Application of Computer Vision in Automatic Color Extraction and Color Scheme Generation of Oil Paintings

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ABSTRACT As an important category of visual art, oil painting's use and matching of colors directly determine the emotional expression and aesthetic value of the artwork. In scenarios such as digital preservation, art design assistance, and online exhibitions, how to efficiently and accurately extract representative colors from oil painting images and generate harmonious color schemes has become a research hotspot in the interdisciplinary field of art and technology. This paper constructs a complete methodological system for automatic oil painting color extraction and color scheme generation based on computer vision technology. First, a color feature model of the oil painting image is constructed through color space transformation and image preprocessing. Then, the main color tone is extracted by combining an improved K-Means clustering and color frequency statistics method. Finally, a color scheme generation strategy is constructed based on color harmony theory. Experiments were conducted using a dataset containing 200 oil paintings of different styles, and systematic tests were performed on color extraction accuracy and subjective and objective evaluation indicators of color schemes. The results show that the proposed method achieves an average color extraction accuracy of 91.2%, and the consistency between the color schemes and art expert evaluations is 86.7%, effectively supporting the automated analysis and design application of oil painting colors. This study provides a reproducible technical path for the digital processing of oil painting colors and lays a methodological foundation for the in-depth application of computer vision in the field of art.

INDEX TERMS Computer vision; oil painting color; color extraction; color scheme; K-Means clustering

I. INTRODUCTION

Oil painting is an art form that has remained a rich expressive medium for the artist since its inception, and the use of color is a key element in how artists can communicate emotion, create spatial relationships, and direct viewers' attention. Each oil painting is frequently composed of intricate visual and aesthetic logic and rules in the colours used. As digital museums, virtual exhibitions, and art design support systems are being developed rapidly, how to automatically analyze the color composition of oil paintings and generate color scheme that can be applied to subsequent designs has slowly emerged as an important topic in the interdisciplinary research of computer vision and art.

The traditional process of extracting color and analyzing its attributes of oil paintings are based on manual observation and generalisation by experience. The process can be time-consuming and it is subject to the observer's personal tastes. Large-scale digitized oil painting resources can't be fulfilled by manual procedures to satisfy the requirement of efficient and standardized processing. In recent years, computer vision has gained a lot of improvements in image segmentation, feature extraction and pattern recognition, etc., which has brought a lot of technological opportunities to the automated analysis of oil painting colors. By using image processing and machine learning methods, from an image of an oil painting, key color regions can be identified, representative colors can be extracted and more, color schemes that meet visual aesthetics can be generated from color theory.

In this paper, a comprehensive solution to automatic color extraction and color scheme generation from oil paintings is proposed, which includes color space selection, dominant color extraction algorithm design, color matching rule modeling and result evaluation mechanism. The method needs to be adaptable and robust to different styles, brushstrokes and colour complexity of different oil paintings. Moreover, the accuracy of the colors extracted from the original image and the visual harmony of the derived color scheme play a significant role in the method's applicability.

Based on this background, this paper concentrates on the specific application of computer vision technology in oil painting color processing, and focuses on two key tasks, automatic extraction of oil painting colors and generation of color scheme. Having been reviewed relevant works, in Part III, a methodology of the present invention is explained in detail, which includes three technical modules, namely, color space modeling, dominant hue extraction and color scheme generation, and experimental results and a verification of the effectiveness of the method has been made by using the experimental data in Part IV, and in Part V a summary of the present invention and the future prospects are given.

II. RELATED WORK

Contemporary oil painting research is undergoing a multi-dimensional paradigm shift: Stork[1] showed that computer vision, ML and AI can extract patterns and information that are difficult for the human eye to perceive from a large amount of art data, bringing new insights to art research. Janas et al. [2] used dynamic mechanical analysis, optical measurement and other technologies to quantify the evolution of mechanical properties such as size change, modulus and glass transition temperature of pigment layers during the drying process. Li et al. [3] constructed a large-scale digital image dataset containing abstract paintings, Western oil paintings and Chinese ink paintings. Gomez Lobon et al. [4] used a variety of microspectroscopy and spectroscopic techniques to perform micro-area, non-destructive or micro-destructive analysis on samples to determine the chemical composition, crystal structure and degradation products of cadmium yellow pigment. Davisayahvorakul et al. [5] synthesized a new bio-based product with good performance. Tests showed that the product can be used as a slow-drying agent or adjuvant in oil painting, and can effectively regulate the drying time and fluidity of pigments.

Gardner and Rogge[6] describe the conservation process of Persian oil paintings from the Zand and Qajar periods. Kachkine[7] performs high-precision 3D scanning of damaged paintings and uses digital models to guide the precise filling and shaping of physical materials. The animated film Lover of Vincent is known for its unique hand-painted oil painting style, and Son[8] explores the semiotic imagery of its colors. Valentini et al.[9] have achieved a comprehensive representation of the information of the painting from the surface to the underlying layers. de Mecquenem et al.[10] have shown that the painting medium has a significant impact on the degradation process of celadon pigment. This paper aims to construct a computational framework for automatically extracting color features from digital scans of paintings and generating novel color schemes based on color harmony theory and machine learning models. This study attempts to build a bridge between data, algorithms and artistic semantics, and to provide a computationally achievable and scalable color research method for the digital conservation, stylized reproduction and contemporary creation of oil paintings.

III. METHODS

A. COLOR SPACE MODELING AND PREPROCESSING OF OIL PAINTING IMAGES

The color information of oil painting images exhibits high channel correlation in the original RGB color space, making direct color processing in this space susceptible to interference from factors such as lighting and brightness variations. To more accurately reflect the visual attributes of oil painting colors, this paper first converts the input image from the RGB color space to the CIELAB color space. In the CIELAB space, the L channel represents brightness, while the A and B channels represent the contrasting color information from green to red and from blue to yellow, respectively. Its color difference calculation method is closer to human visual perception.

The image is then converted to color space for preprocessing to minimize noise interference and improve compactness of color regions. No matter what is the texture of the brushstroke in the image of oil painting, bilateral filtering is applied for smoothing the image due to color fluctuations caused by the local texture. In order to preserve the primary color edge information, while smoothing the luminance fluctuations at the micro level selectively, bilateral filtering is used, but the primary characteristics of the brushstroke textures of colors are kept in mind because the information contained in brush stroke can also be very important for the physical color mixing and impasto method in the artistic integrity of the work.

The whole picture is used to form the candidate pool of color information after preprocessing. The number of pixels that are involved in the following color clustering varies from a few hundred thousand to millions for a typical oil painting. A uniform sampling approach is used to select a representative sample of 50,000 pixels to perform clustering calculations, while maintaining colour distribution characteristics, to ensure computational efficiency. During sampling, it is ensured that the sample retention ratio of different brightness levels and hue regions is consistent to avoid color distribution distortion due to sampling deviations.

Another crucial step in color space modeling is constructing statistical measures of the image's color distribution characteristics. This paper calculates the mean, standard deviation, and hue angle distribution of each channel in the CIELAB color space. These statistics are used to set the initial centroids in subsequent clustering algorithms and also provide a reference for color adjustments during the color scheme generation stage.

Through color space modeling and preprocessing, a color feature representation form that conforms to the visual characteristics of the human eye was constructed, providing standardized input data for subsequent extraction of the dominant color tone.

B. A DOMINANT COLOR EXTRACTION METHOD BASED ON IMPROVED K-MEANS AND FREQUENCY STATISTICS

The core task of dominant color extraction is to identify the key color that can represent the overall color tendency of the oil painting from a large number of pixel colors. This paper adopts a strategy that combines the improved K-Means clustering algorithm with color frequency statistics to achieve dominant color extraction [13] .

In K-Means clustering, the number of clusters K directly affects the representativeness of the extracted results. Too small a K value leads to excessive compression of color information, resulting in the loss of visually important secondary colors; too large a K value results in overly fragmented extraction, making it difficult to form a clear color scheme framework. This paper uses the elbow rule combined with color distribution entropy for adaptive selection of the K value. For a single oil painting image, the within-group sum of squares of the clustering results under different K values is first calculated, and the color distribution entropy of the clustering results is also calculated. The K value where the within-group sum of squares decreases gradually and the color distribution entropy first falls below a set threshold is selected as the number of clusters. Experimental statistics show that for oil painting images of different styles, the adaptively selected K value ranges from 8 to 16.

After determining the K value, the selection of initial centroids in K-Means clustering has a significant impact on the final clustering results. Traditional random initialization methods are prone to getting trapped in local optima. This paper adopts a density-weighted initial centroid selection strategy. First, the local density of each sample point is calculated, which is the sum of the inverses of the distances to its nearest neighbor sample points. The point with the highest local density is selected as the first initial centroid. Subsequently, points that are relatively far from existing centroids and have high local density are selected as subsequent initial centroids until the K value is reached. This method can effectively avoid the initial centroids from clustering in the same color region, making the clustering results more evenly distributed across the entire color space.

After clustering is completed, each cluster corresponds to a color center, and the CIELAB value of the center is a candidate color extracted. However, the clustering results alone cannot reflect the visual weight of each color in the image, because some colors in oil paintings may account for a small percentage of pixels, but play an important role in visual composition. Therefore, this paper introduces a color frequency statistics and visual weight correction mechanism on the basis of clustering [14] .

First, the number of pixels in each cluster is counted, and its proportion of the total number of pixels in the image is calculated as the basic weight. Then, a color saliency factor is introduced to adjust the weights. Color saliency is determined by calculating the average color difference between the color center and other colors in the CIELAB space, combined with the spatial distribution range of the color in the image. For an oil painting with strong color contrast, its main color tone often contains a small number of visually impactful colors; the saliency factor can increase the weight of these colors. After weight adjustment, the top 5 to 8 colors are selected as the main color tone of the painting, sorted from highest to lowest weight. Taking a typical Impressionist oil painting as an example, the improved method extracted the main colors including dark blue (weight 23.7%), gray-green (weight 18.4%), warm yellow (weight 15.2%), orange-red (weight 12.8%), light purple (weight 9.3%), and ivory white (weight 7.6%), totaling 87.0%. The color difference of each color in the CIELAB space is greater than 15, ensuring the distinguishability of the extraction results.

C. COLOR SCHEME GENERATION STRATEGY BASED ON COLOR HARMONY THEORY

Based on the extraction of the primary color tone, the goal of color scheme generation is to construct a color combination that conforms to the principles of color harmony and possesses visual appeal. This paper constructs a color scheme generation strategy based on the core rules of hue and tone harmony, while also incorporating a 'stylistic variance' module to accommodate intentional aesthetic subversions. The colour scheme generation process starts with analysing the colour attributes of the colours extracted from the main colours, converting each colour from the CIELAB colour space to the HSL colour space, getting the hue, saturation, and lightness values. To create the candidate color scheme patterns, the color scheme relationships of complementary, contrasting, and analogous colors from the Eaton color wheel are used. For Expressionist or Abstract compositions, the algorithm recognizes appropriate relationships based on hue angle differences, and permits the inclusion of 'discordant' matches that potentially align with the original artist's intent, while maintaining the emotional quality and historical context of the composition. The hue difference between two colors is 120 to 180 degrees, they are complementary or contrasting, so they are appropriate for accent-type color schemes; if the hue difference is within 30 degrees, they are determined to be analogous, suitable for harmonious color schemes.

In terms of color harmony, the overall atmosphere of the color scheme is controlled by the combination of saturation and brightness. This paper sets three color templates: bright (high brightness, medium-high saturation), calm (medium-low brightness, medium saturation), and elegant (high brightness, low saturation). When generating color schemes, colors that match the target color template are selected from the main color set and combined according to the hue harmony relationship. For an oil painting whose main color scheme includes dark blue, gray-green, warm yellow, orange-red, light purple, and ivory white, multiple color schemes can be generated according to different application scenarios. If an accent color scheme suitable for modern design style is required, the algorithm selects dark blue and warm yellow as complementary color pairs as primary and secondary colors, and pairs them with gray-green as a transition color. At the same time, the color saturation and brightness are adjusted to conform to the bright tone template, and finally a combination of dark blue (H210°, S85%, L35%), warm yellow (H45°, S90%, L60%), and gray-green (H150°, S45%, L55%) is generated.

After the color scheme is generated, a color harmony evaluation is introduced to verify its quality. The harmony evaluation constructs a comprehensive evaluation function based on three dimensions: hue, saturation, and brightness, calculating the variance and dispersion of each color in the color combination across these three dimensions. Ideally, the hue difference in a color scheme should exhibit a regular distribution, and the saturation and brightness values should maintain overall consistency or show a gradual change. For color schemes with harmony scores below the threshold, the algorithm automatically performs fine-tuning, improving harmony by slightly shifting hue values or adjusting saturation and brightness, while ensuring that the adjusted colors remain within the color neighborhood of the original main hue, maintaining a connection to the original color scheme's overall character.

Using the above strategy, each oil painting can generate 3 to 5 different color schemes, each containing 3 to 5 colors, which can meet the needs of different application scenarios such as design assistance, product development and digital display.

IV. RESULTS AND DISCUSSION

A. CONSTRUCTION OF EXPERIMENTAL DATASET AND SETTING OF EVALUATION METRICS

To validate the effectiveness and technical performance of the proposed method, a comprehensive experimental dataset consisting of oil painting images was constructed. The dataset consists of 200 images of oil paintings that span across various art styles such as Realism, Impressionism, Expressionism and Abstract Art. Image sources are publicly available digital museum collections and good art image databases. All images will have a resolution not less than 1280 px by 720 px to ensure enough information of colors. The images are from various subjects such as landscapes, portraits and still lifes making sure the diversity and representativeness of the data set.

Remaining in the construction of the dataset, a manually extracted reference dominant color was labelled for each image. These reference dominant colors were extracted independently by three researchers with professional degrees in Fine Arts and over five years of color theory experience. When disagreements occurred, the 'standard answer' was determined by calculating the centroid of the clustered CIELAB values from the three observers, provided the Delta-E distance remained within a perceptual threshold of < 5.. To account for the subjective perception of color in complex artistic works, the 'standard answer' was not defined as a single absolute point, but rather as a probabilistic distribution of agreed-upon color regions, allowing for a tolerance threshold in color distance that reflects the natural variance in human artistic perception. To ensure scientific rigor, the labeling process for the 3 participants was conducted under standardized D65 lighting conditions using professionally calibrated EIZO monitors (Delta-E < 2). This ensures that the 91.2% accuracy figure is derived from a controlled environment rather than arbitrary visual estimation. The number of reference dominant colors was set between 5 and 8, based on the complexness of the colors that are used in the image. For the evaluation of the color schemes, five experts of art designing and color research were invited to subjectively judge color schemes generated by the method presented in this paper. For evaluation metrics, precision, recall, and F1 are used as evaluation metrics for color extraction task. Precision is measured as a percentage of primary colors extracted that match the reference primary color to the number of total primary colors extracted. That is, the matching criterion is that the color distance between the two colors in the CIELAB color space is less than 5. The ratio of the number of extracted matching colors to the total number of primary colors in the reference is a definition of Recall The F1 score is a harmonic mean of precision and recall.

TABLE 1. Performance Comparison of Different Methods on Oil Painting Color Extraction Task

Method type	Accuracy (%)	Recall rate (%)	F1 score (%)	Average processing time (seconds/frame)
Color histogram peak method	74.3	68.2	71.1	2.4
Traditional K-Means clustering	82.6	79.4	80.9	3.1
Improvement methods in this article	91.2	88.5	89.8	4.2

For the work of generating color schemes, a combination of objective and subjective indicators of evaluation were used. The objective evaluation indicator is the color harmony scoring the color distribution of uniformity and the consistency of saturation and brightness quantitatively calculated. The subjective evaluation indicator is composed of five experts that each score the colors schemes on a five-point scale for visual comfort, relevance to the original oil painting and potential of design application, the average score is taken as final subjective score.

B. ANALYSIS OF COLOR EXTRACTION RESULTS AND COMPARISON OF METHODS

The proposed dominant color extraction method was tested on 200 oil painting images and compared with the traditional K-Means clustering method and the peak detection method based on color histogram. Table 1 shows the average performance of the three methods on the color extraction task.

As shown in Table 1, the improved method presented in this paper is significantly better than the comparative method in terms of the accuracy, recall, and F1 score. The accuracy of it is 91.2% with 8.6 percentage points compared with the traditional K-Means clustering method, and recall is 88.5%. This result suggested that the improved K-Means clustering combined with density-weighted initial centroid selection strategy can locate key color regions at oil painting images

TABLE 2. Evaluation of Color Scheme Generation Results

Evaluation dimensions	This article's method	Random color combination benchmark
Objective coordination score	87.3	61.5
Subjective visual comfort rating	4.2	2.8
Relevance rating to the original work	4.3	2.1
Design application potential score	4.1	2.5

more accurately, while avoid the omission important color from low frequency by visual weight correction mechanism.

In terms of average processing time, the proposed method has a higher average processing time of 4.2 seconds per image, which is higher than the traditional K-Means clustering with an average processing time of 3.1 seconds. This is predominantly as a result of the introduction of density-weighted initial centroid calculation, and significance factor correction. However, in practical applications, the 4.2-second processing speed will still be able to satisfy the requirements of offline batch processing and interactive analysis. The higher time cost comes at the price of a considerable improvement in extraction accuracy, which makes it an approach of reasonable cost-effectiveness.

Further analysis of extraction results according to the oil painting styles indicated some differences in performance of proposed method in other styles. In Impressionist pictures and Expressionist pictures, because of the bright brush strokes, color changes and other reasons, the accuracy rate is 89.7% and 88.4% respectively, which is slightly lower than the average. In Realist and Neoclassical the works in which color was clear and color relationship was well-defined, the accuracy rate was 93.2% and 92.8% respectively. This difference means that the color extraction method still has some challenges when processing oil paintings with loose brushstrokes and high color mixing, and it could be further optimized by considering the brushstroke texture features.

C. EVALUATION AND APPLICATION ANALYSIS OF COLOR SCHEME GENERATION RESULTS

Based on the extracted dominant color tone, the method presented in this paper generates 3 to 5 color schemes for each oil painting. The generated color schemes were evaluated for both objective harmony and subjective expert scoring, and compared with benchmark methods based on random color combinations. Table 2 shows the evaluation data for the generated color schemes.

The objective harmony score is the maximum of 100. The color scheme generated by our method has a significant structural advantage in both hue distribution and tonal consistency as the average score is 87.3 compared with 61.5 of the random color combination method. The subjective score is determined on a 5 point scale. In all three areas, our method had a score of 4 or higher for visual comfort, original artwork relevance, and design application potential. The highest score was in relevance to the original artwork, with a score of 4.3, suggesting that the color scheme generated by the algorithm is in line with the original oil painting.

TABLE 3. Color Scheme Adaptability Score in Different Application Scenarios (Out of 5 Points)

Application scenarios	Average rating	Standard deviation
Poster design	4.3	0.5
Web page	4.1	0.6
Product packaging	3.9	0.7

Experts pointed out that the color schemes produced by the method described in this paper have the characteristics of keeping the color characteristics of the original oil painting while being able to adjust the color mode in accordance with the different applications. In an oil painting depicting a richly-colored expressionist scene, the main colors removed from the painting are very saturated red, orange and black. The algorithm appropriately reduces the saturation of orange colors when creating a subdued color scheme, and increases the proportion of blue colors when creating a bright color scheme, so that the generated color scheme can be used as the color system of the Brand image system.

In order to further prove the usability of the color schemes in real-world application scenarios, 30 color schemes were generated and five designers were recruited to carry out simulated applications of the color schemes. The designers used the color schemes in three contexts: creating a poster, designing a web interface and designing a packaging for the product, and rated the appropriateness of the designed color scheme. Table 3 shows the suitability scores of the color schemes in different application scenarios.

As shown in Table 3, the color scheme scored highest in the poster design scenario, reaching 4.3 points. This indicates that the color scheme generated by the method presented in this paper has strong visual impact and information delivery capabilities, making it suitable for promotional designs. The web interface application scored 4.1 points, indicating that the readability and interactivity of the color scheme within the interface are recognized. The product packaging application scored relatively low at 3.9 points. Analysis suggests that some color schemes still have room for improvement in terms of compatibility with packaging materials and printing processes. Further optimization could involve introducing material simulation and color reproduction models.

In summary, the proposed method demonstrates good performance in both color extraction and color scheme generation, providing effective support for the digital processing and design assistance of oil paintings. However, the stability of color extraction still has room for improvement when dealing with highly abstract and minimalist oil paintings. Furthermore, introducing a user preference learning mechanism is an important direction for future research in color scheme generation.

V. CONCLUSION

This paper systematically deals with the application of computer vision in the automatic extraction of colors and generation of color schemes of oil paintings. On the one hand, addressing the complex color distribution and unique artistic characteristics of oil painting images, a complete technical method was built, including color space modeling, dominant hue extraction, and color scheme generation. The color memory representation in a color space by CIELAB space transformation and bilateral filtering preprocessing was made conforming to human visual perception in the color space modeling phase. In the dominant hue extraction stage, the improved method which combined K-Means clustering and visual weight correction was proposed, and the high-precision identification of the key colors was achieved. In the color scheme generation stage, a color harmony template and a harmony evaluation mechanism were built based on the color harmony theory, which would generate a combination of color harmonies ensuring balance between the color character of the original artwork and the needs of the application of the design. The research validates the feasibility and effectiveness of computer vision technology in the automated processing of oil painting colors, providing the technical support for computer vision technology's application in digital art preservation, art design support and online exhibitions.

Future research can be expanded further in the following aspects: First, introduce the deep learning feature extraction methods to the problem to enhance the robustness of color recognition of the painting under complex brushstrokes and textures; second, construct the model of user preferences to realize the personalized color scheme recommendation; and third, the application can be extended to the oil painting restoration and color reconstruction task to explore the wider application of computer vision in the field of art conservation.

AUTHOR CONTRIBUTIONS

Hua Li designed, collected and analyzed the data, and drafted the manuscript. Hua Li conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Hua Li participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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