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Computer-Aided Design and Applications

Optimization Application of Packaging Design Based on CAD and Machine Vision

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Abstract. The integration of computer-aided design (CAD) and machine vision has brought unprecedented convenience and accuracy to packaging design, enabling designers to create packaging designs that meet market demands in a more efficient and precise manner. This article proposes a method that combines CAD and machine vision, which not only optimizes packaging images but also creates packaging design models based on the optimized images, achieving technological synergy. The results show that this algorithm can simplify the model while maintaining its key features and improving computational efficiency. By deblurring, designers can be provided with clearer and more accurate visual information, thereby improving design efficiency. The subjective rating of the designer confirms the superiority of the product packaging CAD system constructed in this article in terms of performance. This research achievement is of great significance for promoting the innovative development of packaging design, enhancing design efficiency, improving designer experience, and providing new possibilities for future progress in the field of packaging design.

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1 INTRODUCTION

Packaging design is not only the appearance of the product but also involves protection, ease of use, attraction, and communication with consumers. Good packaging design can significantly improve product sales and brand image. CAD tools allow designers to design quickly and accurately on the computer and make real-time modifications and tests during the design process. In today's highly competitive market environment, product packaging design has become an important means of shaping brand image and managing consumer expectations. Packaging not only protects the product but also conveys its value, quality, and expectations to consumers. Bae et al. [1] explored the complexity of product packaging and its impact on consumer expectations of the product. Exquisite packaging can enhance consumers' expectations and value perception of products. It can make consumers feel that the product is of higher quality and therefore willing to pay a higher price. Packaging design is an important manifestation of brand image. Packaging that aligns with the brand image can help consumers better understand and recognize the brand, enhancing brand awareness and loyalty. The design and operation of packaging can directly affect consumers' unpacking experience. Packaging that is easy to open and structurally reasonable can increase consumer satisfaction and positive feedback on the product. The design and complexity of product packaging have a profound impact on consumers' expectations of the product. In order to manage consumer expectations and enhance brand image, brands must have a deep understanding of their target consumers and choose and design appropriate packaging for them. Meanwhile, as sustainability becomes a global focus, brands also need to consider how to showcase their commitment and actions to environmental protection through packaging design. CAD technology not only improves design efficiency but also reduces the design cost so that designers can respond to the changes in design requirements more flexibly. With the rapid development of technology and the increasing demands of consumers for food safety, quality, and freshness, intelligent packaging systems have gradually taken an important position in the food supply chain. Chen et al. [2] explored the role of intelligent packaging systems in the food supply chain, including improving food safety, optimizing product freshness, promoting product circulation, and enhancing consumer-product interaction. Every link in the food supply chain plays a crucial role in the quality and safety of products. Although traditional packaging methods can protect products from external environmental damage, they cannot provide real-time environmental data such as temperature, humidity, and light, nor can they monitor the freshness of products in real-time. This makes it necessary for us to introduce intelligent packaging systems to address these issues. The intelligent packaging system can collect and record various data during food production and processing through built-in sensors, such as temperature, humidity, time, etc., to ensure the safety and freshness of food in the supply chain. Once food enters the consumption process, consumers can verify the source and safety information of the food through the QR code or RFID label on the packaging, greatly improving the safety of the food. Intelligent packaging systems can provide not only basic product information but also more product information and personalized services through apps or other interfaces, such as nutritional knowledge, recipe recommendations, etc., enhancing the interaction between consumers and products. In addition, consumers can better understand the production process and quality of products through the data feedback provided by the intelligent packaging system, which improves consumer satisfaction and trust. Machine vision is a branch of artificial intelligence that uses computer algorithms to simulate human visual functions and analyze and understand images and videos. In packaging design, machine vision can be used in image recognition, quality inspection, size measurement, and so on, which greatly improves the production efficiency of packaging.

In today's digital age, intelligent manufacturing has become the core driving force of the manufacturing industry. Digital twin technology, as a key tool for simulating and optimizing physical systems, has been widely applied in the field of intelligent manufacturing. Damjanovic and Behrendt [3] explored how to design and implement digital twins for intelligent manufacturing and introduced some open-source methods. Digital twin technology has brought enormous potential and opportunities to intelligent manufacturing. By designing and implementing digital twin technology, the visualization, prediction, and optimization capabilities of the production process can be improved, thereby improving production efficiency and quality. Open-source methods provide strong support for the implementation of digital twins, which can help enterprises and developers quickly build and expand digital twin systems. In the future, with the continuous progress of technology and the expansion of application fields, digital twins will play a greater role in the field of intelligent manufacturing. Connect the digital twins with the actual production line through a data interface to achieve real-time data interaction. Utilize simulation and optimization algorithms to predict and optimize the performance of the production line, such as scheduling optimization, process parameter optimization, etc. Utilize IoT technology to achieve real-time monitoring of production lines and feedback monitoring data to digital twins for real-time adjustment and optimization. With the continuous progress and innovation of science and technology, CAD and machine vision technology have become important tools in the field of packaging design. The integration of these two technologies has brought unprecedented convenience and accuracy to packaging design, enabling designers to create packaging designs that meet market demand in a more efficient way. With the rapid development of Industry 4.0 and intelligent manufacturing, digital twin technology is gradually changing the face of traditional manufacturing. A digital twin is a technology that closely connects the physical world with the virtual world based on the integration of physical models, sensor updates, and historical and real-time data. In intelligent manufacturing, digital twins use virtual reality (VR) and augmented reality (AR) technologies to control remote devices and simulate virtual machining processes, further promoting structural and multidisciplinary optimization. Geng et al. [4] explored these applications in detail. Digital twin technology can provide real-time structural analysis, helping designers identify and solve potential structural problems in the early stages. By continuously optimizing design, the performance and reliability of products can be improved. In complex product design, multidisciplinary optimization is crucial. Digital twin technology can integrate simulation results from multiple disciplines (such as structure, fluid, heat, etc.), enabling designers to evaluate design solutions and achieve multidisciplinary optimization comprehensively.

With the rapid development of technology, the application of artificial intelligence (AI) is becoming increasingly widespread, surpassing human thinking patterns and bringing unprecedented innovation to various fields. Especially in the field of mechanical design and optimization, the application of AI has changed traditional design and optimization methods, providing engineers with more efficient and accurate tools. Jenis et al. [5] explored the engineering applications of artificial intelligence in mechanical design and optimization. AI can also serve as an intelligent auxiliary design tool to assist engineers in more accurate design. For example, using AI's image recognition and natural language processing technology, engineers can quickly and accurately understand customer needs and automatically perform some design work, thereby shortening the design cycle. Take a certain automobile manufacturing enterprise as an example; it utilizes AI technology for automated design and optimization. Through deep learning technology, AI automatically designs the appearance of cars, greatly shortening the design cycle. At the same time, using optimization techniques such as genetic algorithms, AI automatically optimizes the design scheme, improving the performance and safety of the car. In addition, through predictive maintenance systems, AI successfully predicted and solved potential problems with some equipment, improving the operational efficiency of the equipment. In packaging design, the clarity and accuracy of images often directly affect the final design effect. Due to various reasons, such as photography technology and environmental conditions, packaging images often appear blurred and distorted, which directly affects the quality and effect of packaging design. Based on this, this article proposes a deblurring method for packaging images based on machine vision. This method uses an advanced image processing algorithm, which can effectively remove the blur in the image, improve the clarity and accuracy of the image, and provide a high-quality image foundation for the subsequent packaging design. After obtaining the optimized image, the packaging design model is further established by using CAD technology. With its powerful modeling function and accurate data processing ability, CAD technology enables designers to carry out complex three-dimensional modeling and accurate size control easily. The packaging design model based on the optimized image not only has a high sense of reality but also can accurately reflect the actual size and details of the product. With the increasing complexity of packaging design, the data volume of the model will also increase sharply, which undoubtedly brings great inconvenience to design, production, and management. Quadric Error Metrics (QEM) algorithm is a mesh simplification algorithm based on error quadrilateral. This algorithm simplifies the mesh by calculating the quadratic error metric of vertices in the mesh. Its main goal is to reduce the number of vertices in the mesh while maintaining the geometric and topological characteristics of the original mesh. In this article, a model simplification algorithm based on the Enhanced QEM Algorithm (EQEM) is introduced. This algorithm can significantly reduce the data volume of the model while maintaining the geometric shape and visual effect of the model, thus improving the efficiency of packaging design [6].

In the rapidly developing digital age, machine behaviorism is gradually becoming a dominant force, with the core concept of endowing the behavior and decision-making process of machines or systems with more humanized features. Knox et al., [7] a new type of machine behaviorism, not only has a profound impact in the field of artificial intelligence but also provides a new future vision for "learning" and "digitization" across humans and digital technologies.

Machine behaviorism emphasizes the learning and adaptability of machines or systems in processing information. Traditional machine learning algorithms typically require a large number of preset parameters, while machine behaviorism focuses more on allowing machines to learn and adjust themselves during operation. This learning method not only adjusts one's behavior according to changes in the environment but also gradually improves one's performance through continuous trial and error and learning. Overall, machine behaviorism provides us with new possibilities and opportunities for "learning" and "digitization" across humans and digital technologies. This new type of machine behaviorism can not only help us better understand and master knowledge but also provide individuals with more personalized learning plans by analyzing their learning behaviors and habits. Meanwhile, through its powerful learning and reasoning abilities, machine behaviorism also provides us with effective tools for processing, analyzing, and utilizing big data. Lashkaripour et al. [8] used AI technology to analyze and learn from historical packaging design cases, as well as predict market trends and consumer behavior, providing valuable information and suggestions for designers. By utilizing techniques such as image recognition and visual analysis, designers can quickly generate multiple design solutions and provide suggestions for aesthetic optimization. By combining big data analysis and model training, most of the market research and competitor analysis work is automatically completed, reducing the workload of designers and improving design efficiency. Generate multiple design solutions through intelligent algorithms and adjust and optimize them based on user needs and data feedback, helping designers achieve more innovative and differentiated designs. In packaging design, by analyzing consumer behavior and market trends, targeted suggestions and adjustments are provided to designers to improve product market competitiveness and increase sales.

⊜ In this article, the EQEM algorithm is introduced into the model simplification of packaging design, which realizes the double improvement of design effect and efficiency.

This article expounds on the purpose and significance of the use of CAD and machine vision in packaging design optimization and then summarizes the relevant theoretical basis. Then, this article puts forward an optimization method of packaging design based on CAD and machine vision and analyzes the practicability of this method in practical application. The final conclusion summarizes the achievements and contributions of this study.

2 OVERVIEW OF RELATED THEORIES

Due to the high thermal conductivity of SiC, effective thermal management is crucial for preventing overheating and ensuring the long-term stable operation of the module. SiC modules need to withstand environmental conditions such as vibration, impact, and mechanical stress. Therefore, packaging design must be able to provide sufficient mechanical strength and stability. Lee et al. [9] analyzed the shielding and electromagnetic compatibility of electromagnetic interference (EMI) in packaging design. The use of new packaging materials, such as ceramics and metalized sintering, can provide better high-temperature resistance and mechanical strength. By using more effective heat sinks, more reasonable thermal design, and more advanced heat dissipation technology, the heat generated by SiC modules can be better managed. By optimizing the packaging structure design, such as using more support structures, the mechanical strength and stability of SiC modules can be enhanced. By adding electromagnetic shielding materials and optimizing circuit layout in packaging design, the electromagnetic compatibility of SiC modules in packaging design can be significantly improved. In the field of packaging design, CAD technology can be used to draw the appearance, structure, and internal details of products. Machine vision technology utilizes computer vision algorithms to analyze and process images to extract useful information and features. In packaging design optimization, machine vision technology can be used to detect appearance defects of products, identify product features and shapes, etc. Marion and Fixson [10] optimized the strength, stability, and environmental friendliness of packaging structures by modeling and analyzing them. At the same time, machine vision technology can be used for automated detection and identification of packaging structures to ensure their accuracy and quality. By using machine vision technology to identify and classify products, appropriate packaging materials and specifications are selected based on their characteristics and requirements. At the same time, CAD technology can be used to model and design packaging materials to achieve the optimal packaging effect. Applying machine vision technology to packaging production lines to achieve automation in product inspection, classification, packaging, and other processes. At the same time, CAD technology is used to model and optimize the production line, improving production efficiency and product quality.

With the improvement of environmental awareness, future packaging design will pay more attention to environmental protection and sustainable development. Therefore, the development of environmentally friendly materials, energy conservation, and emission reduction technologies will become important research directions in the future. Menon et al. [11] can significantly improve packaging design efficiency and shorten design cycles through automated analysis and optimization. By modeling and analyzing packaging structure, materials, and production lines, design schemes can be optimized to improve product quality and production efficiency. Through automated design and production line optimization, labor and production costs can be reduced, and the competitiveness of enterprises can be improved. The application of packaging design optimization based on CAD and machine vision can adapt to different product types and production environments and has a wide range of applicability. By introducing more advanced machine learning and artificial intelligence technologies, intelligent and adaptive packaging design can be achieved, improving design efficiency and accuracy. By optimizing production processes, we can achieve refined processing of product details and refined production process management. With the rapid development of technology and the increasing demand for food quality from consumers, the food packaging industry is facing unprecedented challenges. Packaging not only needs to protect food from environmental impacts but also provides healthier and more environmentally friendly solutions. Polysaccharide-based materials, as a new type of food packaging material, are gradually receiving attention due to their unique biocompatibility, biodegradability, and good mechanical properties. NešIć et al. [12] explored the prospects of polysaccharide-based materials as advanced food packaging. Polysaccharide-based materials are non-toxic and odorless and can be used for packaging various types of food to meet consumers' demands for food safety. Polysaccharide-based materials can effectively prevent food oxidation and spoilage and extend the shelf life of food. Polysaccharide-based materials are biodegradable and in line with the concept of sustainable development, helping to reduce their impact on the environment. With consumers' increasing attention to environmental protection and health, as well as strong government support for sustainable development, the market prospects for polysaccharide-based materials are very broad. It is expected that the demand for polysaccharide-based materials will significantly increase in the coming years. Meanwhile, with the continuous progress of scientific research technology, the performance and application fields of polysaccharide-based materials will also be further expanded. A micro intelligent factory is a micro-production facility that integrates automation, information technology, the Internet of Things, and other technologies, with the advantages of fast response, flexible configuration, and efficient production. Digital twin technology is an important means to achieve micro-intelligent factories. Park et al. [13] explored the design and implementation of digital twin applications that connect micro-intelligent factories. Based on the collected data and processing results, a digital twin model is constructed, verified, and corrected through actual operational data. By using digital twin models, real-time monitoring and prediction of the operational status of micro-intelligent factories can be achieved. Based on monitoring and prediction results, optimize and control the production process of micro-intelligent factories to improve production efficiency and product quality. Digital twin technology is an important means to achieve micro-intelligent factories. This article explores the design and implementation of digital twin applications that connect micro-intelligent factories.

Future research should focus on developing smaller, more sensitive, and more durable sensors to better monitor the quality and freshness of food. Through cloud computing and big data technology, real-time analysis and processing of a large amount of food data can be achieved. These data can help enterprises better understand market demand, consumer behavior, and product quality, thereby optimizing production and sales strategies and reducing waste. Future research should focus on developing intelligent packaging that can meet personalized needs. For example, designing different intelligent packaging for different foods to achieve more effective food protection and reminder functions [14]. Intelligent packaging can help save food in various ways. One way is to ensure that food is properly stored during its shelf life by monitoring its quality and freshness. When food is close to expiration, smart packaging can remind consumers to consume it in a timely manner to avoid waste. In addition, intelligent packaging can also provide real-time temperature and humidity data, helping consumers understand the storage environment of food, thereby better protecting food. Wikström et al. [15] searched for more environmentally friendly and sustainable smart packaging materials as a research direction. These materials should have excellent insulation, waterproofing, and breathability while also achieving effective food protection. Sensors used in intelligent packaging need to have higher accuracy and stability.

In the automotive industry, VR-based car styling optimization design has become a trend, and the popularity of the Internet provides a broad development space for this innovative design model. Wu et al. [16] explore the application of virtual reality technology-based automotive shape optimization design in the Internet era. The popularization of the Internet enables designers to use cloud computing and big data for efficient and accurate design. For example, by analyzing user feedback and behavioral data, designers can better understand user needs and optimize design solutions. The Internet has made cross-regional collaborative design possible. Designers can work together in a virtual environment to achieve real-time communication and data sharing, improving design efficiency. Although the optimization design of car styling based on virtual reality technology has broad development prospects in the Internet era, it also faces some challenges. For example, how to ensure the accuracy and real-time performance of data in virtual environments and how to solve the technical challenges of virtual reality technology in real-time rendering and interaction. However, with the continuous progress of technology, we have reason to believe that these challenges will be gradually overcome. With the development of technology, intelligent food packaging has become an important trend in the food industry. Intelligent packaging can monitor the quality and safety of food in real-time through various sensing technologies, providing consumers with safer and healthier food. Yousefi et al. [17] reviewed the application of intelligent sensing technology for monitoring food quality in intelligent food packaging. Temperature is one of the important factors affecting food quality. Intelligent packaging can monitor the temperature of food in real-time through integrated temperature sensors, ensuring that the temperature of food is maintained within an appropriate range during storage and transportation. Humidity is also an important factor affecting food quality. Intelligent packaging can monitor the humidity of food through integrated humidity sensors to maintain its taste and freshness. Oxygen is one of the main factors causing food spoilage. Intelligent packaging can monitor the oxygen content inside food packaging by integrating oxygen sensors, thereby determining whether the food has deteriorated. The application of intelligent sensing technology in food packaging has become an important trend in the food industry. By integrating various intelligent sensors, intelligent packaging can monitor the quality and safety of food in real-time, ensuring that consumers receive safer and healthier food. With the continuous progress of technology and the expansion of application fields, the application of intelligent sensing technology in food packaging will have more innovation and development.

With the improvement of environmental awareness, the concept of green design is becoming increasingly important in product packaging design. As the main tool of modern product design, computer-aided design (CAD) is currently an important research direction in how to apply it to green product packaging design and achieve a perfect combination of environmental protection and design. Yu and Sinigh [18] discussed the application of green concept-based CAD in product packaging design. Through precise design and optimization of CAD, material consumption can be minimized to the greatest extent, and effective utilization of resources can be achieved. By optimizing the design of packaging structure through CAD, excessive packaging can be reduced, the practicality of packaging can be improved, and the impact on the environment can be reduced. Taking the packaging design of an eco-friendly bag as an example, the designer used CAD software to design, taking into account the appearance, structure, and performance of the eco-friendly bag. Through visualization technology and simulation analysis, the designer predicted the effectiveness and performance of environmentally friendly bags during use, achieving the concept of green design. CAD based on green concepts has broad application prospects in product packaging design. With the assistance of CAD software, designers can achieve green design concepts such as selecting environmentally friendly materials, reducing material consumption, and optimizing packaging structure, thereby improving the environmental friendliness and practicality of product packaging. At the same time, the precise design and optimization functions of CAD software can also improve the efficiency and accuracy of design. With the continuous development of technology, it is believed that in the future, CAD-based on green concepts will play a greater role in product packaging design. With the rapid development of technology, people's requirements for food packaging are also constantly increasing. In addition to the basic functions of protecting and preserving food, modern food packaging also needs to have more characteristics, such as improving food quality, providing nutritional supplements, and increasing food sustainability. The electrospinning technology of nanofibers provides new possibilities for food packaging by manufacturing nanofiber materials with special properties to improve the performance and functionality of food packaging. Zhang et al. [19] explored the potential and prospects of electrospinning technology for nanofibers in the field of active food packaging. By selecting different biodegradable or biocompatible materials as raw materials for nanofibers, it can be ensured that the manufactured food packaging has good biocompatibility and biodegradability, which is conducive to environmental protection and sustainable development. The electrospinning technology of nanofibers can also enhance the quality and nutritional value of food packaging by adding active ingredients such as antioxidants and nutritional supplements. By adding active ingredients such as antioxidants and vitamins to nanofibers, food packaging with antioxidant and nutritional functions can be manufactured. This packaging can enhance the antioxidant and nutritional value of food while providing its preservation function.

3 OPTIMIZATION OF PACKAGING DESIGN BASED ON CAD AND MACHINE VISION

3.1 Image Enhancement Method Based on Visual Perception Characteristics

CAD software has powerful 3D modeling capabilities. Designers can use these tools to create complex packaging models and design them with precise dimensions and structures. Through CAD software, designers can perform high-quality rendering of designs, obtain realistic preview effects, and ensure that the appearance of the design in actual production is consistent with expectations. CAD is not just a modeling tool, it can also analyze various data of design, such as structural strength, material usage, etc., to help designers optimize their plans in the early stages of design. Through a series of image processing algorithms, machine vision can remove noise, blurring, etc., from images, making them clearer and providing high-quality raw materials for subsequent design. Machine vision can be used for quality inspection of packaging, such as detecting printing defects, identifying packaging materials, etc., to ensure that every product leaving the factory meets quality standards.

The optimized images obtained through machine vision technology can serve as a reference for CAD design, ensuring that the original intention of the design is closer to the actual effect. During the production process, machine vision can detect the quality of packaging in real-time and provide data feedback to the CAD system. The latter can adjust the model in real-time based on these data, reducing production waste. Based on market feedback data collected by machine vision, CAD can quickly iterate the design, making packaging more in line with market demand. The combination of the two not only improves the quality of packaging design but also enables the design to keep up with the times and closely meet the needs of the market and consumers. The EQEM algorithm is an algorithm used for model simplification, which can significantly reduce the data volume of the model while maintaining its geometric shape and visual effects. This algorithm simplifies the model by optimizing its topology and geometric details. Complex packaging design models often contain a large amount of data, which brings difficulties to design, production, and management. Using the EQEM algorithm for model simplification can reduce model complexity while maintaining design effectiveness, and improve the efficiency of packaging design. Image deblurring is an important issue in the field of machine vision, aiming to restore clear and high-quality images from blurred images. In packaging design, due to photography technology, environmental conditions, and other reasons, packaging images often appear blurry and distorted. To address this issue, this article adopts advanced image deblurring algorithms. By removing blurring effects, enhancing image details, and improving resolution, packaging images are made clearer and sharper. The human visual system has its unique way of perceiving different image contents. For example, the human eye has corresponding sensitivity and perception patterns for edges, textures, and colors. The purpose of image enhancement methods is to highlight key information in the image based on these perceptual characteristics, making it easier to observe and recognize. A blurry packaging image may mislead consumers, damage the brand image, and reduce the attractiveness of the product. Therefore, image enhancement technology based on visual perception characteristics is particularly important. In order to better simulate the visual perception of the human eye, this article adopts a fuzzy estimation method based on deep learning. By training a large number of fuzzy and non-fuzzy images, deep learning models can learn fuzzy features and accurately estimate them. This learning-based method is more accurate than traditional methods and can better adapt to various complex fuzzy scenes. The architecture of the packaging image deblurring model based on machine vision is shown in Figure 1.

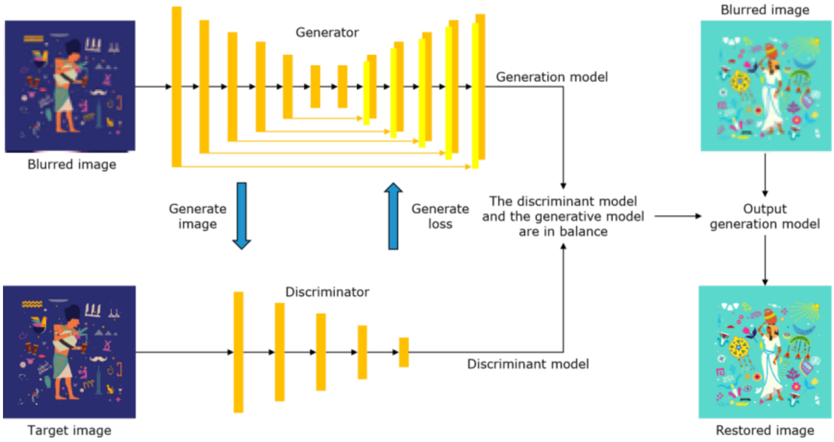

Figure 1: Deblurring model of packaging image.

The process of training the discriminator D is essential to minimize the cross entropy between the expected output and the actual output. The loss function of the discriminator can be defined as:

$$L_D(\theta_D,\theta_G) = -\frac{1}{2}E_{x\sim P_{data}(x)}\left[\log D(x)\right] - \frac{1}{2}E_{Z\sim P_z(z)}\left[\log(1-D(g(x)))\right] \tag{1}$$

Where x represents real data and obeys the distribution of real data P_{data}; z represents the random noise input to generator G, which obeys prior distribution $P_z(z)$; $E(\cdot)$ stands for expected value. When the generator G is fixed, the above formula is minimized to achieve the optimal solution. When the function is continuous, the above formula can be transformed into the following form:

$$\begin{aligned} L_D(\theta_D,\theta_G) &= -\frac{1}{2}\int_x P_{data}(x)\log(D(x))dx - \frac{1}{2}\int_z P_z(z)\log(1-D(g(z)))dz \\ &= -\frac{1}{2}\int_x \left[P_{data}(x)\log(D(x)) + p_g(x)\log(1-D(x))\right]dz \end{aligned} \tag{2}$$

For any non-zero real number a and real number b, and when the real number belongs to the interval from 0 to 1, the following formula is the minimum point at $\frac{a}{a+b}$:

$$-a\log\left(y\right)-b\log\left(1-y\right) \tag{3}$$

Therefore, when the generator G is given, the loss function of the discriminator D takes the minimum value at the following formula, which is the optimal solution in this case:

$$D_G^*\left(x\right)=\frac{P_{data}\left(x\right)}{P_{data}\left(x\right)+P_g\left(x\right)} \tag{4}$$

The GAN model was used in the deblurring process of packaging images, utilizing its powerful generation ability and adversarial training mechanism to achieve better deblurring effects. This adversarial process enables the two networks to promote each other through continuous iteration, resulting in the generator being able to generate images that are very close to real images. During the training process, the loss functions used typically include adversarial loss and content loss

Using the weight coefficient $E\left(i,j\right)$ to count the number of pixels with the gray level a of the image to be enhanced:

$$T\left(a\right)=\sum_x\sum_y E\left(i,j\right) \tag{5}$$

Where: x,y represents the pixel coordinates with the gray level a; $T\left(a\right)$ represents the pixel statistics of the image to be enhanced with the gray level a. The height of the gray level indicates the amount of information represented by the gray level, so the information histogram can be expressed as:

$$T=\sum_{r=0}^{255}T\left(a\right) \tag{6}$$

3.2 Optimization of Product Packaging Model Based on EQEM Algorithm

See Figure 2 for the gray distribution of the character area and the background area. In product packaging design, model optimization is a key link, which directly determines the functionality, aesthetics, and economy of product packaging. In this article, an optimization process of the product packaging model based on the EQEM (Evolutionary Simplification and Enhancement) algorithm is proposed to improve the overall packaging effect. According to the product requirements and design objectives, the initial product packaging model is established by using CAD technology. The model usually contains all design details and features to ensure that the basic packaging requirements of the product are met.

Taking $\left(x_{center},y_{center}\right)$ as the center point. The side length of this area is::

$$l=\delta\min\left(I_{width},I_{height}\right),\delta\in\left(0,1\right] \tag{7}$$

In which, I_{width},I_{height} is the width and height of the image I, and δ is the cropping threshold.

The coordinates of the upper left corner of the circumscribed rectangle $E\left(x,y\right)_s$ with the highest complexity are $\left(x_{\min},y_{\min}\right)$ and the coordinates of the lower right corner are $\left(x_{\min},y_{\min}\right)$, then the coordinates of the center point of $E\left(x,y\right)_s$:

$$\left(x_s,y_s\right)=\left(\left[\frac{x_{\min}+x_{\max}}{2}\right],\left[\frac{y_{\min}+y_{\max}}{2}\right]\right) \tag{8}$$

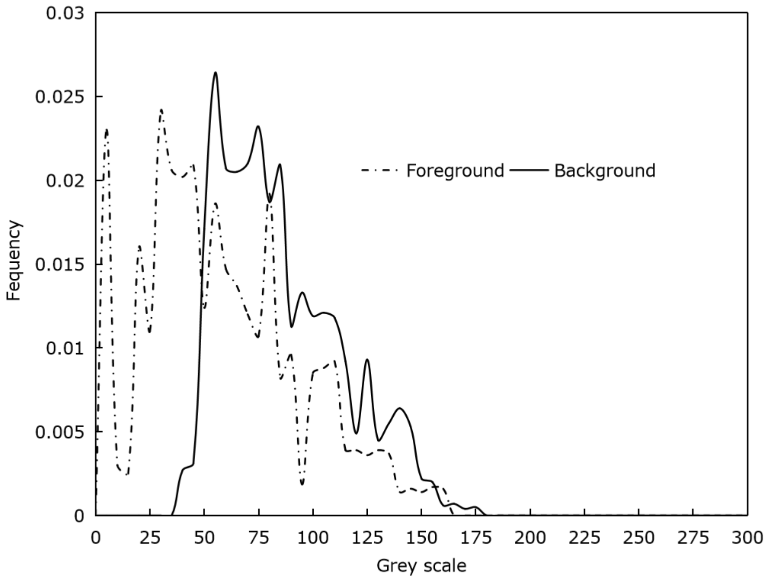

Figure 2: Gray distribution of character area and background area.

In this article, machine vision technology is proposed to extract product packaging modeling features. $f_{ij}\ \theta,H$ is used to represent the activation of the first i element in the j layer of the network, and when $f_{ij}\ \theta,H$ is maximum:

$$H^* = \arg\max_{s.t\|H\|=\rho} f_{ij}\ \theta,H \tag{9}$$

In order to improve computational efficiency and subsequent rendering speed, the EQEM algorithm is used for model simplification. The EQEM algorithm removes redundant and secondary geometric details by analyzing the geometric structure and feature importance of the model while maintaining the main features and overall shape of the model. This can reduce the data volume and computational complexity of the model without significantly affecting the visual effect. Define optimization goals based on the specific requirements of packaging design. These goals can include reducing material usage, improving structural strength, and improving human-machine interaction. Adopting the evolutionary enhancement strategy of the EQEM algorithm to optimize the simplified model. This strategy gradually enhances the performance of the model by simulating the natural evolution process while maintaining its basic shape and functionality. The CAD packaging design process is summarized in Figure 3.

In the optimization process, various constraints need to be considered, such as production process limitations, cost budgeting, human-machine interaction requirements, etc. These constraints can serve as limiting factors in the optimization process, ensuring that the generated optimization scheme is feasible in practical applications. Among the multiple schemes optimized by the EQEM algorithm, based on the comprehensive evaluation results, the scheme with the best effect, meeting all constraint conditions, and having the best performance indicators is selected as the final design scheme. Using professional CAD software, start detailed modeling based on the improved design plan. Utilize CAD software modeling tools to construct product packaging models accurately. According to the needs of subsequent production and manufacturing, convert the CAD model into the corresponding data format. To ensure the traceability and management of the design, version control is carried out on the generated CAD models and related documents, and design history records are saved to facilitate subsequent modifications and updates.

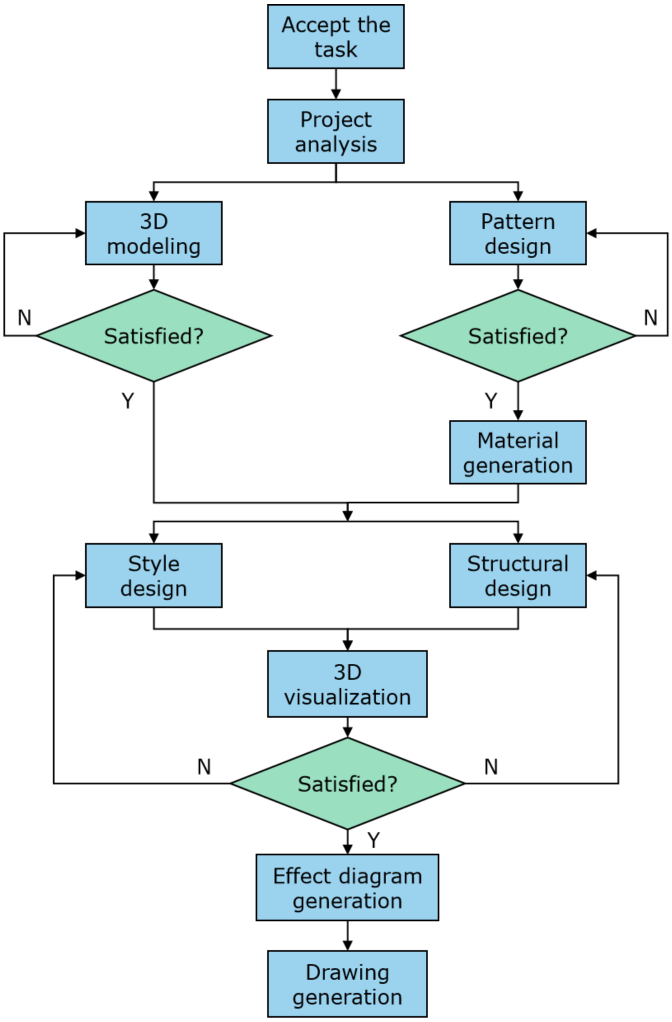

Figure 3: CAD packaging design process.

4 RESULT ANALYSIS AND DISCUSSION

4.1 Data Acquisition and Experimental Design

The main objective of the experiment is to evaluate the performance of the algorithms and techniques proposed in this article in packaging design. The experimental subjects include different types of packaging models, such as paper box packaging and metal packaging. The participants are professional designers who have packaging design experience and are familiar with the use of CAD systems. Firstly, collect various types of raw packaging model data and prepare corresponding testing environments, including the setup and configuration of CAD systems. Then, simplify the original model using the EQEM algorithm and record the simplified model data. At the same time, apply the conventional QEM algorithm for the same simplification operation for subsequent comparison. Use the image deblurring algorithm in this article to process the blurred packaging image and record the image data before and after processing. Encourage participating designers to use the CAD system and other comparison systems constructed in this article for packaging design tasks. After the task is completed, the designers subjectively rate each system. Data collection mainly involves data after model simplification, data before and after image deblurring, and subjective evaluation by designers. To ensure the accuracy and impartiality of the experiment, variables are strictly controlled during the experiment, and only designated independent variables are operated and tested.

4.2 Experimental Results

Figure 4 clearly shows the comparison of execution time between the EQEM algorithm and the conventional QEM algorithm. As the complexity of product packaging images increases, the execution effect of the EQEM algorithm gradually demonstrates its superiority.

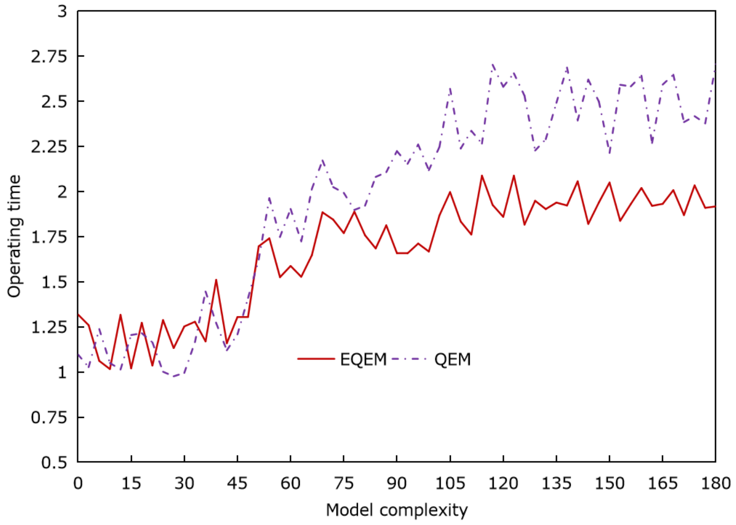

Figure 4: Comparison chart of algorithm calculation time.

In the fields of image processing and computer vision, the execution time of algorithms is usually closely related to the complexity of the input image. Complexity can be measured from multiple dimensions, such as resolution, color richness, and amount of detail. As the complexity of images increases, algorithms typically require more computational resources to process this information, resulting in an increase in execution time. In the initial stage of Figure 4, the execution time of the EQEM algorithm and the conventional QEM algorithm is almost the same, indicating that the performance of the two algorithms is similar at lower image complexity. As the complexity of product packaging images increases, the execution time of the EQEM algorithm gradually decreases compared to conventional QEM algorithms. This indicates that the EQEM algorithm has higher efficiency in processing complex images.

The experiment utilized the EQEM algorithm to simplify several typical 3D models, structured 3D models, and 3D scene models automatically reconstructed through dense matching and compared them with traditional QEM algorithms. The EQEM algorithm is suitable for various grid models in different formats. Generally, it is required that the vertices in the mesh model have basic coordinate information, vertex attributes, face attributes, material colors, and textures. Through a format converter, format conversion can be carried out for various formats of 3D models, achieving the goal of universality. During the preprocessing process, all objects will be triangulated. For models without textures, it is also possible to simplify only the color differences of the edge material colors. Because the algorithm is an extension of QEM, it is very fast, and when simplifying different types of models, the algorithm can achieve optimal simplification through parameter allocation. The disadvantage is that it is not possible to perform adaptive parameter tuning and requires manual participation.

Figure 5 illustrates the appearance changes of the previous and subsequent models at a 50% simplification level, which overall remains consistent with the original model. The data in Table 1 reflects the comparison of simplification speed between QEM and EQEM algorithms for the paper box packaging model, and it can be seen that the execution speed of the two algorithms is equivalent.

Before simplification   After simplification

Figure 5: Effect of simplified carton packaging model before and after.

Tri number	*3817*	*1899*	*1024*	*256*
QEM	0	0.178	0.141	0.18
EQEM	0	0.189	0.164	0.21

Table 1: Comparison of simplification time of carton packaging model.

Figure 5 shows the appearance changes of the model before and after 50% simplification. The simplified model remains highly consistent in appearance with the original model. This means that even if half of the details of the model are removed, the method proposed in this article can still maintain its original form and visual effect. Table 1 reflects the comparison of QEM and EQEM algorithms in terms of simplification speed for paper box packaging models. The data shows that the QEM and EQEM algorithms have roughly the same simplification speed. Although EQEM has advantages in certain aspects, it has not significantly surpassed QEM in terms of simplified speed. In terms of appearance design, the EQEM algorithm can greatly simplify while maintaining a consistent appearance with the original model; In terms of computational efficiency, EQEM is equivalent to QEM and does not introduce additional computational burden. These characteristics make the EQEM algorithm more widely applicable and practical in practical applications.

Figure 6 shows the 50% simplification effect for the metal packaging model. Similar to the cardboard box packaging model in Figure 5, the metal packaging model can still maintain its overall shape and key features at a 50% simplification level. Compared to paper box packaging, metal packaging usually has more details and textures. Therefore, effectively simplifying it without losing its visual characteristics is a greater challenge. The results in Figure 6 demonstrate that the EQEM algorithm can effectively address this challenge.

Table 2 shows the comparison results of simplified time for metal packaging modes. Compared with the paper box packaging model data in Table 1, the QEM and EQEM algorithms for metal packaging models still have similar simplification speeds. This indicates that both algorithms can provide real-time simplification speed for both paper boxes and metal packaging.

Figure 6: Comparison of the appearance between the original model and the simplified model.

Tri number	*2799*	*2848*	*1326*	*889*
QEM	0	0.268	0.199	0.179
EQEM	0	0.315	0.188	0.221

Table 2: Comparison of simplified time for metal packaging patterns.

For metal packaging models, the EQEM algorithm also demonstrates superiority in simplification and execution speed, which is comparable to the QEM algorithm and can meet the needs of real-time simplification. This means that the EQEM algorithm is not only applicable to paper box packaging but also widely applied to the simplification of metal packaging and other complex models.

When evaluating the performance of a system, objective data is important, but the subjective feelings of users are also crucial. Especially for design tools such as CAD systems, the user experience, and intuitive perception directly affect their efficiency and satisfaction. Figure 7 shows the subjective rating results of designers on product packaging CAD systems in packaging design experiments. The rating result intuitively reflects the designer's satisfaction and acceptance of various CAD systems.

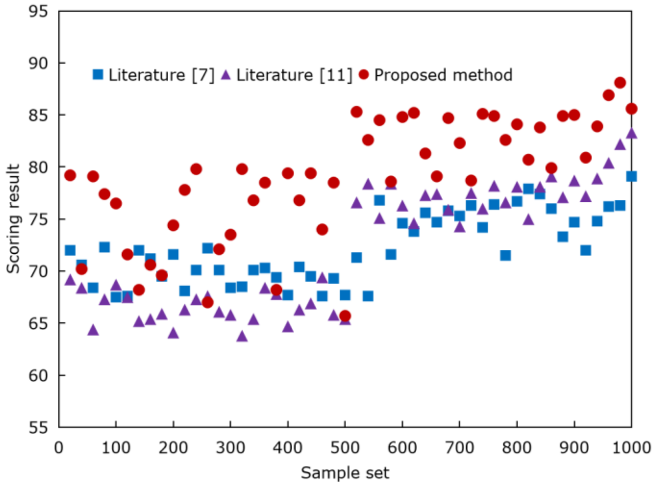

Figure 7: Designer's subjective scoring results.

The image deblurring and model simplification algorithms proposed in this article have to some extent improved the performance of packaging design systems, thus obtaining the highest subjective rating from designers. This not only verifies the effectiveness of the method proposed in this article but also demonstrates the important role of image clarity and model simplification in CAD system performance in packaging design.

4.3 Discussion

By using the EQEM algorithm for model optimization, the complexity of the model can be effectively reduced while maintaining the key features of the model. This optimization method can improve computational efficiency and rendering speed while ensuring the quality of packaging design. The application of image deblurring algorithms provides designers with clearer and higher-quality visual information, enabling them to carry out packaging design more accurately. Meanwhile, model simplification algorithms can help designers process complex models more quickly. Through the subjective evaluation of the packaging CAD system by the designer, it can be seen that the product packaging CAD system constructed using the method described in this article achieved the highest score. This result verifies the effectiveness of the image deblurring algorithm and model simplification algorithm proposed in this article in improving the performance of packaging design systems.

By introducing advanced algorithms and technologies, the packaging design process can be more efficient, and precise, and provide designers with a better work experience. This technology-driven innovation has not only been validated in current research but also provides new possibilities and ideas for the further development and innovation of packaging design in the future.

5 CONCLUSION

Packaging design is not only about the appearance of a product, but also about its protection, ease of use, attractiveness, and communication with consumers. During the production process, machine vision can detect the quality of packaging in real-time and provide data feedback to the CAD system. The latter can adjust the model in real time based on these data, reducing production waste. This article studies a machine vision-based method for deblurring packaging images and introduces a model simplification algorithm based on the EQEM algorithm. The effectiveness of the EQEM algorithm in optimizing packaging models was experimentally verified. This algorithm can effectively simplify the model while maintaining its key features, thereby improving computational efficiency. By deblurring, designers can be provided with clearer and more accurate visual information, thereby improving design efficiency. The subjective rating of the designer confirms the superiority of the product packaging CAD system constructed in this article in terms of performance, which has been widely recognized by designers. By introducing advanced algorithms and technologies, the packaging design process can be more efficient, and precise, and provide designers with a better work experience. This article mainly validates the algorithm at the theoretical and experimental levels and can be applied and tested in more real scenarios in the future to further verify its practicality.

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