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Application of Deep Learning in Computer Aided Jewelry Product Design

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Abstract. Computer-aided jewelry design is one of the commonly used expression methods in the stage of modern jewelry design. Due to the rapid growth of computer-aided manufacturing technology, using computer to design and making jewelry samples through jewelry rapid prototyping equipment has developed into an important link for jewelry enterprises to develop products. In this study, deep learning (DL) and computer-aided design (CAD) technologies are applied to jewelry product design, and a three-dimensional modeling algorithm of jewelry products based on convolutional neural network (CNN) is proposed, so as to realize intelligent computer-aided jewelry product design. The test results show that the algorithm is simple, excellent in performance, capable of extracting the object contour and accurately obtaining the object boundary. The number of test samples began to increase, and the image recognition errors of different recommended methods showed a downward trend. However, compared with the traditional support vector machine (SVM) and back propagation neural network (BPNN), the image recognition error of this method is obviously lower. Parametric design can not only reduce the designer's time cost, but also achieve many design effects that traditional jewelry modeling can't achieve.

Keywords: Computer Aided Design; Jewelry Design; Deep Learning; Image Recognition.
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1 INTRODUCTION

With the change of product market from seller to buyer, the function of products is no longer the most important factor for consumers to decide whether to buy or not, and the accuracy of product

positioning, innovation, aesthetic appearance and pleasant use are paid more and more attention [1]. People's living standard and consumption level are constantly improving, the jewelry market has a bright future, and foreign brands are constantly stationed in China, which stimulates the fierce competition in China's jewelry market and increases the competitive pressure of jewelry enterprises [2]. If an enterprise wants to be bigger and stronger, independent R&D design is the key factor to establish its core competitiveness. Computer-aided jewelry design is one of the commonly used expression methods in the stage of modern jewelry design. With the rapid growth of computer-aided manufacturing technology, using computer to design and making jewelry samples through jewelry rapid prototyping equipment has developed into an important link for jewelry enterprises to develop products [3]. With the increasingly perfect and widely used design automation technology, the efficiency and level of product design have been greatly improved. However, according to the idea, method and innovative design thinking mode of modern industrial design, and starting from the market demand, the overall design of the product in terms of its functional structure, appearance, man-machine performance and working environment is still immature in both theory and method [4].

In computer-aided jewelry design, the use of software, like hand-painting, is an intuitive way to show the designer's thinking, and it is also a visual communication to express jewelry language. In the stage of drawing and designing, on the one hand, it is accurate, efficient and rigorous in technical level, and on the other hand, it is exquisite in jewelry form aesthetics and jewelry technology [5]. Parametric design method is a self-contained system, which can combine many design factors into jewelry design schemes, thus becoming a medium that links other disciplines with jewelry design, and transforming it into a brand-new design method.

In computer-aided jewelry design, the use of software, like hand painting, is an intuitive way to show designers' thinking, and also a visual communication to express jewelry language. In the drawing and design stage, on the one hand, it is accurate, efficient and rigorous in technical level; on the other hand, it is exquisite in jewelry form aesthetics and jewelry technology. Parameters determine the change rules of the design system. This relationship and its variability bring great controllability to the design. When the design conditions or ideas change, the model itself will not change, and the established parametric logic relationship will not change. When different parameter values are input, the final results will change accordingly due to the existence of the initial relationship. Designers are always willing to imitate the form of nature, but compared with the complexity of nature itself, this imitation is still not enough to achieve perfect results. Parametric design has many applications in jewelry design, such as parametric control of existing jewelry shape, parametric design of jewelry structure nodes, parametric fractal study of jewelry surface effects, etc. Parametric design can not only reduce the time cost of designers, but also achieve many design effects that cannot be achieved by traditional jewelry modeling. This research applies DL and CAD technology to jewelry product design, and proposes a 3D modeling algorithm for jewelry products based on CNN to achieve intelligent computer-aided jewelry product design.

In this study, a parametric design model of jewelry products based on DL and CAD is constructed, and its main innovations are as follows:

(1) In this paper, feature extraction and modeling of jewelry images are carried out by CNN, and most of the noise background is removed by morphological gradient operation, so as to obtain the edge boundary of ceramic images.

(2) The parametric design method of jewelry products based on DL and CAD can effectively solve the problem that the image is not clear and stereo enough, and keep the clarity of jewelry products' image.

2 RELATED WORK

Parameters determine the change rules of the design system. This relationship and its variability bring great controllability to the design. When the design conditions or ideas change, the model itself will not change, and the established parametric logic relationship will not change. Liu and Yang [6] designed an innovative teaching mode of contemporary art computer-aided design, aiming to explore an open learning mode based on the Internet. According to the principle of modular design, the innovative teaching mode of contemporary art computer-aided design adopts the MVC three-tier architecture mode based on B/S. This article selects Microsoft's ASP computer assistance. NET technology, as the development language of the innovative teaching mode of contemporary art CAD, constructs the innovative teaching mode of information service based on IIS server. When different parameter values are input, the final result will change accordingly due to the existence of the initial relationship. Although ionic liquids (IL) have been widely used as solvent for fuel oil extraction desulfurization (EDS), systematic research on the optimization design of IL is still rare. The UNIFAC-IL model was first extended to describe an EDS system based on detailed experimental data. Then, based on the UNIFAC-IL model and group contribution model obtained for predicting the melting point and viscosity of ionic liquids, Song et al. [7] proposed a mixed integer nonlinear programming (MINLP) problem for computer aided ionic liquid design (CAILD). Considering the constraints of IL structure, thermodynamics and physical properties, the MINLP problem was solved to optimize the liquid-liquid extraction performance of IL in EDS system with a given multi-component model. Tamke et al. [8] established a new architecture design practice that can be based on machine learning methods to better utilize data rich environments and workflows. By referring to recent architectural research, we describe the application of machine learning throughout the design and manufacturing process to develop various relationships between design, performance and learning. In two cases, the author evaluated the impact of machine learning on performance-based design and manufacturing practices. Then, we summarize the current restrictions on wider application, and provide prospects and directions for future research on machine learning in architectural design practice. In order to improve the efficiency of gem design and manufacturing, Xu et al. [9] proposed a new computer aided design (CAD) method for convex facet gem cutting (CFGC) based on half edge data structure (HDS). It includes the implementation algorithm, the classification of the geometric elements of CFGC, and the establishment of the corresponding geometric feature class. Each class is implemented and embedded based on gem procedure. The affine transformation and cutting algorithms are derived using matrix algorithm and analytic geometry. Based on the demand for diversity of gem cutting, the parametric design of free facet cutting and typical cutting as well as the CAD functions of visualization and human-computer interaction (including 2D and 3D interaction) of CAD system have been realized, which enhances the flexibility and universality of CAD system. Computer aided design technology has been widely used in the field of dental prosthetics. Embedment is a common type of restoration to reconstruct partially damaged teeth and restore occlusal function. The occlusal surface designed by Zhang et al. [10] should conform to the anatomical structure of each defect area, and the modeling process should be effectively used for clinical application. This paper presents a robust two factor constrained deformation framework for dental inlay modeling. Tooth surface segmentation is carried out by sampling ray tracing collision, and occlusal surface reconstruction based on two factor constraint deformation is realized by defining segmentation constraint and cavity contour constraint.

In design thinking, designers want to use parametric design, but also cultivate their own parametric design thinking. In this paper, taking jewelry product design as the breakthrough point, feature extraction and modeling of jewelry product images are carried out through CNN, so as to avoid the sample blocks with a large number of unknown pixels from being processed, thus realizing computer-aided jewelry product design.

3 METHODOLOGY

3.1 Design Elements of Jewelry Products

Jewelry products, as ornaments of people's clothes and appearance, have basically become the necessities of people's daily decoration. In the face of consumers with increasingly strong personalized demand, designers need to start with the shape, materials, technology, functions and other aspects of jewelry, so as to make it diversified and promote the growth of jewelry. In the innovative technology promotion mode, the growth of science and technology and its application in industry will definitely promote product innovation. A major breakthrough in science is the motive force of innovation, and it is the fundamental motivation that drives the emergence and growth of technological innovation activities. Material is the carrier of all products, and each material has its own character. Many visually appealing works of art pay more attention to the language expression value of the material itself. Different materials play a crucial or even decisive role in the style of jewelry, which requires designers to design and process their materials in a targeted manner, and finally achieve unexpected results. In terms of product appearance, beauty is still a factor that can't be ignored. Intelligent jewelry often adopts simple modeling design, which endows it with scientific and technological features on the basis of beauty, so that it can meet the basic needs of people's intelligent life in addition to its decorative function.

Traditional jewelry is often restricted by technology, which makes some ideas impossible to realize. Nowadays, technology and technology will no longer be the factors that limit the realization of creativity. Compared with technology promotion, market demand is a more important power source to stimulate enterprises' technological innovation activities. In the manifestation of jewelry products, the shapes, materials and techniques are all integrated with modern science and technology, and new shapes with a sense of science and technology are tried by using high-tech materials and techniques. In modern enterprises, product innovation is a complex process, and it is not clear that a certain factor is the only or most basic determinant of innovation activities. Therefore, for product innovation design, a product innovation model of technology promotion and market promotion is adopted. Product innovation takes the potential market demand as the starting point and technology application as the support, and its innovation results are often to develop brand-new products, thus activating the potential market into a realistic market. The existing smart jewelry products in the market mainly include medical health, safety precautions, sports and fitness, etc. Some products also have online payment, audio and video recording and other functions, but the homogenization is relatively serious. The future growth of intelligence must grasp the core needs of consumers, abandon the previous pursuit of comprehensive functions, and instead carry out targeted design, so that products can meet the needs of consumers, reduce the purchase cost of consumers, and thus increase the market share.

3.2 Parametric Design Model of Jewelry Products Based on CNN

In the past, the traditional jewelry technology can achieve good results in the corresponding fields until now, but no matter which technology has its own limitations. Many rich sense of order and high-precision three-dimensional forms can hardly be realized by human hands. Combining parametric design with jewelry design, it's important to be familiar with the method of parametric design, so that jewelry design works can be transformed from two-dimensional drawing effect into a product of data combination, and jewelry creation can be carried out through the adjustment of parameter variables, in which data is the key of design, and the programming mode of parametric design is the medium of design. Innovation is to conceive a new working principle of the product, and find out a new original understanding with market competitiveness and practical realization possibility for the target function of the product. Science plays an important role in design, and each effect may correspond to a solution to a design problem. The DL model of computer-aided jewelry product design is shown in Figure 1.

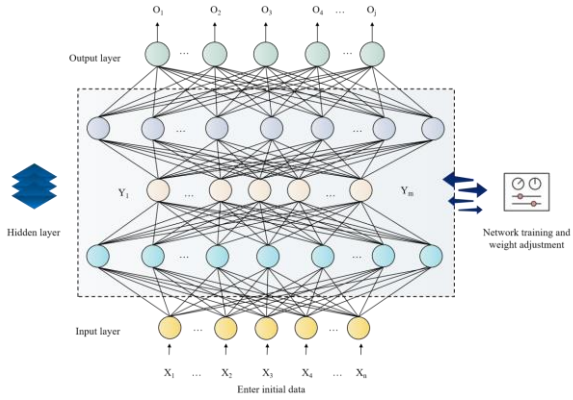

Figure 1: DL model of computer-aided jewelry product design.

With the help of parametric design method, by changing some data or some data in the program, the relevant parts of the design model can be changed automatically, thus realizing the driving of the design model by parameters, in which the geometric information and topological information needed for driving are automatically extracted by the computer. Assuming that the jewelry product image is represented as an d -dimensional feature vector, the features of two given images are:

$$x=\left(x_1,x_2,\ldots,x_d\right)^T \tag{1}$$

$$y=\left(y_1,y_2,\ldots,y_d\right)^T \tag{2}$$

The cosine of the angle between them can be used as a similarity measure:

$$Sin_t\left(x,y\right)=\frac{x\cdot y}{\|x\|\|y\|} \tag{3}$$

The distance between two histograms can be measured by histogram subtraction:

$$D_h\left(x,y\right)=\frac{\sum_i^d \min\left(x_i,y_i\right)}{\min\left(\sum_i^d x_i,\sum_i^d y_i\right)} \tag{4}$$

Minkowski distance is defined as:

$$D_p\left(x,y\right)=\left(\sum_{i=1}^d\left|x_i-y_i\right|^p\right)^{1/p} \tag{5}$$

In order to distinguish the functions of different feature components in similarity measurement, they are often weighted:

$$D_1\left(x,y,w\right)=\sum_{i=1}^d w_i\left|x_iy_i\right| \tag{6}$$

Let the gray value range of the original image $f\left(x,y\right)$ be $\left(g_{\min},g_{\max}\right)$, choose a suitable threshold T, and:

$$g_{\min} \le T \le g_{\max} \tag{7}$$

Image segmentation with a single threshold can be expressed as:

$$g(x,y) = \begin{cases} 1, & f(x,y) \ge T \\ 0, & f(x,y) < T \end{cases} \tag{8}$$

$g(x,y)$ is a binarized image. The object can be easily revealed from the background through binarization. The key to image binarization is the reasonable selection of the threshold T.

When the designer starts a design task, the general demand analysis begins. The design task and the engineering characteristics of the product are obtained by comprehensively analyzing the customer's demand and production conditions, and the design problem is redefined from an appropriate angle according to the results of the demand analysis. According to the different angles of design problems, different innovative strategies, innovative tools and innovative methods are adopted, combined with various knowledge and information, and finally the innovative conceptual scheme is obtained. The image recognition stage of computer-aided jewelry product design based on CNN is shown in Figure 2.

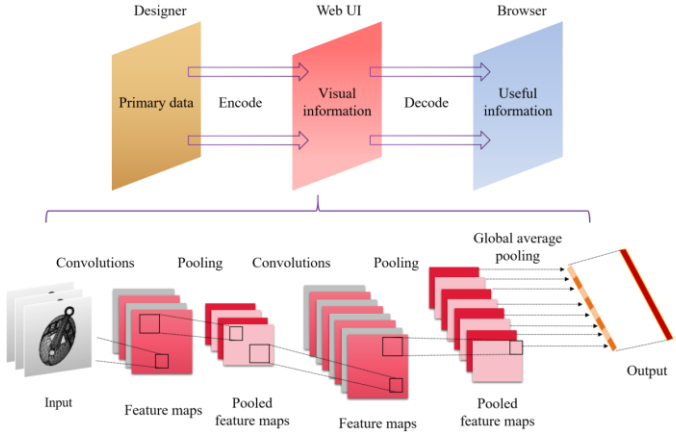

Figure 2: CNN model.

For a digital image, $p(i)$ is the histogram probability of the image, i is the gray value of the image, $0 \le i \le L$. The histogram potential function is expressed as follows:

$$P_H(k) = \frac{1}{P_{\max}} \sum_{i=0}^{L} \frac{P(i)}{1+\alpha(i-k)^2} \tag{9}$$

$$P_{\max} = \max\left\{ \sum_{i=0}^{L} \frac{P(i)}{1+\alpha(i-k)^2} \right\} \tag{10}$$

Among them, α is a parameter. Let $I = [f(x,y)]_{m \times n}$ be an array of digital images, where:

$$x \in \{0,1,2,3,\ldots,m-1\} \qquad y \in \{0,1,2,3,\ldots,n-1\} \tag{11}$$

$f(x,y)\in\{0,1,2,3,\ldots,G-1\}$ is the gray value of the pixel at the position (x,y) of the image array; G is the maximum gray value of the image I. The histogram function of image I is defined as:

$$h(i)=\sum_{x=0}^{m-1}\sum_{y=0}^{n-1}\delta(f(x,y)-i)\quad i\in\{0,1,2,3,\ldots,G-1\} \tag{12}$$

In the formula, the function $\delta(0)=1$, $\delta(i\neq 0)=0$. $h(i)$ represents the number of pixels whose gray value is i in the image I.

Generally, the histogram potential around the peak of potential function is relatively large. In order to achieve multi-threshold image segmentation, after finding the peak of the first histogram potential function, it is need to attenuate the first peak to eliminate its influence on finding the second peak. Define the residual potential function of the histogram:

$$P_c(i)=P_{c-1}(i)-p_c^*\frac{1}{1+f_\alpha(i-x_k)^4} \tag{13}$$

$$p_c^*=\max\{P_{c-1}(i)\}\qquad x_k=\{i|P_{c-1}(i)=p_c^*\}\qquad f_\alpha=\left\|\frac{D_H}{2}\right|^2\times\frac{\beta}{C-1}\Bigg|^{-1} \tag{14}$$

Among them, D_H represents the difference between the maximum gray value and the minimum gray value. β is the parameter, and Figure 3 lists the first-order residual potential function of the Lena image after decaying the highest peak.

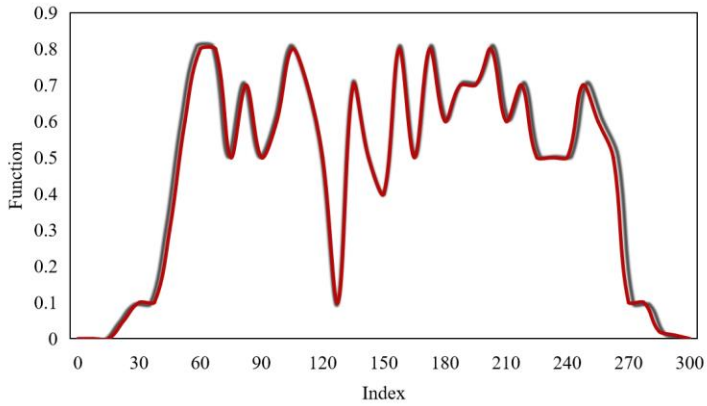

Figure 3: The first-order residual potential function of the image.

Assuming that the input and output functions of jewelry product image feature information are expressed as R and R' respectively, the bilateral filtering discrete form expression of jewelry product image feature information is as follows:

$$R'=[k,j]=\sum_{m=-p}^{p}\sum_{n=-p}^{p}B[m,n,k,j]R[k-m,j-n] \tag{15}$$

Where p represents a pixel of jewelry product image feature information; m represents the variance of jewelry product image feature information; n represents the standard deviation of jewelry product image feature information; $B[m,n,k,j]$ represents Gaussian kernel function of jewelry product image feature information, and its calculation expression is as follows:

$$B[m,n,k,j]=\frac{\exp\left(-\frac{m^2+n^2}{2\sigma_\delta^2}-\frac{R[k-m,j-n]}{2\sigma_\xi^2}\right)}{R(k,j)} \tag{16}$$

Where σ represents the scale parameter of jewelry product image feature information. The above formula is used to smooth the feature information of jewelry product images from geometric and photometric domains, eliminate the influence of noise, and keep the feature details of jewelry product images.

Modeling is generated by data, and the characteristic of parameterization is that as long as the algorithm of an initial model is determined, different design schemes can be quickly obtained by changing these parameters. In design thinking, designers want to use parametric design, but also cultivate their own parametric design thinking. Designers should be familiar with parametric language description, refine jewelry design details to model structure and structure to data, and know which part of the controlled design model each data is, so as to know the construction of parametric logic.

4 RESULT ANALYSIS AND DISCUSSION

With the deepening of social informatization, parametric design has been gradually applied in various design fields. If modern jewelry design industry wants to innovate and develop, it should also introduce new technologies in addition to the innovation of design concepts. In this paper, CNN is used to extract and model the features of jewelry images, and morphological gradient operation is used to remove most of the noise background, so as to obtain the edge boundaries of ceramic images, while keeping the clarity of jewelry images. The training results of different networks are shown in Figure 4.

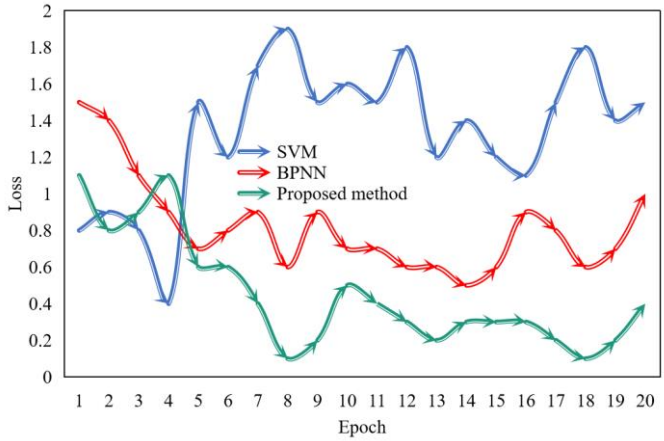

Figure 4: Training experiment results of different networks.

In parametric design, data determines the model, so parameterization itself is full of rational beauty. Every shape and texture of a parametric work is completely controlled by data. Therefore, some rhythmic effects can be realized by parametric design. The accuracy test results of different algorithms are shown in Figure 5. The recall test results of different algorithms are shown in Figure 6.

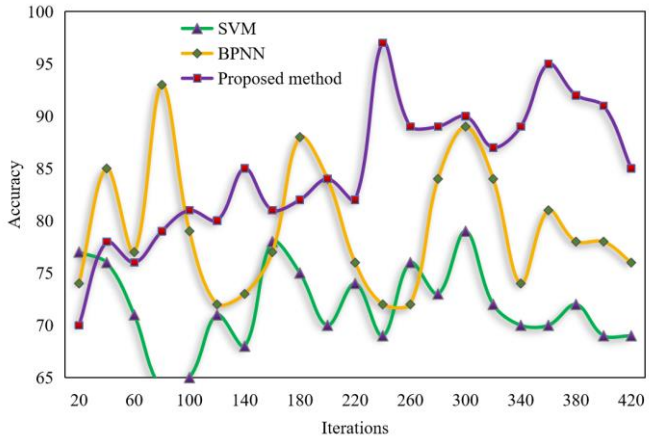

Figure 5: Accuracy test results of different algorithms.

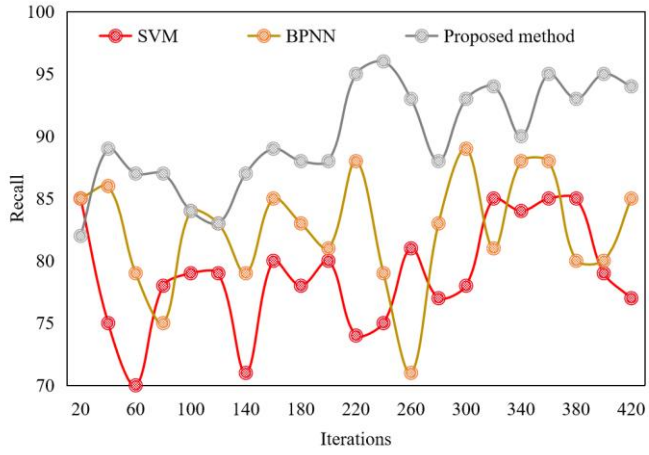

Figure 6: Test results of recall of different algorithms.

It can be seen that the accuracy and recall of this algorithm are at a high level. This algorithm has the advantages of simplicity, excellent performance, good extraction of object contour and accurate boundary. F1 test results of different algorithms are shown in Figure 7.

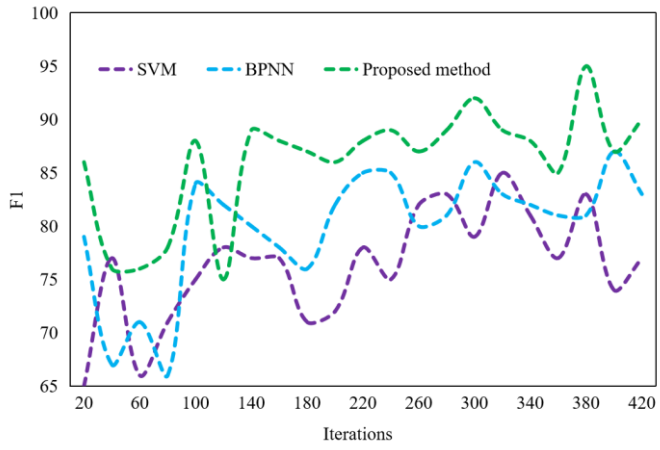

Figure 7: F1 test results of different algorithms.

It can be concluded that the overall performance of this model is better than that of the comparison model. Fusion of different levels of features can provide more context information for the final prediction, and the overall generalization performance of the model is good.

In the stage of CAD, designers need to draw hand-drawn sketches in advance according to the design orientation of jewelry products or customers' needs. On the basis of the sketches, the detailed contents such as shape characteristics, size data, size and quantity of gemstones, color matching, jewelry structure and weight of jewelry are determined. Then, reasonable computer design software is selected to create jewelry models, and software tools are used to complete the construction of jewelry details. The image recognition error of jewelry products is taken as the test index, and the traditional SVM and BPNN are selected as the contrast objects. The experimental results are shown in Table 1 Table 2 and Table 3.

Sample size	*Image recognition error (%)*
50	5.88
100	2.85
150	0.88
200	1.07
250	0.88
300	0.26
350	0.19

Table 1: Image recognition error of jewelry products by this method.

Sample size	*Image recognition error (%)*
50	7.05
100	6.28
150	3.1

200	2.22
250	1.27
300	1.76
350	0.75

Table 2: SVM jewelry product image recognition error.

Sample size	*Image recognition error (%)*
50	8.64
100	7.55
150	5.41
200	5.82
250	3.25
300	3.21
350	2.75

Table 3: BPNN jewelry product image recognition error.

According to the experimental data, when the number of test samples starts to increase, the image recognition errors of different recommended methods all show a downward trend. However, compared with traditional SVM and BPNN, the image recognition error of this method is obviously lower. When the designer gets the corresponding design task or problem to be solved in the design from the requirement analysis, he should decide how to understand the task or problem. Further expanding or narrowing the problem will help the designer to find an appropriate angle to understand the design task, and then make the designer choose appropriate innovative strategies and methods.

5 CONCLUSIONS

With the rapid growth of computer-aided manufacturing technology, designing by computer and making jewelry samples by jewelry rapid prototyping equipment has become an important link for jewelry enterprises to develop products. In computer-aided jewelry design, the use of software, like hand-drawing, is an intuitive way to show the designer's thinking, and also a visual transmission of jewelry language. In this paper, taking jewelry product design as the breakthrough point, feature extraction and modeling of jewelry product images are carried out through CNN, so as to avoid the sample blocks with a large number of unknown pixels from being processed, thus realizing computer-aided jewelry product design. The results show that this algorithm has the advantages of simplicity, excellent performance, better extraction of object contour and accurate boundary. Fusion of different levels of features can provide more context information for the final prediction, and the overall generalization performance of the model is good. The number of test samples began to increase, and the image recognition errors of different recommended methods showed a downward trend. However, compared with traditional SVM and BPNN, the image recognition error of this method is obviously lower. It is not difficult to find that the overall performance of this model is better than that of the comparison model.

In the stage of jewelry design and creation, designers should still follow the principle of high efficiency and use the most appropriate method to design the scheme and choose the shape. I

believe that in the future jewelry design, incorporating parametric design will be an important way of modern jewelry design.

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REFERENCES

[1] Buonamici, F.; Furferi, R.; Governi, L.; Lazzeri, S.; McGreevy, K.-S.; Servi, M.; Volpe, Y.: A practical methodology for computer-aided design of custom 3D printable casts for wrist fractures, The Visual Computer, 36(2), 2020, 375-390. https://doi.org/10.1007/s00371-018-01624-z

[2] Ge, M.; Tian, Y.; Ge, Y.: Optimization of Computer Aided Design System for Music Automatic Classification Based on Feature Analysis, Computer-Aided Design and Applications, 19(3), 2021, 153-163. https://doi.org/10.14733/cadaps.2022.S3.153-163

[3] Hinz, S.; Bensel, T.; Bömicke, W.; Henningsen, A.; Rudolph, J.; Boeckler, A.-F.: Impact of the Veneering Technique and Framework Material on the Failure Loads of All-Ceramic Computer-Aided Design/Computer-Aided Manufacturing Fixed Partial Dentures, Materials, 15(3), 2022, 756. https://doi.org/10.3390/ma15030756

[4] Jin, H.; Yang, J.: Using Computer-Aided Design Software in Teaching Environmental Art Design, Computer-Aided Design and Applications, 19(1), 2021, 173-183. https://doi.org/10.14733/cadaps.2022.S1.173-183

[5] Lim, L.-A.; Keles, H.-Y.: Foreground segmentation using convolutional neural networks for multiscale feature encoding, Pattern recognition letters, 112(9), 2018, 256-262. https://doi.org/10.1016/j.patrec.2018.08.002

[6] Liu, F.; Yang, K.: Exploration on the Teaching Mode of Contemporary Art Computer Aided Design Centered on Creativity, Computer-Aided Design and Applications, 19(S1), 2021, 105-116. https://doi.org/10.14733/cadaps.2022.S1.105-116

[7] Song, Z.; Zhang, C.; Qi, Z.; Zhou, T.; Sundmacher, K.: Computer-aided design of ionic liquids as solvents for extractive desulfurization, AIChE Journal, 64(3), 2018, 1013-1025. https://doi.org/10.1002/aic.15994

[8] Tamke, M.; Nicholas, P.; Zwierzycki, M.: Machine learning for architectural design: Practices and infrastructure, International Journal of Architectural Computing, 16(2), 2018, 123-143. https://doi.org/10.1177/1478077118778580

[9] Xu, L.; Li, X.; Rao, J.; Han, Y.; Li, Z.; Li, J.: Computer aided design technology for convex faceted gem cuts based on the half-edge data structure, J Beijing Inst Technol, 28(101), 2019, 03. https://doi.org/10.15918/j.jbit1004-0579.18053

[10] Zhang, C.; Liu, T.; Liao, W.; Tao, Y.; Jiang, L.: Computer-aided design of dental inlay restoration based on dual-factor constrained deformation, Advances in Engineering Software, 114(12), 2017, 71-84. https://doi.org/10.1016/j.advengsoft.2017.06.005