Multi-scale Wavelet Transform Based Optimization of Edge Detection Algorithm for Package Design Process

Min Zhao[1] and Hua Tian[2]

[1]Department of Art and Design, Shanxi Technology And Business College, Taiyuan 030006, China, zhaomin@sxtbu.edu.cn
[2]Department of Art and Design, Shanxi Technology And Business College, Taiyuan 030006, China, tianhua@sxtbu.edu.cn

Corresponding author: Min Zhao, zhaomin@sxtbu.edu.cn

Abstract. In order to promote the application of computer-aided design (CAD) and virtual reality (VR) in package design, this article puts forward an edge detection algorithm for packaging images based on multi-scale wavelet transform (WT), and uses the multi-scale method of wavelet local modulus maxima to detect edges, so as to optimize the package design process. According to the design requirements of the best edge filter, the selection criteria of wavelet bases for edge detection are determined. In the process of using local maximum of wavelet modulus, aiming at the selection of local maximum, the modulus maximum is calculated along the gradient direction. The results show that the WT algorithm in this article shows high efficiency in optimizing packaging images. It can effectively control the noise of the image, enhance the definition of the image outline and improve the contrast of the image. Moreover, compared with the traditional algorithm, this algorithm has significantly improved the recall and accuracy of product packaging image feature detection. The method in this article has obvious advantages in realizing VR presentation and user experience of package design, mainly in the aspects of good image processing effect, strong interactivity and immersion, and high algorithm efficiency.

Keywords: Computer Aided Design; Virtual Reality; Package Design; Edge Detection
DOI: https://doi.org/10.14733/cadaps.2024.S12.236-250

1 INTRODUCTION

In the field of package design, the application of CAD software effectively enhances the visual perception of product packaging, shortens the package design cycle, and reduces package design costs. Wavelet analysis is a multi-scale analysis tool that can provide information at different scales and has a good response to edges in images. By utilizing the characteristics of wavelet analysis, we can perform multi-scale decomposition of images and detect edges at different scales.

Through this approach, we can capture edge information at different scales and enrich the details of edge detection. Edge detection is a key step in optimizing packaging design. By accurately detecting edges in images, tasks such as image segmentation and feature extraction can be effectively carried out, further achieving automation and intelligence in packaging design. Berni and Borgianni [1] proposed a new approach for edge detection using multi-scale methods based on wavelet local modulus maxima. Firstly, we use wavelet transform to perform multi-scale decomposition of the image and obtain wavelet coefficients of different scales. Then, local modulus maximum detection is performed on the wavelet coefficients to identify edge information in the image. The local modulus maximum referred to here refers to the situation where the wavelet coefficients at a certain point are either maximum or minimum in the local range within the wavelet domain, which usually corresponds to the edges of the image. Package design not only has the function of commodity application, but also has the artistic pursuit of beauty. The product it creates is the result of the dual influence of material and spirit. The product is an artistic creation that uses external materials to reflect internal spiritual activities. Traditional edge detection methods, such as Sobel, Canny, etc., mainly detect edges based on changes in pixel values, but these methods may not perform well when dealing with complex images. In contrast, clifford algebra can better handle this situation because it can describe the geometric relationships between pixels, thereby better detecting edges. Bhatti et al. [2] conducted experiments using a set of satellite images. In the experiment, we compared this method with traditional edge detection methods. The experimental results show that this method has higher accuracy and robustness in detecting edges in satellite images. Especially for complex images, the performance of this method is significantly better than traditional methods. The advanced color edge detection method based on clifford algebra has broad application prospects in satellite image processing. Firstly, this method can be used to identify and segment target objects in satellite images, such as buildings, vegetation, etc. Secondly, this method can be used in fields such as map production, terrain analysis, and land resource survey. In addition, this method can also be used to monitor natural disasters and environmental changes. In summary, the advanced color edge detection method based on clifford algebra provides a new and effective means for satellite image processing. A package design work is both a material product and a spiritual product, and it is an artistic creation that reflects people's spiritual activities through surface materials. In addition to its function, package design is also one of the elements. If packaging does not bring people the enjoyment of beauty, then this commodity will lose its due value. In order to repair these images, researchers have proposed various algorithms and techniques. However, most methods often overlook the edge information of the image while repairing it, resulting in the repaired image losing its original shape and structure. To address this issue, Chen et al. [3] proposed a multi-scale image patching GAN (MS-EBGAN) with edge detection. This method not only effectively repairs the image, but also preserves and enhances the edge information of the image. In the edge detection stage, we adopted an algorithm based on convolutional neural networks (CNN). This algorithm first performs multi-scale decomposition on damaged or missing images to extract features at different scales. Then, it uses these features to train a deep learning model and predict the edge information of the image. VR technology provides strong support for designers to create and experience the virtual world of commodity packaging. Applying virtual technology to the CAD design of commodity packaging can not only enable designers to give full play to their design intentions, but also bring consumers into this virtual world full of artistic atmosphere and give them a brand-new visual experience. Insulators are an important component of the power system, and the detection of their waterproof performance is one of the key links to ensure the safe operation of the power system. The algorithm for edge detection of insulator waterproof images is one of the effective means to achieve this detection task. Ding and Nan [4] introduced an edge detection algorithm for insulator waterproofing images that considers effective methods, aiming to improve detection efficiency and accuracy. In order to verify the accuracy and robustness of the algorithm proposed in this article, a series of experiments were conducted. The experimental results show that compared to traditional edge detection algorithms, this algorithm can more effectively detect the edge information of insulator waterproof images, improving detection efficiency and accuracy. At the same time, this algorithm has good adaptability to different environmental conditions and insulator types, and has broad application prospects.

Faheem et al. [5] using LSB and smart edge detection techniques to create image watermarks is effective. This technology can achieve good watermark effects. Due to this technology, watermark information is hidden in the least significant bit of the image. Therefore, it can ensure the concealment of the watermark while avoiding any impact on the visual effect of the image. The use of LSB and smart edge detection technology to create image watermarks has good results. In terms of objective evaluation, this technology exhibits high robustness and transparency. After a series of image processing operations, the watermark can still maintain good integrity while having little impact on the visual effect of the image. In addition, by extracting edge information from images, this technology can enhance the robustness and detectability of watermarks. Therefore, LSB and smart edge detection technology are suitable for watermark production in digital images, and have important application value and broad application prospects. In future research, we will further explore how to improve the robustness and transparency of LSB and smart edge detection techniques to adapt to more complex image processing environments. In addition, we will also study how to apply this technology to other fields, such as video watermarking, audio watermarking, etc., in order to expand its application scope. The traditional package design process usually relies on manual operation, which is not only time-consuming, but also designers may have deviations in understanding product characteristics and market demand, which may lead to a decline in the success rate of package design and increase the design cost. The introduction of CAD and VR technology brings the possibility of innovation for package design, which enables designers to design more efficiently and reduces costs and risks. CAD can improve the efficiency and accuracy of design. However, most of the existing CAD software focuses on the creativity and aesthetics of design, while ignoring the cost and productivity of design. The introduction of VR technology can provide a realistic and three-dimensional package design environment for designers, so as to better predict the appearance and performance of products. However, how to effectively use these technologies to optimize the package design process still needs further discussion. In this article, an edge detection algorithm of packaging image based on multi-scale WT is proposed to solve the above problems. WT is a tool widely used in image processing, which can analyze image information on different scales. By using wavelet local modulus maxima multi-scale method for edge detection, the edge information of packaging images can be identified more accurately and quickly. In addition, this method can also automate the complicated package design process, thus reducing the workload of designers and improving the design efficiency.

In computer-aided package design, edge detection of packaging image is a key link. Accurate and fast edge detection methods can effectively reduce design time, improve design efficiency, and help to achieve more accurate cost estimation and prediction. In essence, edge pixels refer to the sharp change of gray level in the local image (called singular points), so the image edge is the set of singular points in the two-dimensional image. Important visual information such as object shape, object boundary, position occlusion, shadow outline and surface texture all have edges in the image. WT is a tool widely used in image processing, and its multi-scale characteristics make it have a good effect on edge detection. Because WT has good local characteristics and multi-scale characteristics, it can meet the needs of extracting edges on multiple scales, so applying WT to image edge detection is considered to be an effective method. In this article, an edge detection algorithm of packaging image based on multi-scale WT is proposed, which further optimizes the package design process. The research includes the following innovations:

(1) In this article, VR technology is introduced into the package design process. By establishing a realistic three-dimensional package design environment, designers can feel and predict the appearance and performance of products more intuitively, so as to better meet the market demand.

(2) By combining CAD and VR technology, the precision and automation in the process of package design are realized, which reduces the workload and cost of designers and improves the efficiency and quality of design.

(3) A new packaging image edge detection algorithm based on multi-scale WT is proposed.

The structure of this article is as follows:

The first section introduces the application and advantages of CAD and VR technology in package design.

The second section discusses the theoretical basis of CAD and VR technology and the feasibility of its application in package design.

The third section introduces the principle and implementation process of edge detection algorithm of packaging image based on multi-scale WT.

In the fourth section, the edge detection algorithm of packaging image based on multi-scale WT is verified and analyzed experimentally.

The fifth section summarizes the main contributions and research results of this article, and looks forward to and discusses the future research direction.

2 THEORETICAL BASIS

With the rapid development of deep learning and neural networks, recurrent neural networks (RNNs) have shown strong capabilities in processing temporal data and sequence information. Especially 3D RNN, which models sequence information in 3D space, has been widely used to handle complex 3D global feature learning tasks. Han et al. [6] detailed how to use 3D RNN technology to learn 3D global features and aggregate sequence views with attention. 3D RNN is a special type of RNN that better processes sequence data with spatial information by establishing models in three-dimensional space. It can consider the correlation of input sequences in three dimensions, thereby more accurately learning and predicting sequence information. In terms of aggregating sequence views with attention, we first need to define sequence views. Sequence view refers to the transformation of sequence data from the time dimension to the spatial dimension, where each data point corresponds to a spatial vector. Next, we use an attention mechanism to aggregate these spatial vectors, obtain the weights of attention, and reconstruct the sequence view based on them. Attention mechanism can help us automatically learn the focus and importance of data when processing sequence data. Image edge detection is one of the key technical issues in the fields of image processing and computer vision, aiming to quickly and accurately locate and extract image edge feature information. Traditional image edge detection methods are mainly based on the first and second derivatives of image strength. These methods determine the position and intensity of edges by calculating the gradient or second-order derivative of local areas in the image. Although these traditional methods have made significant progress, their limitations are also evident, such as sensitivity to noise, high computational complexity, and loss of edge strength. With the development of deep learning technology, especially the emergence of convolutional neural networks (CNN), image edge detection methods based on deep learning have become a new trend. Li and Qu [7] will review the research status and development trends of image edge detection algorithms based on deep learning. Machine learning technology can optimize and improve existing designs, improving their efficiency and accuracy. For example, machine learning can analyze a large number of architectural drawings, automatically extract various design elements, and automatically generate the best architectural design scheme, greatly reducing the time and effort required for manual design. Machine learning can also extract various design elements from a large number of artworks, providing creative inspiration for artists and designers. Liow et al. [8] used this edge detection method based on wavelet local modulus maxima to process different packaging design images, verifying its effectiveness and superiority. The experimental results show that this method can accurately and efficiently detect edges in images, which has positive significance for optimizing the packaging design process. In summary, the edge detection method based on wavelet local modulus maximum is an effective image processing tool that can be applied to packaging design images of different scales and types.

The cuckoo algorithm is an optimization algorithm based on bird swarm behavior, which has advantages such as strong global search ability and fast convergence speed. In order to further improve the performance of the algorithm, Liu et al. [9] proposed an improved cuckoo algorithm based on quaternion. This algorithm introduces quaternions into the Rhododendron algorithm and improves its global search ability and convergence speed by adjusting the population position and speed. Specifically, we defined an individual position represented by a quaternion and introduced a new velocity variable to control the updating of individual positions. The experimental results show that the improved Rhododendron algorithm based on quaternion has better performance in edge detection of color drone images. Specifically, this algorithm can detect more real edges while reducing the number of false and missed detections. In addition, the running time of this algorithm is also shorter than traditional methods, and it has good real-time performance. Remote sensing image edge detection is one of the important tasks in remote sensing image processing, which is of great significance for subsequent applications such as object detection, image segmentation, and change detection. High resolution remote sensing images have rich details and information, but they also bring higher noise and complexity. Therefore, how to accurately and efficiently detect their edges has become a challenging problem. Liu et al. [10] proposed a high-resolution remote sensing image edge detection method based on super-pixel and dual threshold edge tracking, aiming to improve detection efficiency and accuracy. Hyperpixel is an image processing technology based on pixel clustering, which reduces the dimensionality of the image and improves processing efficiency by combining adjacent pixels into super-pixels. The main applications of super-pixels include image segmentation, object detection, feature extraction, etc. Double threshold edge tracking is a method of edge detection based on image edge information. By setting two thresholds to detect coarse-grained and fine-grained edge information, more accurate edge detection results can be obtained. Intelligent packaging is an important trend for future development, which will continuously optimize supply chain management, improve user experience, and enhance product safety. With the continuous emergence and application of new technologies, intelligent packaging will have more innovation and development, bringing broader application prospects and commercial value to modern enterprises. Therefore, modern enterprises need to actively explore and research intelligent packaging technology to enhance their competitiveness and sustainable development capabilities. Lydekaityte and Tambo [11] utilize RFID technology to achieve precise tracking and management of individual or batch products, improving supply chain transparency and efficiency. By using QR codes, invisible codes, and other means, product information is connected to digital platforms, making it convenient for consumers to search for detailed product information and trace its source. Utilize AR/VR technology to enable packaging to interact with consumers and provide a richer product experience.

Pelliccia et al. [12] validated the application effect of 3D factory simulation software in computer-aided participatory design of industrial workplaces and processes. With the assistance of simulation software, engineers successfully detected potential problems in the early design stage and made timely corrections. In addition, the visualization function of the software also helps designers better communicate with the production department, achieving more efficient design feedback and improvement. In the end, the construction and operation of this new factory achieved significant success, with production efficiency higher than expected and stable operation. In summary, 3D factory simulation software has significant advantages in computer-aided participatory design of industrial workplaces and processes. It can improve design efficiency and accuracy, enhance design maintainability, and provide more efficient collaboration methods. Through the analysis of actual cases, we can see the key role played by 3D factory simulation software in optimizing design and production processes. High degree of wrapping dough forming machine is an important food processing equipment widely used in the production of bread, biscuits, and other food products. This device can wrap dough inside the mold and produce various shapes and specifications of food through compression and molding. In order to improve the production efficiency and manufacturing accuracy of equipment, Salahuddin et al. [13] introduced how to use three-dimensional computer-aided design (CAD) for conceptual design and finite element analysis. In terms of mechanical structure, it is necessary to consider the main components such as dough bin, mold cavity, hydraulic system, conveyor belt, etc. The dough bin is used to store dough, while the cavity determines the shape of the food produced. The hydraulic system is used to provide the required pressure for molding, and the conveyor belt is responsible for delivering the formed food. By using CAD software, the shape and size of these components can be accurately designed, and their working state can be simulated to obtain the optimal structural design. Saleh et al. [14] explored the importance of computer-aided design in high-quality product design. Throughout the entire process of product design, computer-aided design plays a huge role. Firstly, CAD software can help designers quickly obtain design results. Compared to traditional manual drawing, CAD software has higher accuracy and efficiency. Designers can quickly complete the construction and detailed design of product structures through simple drag and drop operations. In addition, CAD software also provides powerful rendering capabilities, allowing designers to preview the appearance and effects of products in the early stages of design, in order to optimize and adjust them in a timely manner. Computer aided design is also widely used in product appearance design. Through CAD software, designers can easily adjust and optimize the shape, color, and material of products. At the same time, CAD software can also perform rapid prototyping, allowing designers to quickly translate design concepts into actual products for better evaluation and improvement of design. On the basis of noise estimation, Singh et al. [15] further trained a denoised CNN model. This model takes the original noisy CT image and the estimated noise type as inputs, and updates the weights through a backpropagation algorithm to achieve the denoising target. The CNN model adopts a residual structure, effectively solving the problem of gradient vanishing during deep network training. In addition, we have introduced batch normalization and dropout techniques to improve the robustness and generalization ability of the model. To verify the effectiveness of this method, we collected multiple sets of CT image data, including images of the lungs, liver, and kidneys. We added noise to these images and used this method for denoising. The experimental results show that this method can effectively remove noise in CT images, significantly improving the quality of images and diagnostic accuracy. Compared with traditional denoising methods, this method has better performance and higher robustness.

Image edge detection is an important task in the field of computer vision, with the aim of identifying the contours of objects in the image and providing key information for subsequent processing such as image analysis, object detection, and tracking. With the development of deep learning technology, image edge detection methods based on deep learning have made significant progress. Versaci and Morabito [16] review a new method based on fuzzy entropy and fuzzy divergence, aiming to provide reference for researchers in related fields. Edge detection is a technique that determines the position of image edges by identifying changes in pixel intensity in the image. Traditional methods such as Sobel and Canny use image gradients or filter responses to detect edges, but these methods have poor performance in processing complex images. To overcome this problem, researchers introduced the concepts of fuzzy entropy and fuzzy divergence. In engineering and science, the fracture and fatigue behavior of materials are key research areas. Especially for materials in complex stress states, such as bridge structures, pressure vessels, etc., their fracture behavior is particularly related to the safety and stability of the structure. Cross valley edge cracks are a common crack morphology in fracture mechanics, and their identification and prediction are of great significance for preventing structural failure. However, due to the complexity and diversity of material fracture, accurate identification of cross valley edge cracks remains a challenging issue. In recent years, fractional differential multiscale analysis methods have been widely applied in image processing, providing new ideas for solving this problem. Wang et al. [17] designed a cross valley edge crack image recognition method using fractional differential multiscale analysis, combined with support vector machines and deep learning algorithms. Through comparative experiments, this method exhibits good accuracy and efficiency in processing cross valley edge crack images. The traditional methods for coal gangue image segmentation mainly include threshold-based methods, edge detection-based methods, and region growth based methods. Among them, the threshold-based method divides the image into different regions by setting different thresholds, but this method is susceptible to factors such as noise and lighting. Wang et al. [18] used an edge detection-based method to separate different regions by detecting edge information in the image, but this method did not achieve ideal segmentation results for complex background images. The method based on region growth aggregates adjacent pixels to form different regions, but it is difficult to distinguish the features of different regions. With the development of computer technology, some emerging algorithms are gradually being applied to coal gangue image segmentation, such as deep learning-based algorithms and wavelet transform based algorithms. These emerging algorithms can automatically and accurately segment coal and gangue in coal gangue images, but they require a large amount of training data and have high computational complexity and poor real-time performance. With the continuous development of digital image processing technology, image manipulation detection technology has become a research hotspot. Image manipulation detection aims to detect whether an image has been tampered with or manipulated, including adding, deleting, moving, or modifying parts of the image. This type of technology is widely used in fields such as image authentication, security monitoring, and digital watermarking. However, traditional image manipulation detection algorithms have some problems, such as inaccurate positioning of tampered areas and limited processing capabilities for various operations. Therefore, this article proposes an image manipulation detection algorithm based on edge detection and faster r-CNN, aiming to solve these problems and improve detection accuracy and efficiency. Traditional image manipulation detection algorithms are mostly based on pixel values or feature extraction methods. These methods have certain effects when dealing with common image operations, but their accuracy and robustness are challenged when faced with complex or detailed manipulations. In addition, these methods often require significant computational resources and have limited ability to locate tampered areas. Therefore, Wei et al. [19] proposed an image manipulation detection algorithm based on edge detection and faster r-CNN to address these issues.

3 MULTI-SCALE WT EDGE DETECTION ALGORITHM FOR PACKAGING IMAGE

Through the analysis of the above theoretical basis, we can see the potential and advantages of CAD and VR technology in package design. These technologies can not only improve the efficiency and accuracy of design, but also provide better user experience and market feedback, thus promoting the development and innovation of package design. In the field of application of CAD and VR technology in product package design, scholars have conducted research from different angles. These studies mainly focus on packaging image processing, virtual package design and user interaction experience. The following is a summary of related research work.

This section will introduce the principle and implementation process of edge detection algorithm of packaging image based on multi-scale WT in detail. This algorithm is an innovative method to optimize the package design process proposed in this article. Through multi-scale WT, the edge information of packaging image can be effectively detected, and then high-quality package design can be realized. WT is a widely used method in the field of signal processing, which can analyze the characteristics of signals at different scales. Multi-scale WT can analyze the characteristics of signals on multiple scales and extract more abundant information. In image processing, multi-scale WT can effectively extract important features such as edges and textures of images. The structure of WT model for edge detection of package design image is shown in Figure 1.

Firstly, the input packaging image is preprocessed, including denoising, graying and other operations to eliminate the interference noise in the image and improve the operation efficiency of the algorithm. Multi-scale WT is applied to the pre-processed packaging image to obtain sub-images at different scales. These sub-images contain the feature information of the original image at different scales. The edge information of different scales is fused to obtain a complete edge detection result of packaging image. The fusion strategy can be used (to fuse the edge information at different scales. Visualize the edge detection results to get the optimized package design image.

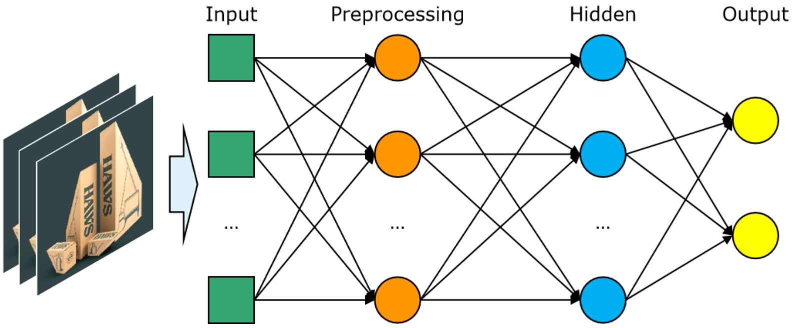

Figure 1: Structure of WT model.

Let the basic model of a signal polluted by noise be:

$$f(t)=s(t)+n(t) \tag{1}$$

Where $s(t)$ is a useful signal and $n(t)$ is a wide stationary Gaussian white noise of $N\sim(0,\sigma^2)$.

Assuming that the transformation matrix is W, wavelet transform the above formula:

$$W[p(i,j)]=W[f(i,j)]+W[n(i,j)] \tag{2}$$

Order:

$$\begin{cases} P=W[p(i,j)] \\ F=W[f(i,j)] \\ N=W[n(i,j)] \end{cases} \tag{3}$$

Then:

$$P=F+N \tag{4}$$

Before packaging image classification and recognition, a series of preprocessing operations are needed for the input image, including image denoising, image enhancement, image segmentation and so on. These operations are aimed at improving the image quality and readability, and making the subsequent classification and recognition process more accurate and reliable. The framework for packaging image classification and recognition is shown in Figure 2.

According to different characteristics of package images, a threshold formula is designed:

$$T_G=C_i\frac{\sigma}{2^{j/2}} \tag{5}$$

C_i is the image adjustment coefficient and j is the decomposition scale.

Optimize image error:

$$T_G=C_i\frac{\sigma}{2^{j/2}}\ n^{-1}E\left\|\hat{f}-f\right\|_{l_n^2}^2=n^{-1}\sum_{i=0}^{n-1}E\left(\hat{f}\left(\frac{i}{n}\right)-f\left(\frac{i}{n}\right)\right)^2 \tag{6}$$

Let $y_{i,j}$ represent the expression of the output image:

$$y_{i,j}=\begin{cases} med\left(W\left\lfloor f_{i,j}\right\rfloor\right), & f_{i,j}\in N \\ f_{i,j}, & f_{i,j}\in S \end{cases} \tag{7}$$

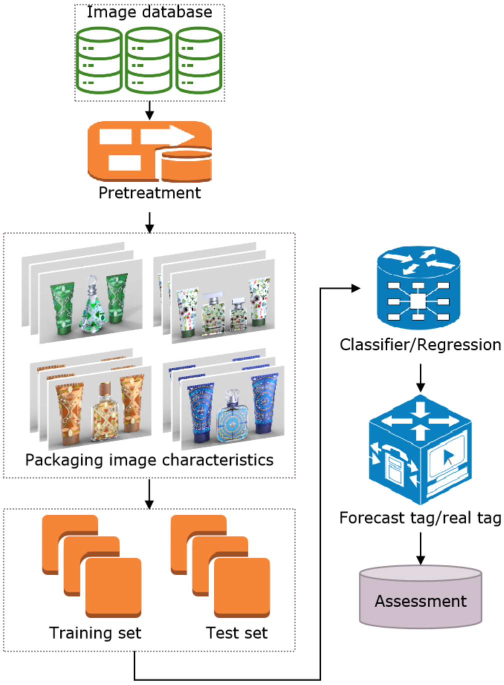

Figure 2: Framework for packaging image classification and recognition.

After preprocessing, it is needed to extract various features from the packaging image, such as texture, shape, color and so on. After the classifier is designed, a large quantity of labeled data needs to be used to train and optimize the classifier. These data can be actual packaging images and their corresponding category labels, or they can be simulated data. Through training and optimization, the accuracy and robustness of the classifier can be improved, so that it can better classify and identify new packaging images.

Constructing the corresponding adjacency matrix:

$$Se_{ij} = 1 - \frac{|n_i - n_j|}{\max(n_i, n_j)} \tag{8}$$

$$Sa_{ij} = 1 - \frac{|a_i - a_j|}{\max(a_i, a_j)} \tag{9}$$

In the formula: n_i and a_i represent the quantity of sides and area of a surface f_i, n_j and a_j represent the quantity of sides and area of a surface f_j,. The similarity coefficient of two different faces is:

$$\phi = \begin{cases} 0, \ T_s = 0 \\ \alpha_1 Se_{ij} + \alpha_2 Sa_{ij}, \ T_s = 1 \end{cases} \tag{10}$$

In the formula: α_1 and α_2 represent the weight value, and $\alpha_1 + \alpha_2 = 1$.

In order to facilitate users to understand and trust the results of packaging image classification and recognition, interpretable technology and visual means can be used to present the classification and recognition results to users. For example, interpretable technology can be used to analyze the decision-making process and results of the classifier to help users understand how the classifier classifies and recognizes the input packaging images; Visual presentation technology can also be used to present the classification and recognition results to users in a graphical way to improve interactivity and operability.

4 RESULT ANALYSIS AND DISCUSSION

This section studies the application of CAD and VR in product packaging design, and compares the performance and effect of different algorithms in processing packaging images and constructing packaging design VR system. In this article, WT is used to optimize the packaging image, and the VR system of package design is constructed by using CAD and VR technology. In the course of the experiment, we will use this algorithm, SVM algorithm and CNN algorithm to process a group of packaging images respectively, and compare and analyze the processing results. A group of actual product packaging images were selected as experimental materials. Moreover, a VR scene containing many different types of packages will be built to handle and compare different algorithms. During the experiment, a large quantity of experimental data will be collected and processed, including processing time, calculation efficiency, subjective scoring, etc. Through the analysis of these data, we can evaluate the performance and effect of different algorithms in processing packaging images and building package design VR system.

See Figure 3 for the comparison of the effects of packaging image optimization with different methods. The algorithm in this article is the best in optimizing packaging images, which can effectively reduce noise, enhance image outline definition and improve image contrast. In contrast, although SVM algorithm and CNN algorithm have certain effects in some aspects, they are not as good as this algorithm in noise reduction, contour extraction and contrast improvement.

Paper algorithm SVM CNN

Figure 3: Comparison of packaging image optimization effect.

Observing the processing effect of the algorithm in this article, we can find that the algorithm has obvious advantages in optimizing packaging images. After the processing of this algorithm, the noise of the packaging image is effectively controlled and the basic outline of the image is clearly visible. In addition, the contrast of the image has also been improved to some extent, which makes the image effectively enhanced. This means that the algorithm in this article has high performance in extracting and retaining key information of images. Observing the processing effect of SVM algorithm, although SVM algorithm can also optimize the packaging image to some extent, its performance in noise reduction and contour extraction is slightly worse than this algorithm. The SVM algorithm may over-fit the data to a certain extent, which leads to its inferior effect in processing actual images. In addition, the improvement of contrast of packaging images by SVM algorithm is relatively limited. Observing the processing effect of CNN algorithm, we can find that CNN algorithm also has certain effect in optimizing packaging images. However, its noise reduction effect is still not as good as this algorithm, which may lead to the loss of details of the image.

WT is a method to analyze an image on multiple scales. It decomposes the image into multiple wavelet coefficients, which contain the information of the image on different scales. Although the total amount of data after WT is equal to that of the original image, it provides the ability to analyze the image on different scales, so that the image can choose to keep important information and discard relatively unimportant information, thus realizing image compression.The recall and accuracy of product packaging image feature detection algorithm are shown in Figure 4 and Figure 5.

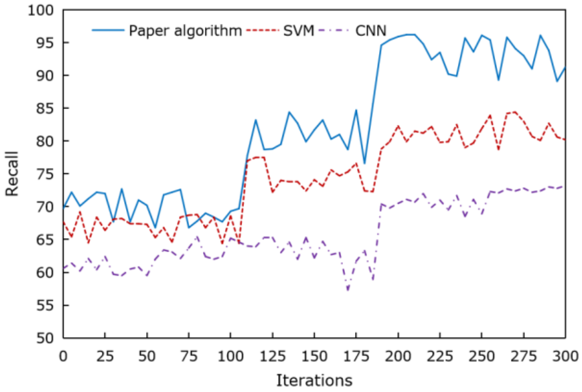

Figure 4: Recall of packaging image feature detection.

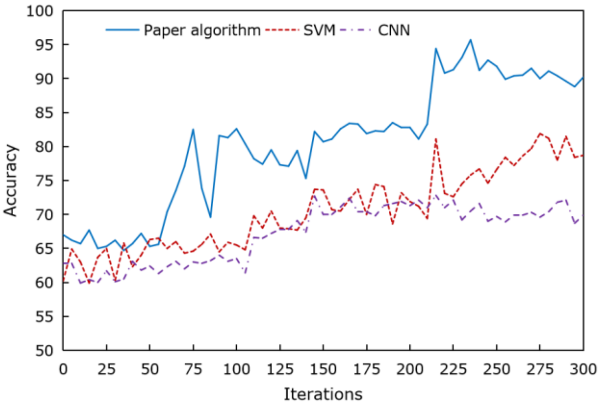

Figure 5: Accuracy of packaging image feature detection.

Observing the recognition time of the algorithm in this article, we can find that the running time of the algorithm in packaging feature detection is relatively short, as shown in Figure 6. This means that the algorithm in this article has high efficiency in realizing packaging feature detection and can complete the recognition task in a short time.

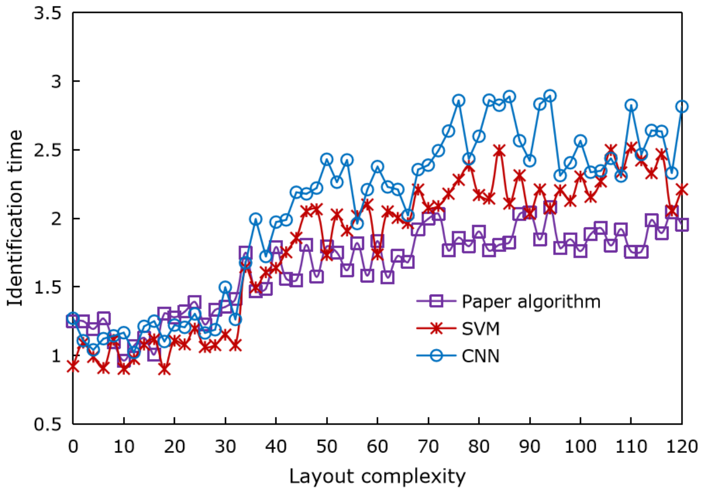

Figure 6: Comparison of packaging feature detection time.

Comparing the recognition time of SVM algorithm, we can find that the running time of SVM algorithm on some test sets is slightly longer than that of this algorithm. This may be because SVM algorithm needs to deal with more data in the process of training and classification, which leads to a long running time. Nevertheless, SVM algorithm still has good performance on the whole, and can be selected according to the requirements in practical application. Observing the recognition time of CNN algorithm, we can find that CNN algorithm runs for a long time on some test sets. This may be because CNN algorithm needs to process a large quantity of image data, and it needs multi-level convolution and pooling operations, which leads to a long running time. Nevertheless, CNN algorithm still has good performance in image classification and feature extraction, and can be applied in specific scenes. To sum up, according to the analysis of the experimental results in Figure 6, the running time of this algorithm in packaging feature detection is short and it has high efficiency. In contrast, although SVM algorithm and CNN algorithm have certain advantages in different aspects, they may have certain limitations in running time. In practical application, we can choose the appropriate algorithm according to the specific needs and scenarios.

Figure 7 shows the subjective scoring results of product packaging CAD design in VR system. According to the display in Figure 7, it can be seen that in the VR system, the highest subjective score is obtained by using this method for product packaging CAD design, which is obviously higher than that by using CNN method and SVM algorithm.

This method combines CAD and VR technology, and optimizes the packaging image through WT. The main advantages of this method include the following: ⊖ Good image processing effect. Through WT, this method can effectively reduce image noise, enhance image outline definition and improve image contrast. This makes the visual effect of package design more prominent and improves the user's experience in VR environment. ⊜ Strong interactivity and immersion. Based on VR technology, this method can provide users with a realistic three-dimensional package design environment. Through intuitive operation and real-time feedback, users can feel the charm of package design more directly, thus enhancing their awareness and interest in products. ⊛ The algorithm is efficient. The method in this article has high computational efficiency and real-time performance in the process of VR presentation of package design. This enables the VR system to keep smooth in practical applications, and reduces the impact of congestion and delay on the user experience.

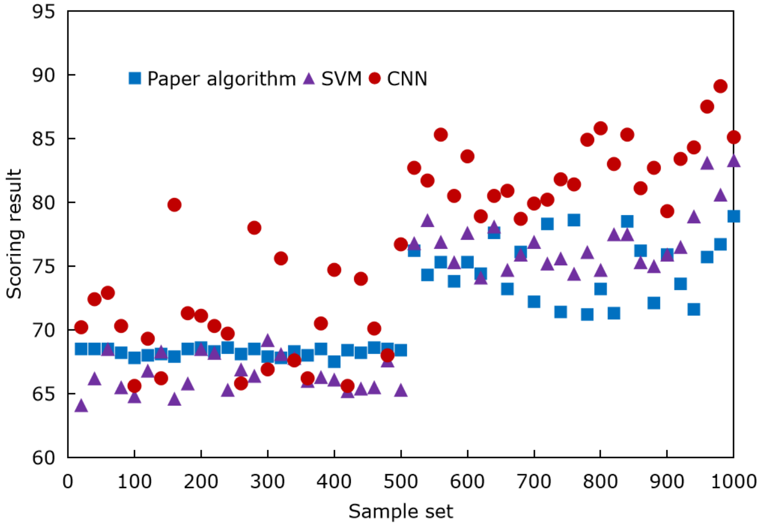

Figure 7: Subjective scoring results.

In contrast, although CNN method and SVM algorithm have certain advantages in some aspects, they may have limitations in VR presentation of package design. For example, although CNN method is excellent in image classification and feature extraction, it may not be as good as this method in dealing with specific problems of packaging images, such as noise, contour and contrast. Although SVM algorithm has good performance in classification and regression, there may be some challenges in processing high-dimensional image data.

To sum up, according to the analysis of the experimental results in Figure 7, the package design VR system constructed by the method in this article has the highest subjective score, which is significantly higher than CNN method and SVM algorithm. This result shows that the method in this article has obvious advantages in VR presentation and user experience of package design, which is mainly reflected in good image processing effect, strong interactivity and immersion, and high algorithm efficiency. In practical application, we can choose appropriate methods to optimize the VR design of product packaging according to specific needs.

5 CONCLUSION

The traditional package design process usually relies on manual operation, which is not only time-consuming, but also designers may have deviations in understanding product characteristics and market demand. Most of the existing CAD software focuses on the creativity and aesthetics of design, while ignoring the cost and productivity of design. The introduction of VR technology can provide a realistic and three-dimensional package design environment for designers, so as to better predict the appearance and performance of products. In this article, an edge detection algorithm of packaging image based on multi-scale WT is proposed, which further optimizes the package design process. According to the analysis of experimental results, the WT algorithm in this article shows high efficiency in optimizing packaging images. It can effectively control the noise of the image, enhance the definition of the image outline and improve the contrast of the image. Moreover, compared with the traditional algorithm, this algorithm has significantly improved the recall and accuracy of product packaging image feature detection, and can locate the image edge contour more accurately. The package design VR system constructed by this method has the highest score in subjective evaluation, which is significantly higher than CNN method and SVM algorithm. This result shows that this method has obvious advantages in VR presentation and user experience of package design, and it is worth popularizing in practical application.

VR technology is one of the important research directions of CAD and package design, and deep learning has strong application ability in image processing and computer vision. In the future, we can explore the use of deep learning in VR technology to further improve the interactivity and immersion of package design.

6 ACKNOWLEDGEMENT

This work was supported by Shanxi Province Philosophy and Social Science Planning Project: Research on the Digital Survival and Communication of Pingyang Woodblock New Year Paintings, (No. 2022YY221); 2022 Project of Shanxi Provincial Education Science "14th Five Year Plan": Research on Digital Promotion and Inheritance of Shanxi Pingyang Woodblock New Year Paintings (No. GH-220347); Shanxi Province Higher Education Teaching Reform and Innovation Project: Research on the Practice and Inheritance of Pingyang Woodblock New Year Paintings in Art and Design Courses (No. J20221321).

Min Zhao, https://orcid.org/0009-0001-9741-0879
Hua Tian, https://orcid.org/0009-0005-8763-0105

REFERENCES

[1] Berni, A.; Borgianni, Y.: Applications of virtual reality in engineering and product design: why, what, how, when and where, Electronics, 9(7), 2020, 1064. https://doi.org/10.3390/electronics9071064

[2] Bhatti, U.-A.; Zhou, M.; Huo, Q.; Ali, S.; Hussain, A.; Yan, Y.; Yu, Z.; Yuan, L.; Nawaz, S.-A.: Advanced color edge detection using clifford algebra in satellite images, IEEE Photonics Journal, 13(2), 2021, 1-21. https://doi.org/10.1109/JPHOT.2021.3059703

[3] Chen, G.; Zhang, G.; Yang, Z.; Liu, W.: Multi-scale patch-GAN with edge detection for image inpainting, Applied Intelligence, 53(4), 2023, 3917-3932. https://doi.org/10.1007/s10489-022-03577-2

[4] Ding, Y.; Nan, X.: On edge detection algorithms for water-repellent images of insulators taking into account efficient approaches, Symmetry, 15(7), 2023, 1418. https://doi.org/10.3390/sym15071418

[5] Faheem, Z.-B.; Ishaq, A.; Rustam, F.; Torre, D.-I.; Gavilanes, D.; Vergara, M.-M.; Ashraf, I.: Image watermarking using least significant bit and Canny edge detection, Sensors, 23(3), 2023, 1210. https://doi.org/10.3390/s23031210

[6] Han, Z.; Shang, M.; Liu, Z.: SeqViews2seqlabels: learning 3d global features via aggregating sequential views by RNN with attention, IEEE Transactions on Image Processing, 28(2), 2019, 658-672. https://doi.org/10.21834/ebpj.v5iSI3.2545

[7] Li, C.; Qu, Z.: Review of image edge detection algorithms based on deep learning, Journal of Computer Applications, 40(11), 2020, 3280-3288. https://doi.org/10.11772/j.issn.1001-9081.2020030314

[8] Liow, K.-M.; Ng, P.; Eaw, H.-C.: Jommachinelearning: bringing artwork nearer with designlab, International Journal of Business Strategy and Automation, 2(2), 2021, 54-71. https://doi.org/10.4018/IJBSA.20210401.oa5

[9] Liu, D.; Pu, G.; Wu, X.: Quaternion - based improved cuckoo algorithm for colour UAV image edge detection, IET Image Processing, 16(3), 2022, 926-935. https://doi.org/10.1049/ipr2.12398

[10] Liu, Y.; Dong, Z.; Feng, Y.; Chen, Y.; Yang, L.: Edge detection method for high-resolution remote sensing imagery by combining superpixels with dual-threshold edge tracking,

Photogrammetric Engineering & Remote Sensing, 89(8), 2023, 469-476. https://doi.org/10.14358/PERS.23-00003R2
[11] Lydekaityte, J.; Tambo, T.: Smart packaging: definitions, models and packaging as an intermediator between digital and physical product management, The International Review of Retail, Distribution and Consumer Research, 30(4), 2020, 377-410. https://doi.org/10.1080/09593969.2020.1724555
[12] Pelliccia, L.; Bojko, M.; Prielipp, R.: Applicability of 3D-factory simulation software for computer-aided participatory design for industrial workplaces and processes, Procedia CIRP, 99(1), 2021, 122-126. https://doi.org/10.1016/j.procir.2021.03.019
[13] Salahuddin, M.-B.-M.; Atikah, A.-F.; Rosnah, S.: Conceptual design and finite element analysis of a high inclusion dough shaping machine using 3D-computer aided design (CAD) (SolidWorks), Materialwissenschaft und Werkstofftechnik, 50(3), 2019, 267-273. https://doi.org/10.1002/mawe.201800205
[14] Saleh, B.; Rasul, M.-S.; Affandi, H.-M.: The importance of quality product design aspect based on computer aided design (CAD), Environment-Behaviour Proceedings Journal, 5(3), 2020, 129-134. https://doi.org/10.21834/ebpj.v5iSI3.2545
[15] Singh, P.; Diwakar, M.; Gupta, R.; Kumar, S.; Chakraborty, A.; Bajal, E.; Paul, R.: A method noise-based convolutional neural network technique for CT image denoising, Electronics, 11(21), 2022, 3535. https://doi.org/10.3390/electronics11213535
[16] Versaci, M.; Morabito, F.-C.: Image edge detection: A new approach based on fuzzy entropy and fuzzy divergence, International Journal of Fuzzy Systems, 23(4), 2021, 918-936. https://doi.org/10.1007/s40815-020-01030-5
[17] Wang, W.; Li, L.; Zhang, F.: Crack image recognition on fracture mechanics cross valley edge detection by fractional differential with multi-scale analysis, Signal, Image and Video Processing, 17(1), 2023, 47-55. https://doi.org/10.1007/s11760-022-02202-6
[18] Wang, X.; Wang, S.; Guo, Y.; Hu, K.; Wang, W.: Coal gangue image segmentation method based on edge detection theory of star algorithm, International Journal of Coal Preparation and Utilization, 43(1), 2023, 119-134. https://doi.org/10.1080/19392699.2021.2024173
[19] Wei, X.; Wu, Y.; Dong, F.; Zhang, J.; Sun, S.: Developing an image manipulation detection algorithm based on edge detection and faster R-CNN, Symmetry, 11(10), 2019, 1223. https://doi.org/10.3390/sym11101223