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Research on Pattern Elements and Colors in Apparel Design through Fractal Theory

Dan Li[1] and Chengjun Yuan[2,*]

Abstract
Excellent apparel design can increase market competitiveness. This article briefly introduced the theory of fractals and its application in the field of apparel design. The convolutional neural network (CNN) algorithm was used to assist in the evaluation of apparel designs. In the case analysis, the accuracy of the evaluation was validated by comparing the CNN algorithm with two other intelligent algorithms, support vector machine (SVM) and back propagation (BP). The evaluation of the proposed design showed that compared with SVM and BP algorithms, the CNN algorithm had higher accuracy in evaluating apparel designs. The evaluation result of the proposed apparel design not only further verifies the effectiveness of the CNN algorithm, but also demonstrates that the theory of fractals can be effectively applied in apparel design to provide more innovative designs.

Keywords
Apparel Design, Color, Fractal Theory, Pattern

1. Introduction

In modern clothing design, constantly exploring and practicing new technologies is one of the important ways to enhance the quality and expression of clothing. Fractal theory is one of the cutting-edge mathematical fields that has emerged in recent years [1]. It is also one of the widely used methods in modern art, fashion design, and other fields. Fractal theory is a method to describe the infinite complexity in nature with mathematical language, reflecting the evolution and diversity of all things [2]. In the field of apparel design, this mathematical theory provides designers with new inspirations and ideas. Design elements such as texture, pattern, and line can be presented more perfectly through fractal theory. It integrates technology and art, leading the innovative trend of clothing design [3]. Only by deeply exploring and applying fractal theory can garment design better showcase its artistic characteristics and design concepts in the fiercely competitive market. The following are some relevant studies. Kim and Chae [4] studied the relationship between the thoughts and modeling features reflected in the shaping of Korean traditional clothing and fractal geometry [4]. Taking clothing style images as research subjects, Using photos of round-neck T-shirts, Zhang et al. [5] created a collar style sample library and compared and evaluated the benefits and drawbacks of widely used image grayscale,

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* **Corresponding Author:** Chengjun Yuan (lqqcj0@126.com)
[1] School of Arts and Design, Harbin University, Harbin, China (yld05e@126.com)
[2] School of Information Engineering, Harbin University, Harbin, China (lqqcj0@126.com)

sharpening, edge detection, morphology processing, and image segmentation approaches. Artemenko et al. [6] studied the leather ornamentation of Slavic snakes through graphic analysis of snake populations found in modern-day Ukraine. They developed design proposals for male and female clothing for hotel staff. This article briefly introduced the theory of fractals and its application in clothing design. This paper proposed the use of the convolutional neural network (CNN) algorithm to assist in the evaluation of apparel designs. In the example analysis, the accuracy of the evaluation was validated by comparing it with two other intelligent algorithms, support vector machine (SVM) and back propagation (BP). Finally, the design proposed by this paper was evaluated.

2. Application of Fractal Theory in Apparel Design

Fractal theory is a new approach to describing the infinitely complex nature of nature. Fractals, as the name implies, are self-similar and self-fractal, like the branches of a tree. In its basic mathematics, a fractal can be visualized as a whole composed of many parts, all having similarities at different scales, but with differences, which is one of the biggest differences from traditional geometry. Fractals are usually irregular shapes that do not have precise symmetry relationships and have a complex hierarchical structure [7]. Fractal algorithms can construct a variety of graphs with fractal characteristics. The complex iterative generation method is one of the fractal graph generation algorithms, of which the escape time algorithm is widely used [8]. The iteration formula in the escape time algorithm is based on Newton's iteration

$$z_{k+1} = z_k - \frac{p(z_k)}{p'(z_k)}, \quad (1)$$

where z_k and z_{k+1} are the point value before and after the iteration, and $p()$ is the given equation. In the iterative process, the plot range, iteration precision, and maximum number of iterations were set first. Then, initial value z_0 is set to $x + iy$, where (x, y) is the point in the plotting range and i is the imaginary number. The given initial value is iterated according to the iteration formula until the termination condition is reached, and the fractal graph is obtained.

Fractal theory [9] is not only a theoretical study; it has also been widely used in practical applications, including ecology, meteorology, economics, art design, and other fields, achieving the effect of in-depth analysis of the complex rules of things. This article applies fractal theory to apparel design. Fractal theory in apparel design involves two aspects: direct application of fractal theory and combination with apparel design. For the former, designers can use fractal algorithms to generate patterns, textures, and other design elements. They can also use fractal geometry to construct varied cuts and details, making clothing richer and more expressive. For the latter, fractal theory serves as a reference and thought framework for design. Designers try to draw inspiration from the fractal world for their designs. In general, fractal theory is usually used to create textures, patterns, and lines in apparel design. Creatively combining patterns, colors, shapes, and other details with fractal theory can push the fashion industry into a more diversified and personalized direction [10].

3. Intelligent Algorithms for the Evaluation of Fractal Pattern Elements and Colors in Apparel Design

The previous section has briefly introduced fractal theory and its application in apparel design. It can be said that fractal theory effectively enriches the direction and ideas of clothing design. By using fractal theory, the number of pattern designs in clothing can be effectively increased. However, in the process of designing patterns, more design solutions do not necessarily mean better. On the one hand, due to limited materials, not all designs can be realized, and on the other hand, different solutions may have different degrees of fit with the design concept. It is necessary to select the most suitable design or reorganize a new one based on several suitable design solutions [11].

When selecting multiple design solutions, the traditional method is to distribute the solutions to multiple evaluators, who then evaluate the solutions and finally comprehensively evaluate the suitability of the designs. The traditional evaluation method relies on human labor, and although it can obtain evaluations from a human perspective, it is relatively inefficient, especially when faced with multiple designs [12]. The emergence of intelligent algorithms provides new methods to efficiently evaluate apparel designs. The basic steps are listed below.

1) The image of the clothing design that will be evaluated is imported and treated by filtering.
2) This paper focuses on the fractal graphics in the apparel design, and the fractal graphics design can be evaluated in terms of texture and color. Therefore, in order to make a more accurate evaluation of the design, the texture features and color features of the design image are extracted first.
3) By initially determining the gradient of the image pixel using the 3 × 3 Sobel operator [13] template, the texture characteristics are extracted. The non-maximum suppression technique is adopted to choose the pixels that can be utilized as edge points based on the gradient of the pixels. Dynamic thresholding [14] is then used to filter the pixels to add to and link the edge points that the non-maximum suppression technique extracted, making the edges as continuous as possible.
4) To extract color characteristics, the density peak clustering approach is employed. The relative distance and local density of each pixel are computed. Following that, the local density is used as the horizontal coordinate and the relative distance as the vertical coordinate to build the decision diagram of pixel points. Each point in the diagram stands for a pixel point. The point farthest from the coordinate axis is then used as the clustering center [15], and the other pixel points are clustered. The calculation equations of local density and relative distance are

$$\begin{cases} \rho_i = \dfrac{\sum_{j=1}^{N} e^{-\frac{1}{2}\left(\frac{d_i}{d_c}\right)^2}}{d_c^3(2\pi)^{3/2}} \\ d_{ij} = \sqrt{\left(L_i - L_j\right)^2 + \left(a_i - a_j\right)^2 + \left(b_i - b_j\right)^2} \\ \delta_i = \begin{cases} \min\{d_{ij}\} & \rho_i \le \rho_j \\ \max\{d_{ij}\} & \text{else} \end{cases} \end{cases} \tag{2}$$

where ρ_i represents the local density of pixel point i, N represents the number of pixel points, d_{ij} represents the distance between pixel points i and j, which is the color difference, d_c represents the cutoff distance, L_i, a_i, and b_i are the parameter of pixel point i in the International Commission on Illumination (CIE) Lab color space, and δ_i represents the relative distance of pixel point i.

5) The extracted texture and color features are input to the CNN for forward computation to obtain the evaluation results of the design. The basic structure of the CNN is illustrated in Fig. 1.

The forward computation process includes convolution operation and pooling operation. The former uses a convolution kernel to perform convolution calculation during the sliding process on the image to obtain convolutional features. The calculation formula is:

$$y_j^l = f\left(\sum_{i=1}^{N_j^{l-1}} w_{i,j} \otimes x_i^{l-1} + b_j^l\right), j = 1,2,\cdots,m \tag{3}$$

where l stands for the current number of layer, w stands for the weight matrix of the convolutional kernel, x_i^{l-1} stands for the output feature map matrix, f stands for the activation function, $\otimes$ stands for the convolution operation, and b_j^l stands for the bias of the j-th feature map in the l-th layer.

The latter uses a pooling frame to compress the feature map during the sliding process on the convolutional feature map. The compression process involves sliding a pooling box with a specified specification on the convolutional feature map according to the set step length. During this sliding process, the data within the pooling box is either averaged or the maximum value is taken. Finally, the evaluation result is calculated based on the compressed convolution features in the fully connected layer.

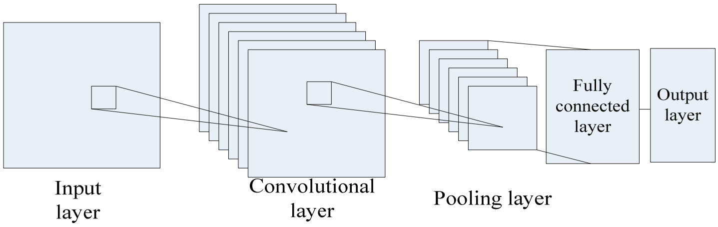

Fig. 1. The basic structure of the CNN.

4. Example Analysis

4.1 Experimental Data

In the example analysis, intelligent algorithms were used to assist in evaluating apparel designs that utilize fractal theory. In addition to the design proposed in this article, more apparel designs that use fractal theory were needed to train and validate the intelligent algorithm to ensure the accuracy of the evaluation. The sample clothing designs used for training and testing come from various apparel designs on the market. One thousand designs were collected, with 70% serving as the test set and 30% as the training set.

4.2 Analysis Methods

To demonstrate the efficacy of the intelligent algorithm for evaluating designs, it was trained and tested prior to analyzing the clothing designs using the design samples that were gathered. In the training and testing process, the design samples needed corresponding labels corresponding to the evaluation results, and the analytic hierarchy process (AHP) method was used to manually label the samples. The hierarchical structure and corresponding weights are shown in Table 1. Ten professionals with more than five years of experience in clothing design determined the weights. Then, the scores were also given by the experts and used to label the samples after computation. The relevant parameters of the CNN algorithm in the training process included three convolutional layers with 32 convolutional kernels with a specification of 3 × 3, two pooling layers with pooling frames with a specification of 3 × 3, and sigmoid. Two intelligent algorithms, SVM and BP, were also tested for comparison.

Table 1. Hierarchical structure and weights used in the manual evaluation

Middle layer	Weight	Target layer	Weight
Texture design	0.5	Novelty	0.6
		Suitability	0.4
Color layout	0.5	Sharpness	0.3
		Reasonableness	0.2
		Innovation	0.5

After validating the CNN algorithm, it was used to evaluate the apparel design proposed in this paper, and the outcomes were contrasted with those of the manual evaluation.

4.3 Analysis Results

Fig. 2 demonstrates the errors of the three intelligent algorithms, SVM, BP, and CNN. The evaluation criteria used to compare errors include "novelty, suitability, sharpness, reasonableness, and innovation" in the target layer, "texture design and color layout" in the middle layer, and "design score" in the top layer. As shown in Fig. 2, the CNN model had significantly smaller evaluation errors for all comparison criteria. It was observed that the error of the model increased as the hierarchical layer became higher. Overall, compared to the BP model, the CNN model showed superior evaluation performance.

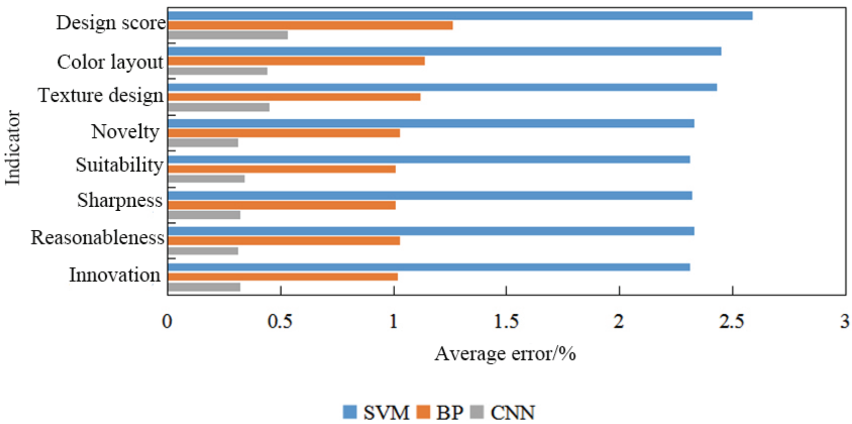

Fig. 2. Evaluation errors of three intelligent algorithms for designs.

Fig. 3. The apparel design proposed in this paper.

After comparing and verifying the accuracy of the three intelligent algorithms in evaluating apparel designs, they were used to evaluate the design proposed in this article. The design proposed in this article is shown in Fig. 3, which is an ancient-style dress with a main color of earthy brown, with patterns generated using the fractal algorithm on the surface of the dress and cuffs. Table 2 shows the scores obtained from the human evaluation of the design using the AHP method, as well as the scores given by the three intelligent algorithms. Based on the weights given by the AHP method, the total manual score for the design was 7.86, the total score given by the SVM model was 7.76, the total score given by the BP model was 7.75, and the total score given by the CNN model was 7.86. From the perspective of the total score, the total score of the CNN algorithm was consistent with the total manual score, while the total scores of the other two intelligent algorithms were different from the total manual score. From the perspective of different layers, the scores for every target layer indicator given by the CNN intelligent algorithm were generally consistent with the human scores, while the scores given by the SVM and BP algorithms were quite different from the human scores.

Table 2. Manual scoring of the apparel design and the scoring by the three intelligent algorithms

Middle layer	Weight	Target layer	Weight	Score			
				Manual	SVM	BP	CNN
Texture design	0.5	Novelty	0.6	8.6	8.4	8.4	8.6
		Suitability	0.4	8.4	8.6	8.2	8.5
Color layout	0.5	Sharpness	0.3	7.1	6.7	7.1	7.1
		Reasonableness	0.2	8.6	8.4	8.5	8.6
		Innovation	0.5	6.7	6.7	6.7	6.6

5. Discussion

As people's standard of living improves, aesthetics are now an important consideration in clothing, in addition to utility. More excellent apparel designs can gain greater advantages in market competition. In modern apparel design, constantly exploring and practicing new technologies is one of the important ways to improve quality and expression, and fractal theory is just one of the methods that have been widely used in modern art, fashion design, and other fields that have emerged in recent years. The most direct application method is to use fractal algorithms to draw graphic patterns and print them on clothing. It is essential to continuously assess the designs and make changes to them while employing fractal theory to create clothing. However, rating clothing designs is a rather subjective process; therefore, it is often necessary for many people to evaluate and then summarize them. This conventional method is inefficient, and the development of intelligent algorithms offers new approaches for rating clothes design.

In this article, after using fractal theory to design clothes, a CNN algorithm was used to help evaluate the designs. Since the main evaluation subject was the fractal pattern in clothing design, the texture and color features were extracted from the design image when using the CNN algorithm. In the following example analysis, the accuracy of the evaluation of the CNN algorithm was first verified, and then the design proposed in this paper was evaluated. Compared with the SVM and BP algorithms, the evaluation of the clothing design obtained by the CNN algorithm was closest to the manual evaluation. In the proposed apparel design, the CNN algorithm further demonstrated its evaluation accuracy.

Based on the CNN and human evaluation results, an analysis of the proposed apparel design was conducted. The proposed design is an ancient-style dress with a main color of earthy brown, and patterns generated using the fractal algorithm are located on the surface of the dress and cuffs. The prototype of the pattern is a lotus. After the abstract simplification of a lotus, the line of the petals and leaves of the lotus is extended using the fractal algorithm and finally forms a palindromic structure. After printing the graphic patterns on the clothes, the combination with the earthy brown color gives the clothes an overall atmospheric and serene appearance. The palindromic structure created by the fractal algorithm in the graphic pattern also adds luck to the overall appearance of the clothes.

6. Conclusion

This article briefly introduced fractal theory and its application in the field of clothing design. The CNN algorithm was used to assist in the evaluation of clothing designs. In the case analysis, the accuracy of the CNN algorithm was verified by comparing it with SVM and BP algorithms. The results of the evaluation of the proposed design are summarized below. (1) In the comparison experiment on the test set, the CNN algorithm had the highest evaluation accuracy, followed by the BP algorithm, and the SVM algorithm had the lowest. (2) The evaluation accuracy of the CNN algorithm was further verified in the proposed clothing design. (3) According to the analysis of the human evaluation and CNN evaluation results, the proposed clothing design effectively used fractal theory to achieve design innovation.

Conflict of Interest

The authors declare that they have no competing interests.

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Dan Li https://orcid.org/0009-0003-4557-8957

She is currently an associate professor of the School of Art and Design of Harbin University. She graduated from Xi'an Engineering University. Her research interests include clothing design, etc. She has published more than 20 papers, 5 textbooks and monographs, and presided over nearly 10 provincial-level scientific research projects.

Chengjun Yuan https://orcid.org/0009-0001-6377-7285

He is a professor of the School of Information Engineering of Harbin University. He graduated from Northeast Normal University. His main research direction is the theory and application of differential equations. He has presided over and participated in the completion of multi-directional scientific research projects such as the National Natural Science Foundation of China and the Natural Science Foundation of Heilongjiang Province. He has published many monographs and textbooks, and more than 50 papers such as SCI and EI. He has won many awards such as the Heilongjiang Provincial Science and Technology Award, served as the executive director of the Heilongjiang Provincial Mathematics Society, and part-time master's tutor of Heilongjiang University and other universities.