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Computer-Aided Design AND APPLICATIONS

Application of Computer Vision-based Chinese Painting Stroke Recognition and Simulation System

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Abstract. The current CAD visual technology has developed to the extent that it can assist Chinese brushes in simulation. In this context, this article investigates the application of Chinese paintbrushes in realistic CAD simulation systems. In this article, Multi-layer perceptron (MLP) is used as a classifier, and an effective method of Chinese painting brush stroke recognition is proposed and compared with other commonly used algorithms. Through experiments, it is observed that MLP is excellent in recognition accuracy and error performance. To further verify the practicability of the system, a user evaluation experiment was carried out, and the results showed that most users spoke highly of the brush stroke simulation's authenticity and the operation's convenience. In addition, the brush strokes simulation CAD system of Chinese painting constructed in this article adopts an integrated modeling framework design, optimization, and innovation in user experience, model flexibility, and data management at all levels. It is helpful to improve the overall performance of the Chinese painting brush stroke simulation CAD system and provide users with a better experience.

Keywords: Computer Vision; Chinese Painting; Stroke Recognition; Computer-Aided Design; Multi-Layer Perceptron
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1 INTRODUCTION

Computer vision is an interdisciplinary field that combines the knowledge of computer science, engineering, psychology, and neuroscience. Multi-point bone trajectories record human actions by tracking the motion trajectories of human joint points in space. During the stroke drawing process, the bone trajectory records key position information, such as the starting point, turning point, and endpoint of the stroke. By analyzing this information, the direction and speed of stroke movement, as well as the connection between strokes, can be identified. When drawing curves in mid air, hovering the stroke is a common operation. By identifying the hovering intention of the stroke, the operator's drawing intention can be determined, thereby achieving accurate curve drawing. The recognition of the hovering intention of strokes is analyzing local stroke trajectories, such as speed, direction, etc. When the stroke speed decreases and maintains for a period of time, it can be determined that the stroke is hovering. At this point, the system will wait for the operator's next action, which may be to continue drawing the curve or end the drawing. Bohari et al. [1] studied the recognition and engineering calculation of stroke hovering intention when using multi-point bone trajectories to draw curves in mid-air. By analyzing the key position information and local features of the stroke trajectory, the hovering intention of the stroke is identified, achieving accurate curve drawing and engineering calculations. In the future, we will further optimize algorithms, improve recognition accuracy, and explore more application scenarios to provide technical support for practical production and daily needs. The research content of computer vision includes multiple levels such as image processing, image analysis, and image understanding, from pixel processing at the bottom to semantic understanding at the top. The accuracy and fluency of human body posture and movements are crucial for performance. Echeverria and Santos [2] explored how to use computer vision pose estimation to simulate performance in human motion. Computer vision pose estimation is a technique for inferring human pose from images or videos. By using image processing and machine learning algorithms, it is possible to identify key points of the human body, such as joints and bones, from images or videos in order to estimate the posture of the human body. The application of this technology in human movement is of great significance. Firstly, by analyzing the posture and movements of athletes, their cognitive states, such as concentration and understanding of movements, can be inferred. Secondly, by analyzing the emotional expressions and behavioral responses of athletes, their emotional states, such as excitement and anxiety levels, can be inferred. Finally, by analyzing the motivational performance of athletes, such as their level of effort and goal pursuit, one can infer their motivational state. Calligraphy is a traditional Chinese art that integrates various elements such as brushwork, composition, and artistic conception. Guo and Li [3] explored how to use computer-aided design (CAD) technology to design and produce calligraphy writing art based on video streams. Capture the calligrapher's writing process and generate video stream data through a camera or input device. These data contain important information such as the calligrapher's brushwork, strength, and speed. Utilize computer image processing technology to process video stream data and extract key calligraphy features. For example, image recognition technology can be used to identify the beginning and end of strokes, as well as changes in the depth of ink. Based on the processed video stream data, use computer-aided design software to design calligraphy writing. This includes aspects such as the layout of strokes and the optimization of glyphs. Produce designed calligraphy works through 3D printing technology or other manufacturing methods. In this process, computer-aided design can be used for precise modeling and simulation to improve production efficiency and effectiveness.

With the rapid growth of Deep learning (DL) technology, the research and application of computer vision have also made remarkable progress. Chinese painting is a very important part of traditional art in China. Chinese painting, with its unique brushwork and rendering skills, shows profound cultural heritage and artistic charm. The application of computer-aided modeling design has brought more possibilities to sculpture art, providing artists with new creative tools and innovative methods. Guo and Wang [4] use computer-aided design software, sculpture artists can create and modify three-dimensional models, from basic geometric shapes to complex free forms, all of which can be modeled on a computer. Digital modeling also allows artists to create virtual "solid sculptures" by simulating the real carving process to create three-dimensional models. A modeling method based on mathematical relationships, which allows artists to change the form and structure of the model by adjusting parameters. In sculpture art, parametric design can be used to create sculptures with complex forms and dynamic sensations. 3D printing technology can transform digital models into physical objects, providing sculpture artists with new production methods. However, the traditional Chinese painting creation is highly dependent on the artist's skills and experience, and it is not easy for ordinary people to learn and master this skill. Including computer-aided calligraphy and art teaching. Artificial intelligence technology has provided new possibilities in this field, enabling students to learn and master calligraphy and art skills more effectively [5]. This feedback can be based on in-depth analysis and comparison of student works, using AI technology to personalize teaching arrangements based on each student's learning progress and style. For students with slower learning progress, AI can provide more basic exercises and targeted guidance; For students with a learning style that leans towards visual memory, AI can provide more graphical teaching materials. Through deep learning and natural language processing techniques, AI can automatically recognize and classify students' calligraphy works, and provide corresponding feedback and suggestions. For example, AI can evaluate students' works based on criteria such as stroke order and structural rules, and provide specific suggestions and guidance. AI can collect and analyze students' learning data in real-time, such as practice frequency, stroke accuracy, etc., and provide real-time feedback and suggestions. This feedback can be presented in the form of text, images, or videos, so that students can better understand and improve their calligraphy skills. Moreover, the existing CAD system has limitations in simulating the strokes of Chinese painting, which can not meet the high requirements of Chinese painting. In today's industrial production, the detection and classification of fabric defects is an important and challenging task. Traditional detection methods typically require manual labor, which is not only inefficient but also susceptible to fatigue and subjectivity. With the rapid development of computer vision and deep learning technology, we have the opportunity to solve this problem through automatic detection and classification systems. Jeyaraj and Samuel [6] explore how to use deep learning algorithms combined with computer vision technology to achieve automatic detection and classification of fabric defects. Deep learning is a machine learning technique that simulates the workings of human brain neural networks for learning and prediction. Computer vision is a technology that enables computers to "see" and understand images and videos. The combination of deep learning and computer vision has formed a powerful tool that can handle complex image recognition tasks, such as fabric defect detection. Therefore, it is particularly important to develop a CAD system specifically for the recognition and simulation of Chinese painting strokes, so as to make up for the shortcomings of the existing system and better show the unique charm and cultural connotation of Chinese painting.

In aesthetic design, students can use computer-aided design software to create aesthetic models and perform complex calculations, such as sunlight analysis and wind direction simulation. This helps students to have a deeper understanding of aesthetic design [7]. In landscape design, students can use computer-aided design software for terrain analysis, vegetation layout, etc. By simulating the natural environment, students can better grasp the overall effect of landscape design. In interior design, students can use computer-aided design software for spatial layout, material selection, etc. Through virtual reality technology, students can experience real indoor space experiences, improving the comfort and practicality of design. Based on the above background, the recognition and simulation of Chinese painting strokes will not only help to promote the technical development in the field of computer vision, but also open up a new way for the inheritance and popularization of traditional art in China. This is the important significance of this research topic. This study will adopt many computer vision technologies such as image processing, DL and pattern recognition. Firstly, the effective information of Chinese brush strokes is obtained by preprocessing and feature extraction of the image of Chinese brush strokes; Then, the information is identified and classified by using the designed classification algorithm. Finally, based on the results of recognition and classification, a CAD system which can simulate the strokes of Chinese painting is constructed. The innovations of this article are summarized as follows:

(1) Integrated modeling framework: This article constructs an integrated modeling framework including upper application layer, user layer, model assembly layer and data layer, which provides a clear and structured design for the growth of Chinese painting brush stroke simulation CAD system.

(2) Hierarchical design idea: Through hierarchical design, the complex system is divided into several relatively independent modules. This design method helps to reduce the complexity of the system and improve the maintainability and expansibility of the system.

(3) Flexibility of model assembly: In the model assembly layer, different stroke simulation algorithms and models can be flexibly integrated and assembled to meet different scenarios and requirements, emphasizing the configurability and expansibility of the model.

(4) Stability and security of data management: The design of data layer pays attention to the stability and security of data, and ensures that important data such as user settings, brush stroke parameters and simulation results are properly preserved and protected.

This article is divided into seven sections. The first section mainly introduces the research background, current situation, objectives, contents and methods. The following chapters will focus on computer vision foundation, Chinese painting brush stroke recognition, CAD system design and implementation and other aspects in detail. The last section will summarize and prospect the whole research work.

2 RELATED WORK

Chinese painting is a unique art form, and the recognition and simulation of its strokes are of great significance for artistic creation, restoration, teaching. The development of computer-aided design (CAD) technology has provided a new way to solve this problem. Liu and Yang [8] encourage open themes and projects to unleash imagination and creativity, and try new art forms and expression techniques. It explores the application of a Chinese painting stroke recognition and simulation CAD system based on computer vision. The stroke recognition of Chinese painting involves feature extraction and classification of painting works. Traditional stroke recognition methods mainly rely on manual observation and judgment, but this method is not only time-consuming, but also susceptible to subjective factors. Liu and Liu [9] discussed this interdisciplinary intelligent teaching method and its importance in the field of computer-aided design and application. Designers use computer technology for creation, modeling, rendering, and output through CAD software. This interdisciplinary teaching method helps students combine traditional design skills with modern technology, improving their innovation and adaptability. The intelligent teaching method of interdisciplinary art design and CAD is the key to cultivating innovative design talents. By combining traditional design skills with modern technology, students can better understand and apply design principles, improve their practical abilities and creativity.

Although CAD tools have significant advantages in accuracy and efficiency, they often lack the ability to innovate and express symbols. Graphic semiotics, as a discipline that studies graphics, symbols, and their relationships. Graphic semiotics focuses on the generation, understanding, and communication of graphics, symbols, and meanings. In modeling language, graphic semiotics emphasizes the significance and symbolism of visual elements such as shapes, lines, and colors. Reyes and Sonesson [10] introduced the concepts and methods of graphic semiotics. Computer aided design can better understand and express the meaning of shapes, thereby promoting innovation in styling. The application of computer-aided methods in graphic design and manufacturing is becoming increasingly widespread, but their development still faces some challenges. One of them is the limitation of computer-aided methods in symbol understanding and expression. Immersive Virtual Reality (IVR) is a computer technology that creates an artificial environment with which users can interact through special devices, achieving the participation of various senses such as vision, hearing, and touch. Aesthetic art modeling is a process that requires high precision and complex skills. By utilizing immersive virtual reality technology, aesthetic art modeling can be more intuitive and efficient. Tastan et al. [11] explored how to use handheld user interfaces and direct operations to achieve architectural modeling in immersive virtual reality. Direct operation allows users to model buildings more intuitively without the need for complex menus and commands. This operating method can improve efficiency while enhancing user immersion. In immersive virtual reality, users can directly manipulate building models in the virtual environment through techniques such as gesture recognition and eye tracking. For example, users can move, rotate, or scale building models through gestures. Direct operation requires ensuring the accuracy of the operation. This requires the use of advanced algorithms and tracking techniques to accurately track and analyze user actions. In the actual building modeling process, handheld user interfaces can be combined with direct operations. For example, users can first conduct preliminary building modeling through a handheld user interface, and then use direct operations for fine-tuning when precise adjustments are needed [12].

With the rapid development of new media, visual communication design is gradually becoming a comprehensive field that integrates technology and art. Computer aided design (CAD), as an important technical support, provides unlimited possibilities for visual communication design. Wang [13] explores the computer interaction new media scenarios, as well as the application of computer-aided design. By utilizing computer image processing technology, designers can edit, synthesize, and optimize images to meet design requirements. Through 3D modeling software, designers can create highly realistic three-dimensional scenes and models, bringing an immersive visual experience to the audience. By utilizing computer animation technology, designers can create dynamic visual effects with temporal and spatial movements, enriching the expression forms of design. Through computer program control and sensor technology, designers can introduce interactive elements into their work, enabling users to interact with the work, enhancing the interactivity and sense of participation of the design. Computer assisted design plays a crucial role in visual communication design. Chinese painting is a unique art form, and the recognition and simulation of its strokes are of great significance for artistic creation, restoration, teaching, and other aspects. The development of computer-aided design (CAD) technology provides a new way to solve this problem. Wang et al. [14] explored a hybrid network model based on CNN and RNN. CNN performs well in processing image data and is suitable for extracting local features of images; RNN has advantages in processing sequence data and is suitable for processing time series or text data. The stroke recognition of Chinese painting involves image processing and sequence processing, so a hybrid network model of CNN and RNN can be used for stroke recognition. Sand painting, a form of expression full of artistic charm, has always attracted people's attention due to its unique visual effects and creative process. However, the creative process of sand painting requires a high level of skill and patience, and cannot be modified and adjusted in real-time. Therefore, Yang et al. [15] proposed an adaptive algorithm for real-time simulation of sand paintings, which is simulated from an electronic perspective to achieve real-time creation and modification of sand paintings. The sand painting simulation algorithm is mainly based on image processing and computer vision technology. In this process, we used adaptive algorithms to optimize computational efficiency while also ensuring image quality. Adaptive algorithms play a crucial role in sand painting simulation. This algorithm can adjust the allocation of computing resources based on the characteristics of the image, thereby ensuring image quality while reducing the resource consumption of the algorithm. In addition, adaptive algorithms can also adjust the rendering effect of images based on user input, allowing users to see their creative effects in real-time.

Computer graphics and image software can provide powerful visual representation and simulation capabilities, helping designers better understand and represent the marine environment, and providing support for fields such as marine protection, marine energy development, and marine transportation. Zhang [16] used computer graphics technology to simulate complex ocean scenes, including dynamic changes such as waves, tides, and currents. Provide visual support for ocean engineering design, ocean energy development, etc. Using image software, designers can perform various processing operations on ocean images, such as adjusting brightness and contrast, and adding filter effects to improve image quality and visual effects. Image software can help designers analyze and extract data information from ocean images, such as water depth, seabed topography, etc., providing data support for marine scientific research. The application of computer graphics and image software in ocean graphic design has broad practical significance and value. They can help designers better understand and represent complex marine environments, improve design efficiency and work quality. With the rapid development of computer technology, computer image processing technology has been widely applied. This technology provides artists with a new way of painting creation, enabling them to better realize their artistic concepts during the creative process. Zhao et al. [17] analyzed its impact and future development trends. Computer image processing technology enables artists to create paintings more conveniently. Through various tools in the software, artists can easily achieve their creative intentions, reducing the tedious steps in traditional painting. The application of computer image processing technology in painting creation has had a profound impact on the creative methods and artistic concepts of artists. Firstly, this technology makes artists' creations more convenient and efficient, thereby improving creative efficiency and quality. Secondly, the various effects and tools brought by computer image processing technology enrich artists' expressive techniques and language forms, making their works more diverse and innovative. Finally, the application of this technology has had a positive impact on art education, providing students with more practical opportunities and creative means. Zhao et al. [18] explored how to achieve artistic style the assistance of intelligent computers. Intelligent computer-aided design can excavate consumers' aesthetic trends through the analysis of a large amount of data, providing innovative design concepts for agricultural product packaging design. For example, using the image of agricultural product packaging in the market, summarizing popular packaging design elements and styles, providing inspiration for designers. In agricultural product packaging design, the cultural connotation and attractiveness of products can be enhanced by integrating traditional artistic styles. For example, incorporating traditional painting and handicraft elements into packaging design showcases unique artistic charm. The simple and elegant design style has a sense of modernity and fashion, suitable for the aesthetic needs of young consumer groups. In agricultural product packaging design, simple lines, bright colors, and clear layout can be used to create a simple and elegant packaging design style. The packaging design of agricultural products is also increasingly focusing on natural and environmentally friendly design styles. For example, using biodegradable materials for packaging and using green printing processes can reduce environmental pollution.

3 THEORETICAL BASIS

3.1 The Application of Computer Vision in the Field of Art

Computer vision involves a series of basic technologies, which are the basis of constructing a computer vision system, including image processing, feature extraction, target detection and recognition, image segmentation, and so on. At present, the application of computer vision technology in the art field is increasing day by day, which provides new possibilities for artistic creation and analysis. Some application examples include artistic style transfer: using computer vision and DL technology, the artistic style of one image can be transferred to another image to realize style conversion. Analysis of artistic works: Computer vision technology can be used to analyze the composition, color, texture, and other characteristics of artistic works, providing objective data support for artistic research and appreciation. Interactive art: Interactive works of art based on computer vision can interact with the audience in real-time, bringing the audience an immersive artistic experience. Identification and anti-counterfeiting of artworks: Computer vision technology can be used for identification and anti-counterfeiting of artworks, and through image analysis and comparison, it can assist experts in judging the authenticity. Generally speaking, the basis of computer vision involves a series of technologies and methods which have broad application prospects in the art field and can provide strong support for artistic creation, appreciation, and research.

3.2 Characteristics and Recognition Difficulty of Chinese Painting Strokes

As the core element of traditional Chinese painting in China, the strokes of Chinese painting have unique artistic characteristics, which also bring some difficulties to its recognition. Table 1 embodies the characteristics of Chinese painting strokes and the difficulty of recognition.

Characteristic	*Describe*	*Identification difficulty*
Variety	There are many kinds of brush strokes in Chinese painting, such as hook, curl, dot and dye, and each brush stroke has many	Because of the variety and variety, it is a complex task to accurately identify all kinds of strokes.

	changes.	
Hierarchical feeling	Chinese painting pays attention to the layering of pen and ink, and the same brush stroke may have different performances in different situations.	The layering of brush strokes involves many factors, such as the shade of ink and the weight of pen, which increases the complexity of recognition.
Artistic conception first	Different from western painting, Chinese painting pays more attention to the expression of artistic conception, and the subtle changes of brush strokes may carry profound cultural connotations.	Recognizing brush strokes requires understanding the artistic conception and cultural connotation behind them, and requires higher algorithms and models.
Limitations of traditional processing technology	Traditional image processing technology is difficult to be directly applied to the recognition of Chinese painting strokes.	Traditional image processing technology is usually based on fixed features and rules, which is difficult to adapt to the diversity and layering of Chinese painting strokes.
Demand for specialized research and design	It is necessary to conduct special research and design according to the characteristics of Chinese painting.	In order to effectively identify the strokes of Chinese painting, it is necessary to deeply study its artistic characteristics and design corresponding algorithms and models.

Table 1: The characteristics of Chinese painting strokes and the recognition difficulty.

The diversity, layering, and artistic conception of Chinese painting strokes make it more difficult to identify them. Traditional image processing technology can not be directly applied to the recognition of strokes in Chinese painting, so it is necessary to carry out special research and design for the characteristics of Chinese painting in order to realize accurate and effective recognition of strokes.

3.3 Existing CAD System and Its Limitations in the Simulation of Chinese Painting Strokes

Most of the existing CAD systems are developed for Western painting or industrial design, and their stroke simulation functions are often based on simple texture mapping or stroke replication. These systems face the limitations shown in Table 2 when simulating Chinese painting strokes.

Limitations	*Describe*
Lack of diversity of brush strokes	The stroke simulation function of the existing CAD system is usually based on simple texture mapping or stroke replication, which can not cover the rich types and changes of strokes in Chinese painting. Therefore, these systems cannot truly reproduce the diversity of Chinese painting.
It is difficult to express a sense of hierarchy	The level and artistic conception of Chinese painting are its essence, but it is difficult for the existing CAD system to simulate this subtle level change. This makes the simulation results lack depth and three-dimensional sense and cannot truly reflect the unique charm of Chinese painting.
Cultural deficiency	Because most of the existing CAD systems are developed for Western painting or industrial design, their development background and design

	concept are different from those of Chinese painting. This difference makes it difficult for the existing CAD system to reflect the unique cultural connotation of Chinese painting and to truly convey the artistic value of Chinese painting.

Table 2: Characteristics and identification difficulty of Chinese painting strokes.

This article proposes a computer vision-based Chinese painting brush stroke recognition and simulation CAD system. This system combines computer vision technology and DL to identify and classify Chinese painting strokes with high precision and then realize its accurate simulation. The core ideas of this system include (1) Speciality: Design according to the characteristics of brush strokes of Chinese painting and consider its diversity, layering, and cultural connotation in all directions. (2) High-precision recognition: The advanced computer vision technology is used to realize high-precision recognition and classification of Chinese painting strokes. (3) Intelligent simulation: Combining DL technology, develop algorithms and tools that can intelligently simulate the strokes of Chinese painting. Through the research and growth of this system, I hope to provide a powerful tool for the creation, teaching, and research of Chinese painting and, at the same time, open up new ideas for the cross-study of computer vision and art.

4 CHINESE PAINTING BRUSH STROKE RECOGNITION BASED ON COMPUTER VISION

4.1 Chinese Painting Brush Stroke Recognition Model Construction

Image preprocessing plays the role of "scavenger" in the task based on computer vision. In the process of real image acquisition, the original image often contains a lot of unnecessary interference information due to camera quality, lighting conditions, and environmental factors. For Chinese painting stroke recognition, these interferences may block or blur the real stroke information, so preprocessing is a necessary and key step. The preprocessing work in this article includes the following steps: image clarity: blur and jitter are common problems in image acquisition. Blur may be caused by camera movement, insufficient light, or moving objects. In this article, Wiener filtering algorithm is used to reverse the blur and make the image clearer. The jitter effect is caused by the rapid movement of the camera, which can be corrected by the image stabilization algorithm. Color space conversion: the gray space turns the image into black and white, which makes the contrast between brush strokes and background more obvious. Contrast enhancement: Enhancing contrast can make strokes more prominent, so they are easier to detect and recognize. Laplacian sharpening method is adopted in this article. Noise removal: The noise in the image may come from camera, circuit interference or environmental factors. In this article, Gaussian filtering is adopted, which is suitable for removing Gaussian noise. Peak signal-to-noise ratio (PSNR) is used as the measurement method of signal reconstruction quality, and its measurement formula is as follows:

$$\mathrm{PSNR}=10\times\log_{10}\left(\frac{MAX_i^2}{MSE}\right) \tag{1}$$

$$MSE=\frac{1}{\mathrm{N}}\sum_{\mathrm{x,y}}\left\|Rco\ \ nx,y\ \ -Or\ \ ix,y\ \right\|^2 \tag{2}$$

After preprocessing, the image has become much cleaner, but it isn't easy to classify such images directly. Therefore, it is necessary to extract the key information in the image, that is, features. For the recognition of Chinese painting strokes, the shape feature is the key because different brush strokes represent different painting techniques and emotional expressions. For example, a long and curved brush stroke may represent soft lines, while a short and straight brush stroke may represent tough techniques. Texture features describe the surface characteristics of brush strokes, such as roughness and granularity, which can provide powerful clues for recognition. Moreover, color characteristics are also very important because the use of color in Chinese painting is also part of the technique. The color distribution, saturation, and brightness can give information such as the material and ink consumption of the brush. The advantage of using CNN for feature extraction in this article is that it can automatically learn advanced features in images. These advanced features may be difficult to consider when designing features artificially, but they are very useful for classification and recognition. An $\mathrm{M}\times\mathrm{N}$ binary image can be represented as a two-dimensional array:

$$\mathrm{A}_{M\times N}=[\mathrm{a}_{\mathrm{ij}}] \tag{3}$$

$$\mathrm{B}=\{(\mathrm{x,y})|\mathrm{a}_{\mathrm{xy}}=0\} \tag{4}$$

Then, the distance transformation is to find all the pixel points $(\mathrm{i,j})$ in A:

$$\mathrm{d}_{\mathrm{ij}}=\min\{\mathrm{D}\left[(\mathrm{i,j}),(\mathrm{x,y})\right],(\mathrm{x,y})\in\mathrm{B}\} \tag{5}$$

Among them:

$$\mathrm{D}\left[(\mathrm{i,j}),(\mathrm{x,y})\right]=\sqrt{(\mathrm{i\text{-}x})^2+(\mathrm{j\text{-}y})^2} \tag{6}$$

Thereby obtaining the Euclidean distance transformation image $\mathrm{D}_{\mathrm{M\times N}}$ of the binary image A. Let the set R represent the whole Chinese painting image area, and the brush stroke recognition of R can be regarded as dividing R into N non-empty subsets $R_1,R_2,R_3,\ldots,R_N$ that meet the following five conditions:

$$\bigcup_{i=1}^{N}R_i=R \tag{7}$$

For all i and j, $i\neq j$, there are:

$$R_i\cap R_j=\varnothing \tag{8}$$

For $i=1,2,\ldots,N$, there are:

$$P\ R_i\ =TRUE \tag{9}$$

For $i\neq j$, there are:

$$P\ R_i\cup R_j\ =FALSE \tag{10}$$

Among them, $P\ R_i$ is a logical predicate for all elements in the set R_i, and $\varnothing$ represents an empty set.

With the features, the next task is classification. The choice of the classifier depends on the complexity of the task, the amount of data, real-time requirements, and so on. For example, support vector machine is suitable for small sample data, while Random forest (RF) is suitable for processing a large number of data and has good over-fitting resistance. DL classifiers such as MLP are suitable for processing large-scale and high-dimensional data, and can learn more complex decision boundaries from the data. This article adopts MLP. MLP is a DL classifier, which belongs to a kind of feedforward neural network. Through forward propagation and backward propagation algorithms, MLP can learn complex decision boundaries from large-scale and high-dimensional data. The input layer in its structure is used to receive the original data features, and the number of neurons is usually consistent with the feature dimension. The hidden layer has one or more layers of fully connected neurons, which are responsible for learning the internal representation of data and decision boundaries. Among them, the Sigmoid function is mathematically defined as:

$$Sigmoid\ x\ =\frac{1}{1+e^{x}} \tag{11}$$

Softmax classifier is shown in the following formula:

$$y\ x_i\ = \frac{\exp\ x_i}{\sum_{i=1}^{M} \exp\ x_i} \tag{12}$$

Where x is the feature vector output by the full connection layer; M is the number of categories of classification.

Each neuron linearly combines the inputs and introduces nonlinearity through the activation function. Finally, the output layer outputs the prediction probability of each category. Backpropagation and parameter updating stage: by calculating the error between the prediction probability of the output layer and the real label, the backpropagation algorithm propagates the error back to the previous layer by layer, and updates the weights and bias parameters of neurons in each layer by gradient descent, to minimize the prediction error.

In this article, MLP is chosen as a classifier because of its ability to process large-scale and high-dimensional data and its ability to learn complex decision boundaries. By training and optimizing MLP, the effective classification, and recognition of Chinese painting strokes can be realized.

4.2 Experimental Results and Analysis

In order to verify the effectiveness of Chinese painting brush stroke recognition based on computer vision, a series of experiments are needed. In this article, RF and Ant colony optimization(ACO) are selected as comparison algorithms. In order to compare the performance of MLP, RF, and ACO in the recognition of Chinese painting strokes, the following experimental settings are carried out in this section: Select a data set containing various characteristics of Chinese painting strokes to ensure that there are enough samples in the data set for training and testing. For each brush stroke of Chinese painting, the relevant features are extracted by computer vision technology. These features can include texture, color, shape, etc., which are used to describe the unique properties of brush strokes. For each algorithm, the parameters are tuned, and the best parameter configuration is selected. For RF, adjust the parameters such as the number and depth of trees; For ACO, adjust the parameters such as the volatilization speed of pheromone and the number of ants; For MLP, adjust the parameters such as the number of hidden layers and the number of neurons. Accuracy and Mean-squared error (MSE) were used as evaluation indexes. Accuracy is used to measure the proportion of correct classification of the algorithm, while MSE is used to measure the degree of error of the algorithm's prediction results. The comparison of accuracy and MSE of Chinese painting brush strokes recognition using the algorithm is shown in Figure 1 and Figure 2.

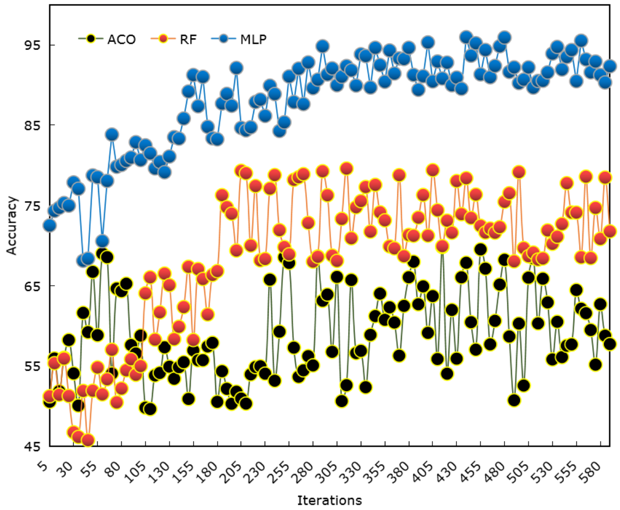

Figure 1: Comparison of the accuracy of stroke recognition.

Accuracy comparison: Figure 1 shows that MLP is the best in accuracy, followed by RF and ACO. This shows that MLP has stronger classification ability and can identify different brush strokes more accurately when dealing with the task of Chinese painting brush strokes recognition.

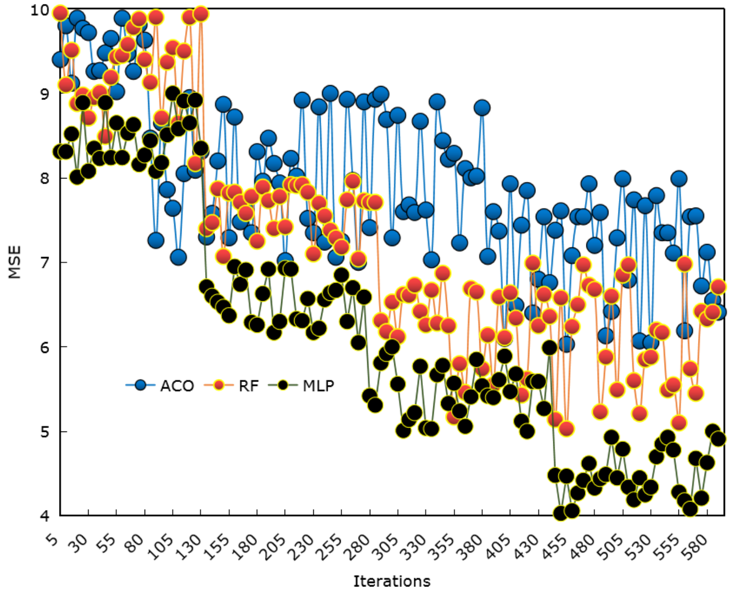

Figure 2: MSE comparison of stroke recognition.

MSE comparison: Figure 2 shows that MLP has the lowest MSE, followed by RF, and ACO has the highest MSE. This shows that the prediction error of MLP is the smallest, that is, its prediction result is closer to the actual result, while the prediction error of ACO is relatively large.

According to the comprehensive analysis of the comparison results shown in Figure 1 and Figure 2, MLP performs best in the task of Chinese painting brush strokes recognition, with high accuracy and small prediction error. RF also shows some recognition ability, but it is inferior to MLP. The performance of ACO in this task is relatively poor, which is due to its limited learning ability for complex features. Therefore, MLP is a better choice when choosing an algorithm.

5 DESIGN OF BRUSH STROKES SIMULATION CAD SYSTEM FOR CHINESE PAINTING

The framework of Chinese painting brush strokes simulation CAD system is based on application scenarios, analyzes problems from the perspective of realization, and designs feasible architecture schemes. According to the different roles, this system adopts a multi-level structure to meet the needs. The modeling framework includes four main layers: upper application layer, user layer, model assembly layer and data layer. Its overall framework is shown in Figure 3.

Upper application layer: This layer contains various application functions of CAD system, such as brush stroke simulation, image editing, brush stroke parameter adjustment and so on. Through these functions, users can simulate and edit the strokes of Chinese paintings. Features: It provides an intuitive and easy-to-use interface, and encapsulates complex algorithms and operations behind simple operations, so that users can edit and simulate efficiently without caring about the underlying details.

User layer: Responsible for direct interaction with users, receiving input instructions from users and feeding back the results to users. Features: The ease of use and interactivity are emphasized to ensure that users can complete the operation tasks smoothly and efficiently. It can include user interface design, interactive logic, etc.

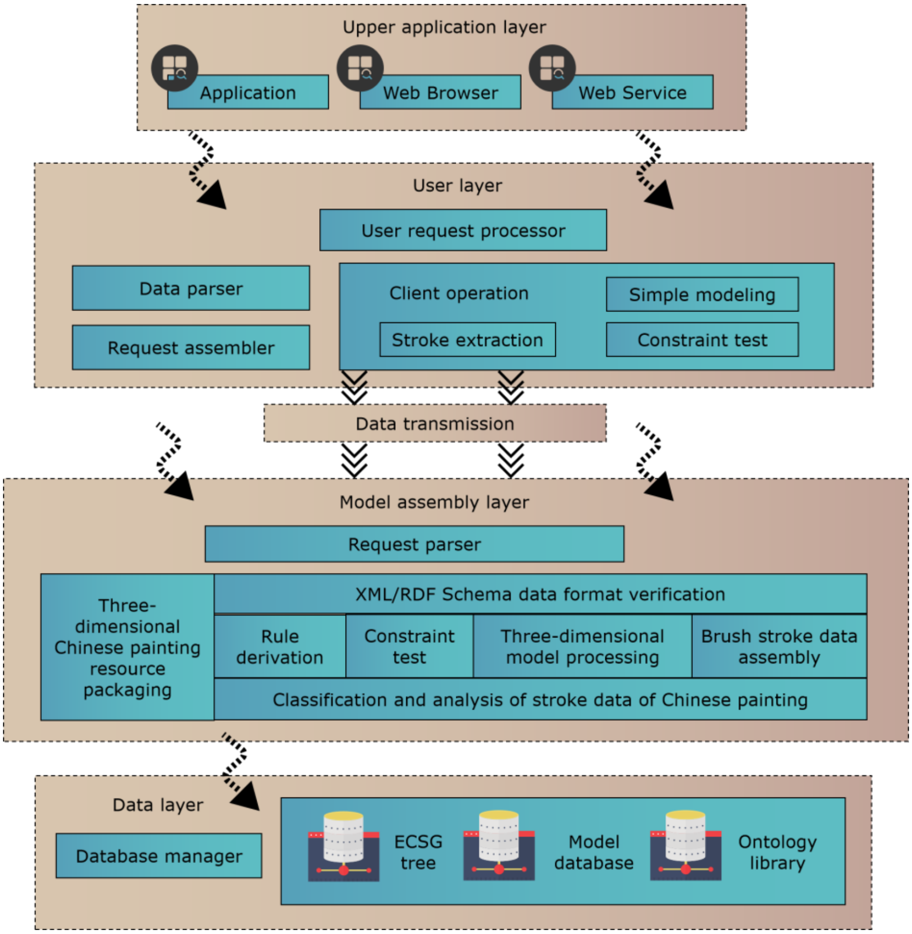

Figure 3: CAD modeling framework for brush stroke simulation of Chinese painting.

Model assembly layer: At this layer, different stroke simulation algorithms and models are integrated and assembled to realize the core function of stroke simulation. These models can be based on DL, image processing, and other technologies. Features: The model assembly layer emphasizes flexibility and expansibility and can quickly assemble and configure suitable models according to different needs and scenarios.

Data layer: This layer is responsible for data storage and management, including user settings, brush stroke parameters, simulation results, and other data. Provide persistent storage and efficient access mechanism of data. Features: Emphasize the stability and security of data. This layer usually includes database design, data access interface, etc.

Through such a hierarchical framework design, the complex CAD system can be divided into several relatively independent levels, which reduces the complexity of the system and improves the maintainability and expansibility. Moreover, this design is also conducive to the parallel development between teams, and developers at different levels can work relatively independently, which improves the development efficiency. For example, Table 3 summarizes the development environment and tools for developing the brush stroke simulation CAD system of Chinese painting.

Category	*Tool*	*Describe*
Programming language	Python	Python is often the first choice because of its rich libraries and frameworks and easy-to-learn features. Suitable for rapid development and prototype design.
Development framework	Django	For Web applications, Django provides a full set of Web development functions, including ORM and template system.
Database management system	MySQL	MySQL is a relational database management system, which is suitable for small and medium-sized applications.
Image processing library	OpenCV	OpenCV is an open-source computer vision library, which provides rich image processing functions.
DL framework	TensorFlow	TensorFlow is an open-source framework for machine learning and DL, which supports the implementation of algorithms such as CNN.

Table 3: Development environment and tools.

The main function modules of the system are realized:

Image loading and preprocessing module: this module is responsible for reading images and performing necessary preprocessing operations, such as denoising and color space conversion. The preprocessed image provides clearer and more useful information for subsequent operations.

Stroke simulation module: this is the core module, which uses DL technology or other algorithms to generate simulated strokes of Chinese painting. This module may include the functions of brush stroke parameter setting, brush stroke generation and real-time preview.

Database interaction module: this module is responsible for interacting with the database, storing and reading data such as user settings, brush stroke parameters and simulation results.

User interface module: this module is responsible for interacting with users, providing functions such as parameter adjustment, brush stroke selection, simulation result display, etc. You can use the existing UI framework for rapid development.

File output and management module: this module allows users to save and export simulation results, and also provides file management functions, such as deleting and renaming.

Module integration: after realizing each functional module, it is necessary to integrate them into a complete system. This involves communication and data transmission between modules to ensure the smooth flow of data and information.

Unit test: each functional module is tested separately to ensure that it can work normally in an independent environment. This helps to locate the problem and fix it quickly. See Table 4 for details.

Functional module	*Test case description*	*Test input*	*Expected output*	*Actual output*	*Test result*
Module 1	Test the basic functions of functional module 1.	Input data 1	Expected result 1	Consistent with the expected results	Pass
Module 1	Test the boundary condition of functional module 1.	Boundary input data	Boundary expected result	Consistent with the expected results	Pass

Module 2	Exception handling of test function module 2	Abnormal input data	Exception handling result	Exceptions are correctly caught and handled.	Pass
Module 2	Test the performance of functional module 2.	A lot of input data	Expected result	Finish within the specified time	Pass
...	...	...	...	...	...

Table 4: Unit test.

In this table, corresponding test cases are designed for each functional module, and test input is provided. And compares the actual output with the expected output to determine the test result. If the actual output is consistent with the expected output, it is marked as "Pass", indicating that the test case is successful.

6 REALIZATION AND SIMULATION OF CHINESE PAINTING BRUSH STROKE SIMULATION CAD SYSTEM

In order to test the reliability of Chinese painting brush stroke simulation CAD system, this section carries out experimental simulation. When evaluating the performance of Chinese painting brush stroke simulation CAD system, it is necessary to consider multiple indicators to ensure that the effect of the system in practical application is consistent with expectations. Firstly, a certain number of simulated strokes are generated by using the system. These simulated strokes are obtained by inputting random or specific parameters and generating models. The similarity evaluation algorithm in image processing and computer vision, such as PSNR, is used to quantitatively evaluate the similarity between the simulated strokes generated by the system and the real strokes. In order to test the speed of generating simulated strokes by the system, the time spent by the system to generate a certain number of simulated strokes under the fixed hardware configuration was recorded experimentally. In order to test the stability of the system under continuous large-scale data input, the continuous input data stream is used in the experiment, and the performance indexes of the system at different time points are recorded. The similarity between the simulated brush strokes generated by the system and the actual brush strokes is shown in Figure 4. The speed at which the system generates simulated strokes is shown in Figure 5. The stability of the system under continuous large-scale data input is shown in Figure 6.

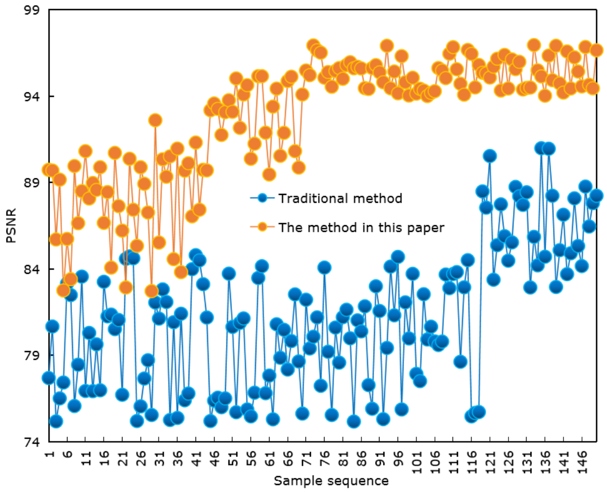

Figure 4: PSNR.

Figure 4 shows that most of the simulated strokes generated by the system are highly similar to the actual strokes, which means that the system can simulate and restore the real Chinese painting strokes well. However, there are also a few points with low similarity, which may be caused by the complexity of some specific strokes or the limitations of the model in these cases.

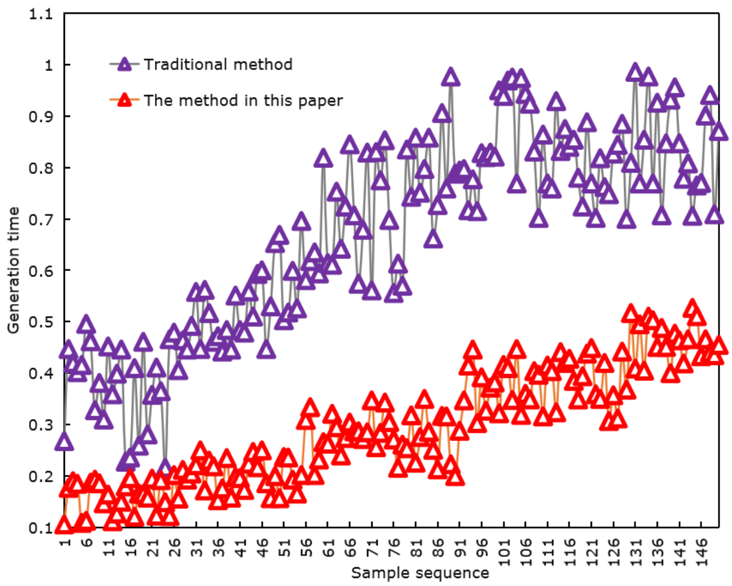

Figure 5: The speed at which the system generates simulated strokes.

According to Figure 5, we can see that the system's speed of generating simulated strokes is relatively stable, and there is no significant fluctuation. This shows that the generation speed of the system is reliable and can meet real-time or near-real-time application requirements.

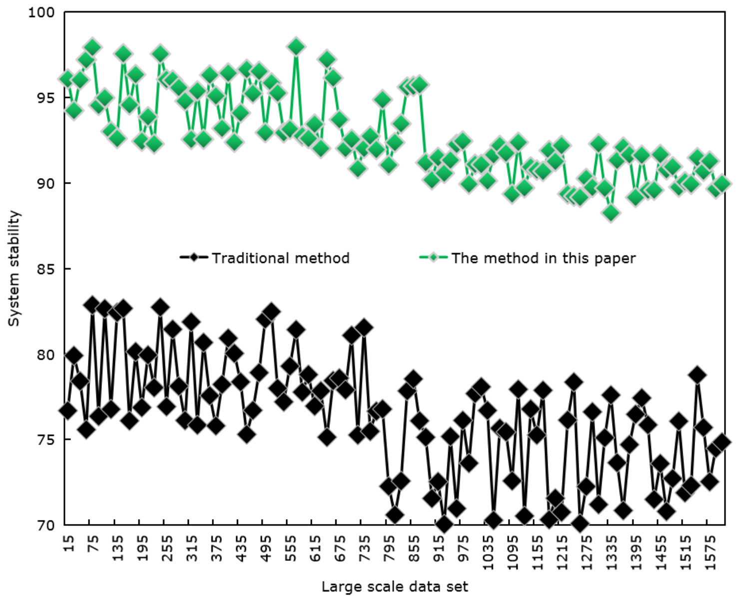

Figure 6: Stability.

Figure 6 shows the stability index of the system under continuous large-scale data input. The curve of the method in this article is stable after long-term operation, which shows that the system has good stability. There is an obvious downward trend in the comparison method, which indicates that the system has resource leakage or performance bottleneck in some aspects.

The goal of the following experiment is to verify the simulation effect and performance of the brush stroke simulation CAD system of Chinese painting. By comparing the simulation results generated by the system with the actual Chinese painting works, the simulation ability and accuracy of the system in different scenes and conditions are evaluated. As shown in Figure 7, the simulation results of using the brush strokes simulation CAD system of Chinese painting are shown.

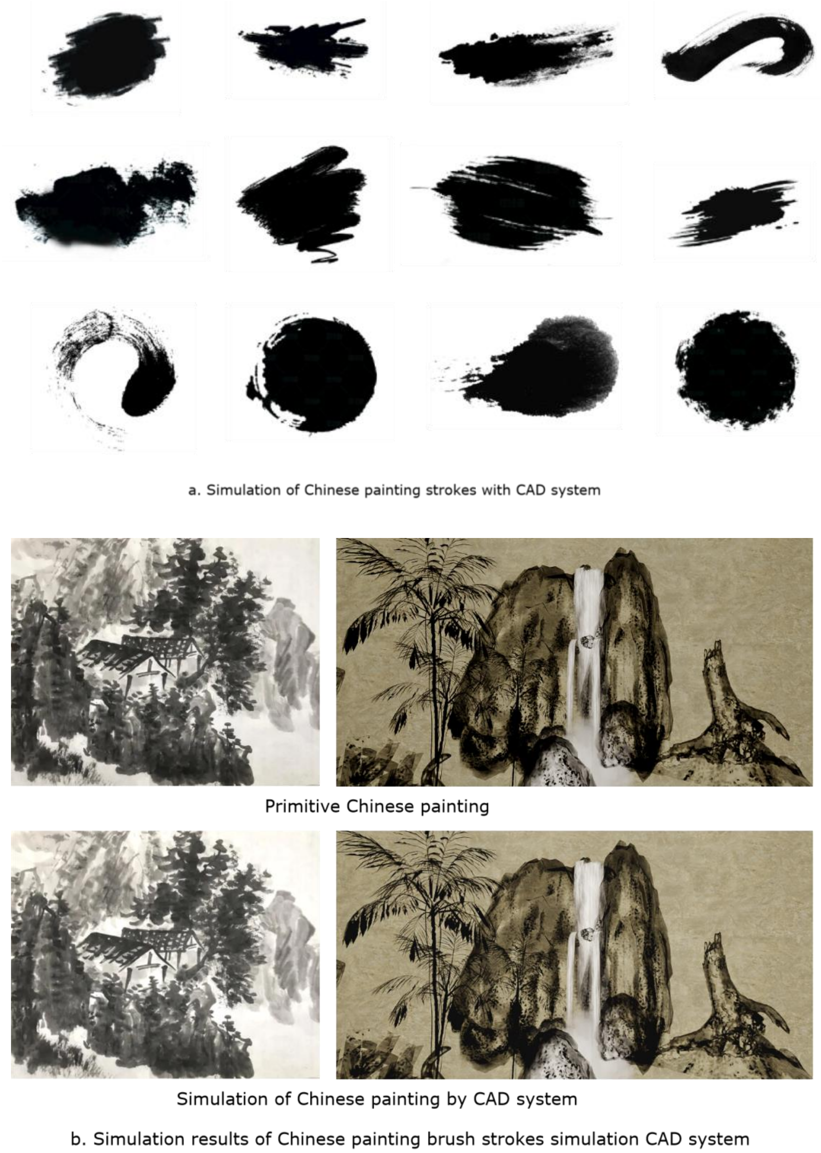

Figure 7: Simulation results of Chinese painting brush strokes simulation CAD system.

It can be clearly seen from Figure 7 that compared with the traditional method, the simulation results by using the brush stroke simulation CAD system of Chinese painting in this article are more consistent with the actual picture. The color, texture, and overall style of the simulation results generated by this system have been well restored, showing the system's excellent performance in visual similarity. Observing the simulation results carefully, we can also see that the system successfully simulates the unique brushwork effect of Chinese painting, including the thickness change of lines, the penetration and transition of ink color, etc. This shows that the system has high precision and accuracy in retaining and simulating the details of brush strokes.

Finally, the user's satisfaction with the interface and operation process of the system is investigated. This section is collected through user questionnaires or interviews. The questionnaire covers the interface design, operation flow, usability, interactivity and system performance of the system. Each aspect contains several specific questions, and users need to choose appropriate answers or make their own suggestions for each question. The user evaluation of the system is shown in Figure 8.

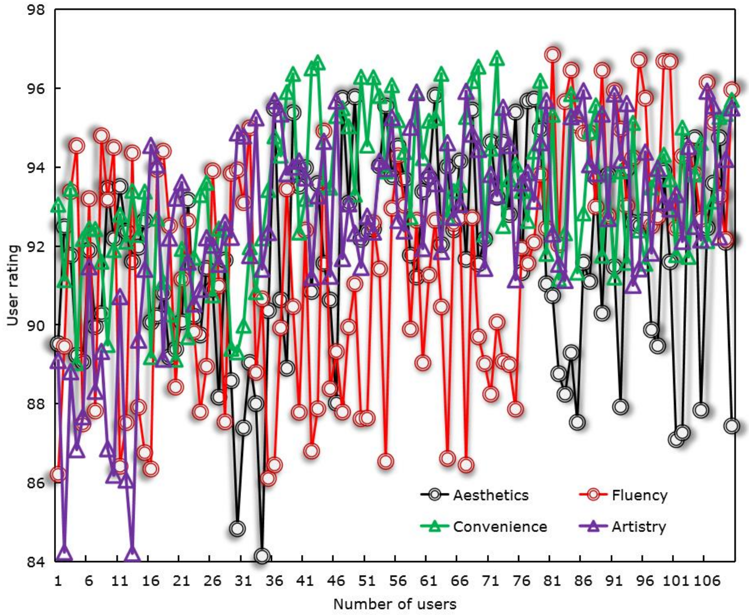

Figure 8: User evaluation of the system.

According to the user evaluation results shown in Figure 8, it can be seen that the user's satisfaction is high, indicating that the user thinks that the interface design is beautiful and clear, which conforms to their expectations and operating habits. According to the results and discussion of simulation research, it can provide decision support for the subsequent development, optimization or upgrade of the system, and ensure that the system can provide users with high-quality and efficient simulation function of Chinese painting strokes in practical application.

7 SUMMARY AND PROSPECT

The research work of this article mainly focuses on the development and application of the stroke simulation CAD system of Chinese painting based on DL. In order to achieve this goal, this article adopts systematic methods, including designing experiments to evaluate and compare different algorithms, and collecting and analyzing user feedback to evaluate the practicability of the system. Through the simulation results, it can be concluded that the Chinese painting brush stroke simulation

CAD system has good performance in simulation effect and performance. It can accurately simulate the characteristics and style of Chinese painting strokes, and achieve satisfactory results in visual similarity and the degree of detail preservation of strokes. The system has high fidelity in generating simulated strokes, and its speed is relatively stable, and it can maintain good stability under continuous large-scale data input. However, in practical application, further optimization and adjustment are needed according to specific scenarios and requirements to ensure the best performance and effect in all situations.

The research results of this article not only verify the effectiveness of the stroke simulation CAD system of Chinese painting based on DL, but also lay a foundation for its further application and promotion in the field of art and CAD. Future research directions include optimizing the algorithm to improve the processing speed and accuracy, and expanding the system to adapt to more kinds of artistic strokes. It is believed that with the continuous progress of technology and in-depth research, the stroke simulation CAD system of Chinese painting based on DL will play a greater role in the field of art and design, and help people to better understand and inherit the traditional art of China.

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