Study on the Color Selection Characteristics of Kazakh Embroidery Based on K-means Clustering

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Abstract. To explore the color characteristics of Kazakh embroidery in Xinjiang, 12 typical wall hanging embroideries were selected as experimental samples. Color extraction was performed using the K-means clustering algorithm with the assistance of MATLAB software; Based on the results of the image color extraction, we first utilized the HSV color space and quantitative analysis methods to examine the color characteristics of the embroidery threads themselves through the encoded or calculated results of four indicators: hue (warmth/coolness), average saturation, average lightness, and color entropy. Second, using the Lab color space, we examined the color characteristics of the figure-ground relationship through the calculated results of two aspects: lightness difference and total color difference. The study indicates that the color system of Kazakh embroidery exhibits a color scheme characterized by "dominant warm tones, medium saturation, high brightness, and strong contrast," This color scheme serves not only as a psychological and emotional refuge for the Kazakh people—developed in response to the harsh, cold environment of the grasslands and drawing on warm visual imagery—but also as a direct reflection of their reserved, gentle, and unpretentious aesthetic sensibilities. At the same time, these color characteristics meet the practical need for high visual distinctiveness in nomadic life, thereby uniting aesthetic value with practical functionality.

Keywords: Kazakh embroidery; color characteristics; K-means color extraction; HSV color space; Lab color space; calculation and analysis of color metrics

1 Introduction

As an important tangible expression of Kazakh ethnic culture, Kazakh embroidery is widely used in clothing, headscarves, bedding, and interior decorations. Its patterns feature rigorous structure, rich composition, vibrant colors, bold lines, and elegant forms, embodying the distinctive characteristics of Kazakh steppe culture. Based on the material used, it is divided into two types: felt embroidery and fabric embroidery. In terms of fabric composition, it can be categorized into two types: one features a simple

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design with a single-color base fabric bearing the main embroidery; the other features a complex design with a multi-colored patchwork base fabric, created by piecing together or inlaying two or more different colored base fabrics, combined with embroidered decorations in distinct sections. Typically, whether using a single-color base fabric or a multi-color patchwork base, the fabric is adorned with edging, which can be either single-layer or multi-layer. In terms of color schemes, Kazakh embroidery typically features vivid contrasting colors as its primary palette, with color combinations carrying strong symbolic meanings. For example, blue represents the sky and freedom; white symbolizes purity and celebration; green symbolizes spring and youth; red symbolizes the sun and light; yellow symbolizes knowledge, wisdom, or melancholy; and black symbolizes the earth and harmony.

In recent years, with the rapid pace of urbanization, the traditional Kazakh lifestyle of "following water and grasslands" has gradually evolved into a settled urban way of life. As a result, the scope for Kazakh embroidery has been progressively narrowed, and its presence is now primarily preserved in the decorations and embellishments of traditional clothing. Kazakh embroidery embodies the aesthetic values and cultural identity of the Kazakh people and holds significant cultural and artistic value. In June 2008, with the approval of the State Council, Kazakh felt and cloth embroidery were included in the second batch of the National Intangible Cultural Heritage List and received support from national special funds. In May 2021, Kazakh embroidery was selected for the fifth batch of the National Intangible Cultural Heritage List, further expanding the scope of its protection. In the same year, the Ministry of Culture and Tourism issued the "14th Five-Year Plan for the Protection of Intangible Cultural Heritage," which identified the systematic protection of traditional ethnic embroidery techniques and the advancement of digital archiving as key tasks for the 14th Five-Year Plan period. As the state continues to place greater emphasis on Kazakh embroidery, numerous scholars have conducted extensive research on the subject from diverse perspectives.For example, Chang Yaheng et al. [1] systematically elaborated on the artistic characteristics of Xinjiang Kazakh embroidery from three aspects: motif forms and religious culture, color schemes and regional aesthetics, and embroidery techniques; Ke Yun et al. [2] analyzed the artistic characteristics of Kazakh felt and fabric embroidery motifs; Nuo Jin [3] proposed an industrial development pathway for the Kazakh embroidery industry in Mulue County, centered on "product R&D—integration of culture and tourism—promotion and marketing—financial support"; Yang Wenguang et al. [4] analyzed the industrial chain and market challenges of Kazakh embroidery in Burqin County from an economic perspective and put forward corresponding countermeasures and recommendations; Liu Ping [5] addressed the issue of digital preservation of Kazakh felt embroidery art by proposing a preservation pathway involving 3D modeling, VR display, and digital storage. Based on existing research, studies primarily focus on three dimensions: ontological research, industrial development, and preservation and inheritance, with qualitative research methods predominating. In terms of disciplinary distribution, research is concentrated in fields such as art studies, ethnology, economics, and archival science, but lacks studies from an interdisciplinary perspective. Furthermore, the research foundation is relatively weak, and high-quality papers are scarce. Therefore, this paper focuses on the study of color scheme characteristics in Kazakh embroidery. Adopting an interdisciplinary perspective, it integrates HSV and Lab color analysis with quantitative research methods such as K-means clustering to provide parametric data support for the color scheme characteristics of Kazakh embroidery, while simultaneously broadening the scope of research on this subject.

2 Fundamental Theory and Technology

2.1 Color Space Theory

The HSV color space is a color model based on the fundamental properties of color and is the color space model that most closely aligns with visual perception. In contrast to the RGB color model—which is designed for hardware devices such as computers and where color display is often subject to interference from hardware performance—the HSV color model represents color through three channels: hue (H), saturation (S), and value (V). Compared to other color models, it more accurately reflects how the human visual system perceives color [6]. Existing research clearly demonstrates that the HSV color space aligns with the human eye's color perception. The light-dark variations caused by the raised textures of embroidery and photographic shadows only affect the V value, while the inherent H and S values of the patterns remain unaffected, making it the preferred space for parameterizing the color characteristics of intangible cultural heritag[7].

Since HSV can only reflect the basic color characteristics of the embroidery threads used in the main subject and cannot capture the overall color perception of the embroidery, this study, building upon HSV color extraction, further combines the LAB color space to measure the contrast relationship between the figure and the background in terms of both luminance difference and chromatic difference. The LAB color space is also a color model based on human physiological visual characteristics, consisting of a luminance (L) channel and two color channels, a and b. The L (luminance) value ranges from 0 to 100, representing the transition from pure black to pure white; the a and b color channels represent the transitions from red to green and from yellow to blue, respectively, with values ranging from +127 to -128, where positive values correspond to warm colors and negative values to cool colors [8]. This model is also unaffected by display devices, and its color gamut even exceeds that of computer monitors.

2.2 K-means Color Extraction Technique

K-means color extraction is an intelligent extraction technique based on the K-means clustering algorithm [9]; it is a distance-based clustering algorithm that is currently widely used in color extraction from digital images. In the specific computational process, a K value is first randomly selected based on experience as the initial cluster center. The distances between the initial cluster centers and other color pixels are calculated. These color pixels are then re-clustered according to the nearest-neighbor principle, and new cluster centers are recalculated. This process is repeated continuously until the algorithm terminates upon meeting the set criteria. The specific steps are as follows:

Based on the number of distinct colors in the sample image, the colors in the image are divided into K clusters: For each color pixel, the distance to each of the K cluster centers is calculated, and clustering is performed according to the nearest-neighbor principle. The distance D from each color pixel to the cluster center is calculated as shown in Equation (1) [10]:

$$D = \sqrt{(H_i - H_j)^2 + (S_i - S_j)^2 + (V_i - V_j)^2} \tag{1}$$

In the equation, H_i, S_i, and V_i represent the hue, saturation, and brightness values of data point X_i, while H_j, S_j, and V_j represent the hue, saturation, and brightness values of center point C_j, respectively.

Since different values of K in the K-means clustering algorithm lead to different clustering results, this study employs the elbow method to determine the optimal value of K. calculating the mean squared error between each K value and the centroids within its respective clusters [11], and plotting loss function graphs (such as SEE) for different K values. Subsequently, by observing the inflection points (elbows) of the curves, the point at which the rate of decline in the SEE curve significantly slows down is selected as the optimal K value.

3 Research Methods and Approach

3.1 Sample Collection and Pretreatment

To ensure the authenticity of the cultural context of the collected image samples, this study used the 1980 edition of *Collection of Kazakh Folk Patterns*, published by Xinjiang People's Publishing House, as a reference. Kazakh embroidery images were digitized using high-resolution scanning equipment. This book meticulously compiles a total of 178 images of Kazakh crafts, including embroidery, appliqué, patchwork, and lacquerwork. Among these, 34 images depict typical embroidery techniques, covering everyday items such as wall hangings, bedding, and clothing. To ensure the accuracy of color extraction and the reliability of academic research, this study selected wall hangings with complex compositions and rich colors as the original samples.

Since the sample images were scanned from book pages, they inevitably contained elements outside the main design. Therefore, preprocessing of the sample images was necessary. This preprocessing involved removing distracting elements outside the main design and standardizing the image dimensions. Additionally, it included noise reduction of the digital images to ensure the accuracy and scientific rigor of subsequent color extraction.

3.2 Extraction of Image Color Features

Given the visual characteristics of Kazakh embroidery, which feature distinct color distinctions and minimal interference from color gradients, this paper utilizes the K-means clustering algorithm in MATLAB to accurately extract color data from embroidery samples. All algorithms were implemented and data processed entirely within MATLAB. To ensure that the extracted color data is not affected by hardware devices and aligns with human visual perception, this study converts images into both the HSV and Lab color spaces to obtain color data. First, HSV is a color space specifically designed for color perception attributes, allowing for the direct and precise extraction of the fundamental parameters of hue, saturation, and value, which is well-suited for quantifying the characteristics of embroidery primary colors. Second, the core advantage of the Lab color space lies in its ability to calculate color differences, luminance variations, and color contrast relationships based on the a and b channels, making it suitable for analyzing the contrast between patterns and backgrounds and compensating for the shortcomings of HSV in terms of color uniformity. The complementary analysis of these two color spaces ensures both the accuracy of primary color feature extraction and the objective quantification of color hierarchy contrast features, thereby providing comprehensive support for the multidimensional quantitative analysis of the embroidery color system.

During the actual extraction process, the results of the K-means clustering algorithm vary significantly depending on the chosen value of K [12]. To ensure more precise extraction results, this study first determines the optimal K value using the elbow method. and then extracts colors via K-means clustering. Consequently, two sets of code must be written in MATLAB: one for the elbow method calculation and the other for color extraction based on K-means clustering. The final extraction results are presented as color proportions and specific color data across the two color spaces, serving as the foundational parameters required for the study.

3.3 Definition of Color Quantification Metrics

Since this study focuses on an empirical investigation of the color coordination characteristics of Kazakh embroidery, the colors of the embroidery threads—as the primary colors—are analyzed in detail to examine their color attributes and related parameters, thereby exploring the color coordination features of Kazakh embroidery. The base fabric, serving as the structural foundation for the embroidery, belongs to a non-artificial decorative color system. If the relevant indicators of the base fabric's color were treated as an important data source alongside those of the embroidery thread itself, this would significantly skew the proportion of the embroidery's primary colors, leading to distorted color analysis data. Of course, completely disregarding the influence of the background color and considering only the relevant indicators of the embroidery thread's own color would also weaken the accuracy and explanatory power of the research conclusions. Therefore, this study will construct feature indicator parameters based on two levels: the color characteristics of the embroidery thread itself and the figure-ground relationship. Furthermore, considering that sporadic stray colors unrelated to the intended color scheme may still exist after color extraction, it is necessary to combine the original sample images to remove these stray colors, thereby further ensuring the accuracy of the valid color analysis indicators.

In the specific data acquisition process, for the color characteristics of the main subject, the warm-cool relationship of colors is determined by hue proportion, the vividness of colors is measured by average saturation, and the light-dark contrast of color combinations is assessed by average lightness. Color entropy measures the richness of color combinations. Regarding the color characteristics of the figure-ground relationship in the samples, the overall contrast relationship is characterized based on two aspects: the difference in lightness between the background fabric and the embroidery thread, and the total color difference.

3.4 Methods for Calculating Color Index Data

Calculation of Primary Color Metrics.

Color Temperature Coding. Since the human eye perceives color temperature based on an overall assessment, the background color of the fabric must be taken into account. However, most Kazakh embroidery pieces typically feature neutral-colored base fabrics, while those with colored base fabrics are relatively rare. Therefore, for Kazakh embroidery using neutral-colored base fabrics, the determination of warm or cool tones must be based on identifying the core dominant color according to the proportion of the embroidery thread's own color, and then assessing the warm or cool tone based on that core dominant color; for the small number of pieces with colored backgrounds, the dominant color must be determined by combining the background color with the proportion of the embroidery thread's own color, and the classification and coding of the color temperature's warm or cool tendency must be based on the determination of the dominant color's temperature.

Calculation of Average Saturation and Luminance Average. saturation is a key indicator of the overall vividness of embroidery thread colors. A high average saturation evokes a sense of warmth, festivity, and splendor; conversely, a low average saturation conveys an impression of simplicity, tranquility, and rustic charm. The formula for calculating average saturation is as follows:

$$\overline{S} = \frac{1}{N}\sum_{i=1}^{N} S_i \tag{2}$$

In this context, $\overline{S}$ represents the average saturation of all colors within the main color region of the sample; N denotes the total number of colors within the main color region; i ndicates the color index of the sample;and S_i represents the saturation value of the th color extracted from the image.

Average lightness is a key indicator of the light-dark range of a sample's primary color. The average lightness of the primary embroidery thread determines the overall tonal range of the design; the higher the lightness, the brighter, lighter, and livelier the visual impression of the sample; conversely, the lower the lightness, the more subdued, rich, and rustic the impression. The formula for average lightness is as follows:

$$\overline{V} = \frac{1}{N}\sum_{i=1}^{N} V_i \tag{3}$$

In the formula, $\bar{V}$ represents luminance contrast; N represents the total number of valid colors; i denotes the sample color index; V_i represents the luminance value of a single color.

Calculation of Color Entropy. Color entropy is a key metric for measuring the richness of colors in an image; a higher entropy value indicates that the image has a richer color palette and a more even distribution. Conversely, a lower value suggests that the colors are more monotonous and the tonal range is more concentrated[13]. Before calculating color entropy, the entropy value is first determined based on data regarding the proportion of colors in the subject.Before performing the operation, you must first set the neutral color threshold $T = 0.1$,Based on the criteria $\Omega=(S<T) \cup (V < T) \cup (V > 1 - T)$,Eliminate the interference from neutral colors such as black, white, and gray, retaining only valid colors for the calculation. Then normalize the data on the proportion of valid colors, divide the normalized hues into N quantization intervals, and calculate the probability distribution P_i of valid pixels for the ith hue,And that's enough$\sum_{i=1}^{N} P_i = 1$,The formula for calculating hue entropy, based on Shannon's theory of information entropy, is given below :

$$H = -\sum_{i=1}^{N} p_i \cdot \log_2(p_i) \tag{4}$$

In the formula, H represents the color entropy, N represents the total number of distinct colors, P_i represents the probability of the ith color occurring, and $\log_2$ is the natural logarithm to base 2.

Calculation of Figure-Ground Color Relationship Metrics.

Calculation of Overall Luminance. The overall luminance difference of a sample image is an objective measure of the intensity of light-dark contrast, serving as a key indicator for evaluating the clarity, visual depth, and decorative effect of embroidery patterns. The greater the luminance difference, the more pronounced the contrast between the base fabric and the embroidery thread, resulting in a striking visual contrast and a strong ethnic flair; conversely, a lower luminance difference indicates greater color blending, yielding a softer visual effect.In the actual calculation process, the luminance of all colors in the base fabric is first weighted according to their respective proportions to obtain the overall average luminance L_D of the base fabric.Next, we apply a weighting to the colors of the main embroidery threads based on their area proportions to calculate the overall average brightness L_Z of the embroidery threads.Finally, calculate the absolute difference between the two as the overall brightness difference ΔL.The specific steps and calculation formula are as follows:

$$\Delta L = | L_Z - L_D | \tag{5}$$

Total Chromatic Aberration Calculation. otal Color Difference Calculation: Total color difference is an overall quantitative color metric derived from the combined differences in the three channels—luminance, rhodochromatic, and chromatic—and comprehensively characterizes the overall visual differences in color [14]. It serves as a core indicator for evaluating the degree of color contrast, comprehensively and objectively reflecting the overall intensity of color contrast between the background fabric and embroidery thread in an entire piece of embroidery. It is an important basis for evaluating color coordination, the visual clarity of patterns, and the aesthetic characteristics of traditional embroidery colors. A higher total color difference value indicates a more significant overall color difference between the base fabric and the embroidery thread, resulting in stronger visual,That isL_D a_D, b_D, and L_Z a_Z, b_Z ; finally, calculate the total color difference using the Euclidean distance formula:

$$\Delta E_{ab} = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \tag{6}$$

In this context,$\Delta L = L_Z - L_D, \Delta a = a_Z - a_D, \Delta b = b_Z - b_D$. In the equation,$\Delta E_{ab}$ represents the CIE total color difference;ΔL represents the difference in the lightness channel;Δa represents the color difference in the red and green channels; and Δb represents the color difference in the yellow and blue channels.

4 An Empirical Analysis of Color Schemes in Kazakh Embroidery

4.1 Collection of Embroidery Samples and Image Preprocessing

This study selected 34 embroidery patterns from *The Collection of Kazakh Folk Patterns* for high-resolution scanning and digitization. To avoid interference with color extraction accuracy caused by differences in embroidery categories and decorative styles, the study limited the selection to wall-hanging embroidery. The initial selection criteria were patterns that were abundantly represented in the collection, featured regular and uniform compositions, and possessed complete color gradient information. A six-member expert panel was formed, comprising ethnographers, intangible cultural heritage inheritors of Kazakh embroidery, and experts in product design. Using the Delphi method, the panel conducted multiple rounds of anonymous written evaluations and scoring: Independent blind evaluations were conducted based on three assessment criteria: pattern distinctiveness, regional representativeness, and color integrity. After aggregating scores, incorporating feedback, and undergoing multiple rounds of refinement, the images were weighted and ranked, resulting in the selection of 12 images as experimental samples. The selected samples were sourced from typical Kazakh-populated regions in Northern Xinjiang, including Ili, Altay, and Mulei;

Since the background of the book pages inevitably appears in the scan, it is necessary to remove the background areas outside the embroidered images. Secondly, due to the thickness of the book, the images on the pages appeared skewed during scanning. Therefore, Photoshop software was used to straighten the images on the pages, ensuring they were positioned directly in front of the viewer's perspective. Furthermore, since Kazakh wall hangings are large in size and vary in dimensions, and their patterns are predominantly repetitive motifs with a certain degree of compositional repetition, Therefore, this study selected a corner of the wall hanging with relatively complete ornamentation as the experimental sample, using a 1:1 scale in Photoshop.

Furthermore, since the sample images were scanned from early published books, and given the limitations of printing technology at the time, the books inevitably contain defects in print quality. Consequently, the collected sample images are prone to color interference and noise, which can affect color extraction. Consequently, this study utilized MATLAB software to apply noise reduction to the image using the median filter command. When applying median filter noise reduction [15], larger filter windows typically yield more pronounced results but may also lead to loss of image detail and blurred edges. Through multiple experiments, a filter window size of 7×7 was ultimately determined to effectively reduce image noise while ensuring that image details are preserved.

4.2 Color Extraction and Definition of Valid Colors

Color Extraction Based on the K-Means Clustering Algorithm.

Before color extraction, the sample images were first converted to the HSV color space. Then, using MATLAB 2022b, a loss function ESS plot was generated via the elbow rule[16] to determine the optimal clustering K value(See Figure 1). Experimental results showed that for Sample 1, the curve began to flatten when the number of clusters K was 8, while for Sample 4, the curve began to flatten when K was 9. Based on this, multiple elbow rule experiments were conducted on the 12 samples, revealing that the optimal K-value for K-means clustering ranged between 8 and 10 for each sample. To ensure significant color extraction results for each embroidery sample, color extraction was performed on the 12 sample images using the K-means+ clustering algorithm with K=8, K=9, and K=10, respectively, and the results were compared. Analysis of the monochromatic distribution plots for each sample's color classification revealed that when K=8, the extracted colors were distinctly differentiated, effectively avoiding the blurring of similar colors and eliminating residual color noise in some sample images.

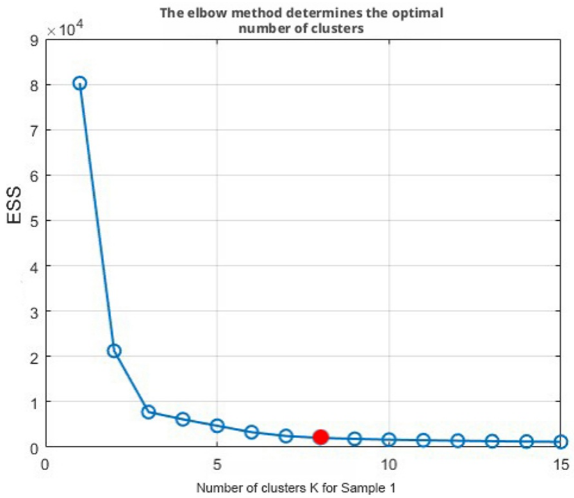


Fig. 1. The ESS plot for the loss function of Sample 1.

After determining the optimal K value, color extraction was performed on the sample images based on the HSV and Lab color spaces to obtain the corresponding color parameters. All operations were implemented using MATLAB software, and the final results of color extraction for all samples are shown in Table 1. The extraction results include two key parameters: the numerical values of each color channel in the sample images and the proportion of each color.

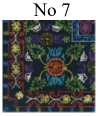
Effective Color Analysis.

To ensure the scientific rigor of subsequent color analysis and the accuracy of valid color metric data, the results extracted by the MATLAB intelligent algorithm must be compared with the results of manual observation of the colors in the embroidery sample images. This process eliminates abnormal colors caused by insufficient image pre-processing or machine recognition errors, ensuring that the valid colors included in the analysis truly and accurately reflect the color characteristics of the sample images, thereby guaranteeing the accuracy of the subsequent valid color data and the scientific validity of the empirical analysis. For example, in Sample 1, a side-by-side comparison of the inherent color count in the sample image with the monochromatic distribution chart from the algorithm's results revealed that two distinct shades of brown—accounting for 4.86% and 3.34% respectively in the MATLAB results—were identified as anomalous colors and were therefore excluded.

For the valid color metrics obtained after removing abnormal colors, foundational data on the sample's valid colors was organized based on two levels: the dominant colors of the embroidery (the colors of the embroidery thread itself) and the background fabric colors. This foundational data includes color proportions and color values in both the HSV and Lab color spaces, providing a solid foundation for subsequent quantitative research. The valid color metrics and foundational data for the samples are shown in Table 1.

Based on the organized basic parameters of the valid colors in the samples, a color indicator database for Kazakh embroidery samples was systematically constructed, focusing on the relationship between the dominant colors and the background colors. The database encompasses various color indicator data required for the study, including basic parameters such as the warmth or coolness of hues in the HSV color space, average saturation, and average lightness of the samples, as well as hue entropy values needed for color richness analysis. Additionally, it includes relevant color parameters in the Lab color space for analyzing the figure-ground relationship.

Table 1. Valid Color Metrics and Baseline Values for the Sample

Sample No	proportion of primary colors	HSV and Lab color values For the primary colors	Background color proportion	Background HSV and Lab color values
No 1 	12.56% 2.48% 6.20% 0.97% 4.95%	HSV:(0.09,0.96,0.87) Lab:(62,35,37) HSV:(0.14,0.87,0.91) Lab:(81,2,77) HSV:(0.12,0.08,0.89) Lab:(89,0, 7) HSV:(0.59,0.79,0.68) Lab:(41,0, -46) HSV:(1.00,0.28,0.82) Lab:(68,23, 9)	64.63%	HSV:(0.13,0.31,0.16) Lab:(15,0, 7)
No 2 	16.52% 8.78% 12.50% 7.74% 6.54% 6.20%	HSV:(0.05,0.59,0.27) Lab:(20,13, 14) HSV:(0.08,0.16,0.89) Lab:(85,5, 11) HSV:(1.00,0.60,0.68) Lab:(44,43, 23) HSV:(0.23,0.36,0.51) Lab:(52,-13,23) HSV:(0.10,0.80,0.82) Lab:(65,20, 60) HSV:(0.59,0.33,0.74) Lab:(63,-4,-21)	25.39% 16.33%	HSV:(0.04,0.85,0.67) Lab:(42,43, 45) HSV:(0.09,0.12,0.27) Lab:(28,1,3)
No 3 	8.89% 6.42% 8.03% 6.31% 4.69% 3.05%	HSV:(0.01,0.78,0.85) Lab:(50,61, 45) HSV:(0.26,0.53,0.56) Lab:(55,-26, 35) HSV:(0.54,0.14,0.65) Lab:(65,-6, -4) HSV:(0.74,0.46,0.59) Lab:(40,24,-34) HSV:(0.05,0.15,0.90) Lab:(84,7, 8) HSV:(0.14,0.89,0.92) Lab:(82,2,79)	50.66% 11.95%	HSV:(0.39,0.07,0.15) Lab:(15,-2, 1) HSV:(0.07,0.60,0.77) Lab:(60,24,38)
No 4 	8.67% 6.69% 8.01% 4.76% 6.86% 4.44% 3.05%	HSV:(0.11,0.76,0.72) Lab:(61,12, 54) HSV:(0.04,0.53,0.94) Lab:(69,36, 32) HSV:(0.03,0.75,0.92) Lab:(58,55, 48) HSV:(0.13,0.90,0.94) Lab:(81,7,78) HSV:(0.83,0.32,0.66) Lab:(55,28, -20) HSV:(0.58,0.96,0.70) Lab:(40,2,-51) HSV:(0.39,0.70,0.59) Lab:(55,-43,28)	57.53%	HSV:(0.06,0.12,0.17) Lab:(16,1,2)
No 5 	8.80% 7.41% 7.99% 4.11% 3.98% 3.13%	HSV:(0.15,0.68,0.82) Lab:(78,-5, 63) HSV:(0.29,0.25,0.53) Lab:(54,-14, 15) HSV:(0.16,0.58,0.79) Lab:(78,-9, 56) HSV:(0.55,0.94,0.71) Lab:(55,-16,-36) HSV:(0.05,0.15,0.90) Lab:(84,7, 8) HSV:(0.14,0.89,0.92) Lab:(82,2,79)	44.57% 20.01%	HSV:(0.55,0.22,0.20) Lab:(1,-3, -3) HSV:(0.02,0.76,0.88) Lab:(54,59,45)
No 6 	13.64% 8.59% 10.92% 6.73% 4.89%	HSV:(0.13,0.25,0.50) Lab:(51,0,15) HSV:(0.21,0.20,0.35) Lab:(37,-5, 10) HSV:(0.08,0.89,0.87) Lab:(61,37, 64) HSV:(0.07,0.56,0.86) Lab:(68,24,38) HSV:(0.07,0.22,0.90) Lab:(83,8,15)	44.75% 6.89%	HSV:(0.58,0.30,0.20) Lab:(17,-2, -6) HSV:(0.65,0.43,0.58) Lab:(40,9,-33)
No 7 	6.23% 3.99% 4.41% 3.15% 3.12% 2.69%	HSV:(0.23,0.44,0.55) Lab:(51,0, 15) HSV:(0.02,0.76,0.80) Lab:(49,54, 42) HSV:(0.71,0.39,0.45) Lab:(32,13, -24) HSV:(0.18,0.04,0.85) Lab:(86,-1,4) HSV:(0.58,0.73,0.70) Lab:(47,5, -40) HSV:(0.15,0.53,0.86) Lab:(83,-6,53)	65.72%	HSV:(0.55,0.29,0.17) Lab:(15,-3,-4)

No 8 	12.74% 9.74% 12.58% 9.23%	HSV:(0.25,0.45,0.61) Lab:(60,-22, 32) HSV:(0.20,0.47,0.72) Lab:(72,-16, 41) HSV:(0.94,0.17,0.59) Lab:(55,11, -1) HSV:(0.10,0.08,0.84) Lab:(84,1,6)	28.25% 11.07% 9.64% 6.75%	HSV:(0.53,0.35,0.20) Lab:(19,-6, -4) HSV:(0.89,0.46,0.42) Lab:(32,26,-10) HSV:(0.01,0.74,0.87) Lab:(54,57,43) HSV:(0.55,0.90,0.72) Lab:(52,-17,-35)
No 9 	10.44% 7.60% 8.91% 6.06% 4.17%	HSV:(0.38,0.23,0.43) Lab:(44,-13, 7) HSV:(0.05,0.48,0.75) Lab:(60,23, 26) HSV:(0.57,0.20,0.60) Lab:(57,-4, -9) HSV:(0.08,0.06,0.86) Lab:(86,2,4) HSV:(0.10,0.87,0.91) Lab:(70,25, 69)	47.58% 6.48%	HSV:(0.45,0.09,0.22) Lab:(23,-2,0) HSV:(0.03,0.79,0.83) Lab:(52,54,47)
No 10 	13.33% 5.92% 3.73%	HSV:(0.57,0.20,0.60) Lab:(57,-4,-9) HSV:(0.58,0.66,0.70) Lab:(49,-6, 37) HSV:(0.13,0.77,0.92) Lab:(81,5,71)	30.27% 29.92% 9.04%	HSV:(0.40,0.25,0.16) Lab:(15,-6,3) HSV:(0.95,0.70,0.80) Lab:(49,59,9) HSV:(0.02,0.07,0.91) Lab:(88,5,3)
No 11 	16.35% 8.65% 11.80% 6.72% 5.97% 5.94%	HSV:(0.02,0.82,0.85) Lab:(50,61,49) HSV:(0.52,0.27,0.67) Lab:(65,-13,-8) HSV:(0.05,0.44,0.70) Lab:(57,20, 22) HSV:(0.47,0.35,0.46) Lab:(46,-16,-1) HSV:(0.12,0.78,0.88) Lab:(75,10,66) HSV:(0.96,0.12,0.83) Lab:(78,10,1)	26.26% 18.30%	HSV:(0.00,0.42,0.46) Lab:(35,21,10) HSV:(0.04,0.19,0.17) Lab:(15,3,2)
No 12 	14.51% 9.19% 13.02% 6.99% 3.92%	HSV:(0.31,0.33,0.67) Lab:(65,-25, 24) HSV:(0.01,0.51,0.84) Lab:(59,-40, 23) HSV:(0.01,0.16,0.79) Lab:(73,11, 5) HSV:(0.13,0.87,0.92) Lab:(79,7,76) HSV:(0.62,0.70,0.68) Lab:(38,11,-51)	35.65% 11.46% 5.27%	HSV:(0.02,0.76,0.76) Lab:(47,52,40) HSV:(0.15,0.14,0.17) Lab:(17,-1,4) HSV:(0.84,0.35,0.52) Lab:(43,25,-17)

4.3 Calculation and Analysis of Primary Color Metrics in the HSV Color Space

Coding for Warm and Cool Tones.

Based on the effective color categories and their proportions summarized in Table 1, for embroidered images on a neutral-colored background, the dominant color is determined based on the proportion of the main color. The samples are then classified and coded using “0” and “1” according to the warm or cool tone of the dominant color, where “0” indicates that the sample does not possess the attribute of that category, and “1” indicates that the sample does possess the attribute of that category.

For example, Sample 1 has a neutral black background fabric; therefore, the dominant color is determined based on the proportion of the embroidery thread’s own color. According to the dominant color proportion parameters in Table 2 above, orange-yellow, with a proportion of 12.56%, is the dominant color. Since orange-yellow belongs to the warm color family, the tonal characteristic of Sample 1 can be determined as warm. The coding results for the warm/cool tonal tendencies of the samples are shown in Table 2 below.

From the statistical results on the warm and cool color tendencies in Table 2, it can be seen that warm-toned samples account for as much as 75%, while cool-toned samples account for only 25%. The data indicates that Kazakh embroidery favors a color palette dominated by warm tones such as red, orange, and yellow, with cool colors primarily used as accent or contrasting colors. This color selection aligns with the

Kazakh people's warm hospitality and their free-spirited, uninhibited national character.

Table 2. Coding for Determining the Warm or Cool Tone of Samples

Sample No	No 1	No 2	No 3	No 4	No 5	No 6	No 7	No 8	No 9	No 10	No 11	No 12
Cool tones	0	0	0	0	0	0	1	1	1	0	0	0
Warm tones	1	1	1	1	1	1	0	0	0	1	1	1

Average Saturation and Average Luminance.

Based on the HSV channel parameters for each color in Table 1, the mean method can be used to obtain specific data for the average saturation ($\bar{S}$) and average brightness ($\bar{V}$) of each sample, which collectively reflect the vibrancy and brightness of the sample images. Taking Sample 1 as an example, Table 1 shows that the specific saturation parameters for each color in Sample 1 are 0.96, 0.87, 0.28, 0.08, and 0.79. Using Equation (3) above, we can calculate the average saturation $\bar{S} \approx 0.60$ for this sample. Similarly, the luminance parameters for each color in Sample 1 are 0.87, 0.91, 0.82, 0.89, and 0.68. Using Equation (4), the average luminance $\bar{V} \approx 0.83$ of Sample 1 can be calculated. The specific data for the average saturation ($\bar{S}$) and average luminance ($\bar{V}$) of the other samples can be obtained by the same method. The calculated results for the average saturation and luminance of the samples required for the experiment are shown in Table 3 below.

Based on the calculated results of the average saturation of each sample required for the experiment in Table 3, the mean saturation of the primary colors across the 12 samples is 0.52, with a standard deviation of 0.26; the mean value for lightness is 0.74, with a standard deviation of 0.05. The data indicates that Kazakh embroidery tends to favor colors with medium-to-high saturation levels in the selection of embroidery threads. This color scheme avoids both the dullness associated with low-saturation colors and the intense visual stimulation caused by excessively high-saturation colors, resulting in an overall vibrant and harmonious palette. The value data reveal that the embroidery threads in Kazakh embroidery generally have a high value, ensuring clear distinguishability of the dominant colors against different fabric backgrounds while also reflecting the Kazakh people's aesthetic preference for bright tones and warm, vibrant colors.

Table 3. Calculated results for the average saturation ($\bar{S}$) and average brightness ($\bar{V}$) of the samples

Sample No	No1	No2	No3	No4	No5	No6	No7	No8	No9	No10	No11	No12
Average saturation	0.60	0.52	0.49	0.70	0.58	0.42	0.48	0.47	0.37	0.60	0.46	0.51
Average brightness	0.83	0.65	0.75	0.78	0.76	0.70	0.70	0.69	0.71	0.76	0.73	0.78

Color Entropy.

Similarly, based on the specific parameters of color proportions for each sample outlined in Table 1 above, the entropy method is used to comprehensively assess the richness of the sample's colors. Before applying the entropy method, it is essential to ensure that the sum of all valid color proportions equals 100%. For example, in Sample 1, after removing extraneous colors, the sum of all valid color proportions does not meet the 100% standard; therefore, the proportions of each color must first be normalized using the following formula:

$$P_i = S_i / \sum_{i=1}^{n} S_i \tag{7}$$

In the equation,$P_i$represents the normalized proportion of the *ith* color,S_i represents the unnormalized proportion of the *ith* color, and *n* represents the number of colors. Using Equation (8), we find that the normalized color proportions for Sample 1 are 0.46, 0.23, 0.18, 0.09, and 0.04, respectively. Next, we calculate the product $P_i \cdot log_2(P_i)$ of each color's , where the base-2 logarithms of the colors can be obtained using a calculator. Finally, using Equation (5), we find that the color entropy of Sample 1 is 1.95. The color entropy results for each sample are shown in Table 4 below.

Table 4. Sample Color Entropy Calculation Results

Sample No	No 1	No 2	No 3	No 4	No 5	No 6	No 7	No 8	No 9	No 10	No 11	No 12
Color Entropy	1.95	1.71	1.73	1.88	1.73	1.67	1.74	1.39	1.55	0.96	1.72	1.52

As shown in the color entropy results in Table 4, the overall mean color entropy of the samples is 1.63, with a standard deviation of 0.26. The data indicate that the color scheme of Kazakh embroidery emphasizes rich color combinations and clear visual hierarchy. In terms of color distribution, the colors are relatively evenly distributed, and the fluctuations in color complexity are gradual; there are no color combinations that are either extremely monotonous or excessively complex.

4.4 Calculation and Analysis of Patterns - Backgrounds Color Relationship Metrics Based on the Lab Color Space

Since the HSV hue channel yields invalid values on an achromatic background and because luminance and chroma are coupled, it cannot objectively reflect the visual differences in embroidery colors. In contrast, CIE Lab is a visually uniform color space with an independent luminance channel that aligns with human visual perception. It allows for precise calculation of luminance difference and total color difference, enabling an objective and comprehensive reflection of the color contrast between samples. Therefore, sample images must be converted to the CIE Lab color space to calculate luminance difference and total color difference.

Overall Brightness Difference.

The overall luminance difference is a measurement indicator that combines the contrast intensity between the background fabric color and the main motif color. Therefore, it must be calculated based on the color proportions of the background fabric and the main motif in each sample listed in Table 1, as well as the specific parameters of the luminance channel, using Equation (6). Taking multi-background embroidery with a relatively complex structure as an example, such as Sample 2, first calculate the sum of the proportions of all background colors, and then apply a weighting to the luminance channel data of the background colors to obtain the overall luminance of each background color. Similarly, the overall average brightness of the sample's main color (the color of the embroidery thread itself) can be obtained. Finally, the overall brightness difference of the sample is calculated using Equation 6. The calculated brightness differences for all samples are shown in Table 5 below.

The data from the statistical results in Table 5 show that the samples of Kazakh embroidery exhibit a strong contrast in terms of light-dark differences. In the statistical results, the overall luminance difference for the vast majority of samples falls between 32 and 44. Among these, Sample 1 exhibits the greatest difference (55.24), while Sample 2 shows the smallest (11.30). This discrepancy stems from the fact that Sample 1 employs a complementary color scheme, whereas Sample 2 uses an analogous color scheme (where the background color and the main embroidery thread color are adjacent on the color wheel). Based on the statistical results in the table above, the mean luminance difference of the experimental samples is 34.29, with a standard deviation of 11.30. The data indicates that Kazakh embroidery generally exhibits high overall luminance contrast, with most samples exceeding 30. This creates a clear visual contrast between light and dark, allowing the outlines of patterns to be quickly identified even from medium to long distances.

Table 5. Calculated results for the overall luminance difference of the sample

Sample No	No 1	No 2	No 3	No 4	No 5	No 6	No 7	No 8	No 9	No 10	No 11	No 12
Luminance difference	55.24	12.29	35.68	44.34	40.00	36.73	41.22	34.58	33.67	19.60	32.25	25.83

Overall Color Difference.

Compared to the overall brightness difference, the total color difference is a comprehensive evaluation based on the differences between the background color and the subject color in each Lab channel—specifically, the Euclidean distance of the sum of the squares of the differences between the background color and the subject color in each Lab channel. Taking Sample 1 as an example, since the background fabric has only one color, its average Lab values are (15, 0, 7). Next, we calculate the weighted average Lab values for the subject color. First, we calculate the sum of the proportions of all subject colors; (2) then, we calculate the weighted averages for the L, a, and b channels of the subject color, which are 70.24, 20.56, and 25.73, respectively. Finally, using Equation (8) above, we obtain a total color difference of 61.85 for Sample 1. The calculated total color differences for all samples are shown in Table 6 below.

Table 6. Calculated Total Color Difference Results for the Samples

Sample No	No 1	No 2	No 3	No 4	No 5	No 6	No 7	No 8	No 9	No 10	No 11	No 12
Total chromatic aberration	61.85	20.59	38.45	54.80	51.78	55.19	45.26	43.20	34.61	34.19	37.69	54.94

Table 6 shows that the maximum total color difference for the sample images was 61.8, the minimum was 20.59, and most values fell between 34 and 56. The data indicates that among all samples, Sample 1 exhibits the strongest color contrast, while Sample 2 has a slightly softer contrast. This is because Sample 1 employs strong contrasting colors in its color scheme, whereas Sample 2 uses adjacent colors for both the background fabric and the main embroidery thread, resulting in a softer color contrast compared to the other samples. A comprehensive analysis of the total color difference statistics for all samples reveals an average total color difference of 44.38 and a standard deviation of 11.85. The results indicate that Kazakh embroidery seeks a color relationship between the figure and the ground characterized by strong contrast and significant differences.

5 Conclusion

As an integral part of the Kazakh ethnic cultural heritage, Kazakh embroidery embodies the ethnic characteristics and aesthetic preferences of the Kazakh people, and its color system serves as a key window into their aesthetic orientation. In this paper, the K-means clustering algorithm was employed, utilizing MATLAB software to extract color features from 12 samples of Kazakh embroidery images. Based on these results, a database for color feature analysis was constructed, examining both the colors of the embroidery threads themselves and the relationship between the thread colors and the background colors. The database encompasses specific parameters for six indicators: warm and cool hues, average saturation, average lightness, color entropy, overall lightness difference, and total color difference. Building on this foundation, the article systematically analyzes the color matching characteristics of Kazakh embroidery based on these six color evaluation indicators. The study reveals that the color system of Kazakh embroidery exhibits a color combination pattern characterized by "warm-color dominance, medium saturation, high lightness, and strong contrast." The "predominance of warm colors" is an aesthetic preference shaped by the Kazakh people's long history of nomadic herding and life on the grasslands. The harsh, cold climate of the grasslands has made warm visual imagery an important source of psychological solace. At the same time, the nomadic society's tradition of valuing kindness, mutual aid, and warm hospitality has led to the gradual integration of warm-toned patterns into domestic settings and festive social occasions, giving rise to a cultural imagery of warmth and friendliness. This represents an aesthetic expression jointly shaped by lifestyle and socio-cultural psychology. The choice of "medium saturation" reflects restraint and subtlety, embodying the Kazakh people's reserved, gentle, and unpretentious aesthetic sensibilities. “High brightness and strong contrast” reflect the practical need for highly recognizable patterns stemming from the nomadic lifestyle.

This study goes beyond previous research that focused solely on the color attributes of embroidery threads. By introducing three new metrics—color entropy, luminance difference, and total color difference—it conducts a comprehensive analysis of the color characteristics of Kazakh embroidery from two perspectives: the color attributes of the threads and the color relationship between the figure and the ground. This study not only enriches the color data repository for Kazakh embroidery and standardizes sampling methods for intangible cultural heritage patterns but also provides empirical references for the digital preservation of intangible cultural heritage and color scheme design in modern cultural and creative industries. However, this study also has certain limitations. For example, the research remains at the stage of quantitative empirical analysis of color and has not yet explored the relationship between color and consumers’ emotional associations. Therefore, future research will expand the sample size and establish a correlation between color parameters and consumer percep.

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