clustering are generally harmonious and aesthetically pleasing.

4.4.2. Color combination harmony

By calculating the differences in hue, saturation, and brightness values for each color pair, and mapping them to the corresponding zones in the color harmony theory interval diagram (Figure 1), it is evident that in the 53 aesthetically pleasing color combinations, the brightness and saturation $\Delta B / \Delta S$ differences predominantly fall within the contrast harmony zone. Regarding hue differences Δ^{H}, 21 combinations (39.6%) fall within the contrast harmony zone, followed by 12 combinations each in the first ambiguous and second ambiguous zones (together accounting for 45.3%), and 9 combinations (16.9%) in the analogous harmony zone.

Brightness and saturation differences primarily fall in the contrast harmony zone, while the hue difference plays a decisive role in the final aesthetic evaluation. Data analysis reveals that the aesthetic effect of hue difference, from most to least harmonious, follows this order: contrast harmony > analogous harmony > second ambiguous zone > first ambiguous zone.

The color network model indicates that the frequency of color combination occurrences does not fully reflect their aesthetic value. In the design of cloth appliqué paintings, it is advisable to increase the frequency of aesthetically pleasing but low-frequency combinations, such as F2–F5, F3–F5, and F4–F7. Conversely, high- or medium-frequency combinations with lower or moderate aesthetic values—such as F1–F3, F3–F6, and F4–F10—should be used more selectively, thereby enhancing the overall aesthetic quality of color application.

5. Application of characteristic cloth appliqué colors in interior space design

5.1. Optimizing homestay space design with cloth appliqué color systems

A unique cultural atmosphere and vibrant human activities significantly enhance tourists' experiences and emotional identification, increasing the visibility and influence of tourist destinations. Thus, it is essential for each region to develop tourism environments tailored to their unique characteristics and establish distinctive cultural tourism brands. For homestay tourism, culture serves as its soul. The integration of culture and tourism is particularly crucial in elevating the overall experience. In designing characteristic homestays, it is important not only to meet basic accommodation needs but also to fulfill tourists' deeper spiritual and cultural desires. Spatial design should fully consider the revitalization of idle rural courtyard resources and optimize space functionality by incorporating elements of daily living, ecology, consumption, communication, experience, and cultural education. The goal is to create interactive and experiential homestays that attract and retain tourists, thereby providing sustainable momentum for rural innovation and revitalization.

As noted in *The Annals of Spring Desires* from *Lüshi Chunqiu*, “The eyes desire to behold five colors”, emphasizing the human longing for colorful visuals. Aesthetic preferences in color are closely tied to regional economic and material development. Due to the early life environment of the creators, cloth appliqué works often focus on themes such as religious belief, romantic love, and labor activities, which are rich in folk elements and feature vivid, saturated colors. It is therefore advisable to establish cloth appliqué-themed homestays in Yan'an’s Yanchuan region to attract tourist traffic

and drive economic growth. In terms of interior color schemes, one should prioritize aesthetically pleasing color combinations that form closed loops in the color network model, while also ensuring alignment with contemporary interior design principles. This approach preserves traditional features while creating livable, harmonious environments. Traditional color schemes can thus serve as a driving force for rural revitalization and local economic development.

6. Conclusion

Taking color as the starting point, this study analyzed the color characteristics of Yanchuan cloth appliqué paintings based on the Munsell-Spencer (M-S) color harmony theory, and arrived at the following conclusions:

1) The fuzzy C-means clustering algorithm effectively extracts the characteristic colors of cloth appliqué paintings and constructs a representative color set. Using the HSB color space to analyze hue, brightness, and saturation, the study concludes that Yanchuan cloth appliqué art predominantly favors red, yellow, and green hues with medium to high brightness and saturation, while blue and purple tones are relatively scarce—accurately reflecting its symbolic color aesthetics.

2) The M-S color harmony theory facilitates intuitive classification of color combinations. The brightness and saturation differences $\Delta B/\Delta S$ in combinations generally fall within the contrast harmony zone, with hue differences being the primary factor influencing color harmony. The effectiveness of harmony zones influenced by hue differences, ranked from most to least harmonious, is as follows: contrast harmony > analogous harmony > second ambiguous zone > first ambiguous zone.

3) Using the Birkhoff aesthetic value model to evaluate the 55 color combinations, the results show that 53 combinations have an aesthetic value greater than 0.5, indicating a high overall aesthetic appeal of the cloth appliqué color scheme.

4) The color network model visualizes the frequency of color combination usage. While the frequencies generally correspond to aesthetic values, one high-frequency color pair exhibits a low aesthetic value. This supports the folk saying “yellow and white should not be placed side by side” and confirms the unsuitability of that color pairing, rather than indicating an error in calculation. This validates the applicability of the M-S color harmony theory in studying traditional folk textiles and provides innovative strategies for optimizing and modernizing the color systems of Yanchuan cloth appliqué, offering fresh perspectives for revitalizing traditional textiles.

The M-S color harmony theory thus offers valuable theoretical and methodological support for researching and innovating the color characteristics of Yanchuan cloth appliqué. It contributes to deeper understanding, preservation, and promotion of this traditional textile art, enabling it to inform contemporary design. Moreover, it expands the scope and vision for research on textile-related intangible cultural heritage, adding momentum to the advancement of Chinese folk textile arts.

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