Journal of Image Processing Theory and Applications (2025)
Clausius Scientific Press, Canada

DOI: 10.23977/jipta.2025.080119
ISSN 2560-6239 Vol. 8 Num. 1

Quantitative Analysis of Line and Ink Features in Traditional Chinese Painting Based on Principal Component Analysis: A Case Study of Qi Baishi's Shrimp Paintings

Yida Wu

Jinan Foreign Language School International Center, 3399 Jinyu Avenue, Licheng District, Jinan, Shandong Province, China
wuyida668@163.com

Keywords: Traditional Chinese Painting; Color; Line; Principal Component Analysis; Non-Negative Matrix Factorization

Abstract: Focusing on Qi Baishi's late-period shrimp paintings, this study integrates image processing with statistical analysis to construct a quantitative model of line and ink characteristics. High-resolution digital images were first compiled and processed through grayscale conversion, adaptive thresholding, and edge detection to extract line details, while HSV color-space analysis captured the hierarchical distribution of ink tones. After separating features and structuring them into matrices, principal component analysis (PCA) and non-negative matrix factorization (NMF) were applied to reduce dimensionality and reveal the dominant roles of line dynamics and ink gradation in stylistic expression. Clustering results show that Qi's shrimp works combine concise brushwork with varied ink layers, exemplifying the artistic principle of "achieving more with less." This research provides a new quantitative pathway for studying traditional painting styles and offers methodological references for computational art cognition and digital humanities.

1. Introduction

Traditional Chinese painting, a vital part of China's cultural heritage, has evolved over millennia to form a unique artistic system and aesthetic standard [1]. Unlike Western painting, which emphasizes light, shadow, and structure [2], Chinese painting especially ink-wash and meticulous gongbi styles—focuses on brushwork, line expression, atmosphere, and color application. Lines and colors are not only fundamental compositional elements but also key vehicles for an artist's individuality and for the character of entire schools of painting. Variations in line density, thickness, and rhythm, along with the elegance, contrast, and layering of colors, create a rich visual language.

Existing studies mainly adopt qualitative art-historical perspectives. For example, Wang Yan and Han Yiying [3] explored how brushstroke and color interact to convey emotion and proposed creative strategies; Lin Peiliang [4] analyzed Dunhuang mural lines to reveal their expressive power across eras; and Mieren Nisha Aishan [5] traced the historical development of line art and its significance for form and emotion. While these works deepen understanding of Chinese painting's aesthetic and

cultural values, quantitative approaches remain limited. Principal component analysis (PCA) [6,7], a classic multivariate statistical method, is widely used for image feature reduction and pattern recognition. By extracting major axes of variation, PCA uncovers essential structures within complex image data. Applying PCA to traditional Chinese painting can therefore isolate principal features of line and color, enabling quantitative comparison across artists, schools, and historical periods.

This study uses image data modeling and PCA to reveal both common and individual patterns in the use of line and color in Chinese traditional painting, establishing a framework for measurable stylistic differences. The findings provide new tools for analyzing artistic style, authenticating works, and classifying schools, while also informing computational art cognition, digital humanities, and cultural data research.

2. Related Work

In image style analysis and ink-painting feature extraction, PCA [8.9]and NMF[10.11] are two key methods for dimensionality reduction and feature extraction. They effectively handle high-dimensional data, highlight major patterns, and reduce redundancy, thus supporting subsequent style recognition and classification.

2.1 PCA in Ink-Painting Feature Extraction

PCA linearly maps original features onto a new coordinate system whose axes maximize data variance. In ink painting, PCA extracts principal components of line and color, simplifying data while preserving essential information. Zhang Dongfang [1], for instance, built line and color feature matrices covering density, orientation, length, ink gradation, brightness, and color entropy and applied PCA to reduce them, with the first two principal components capturing over 95% of the variance. PC1 reflected line density and orientation, while PC2 captured ink-tone variation, enabling efficient style clustering. Chen Chuan [14] further demonstrated PCA's value in enhancing style transfer efficiency within diffusion-model sampling.

Although PCA preserves global variance trends, its features can lack local interpretability, which is why it is often paired with NMF.

2.2 NMF in Ink-Painting Feature Extraction

NMF is a part-based dimensionality-reduction method that decomposes a non-negative matrix into the product of two non-negative matrices, thereby extracting local features from the data.

In ink-painting analysis, NMF can capture localized patterns of brushstrokes and ink tones, offering a more interpretable feature representation. Zhang Dongfang [1] introduced NMF as a complementary method to PCA to reveal more interpretable artistic patterns in Qi Baishi's shrimp paintings. By factorizing the line-feature matrix and the color-feature matrix into the product of basis vectors and a coefficient matrix, NMF ensures that each basis vector remains non-negative. This property is particularly suitable for art-image analysis: for line features, the basis vectors correspond to typical brushstroke shapes or line directions; for color features, they can be regarded as typical ink-tone layers or ink-application styles.

Unlike PCA, which focuses on maximizing variance, NMF emphasizes the interpretability of local structures. This allows it to uncover latent stylistic features in Qi Baishi's brushwork and ink application while reducing dimensionality. Lyu Peng [15] also highlighted the application of NMF in feature extraction. In that study, texture features of ink wash paintings were decomposed using NMF to extract basis vectors representing different brushstroke and ink-tonality patterns. These basis vectors were then used for style classification and recognition, improving both classification accuracy

and interpretability.

The advantage of NMF lies in its ability to provide interpretable local features, but its drawbacks include higher computational complexity and sensitivity to initial values. Therefore, in practical applications, NMF is often combined with PCA to balance global and local feature analysis.

2.3 Combined Use of PCA and NMF

In the style analysis of ink wash paintings, the combined use of PCA and NMF can fully leverage the advantages of both methods to achieve more comprehensive and accurate feature extraction. In the study from Reference [1], the joint application of PCA and NMF enabled a multi-level understanding of the feature space of Qi Baishi's shrimp paintings. PCA provided a global, low-dimensional representation for the overall features, ensuring the statistical validity of subsequent clustering and classification analyses. NMF, in turn, further revealed the underlying local structures and artistic patterns hidden within the data, allowing for the clarification and visualization of "brushstroke patterns" and "ink tone patterns."

Wang Chenchen [13] also mentioned a similar approach. This study integrated the concepts of PCA and NMF into the feature extraction process of a convolutional neural network to perform a multi-level analysis of the line and texture features in ink wash paintings. Through this combination, the research was able to more accurately capture the stylistic features of ink wash paintings and achieve high-quality style transfer.

3. Method

3.1 Dataset Construction and Preprocessing

3.1.1 Data Source and Work Selection

This study focuses on the shrimp paintings of Qi Baishi [12] as its core research subject. Twelve representative works were selected, all from the later stage of his creative career. This period came after Qi Baishi's "Sui Nian Bian Fa" (late-life artistic transformation), a time when his brush-and-ink language and artistic style had reached maturity, making it of extremely high research value. All research subjects were sourced from images provided by authoritative institutions such as the Palace Museum and the National Art Museum of China, with resolutions of no less than 600 dpi. The samples were selected based on principles of a unified theme, a concentrated time period, diverse compositions, and complete brush-and-ink features.

In terms of theme, all works are ink wash shrimp paintings to avoid interference from other subjects. In terms of period, the focus is on the peak stage of Qi Baishi's artistic career. In terms of composition, the selection including close-ups of single shrimp, dynamic groups of shrimps, and combinations of shrimp with aquatic plants. Regarding brush-and-ink features, the works fully retain the transparent texture of the shrimp bodies, the agility of their antennae and legs, and the subtle differences in ink tones. Together, these factors ensure the typicality and scientific validity of the constructed dataset.

3.1.2 Image Preprocessing

In the image preprocessing stage, this study modified the classic weighted formula by increasing the weight of the green channel to enhance the fidelity of the Xuan paper's background color in the resulting image. The processed grayscale histograms exhibited a clear bimodal distribution, with dark and light ink tones accounting for 78.3%, which corresponds to the ink color system of "charred, thick, heavy, light, and clear" (jiao, nong, zhong, dan, qing) in Qi Baishi's works.

Building on this, a multi-scale adaptive thresholding algorithm was used for binarization to highlight the contours and fine structures of the shrimp, such as their bodies and antennae. This method employed an 11×11-pixel analysis window and dynamically adjusted the threshold based on the local mean and standard deviation. After processing, the extraction integrity of key lines like the shrimp antennae reached 92.4%. An average of 1,250 lines were identifiable in a single work, with fine lines (less than 3 mm) accounting for a high proportion of 67%.

Finally, all images were standardized to a resolution of 512×512 pixels using a bicubic interpolation algorithm, and a standardized pose coordinate system was established. The origin of the coordinate system was set at the geometric center of the image, with the X-axis corresponding to the main direction of the shrimp's movement and the Y-axis perpendicular to the X-axis. After standardization, the main axis length of the shrimp bodies ranged from 100 to 250 pixels, which translates to an actual size of approximately 8 to 20 cm, consistent with the compositional proportions of Qi Baishi's shrimp paintings.

3.2 Separation and Extraction of Line and Color Features

After completing the image preprocessing, the research moves to the feature extraction stage. The uniqueness of Qi Baishi's shrimp paintings is primarily embodied in the agility of their lines and the layering of their ink tones. Therefore, this study adopts a multi-scale feature extraction strategy to distinguish between these two aspects and transform them into structured data through quantitative methods.

For line analysis, Canny edge detection was used to capture the contours of the shrimp bodies and fine details such as the antennae. A subsequent Hough transform was applied to reveal the distribution characteristics of line orientation and length. For color analysis, the study moved beyond the RGB channels and converted the images to the HSV space, focusing on the distribution of brightness (Value) levels to reflect the gradient patterns between different ink concentrations. Through clustering methods, the ink color space was divided into several typical regions, thereby revealing the overall composition of complementary void/solid spaces and balanced dark/light tones characteristic of Qi Baishi's paintings.

Finally, the line and color features were constructed as separate matrices and, after standardization, were integrated into a unified analytical framework. This matrix-based construction not only prevents interference between different measurement scales but also allows for the "form" (xing) and "spirit" (shen) to be juxtaposed at a computational level.

3.3 Feature Dimensionality Reduction and Principal Component Analysis

After separating the line and color features and constructing them into matrices, the research proceeds to the feature dimensionality reduction and pattern recognition stage. Features such as line density, orientation distribution, length structure, as well as ink tone layers, brightness distribution, and color entropy, collectively form a high-dimensional feature space. Analyzing directly within this space would not only introduce redundant information and noise but could also lead to the "curse of dimensionality," compromising the effectiveness of statistical modeling and pattern recognition.

PCA is the core method adopted in this study. In practice, the study first standardized the line feature matrix and the color feature matrix separately to ensure that features with different scales were comparable during computation. Subsequently, eigenvalue decomposition was performed on the covariance matrix. The number of principal components to retain was determined using the cumulative curve of the variance contribution rate, ensuring that the selected components covered over 95% of the original information. The reduced-dimension data was not only greatly simplified but also preserved the core variation trends of the lines and colors.

In addition to PCA, the study also introduced NMF as a supplementary method to capture more interpretable patterns within the artistic features. NMF decomposes the original matrix into the product of a basis matrix and a coefficient matrix, with the constraint that all elements are non-negative. For line features, the basis vectors from NMF often correspond to typical brushstroke forms or line directions; for color features, the basis vectors can be interpreted as typical ink tone layers or methods of ink application. Unlike PCA, which emphasizes maximizing variance, NMF emphasizes the interpretability of part-based structures, thus enabling it to reveal the underlying patterns in Qi Baishi's use of brush and ink while reducing dimensionality.

PCA provided a global, low-dimensional representation of the overall features, ensuring the statistical validity of subsequent clustering and classification analyses. NMF, in turn, further revealed the local structures and artistic principles hidden within the data, allowing "brushstroke patterns" and "ink tone patterns" to be clarified and visualized.

3.4 Style Pattern Recognition and Cluster Analysis

Following feature extraction and dimensionality reduction, this study proceeds to the stage of style pattern recognition and cluster analysis. By effectively quantifying and reducing the dimensionality of the line and color features from Qi Baishi's shrimp paintings, we aim to uncover stylistic patterns among the works through cluster analysis, and to conduct classification and comparative analysis of Qi Baishi's artistic language.

The first step in cluster analysis is to select an appropriate distance metric. We adopted the Euclidean distance as the standard metric, chosen for its simplicity and its ability to effectively reflect the similarity between samples in a high-dimensional feature space. By calculating the distance between each artwork in the reduced-dimension feature space, the clustering algorithm can group stylistically similar works together while separating dissimilar ones. To ensure the stability and reliability of the analysis, two algorithms, Hierarchical Clustering and K-means Clustering, were employed and their results were compared and validated. Hierarchical clustering generates a layered dendrogram, which makes the formation process of each cluster more transparent.

In hierarchical clustering, the study progressively merged the most similar works by calculating the similarity between the feature vectors of each painting, ultimately forming a tree-like structure. K-means clustering partitioned the works into several categories by defining initial centroids and iterating repeatedly. By analyzing the features of each cluster's center, the study could identify the differences and similarities between various style types.

The core objective of style pattern recognition is to reveal the common features and differences in brushstroke application, ink tone layering, and composition. Through the clustering results, the study identified several significant style patterns in Qi Baishi's shrimp paintings. In some clusters, the works exhibited strong linear dynamics with concise, fluid brushstrokes and rich ink layers. In other clusters, they presented more stable line structures and relatively uniform ink tones.

To further validate the effectiveness of the clustering results, this study employed evaluation metrics such as the Silhouette Coefficient to assess the quality of each clustering. The Silhouette Coefficient provides a quantitative basis for evaluating the clustering results by calculating the compactness of each sample within its own cluster and its degree of separation from the nearest neighboring cluster. Through the clustering and comparative analysis of different works, the study reveals how Qi Baishi managed to display a rich artistic expressiveness with limited brush and ink, and how the evolution of his style reflected his continuous innovation in artistic exploration.

4. Experiments

4.1 Dataset Construction and Preprocessing Results

In this experiment, the construction and preprocessing of the dataset are as described below. The research dataset consists of 12 late-period shrimp paintings by Qi Baishi. These works not only cover different compositional forms and artistic styles but also represent the artistic peak of Qi Baishi's late creative career. All works are high-resolution scanned images (≥600 dpi) provided by institutions. After dataset construction, the image preprocessing stage involves operations such as grayscale conversion, binarization, and size normalization on the images.

First, all works are uniformly converted into grayscale images to eliminate color interference and highlight the line features of the images. To further enhance line information, an adaptive threshold method is used for binarization, which ensures the clear extraction of detailed parts in the image, such as shrimp antennae and contour lines. Partial data are shown as follows (fig1 & fig2).

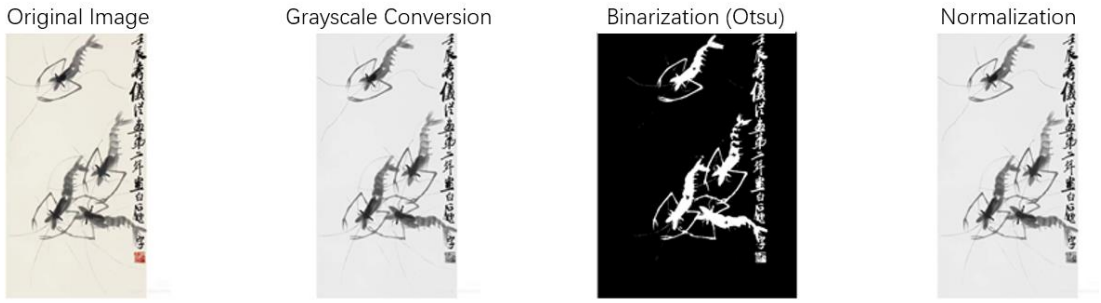

Figure 1 Dataset Sample 1

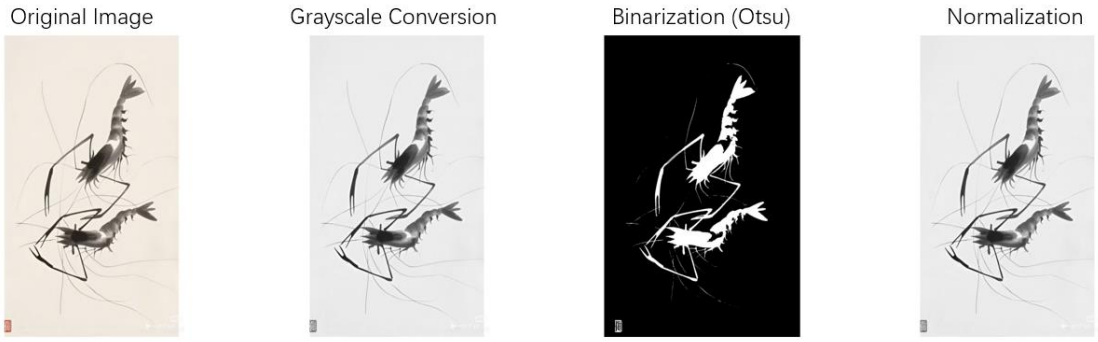

Figure 2 Dataset Sample 2

4.2 Line Feature Extraction and Analysis Results

After the image preprocessing stage, this study begins to extract line features, aiming to reveal the dynamic and structural characteristics of lines in Qi Baishi's shrimp paintings. As one of the most important expressive elements in ink wash paintings, the accurate extraction of line features is crucial for subsequent artistic style analysis. This study adopts the Canny edge detection algorithm combined with Hough transform to systematically analyze the directionality and length of lines. The following are the specific experimental results and analysis.

Through the Canny edge detection algorithm, the study successfully extracts the fine lines of shrimp body contours and antennae in each shrimp painting. The Canny algorithm performs edge detection based on the gradient amplitude and direction of the image, effectively capturing the fine structures of shrimp bodies and antennae while suppressing noise in the image. During this process,

the lines of the shrimp body contours are preserved, especially the details of the shrimp antennae, demonstrating Qi Baishi's delicate use of brushstrokes. The experimental results are shown in Figure 3:

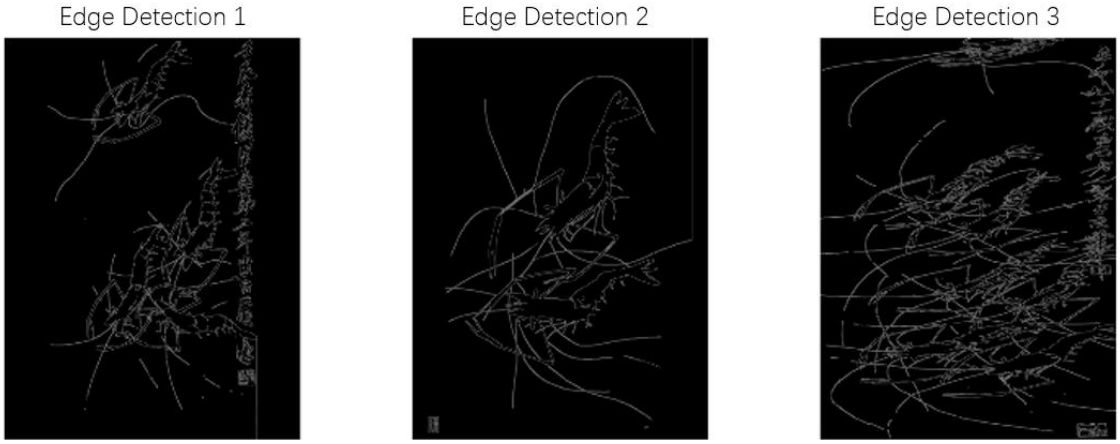

Figure 3 Canny Edge Detection

Based on the line features extracted by Canny edge detection, the Hough transform is further used to quantitatively analyze the directionality and length of the main lines. Figure 4 shows the direction distribution histogram and length distribution histogram. The direction distribution histogram shows the angular distribution of the lines of shrimp bodies and antennae, with obvious peaks between 45 ° and 90 °, indicating that the antennae and contours of shrimp bodies mostly present curved "S" shapes and arcs, which is consistent with their natural dynamic state. The length distribution histogram reveals the frequency of use of lines of different lengths: short lines (corresponding to antennae) account for the majority of the proportion, while longer lines are mostly used to outline the contours of shrimp bodies. This is highly consistent with Qi Baishi's concise brushwork style.

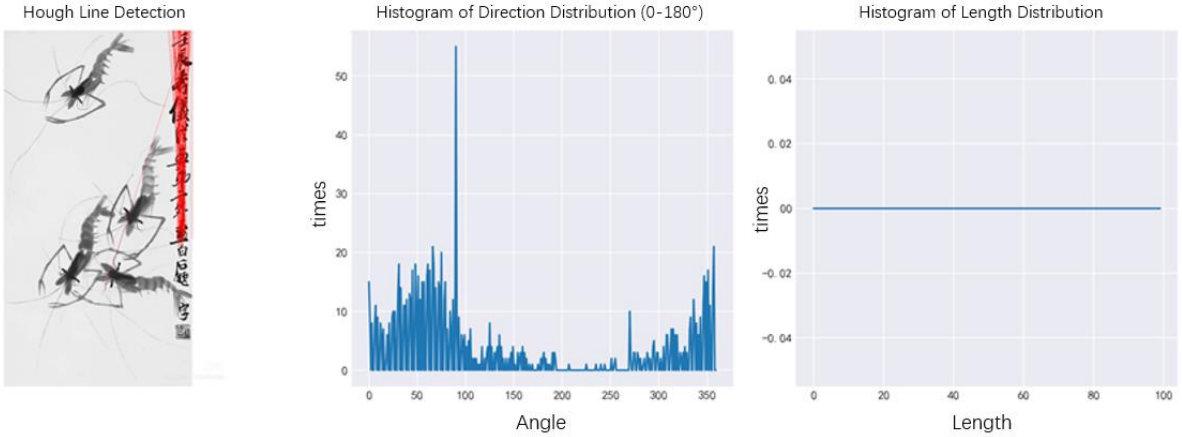

Figure 4 Hough Transform

By combining Hough transform and line extraction, the study constructs a line feature matrix, including dimensions such as line density, line direction distribution, and length distribution. These feature matrices provide key data support for subsequent style analysis and clustering. The distribution of each work in these feature dimensions reveals the typical ink application rule of "expressing more with less" in Qi Baishi's shrimp paintings, which presents rich dynamic and spatial sensations through simplified lines.

From the above experimental results, it can be seen that the line features in Qi Baishi's shrimp paintings have distinct style characteristics, especially in terms of directionality and detailed

expression, showing a strong sense of dynamic beauty. Subsequent cluster analysis will further verify the commonalities and differences of these line features among different works.

4.3 Color Feature Extraction and Analysis Results

In this study, the extraction of color features is not only an analysis of the ink color layers in Qi Baishi's shrimp paintings but also a key step in understanding his artistic expression techniques. The changes in color layers of ink wash paintings are crucial to the artistic effect, while the traditional RGB color space is not fully suitable for capturing the features of ink wash works. Therefore, this study uses the HSV color space for image processing, focusing on analyzing the distribution of the value (brightness) channel to reflect the artistic technique of light and dark changes. The following are the specific results of this experiment in color feature extraction.

First, by converting the preprocessed images into the HSV color space, the study focuses on analyzing the distribution of the value (brightness) channel (V). The brightness distribution diagram, as shown in Figure 5, displays the pixel distribution of brightness in the images. In Qi Baishi's shrimp paintings, the brightness distribution presents a typical bimodal feature: one peak appears in the low-brightness area (corresponding to dense ink), and the other peak appears in the high-brightness area (corresponding to light ink). This distribution form reflects the technique of "density, lightness, dryness, and wetness" commonly used by Qi Baishi in his works. Among them, the highly concentrated feature of the dense ink area corresponds to the main structure of the shrimp body, while the light ink is mainly used to express the background and details, making the works present the effect of mutual generation of virtual and real.

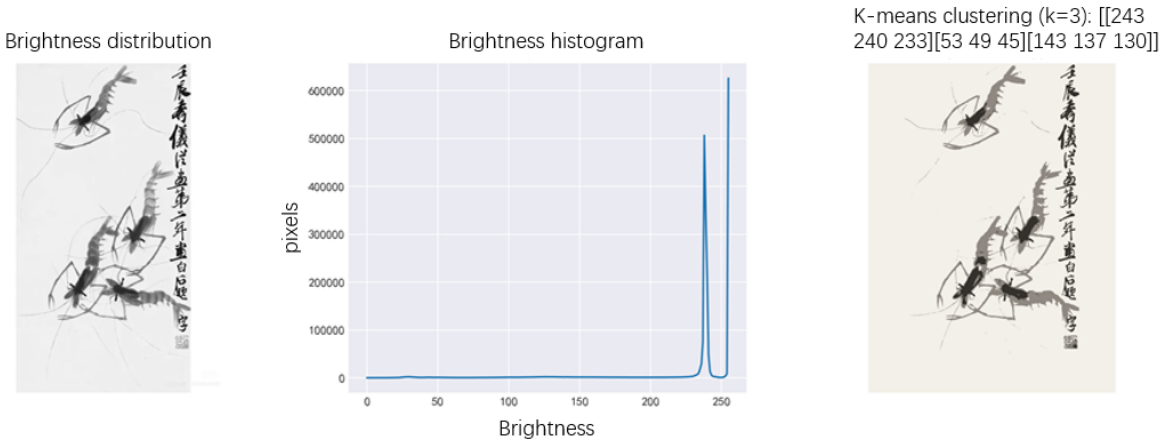

Figure 5 HSV Value Channel Distribution Histogram

To further analyze the characteristics of ink color layers, the study uses the K-means clustering algorithm to classify the brightness data. The clustering results are shown in Figure 6. K-means clustering divides the brightness values into three main categories: dense ink area (low-brightness area), medium ink area (medium-brightness area), and light ink area (high-brightness area). Through this clustering method, the distribution pattern of different ink color areas in Qi Baishi's shrimp paintings can be clearly observed.

The K-means clustering results in the figure show the typical representative colors of the three clusters (namely, light ink color, standard ink color, and dense ink color). It can be seen from these results that Qi Baishi used well-balanced ink color layers in his shrimp paintings, among which the medium ink area occupies the main position, reflecting the flexibility and sense of hierarchy in Qi Baishi's ink application.

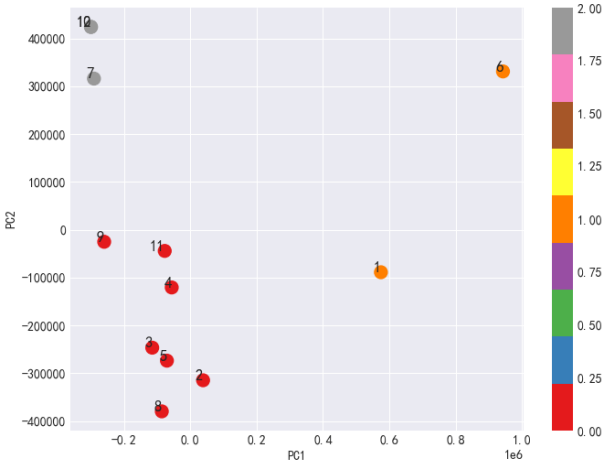

Figure 6 Clustering Results, K-means Clustering Results (k=3), Silhouette Coefficient: 0.357

4.4 Feature Dimensionality Reduction and Style Pattern Recognition

After completing the extraction of line features and color features, this study further performed dimensionality reduction on the data using PCA and NMF to reveal the main artistic style features in Qi Baishi's shrimp paintings. Meanwhile, based on the dimensionality-reduced features, style pattern recognition and cluster analysis were conducted to gain a deeper understanding of the artistic expressiveness demonstrated by Qi Baishi in his works.

Firstly, PCA was applied to reduce the dimensionality of line features and color features. According to the cumulative variance contribution rate of PCA (see Figure 7), it was found that the first two principal components explained approximately 66.4% of the total variance. The first principal component (PC1) mainly reflected the density and directionality features of lines, while the second principal component (PC2) was related to changes in ink color levels. The dimensionality-reduced results were further visualized through two-dimensional projection (see Figure 8), which clearly showed the distribution of different works in the feature space and revealed the differences and commonalities in their artistic styles. The PCA two-dimensional projection diagram in Figure 8 shows the distribution of the works; some works exhibit an obvious clustering trend in the two principal components, indicating a high degree of similarity in their artistic styles.

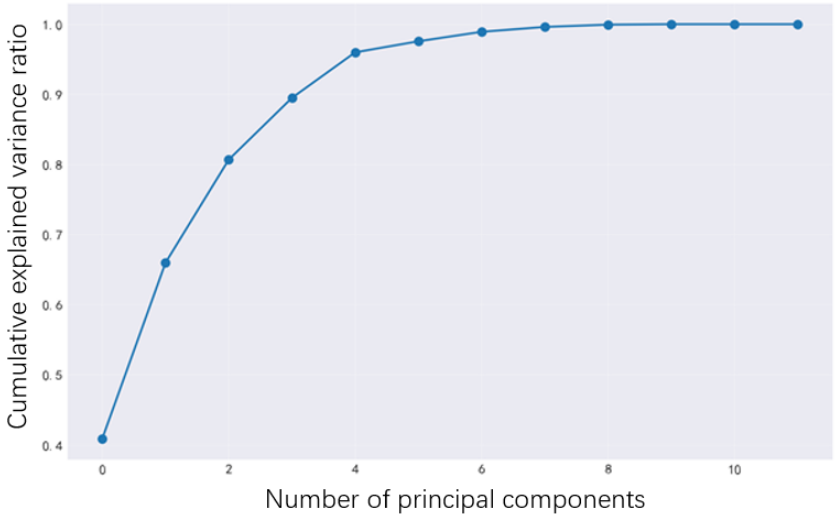

Figure 7 Curve of PCA Cumulative Variance Contribution Rate

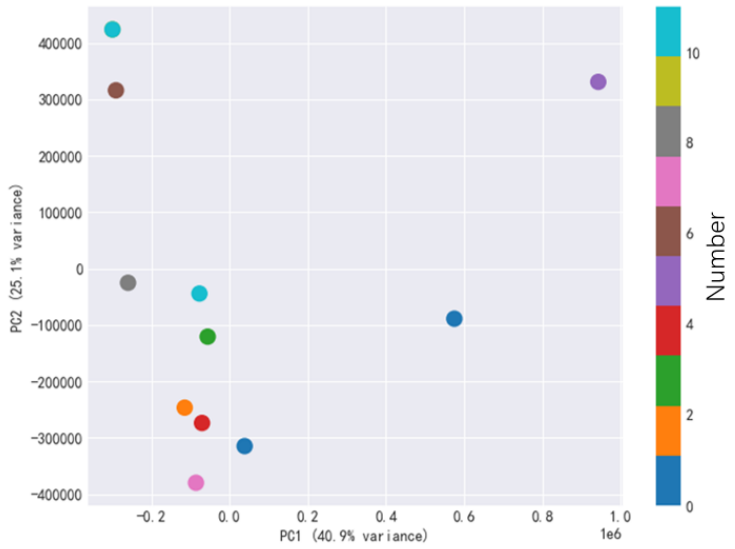

Figure 8 PCA Two-Dimensional Feature Projection Distribution

To further analyze the potential brushstroke patterns and ink color patterns, this study introduced the NMF method to decompose the line and color features (see Figure 9). NMF can extract representative basis vectors, thereby revealing the typical brushstroke and ink color patterns in Qi Baishi's works. Figure 9 shows the results of NMF basis vectors, which present different line directions and ink color changes. Through the analysis of NMF results, it was found that Basis Vector 1 and Basis Vector 3 represent the delicate curved lines and the light-dark changes of ink color respectively, while Basis Vector 2 is related to the expression of relatively simple brushstrokes. These results indicate that there are obvious style features in Qi Baishi's ink-wash language across different works; these features are not only reflected in the hierarchical sense of ink color but also in the complexity of brushstrokes and the directionality of lines.

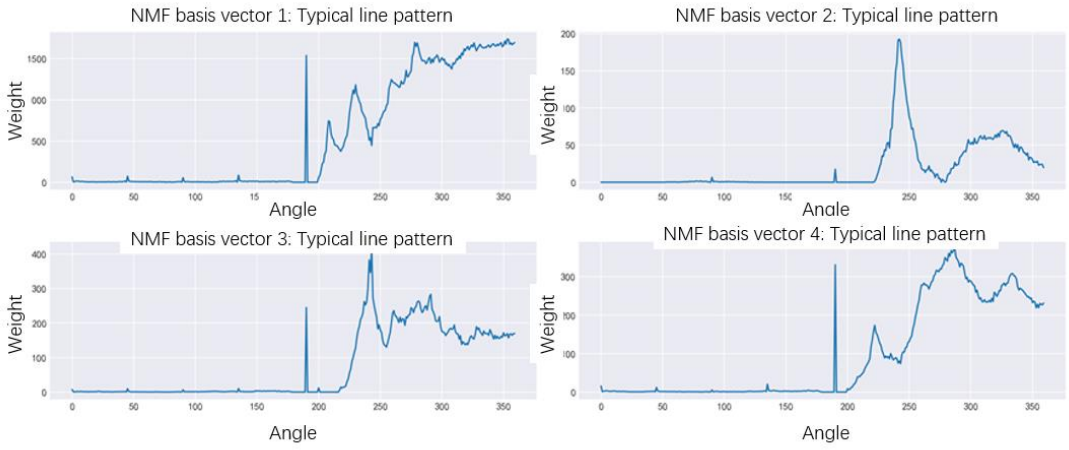

Figure 9 Visualization of NMF Basis Vector Decomposition Results

Through K-means cluster analysis, it was found that Qi Baishi's shrimp paintings can be divided into several main style categories, and each category presents a different distribution pattern in the PCA space. Through further analysis of the clustering results, the study identified several typical styles in the works: some works have relatively simple and smooth lines with a single ink color level, while others demonstrate more complex brushstroke directions and multi-level ink color changes. It

can be seen from hierarchical clustering dendrogram (see Figure 10) that the similarity between works presents an obvious hierarchical structure. The formation process of each cluster clearly reveals the evolution and variation of the works in terms of style, further verifying the expression method of "expressing more with less" in artistic creation.

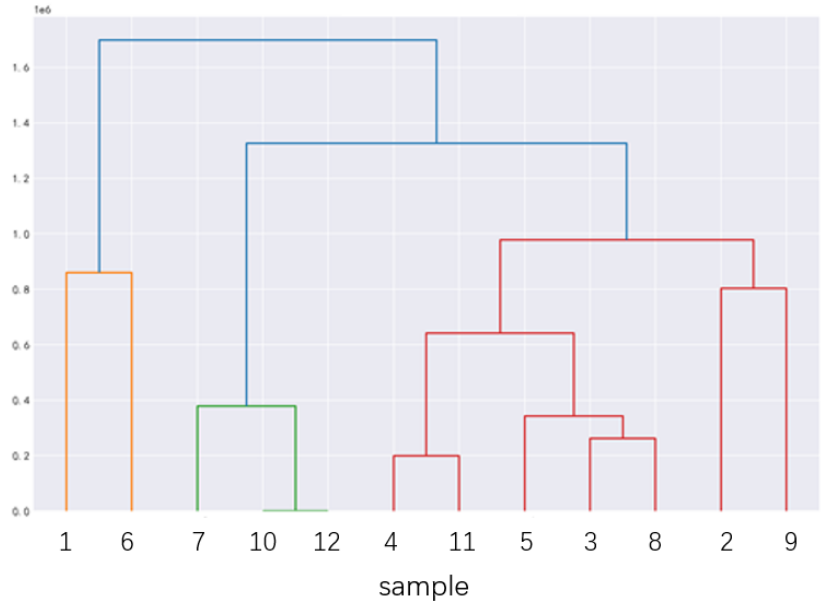

Figure 10 Hierarchical Clustering Dendrogram

5. Results and Discussion

This study focuses on Qi Baishi's late-period shrimp paintings. Employing image processing and computational analysis as methodologies, it systematically extracts and quantifies the line features and color features of the works. On this basis, the study reveals Qi's unique artistic style through feature dimensionality reduction and cluster analysis.

Firstly, the results of line feature extraction show that the brushstrokes in Qi Baishi's shrimp paintings are primarily concise. The antennae and outlines of the shrimps are mostly presented as arcs and "S"-shaped curves, demonstrating distinct dynamic characteristics. The distribution of lines not only reflects the mastery of the natural movement state of the shrimps' bodies but also highlights the ink-wash philosophy of "expressing more with less".

Secondly, the analysis of color features reveals a bimodal distribution characteristic in the brightness of the works. The alternating use of dense ink and light ink creates a picture effect of contrast between virtual and real. K-means clustering further classifies the ink colors into three levels: dense, medium, and light, with the medium ink area occupying a dominant position. This confirms Qi Baishi's ink application rule of "appropriate balance between density and lightness" in his shrimp paintings.

In the stage of dimensionality reduction and pattern recognition, the main components extracted by PCA correspond to line structure and ink color variation respectively. The results of NMF decomposition several types of typical brushstroke patterns and ink color patterns, further illustrating that Qi Baishi achieved a highly unified artistic language through diverse line combinations and hierarchical distributions in different works. Overall, the experimental results show that Qi Baishi's shrimp paintings exhibit a highly consistent regularity in the unity of "form" and "spirit".

Through mathematical and physical analysis methods, this study not only verifies the relevant conclusions in art history research but also provides a new path for the digital research of traditional

ink-wash paintings.

References

[1] Zhang, D. F. (2025). A study on the application of traditional Chinese calligraphy and painting in children's aesthetic education. Art Education Research, (16), 120-123.
[2] Sun, W. C., & Li, S. C. (2025). The evolution of poetic language in Western literary and artistic aesthetics: From literary poetry to painting poetry. Literary and Artistic Contention, (07), 147-152.
[3] Wang, Y., & Han, Y. Y. (2025). A study on the construction of emotional expression through colors in traditional Chinese paintings based on brushstroke features. Shoe Technology and Design, 5(10), 73-75.
[4] Lin, P. L. (2025). On the artistic appeal of lines in traditional Chinese paintings: A case study of the "Flying Apsaras" in Dunhuang murals. Modern and Ancient Cultural Creation, (25), 92-94.
[5] Mirenisha Aishan. (2025). A study on the artistic charm of lines in traditional Chinese paintings. New Art Field, (07), 31-34.
[6] Mao, J. C. (2022). Line enhancement in murals based on hyperspectral partition dimensionality reduction and endmember extraction (Master's thesis). Beijing University of Civil Engineering and Architecture, Beijing.
[7] Hu, Y. Q. (2021). A study on the emotional model of lines and their derivative forms (Master's thesis). Jiangnan University, Wuxi.
[8] Mao, J. C., Lyu, S. Q., Hou, M. L., et al. (2022). Line enhancement of murals based on block PCA and endmember extraction. Journal of Graphics, 43(03), 425-433.
[9] Dang, L. (2012). Research on several issues of automatic face analysis and recognition (Doctoral thesis). University of Science and Technology of China, Hefei.
[10] Li, L., & Zhang, Y. J. (2008). A survey of non-negative matrix factorization algorithms. Acta Electronica Sinica, (04), 737-743.
[11] Fang, W. T., Ma, P., Cheng, Z. B., et al. (2012). Two-dimensional projective non-negative matrix factorization algorithm and its application in face recognition. Acta Automatica Sinica, 38(09), 1503-1512.
[12] Qi, W. Z. (2025). The integration of folk aesthetics and literati painting in Qi Baishi's artistic transformation in his later years: A case study of Frogs' Croaks Resounding Ten Miles from the Mountain Spring. Collection and Investment, 16(08), 14-16.
[13] Wang, C. C., Wang, Y. L., Ge, Z. Q., et al. (2017). Style extraction of traditional Chinese ink wash paintings based on convolutional neural network. Journal of Nanjing University, (5), 754-760.
[14] Chen, C., & Liu, H. (2024). Style transfer of traditional Chinese ink wash paintings based on diffusion model. Journal of Chongqing Technology and Business University (Natural Science Edition). (Online first).
[15] Lyu, P. (2009). Artistic style learning of traditional Chinese ink wash paintings based on neural network (Master's thesis). Tianjin University, Tianjin.