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Computer-Aided Design AND APPLICATIONS

Augmented Reality Enhanced Human-Computer Interaction and Aesthetic Experience in Product Design and Exhibition

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Abstract. This article delves into leveraging augmented reality (AR) technology to elevate human-computer interaction (HCI) and aesthetic enjoyment in product design exhibitions, spurred by the pervasive use of computer-aided design (CAD) technology. Addressing the shortcomings of traditional product design and display, including limited interaction and aesthetic experiences, this study proposes an AR-based approach. This article presents a method for 3D image reconstruction by introducing regularized fine-grained matching. We constructed the display of images using regularization to improve the accuracy of detail characteristics of different image models and simultaneously handling the display process monitoring of distorted images. The research results have enhanced the customization of user preferences in human-computer interaction based on aesthetic perspectives, promoting AR technology to expand customized solutions while meeting user needs. This enhances the visual presentation perspective of product design and meets the personalized needs of customers.

Keywords: AR; Product Design; Human-Computer Interaction; Aesthetic Experience
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1 INTRODUCTION

Virtual Reality (VR), as a new practical technology that has gradually developed and improved since the beginning of the 21st century, is well-known to the public for its unparalleled immersive environment. Along with this immersion comes a large amount of human-computer interaction between users and objects in the virtual environment [1]. Due to the high fidelity of virtual reality technology in simulating real scenes and objects, the interaction behaviour between users and products in virtual scenes is highly compatible with the product interaction behaviour in real scenes. Taking product interaction design methods and processes as the guiding principle, by combining virtual reality technology, the theory and research methods of product interaction design are introduced in virtual reality scenarios. Combining various data indirectly confirms the feasibility of studying user-product interaction behaviour in virtual reality scenarios. Establish a research process and method for product interaction design based on virtual reality scenarios, and establish appropriate evaluation standards for interaction experience [2]. Starting from the analysis of user interaction behaviour in virtual environments, the evaluation criteria are user focus and user behaviour observation research. This provides new ideas for the study of user interaction behaviour among designers and provides important theoretical and guiding significance for the research of virtual reality interaction design. So the interaction behavior and experience evaluation between users and objects in virtual scenes when using virtual reality devices have important reference value for optimizing human-computer interaction methods. Therefore, studying product interaction design methods in virtual reality scenarios has important practical significance and value [3].

Some scholars focus on product interaction design in virtual reality scenarios, applying user interaction experience in virtual reality scenarios to product interaction design by product designers. This article elaborates on the problems and solutions faced by designers in product interaction design through practical cases. By constructing a product interaction design process and method model in virtual reality scenarios, summarize the impact of virtual reality scenarios on the product interaction design process and the significance of improving product interaction design efficiency [4]. This fully utilizes the immersive and experiential characteristics of virtual reality technology. This provides a new approach and method for designers to study the product interaction design process, which is concise and cost-effective. Exploring the human-machine interaction behaviour and process between users and products in product interaction design from the perspective of virtual reality technology. Compare product interaction design methods based on virtual reality scenarios and analyze the differences in human-computer interaction, user experience, and other aspects among different interaction design research methods. Explore the research methods and behaviours of designers in product interaction design based on virtual reality scenarios. And explore the impact of conducting interaction design research in virtual reality scenarios on enhancing user interaction experience, to explore the feasibility of product interaction design in virtual reality scenarios [5]. Starting from this, analyze the existing product interaction design methods through methods such as data collection and case analysis, and construct a research method for interaction design. And demonstrate the potential value of virtual reality technology in the field of product interaction design. In traditional design processes, engineers may need to rely on experience and intuition to adjust the design to avoid potential manufacturing issues. Through this method, the originally implicit design knowledge can be made explicit, greatly assisting engineers in the development process of metal castings. From the perspective of product design, this method not only optimizes the design process but also significantly improves the accuracy and efficiency of the design [6]. Now, through clear design rules and threshold settings, the uncertainty and risk in the design process have been significantly reduced. The core of this method includes three key steps: first, identify the geometric features (i.e. 3D CAD features) and their related parameters that may cause problems during the manufacturing process. Finally, express these design rules within the CAD system to facilitate product design review work. Furthermore, when we combine this method with the concept of human-computer interaction, its potential is further unleashed. Identifying manufacturing issues early on, not only does it improve product quality, but it also greatly reduces the cost of later modifications and remanufacturing. These cases demonstrate that CAD-based tools are an indispensable assistant in avoiding design issues related to metal casting processes [7].

Virtual scene interaction design refers to a way of conducting research on product interaction design in virtual reality scenarios. The traditional interaction design research method requires analyzing user needs first, using user feedback or data obtained from analysis as the starting point. Then, from the perspective of the user, break down their thinking and consider their own needs from a user's perspective. Summarize the design blind spots that other products cannot achieve and integrate them into one's design, ultimately outputting one's interaction design approach and process [8]. The biggest difference between product interaction design in virtual reality scenarios and traditional interaction design is that the entire design process can be completed in virtual reality scenarios. Simultaneously analyze the strengths and weaknesses of other competitors, analyze the thinking of other designers, and identify their weaknesses and shortcomings. Continuously modify and conduct initial model construction, studying the interaction between users and products through simple models. By placing the model in different virtual scenes, designers can simulate different types of users entering them and personally experience the real feelings of users in their usage scenarios [9]. They do not need to convey their feelings through users but rather observe and understand from their perspective. With the continuous updating and improvement of sensing technology and virtual reality devices, so far, except for the inability to reproduce the perception of smell and taste, virtual reality technology can simulate and reproduce most of the perceptual functions that people have. Virtual reality scenes provide users with higher degrees of freedom while perfectly simulating real scenes, allowing them to perform any operation on interactive products. Designers can construct product entities in virtual reality scenarios and conduct interactive design research based on different scenarios. The designer conceptualizes and draws preliminary sketches in a virtual reality scene based on the data collected from user research in the early stage [10]. The interaction design of virtual scenes has a stronger sense of immersion, which refers to the authenticity of the surrounding environment that users experience in virtual reality scenes. The research on product interaction design requires designers to have in-depth communication and interaction with the product, and the immersion brought to users by virtual reality technology perfectly realizes this.

When appreciating visual installation artworks, people's thinking and inner emotions often interact with them, even entering a state of "obsession" and generating interactive empathy. The essence of installation art is art that combines materials, venues, and emotions. Artists use installation artworks to convey the emotions and spiritual culture of individuals or groups. Causing emotional resonance among viewers is the pursuit of contemporary artists in their creations. This kind of interaction process is called emotional interaction. Contemporary visual installation art can resonate with people, and their joy, anger, sorrow, and joy will change with the changes in the artistic plot. For example, people perceive the colour, shape, sound, and other aspects of image installation art through visual, auditory, and other channels. It is worth noting that emotional interaction often requires the intervention of sensory elements to complete, so emotional interaction is usually completed based on sensory interaction [11]. As a result, it brings about emotional changes in people, leading to a state of "obsession" and generating interactive empathy. To some extent, creators often focus on emotional interaction to leave a deep impression on the audience. The result may be a specific aesthetic effect that guides the profound perception of artistic works in the form of emotional interaction. Emotional interaction is contemporary cinema. Therefore, excellent CAD software should have an intuitive user interface, rich design functions, and convenient operation methods to provide a good human-computer interaction experience. This not only improves design efficiency but also allows designers to identify potential issues and make corrections in the early stages of design, thereby saving a lot of time and cost. In addition, we can adopt some solutions to address the phenomenon of planar annotation after 3D mapping and the problem of data transmission between different software during the packaging design process. In response to the problem of outdated and inefficient CNC programming for complex parts of marine diesel engines in actual production, the application experience of CAD technology in product packaging design can be borrowed, and CAD technology can be introduced into the CNC programming of diesel engine parts. For example, we can use standardized data formats to ensure smooth data exchange between different software. At the same time, we can also develop specialized tools or plugins to handle the problem of planar annotation after 3D mapping, thereby improving design efficiency and quality [12]. In addressing the aforementioned challenges, this article endeavours to delve into utilizing AR technology to elevate both HCI and aesthetic appreciation in the realm of product design and exhibition. To accomplish this, the article will delve into the following key dimensions:

First of all, the article offers an introduction to the fundamental principles and distinctive attributes of AR technology, alongside its current application landscape and evolving trends within product design and exhibition. This in-depth examination and analysis of AR technology serve as a theoretical foundation for subsequent research endeavours.

Secondly, this article will focus on how AR technology can improve the HCI experience in product design and display. Through the comparative analysis with the traditional display mode, this article will elaborate on the advantages of AR technology in real-time interaction, feedback, immersive experience and so on.

Thirdly, this article will study how AR technology can improve the aesthetic experience in product design and display. By analyzing the aesthetic elements and standards of product design, this article will discuss how AR technology presents a more realistic, vivid, and artistic product image in the virtual environment.

2 RELATED WORKS

Li et al. [13] systematically summarized and sorted out the evaluation methods for interactive digital interfaces, combined with expert interviews in the fields of human-computer interaction and software development. On this basis, it proposed the concept of a comprehensive human-computer interaction digital interface evaluation software. Meanwhile, through the sorting and analysis of existing human-computer interaction digital interface evaluation software, it is found that the existing interface evaluation software mainly has the following shortcomings. Scored each evaluation method from the perspectives of feasibility and value of software implementation and extracted suitable evaluation methods for software implementation. The evaluation dimension is single, the evaluation object is single, the evaluation level is low, and the degree of automation is low. Further elaborated on each functional module's evaluation indicators, methods, and processes, and designed and developed the QS module in detail. It has designed the basic architecture and user task flow of the software and completed the detailed high-fidelity design of the overall software and the evaluation module based on questionnaire scales. Based on Java language and web technology, the development and implementation were completed, and instance testing was conducted. A usability evaluation index system for interfaces was established through a literature review, expert survey, and other methods, and its reliability and validity were analyzed. Subsequently, the Analytic Hierarchy Process was used to calculate the weights of each indicator, thereby establishing a standardized usability evaluation model based on user experience.

As an important component of human-computer interaction systems, the design quality of digital interfaces is crucial for the impact on user experience. Lorusso et al. [14] summarized and sorted out existing evaluation methods for human-computer interaction digital interfaces, and extracted various evaluation methods suitable for software implementation. It pointed out the shortcomings of existing evaluation software in terms of evaluation objects, dimensions, levels, and degree of automation. Reliability and validity analyses were conducted, constructing a universal interface usability evaluation model. On this basis, a design concept of a comprehensive human-computer interaction digital interface evaluation software containing multiple evaluation function modules was proposed, and the evaluation process and methods of each module were designed. Based on Java language and web technology, the overall framework and QS module of the software were developed and implemented, and functional testing and instance evaluation testing was conducted on it. Based on the analysis of existing human-computer interaction digital interface evaluation software, a design concept of a comprehensive interface evaluation software is proposed, and its typical modules are designed and implemented in detail. Contemporary image installation art, as an artistic carrier, combines the expression of both temporal and spatial dimensions. This combination of time and space dimensions creates a non-linear narrative thinking and brings audiences a multi-sensory and immersive artistic experience. In the process of social development, each stage will produce highly distinctive art forms. To some extent, contemporary visual installation art is an installation art that primarily uses images as a means of communication. From a technological perspective, it is a new media art form that is based on computer information collection technology, and external devices, combined with display space, and mainly focuses on interactive communication. To this day, contemporary image installation art continues to progress with the help of constantly innovating technological forces and has become an important component of contemporary art, a form of artistic expression with diverse concepts and connotations. Qiao et al. [15] interacted with the AR system through an intuitive interface. Compared to traditional easel painting forms, the aesthetic perspective of contemporary visual installation art is not fixed. People can perceive the creator's concept from multiple perspectives in the field space, achieving sensory reshaping of themselves. Improving the accuracy and efficiency of image segmentation, can not only provide designers with more convenient and efficient design tools but also provide users with a more realistic and immersive AR experience.

With the deepening development of digitization, a revolution is taking place in the field of product design. However, despite this, the visual representation generation of product concepts still heavily relies on traditional real-world simulation tools. Reska and Kretowski [16] found that although AR technology provides unparalleled immersion and interactivity, the current connection between modelling paradigms and interaction methods is still weak, spatial loyalty is insufficient, and there are ergonomic issues. Staszak [17] explores the potential of immersive technology in the field of product AR design and why it has not been widely applied in human-computer interaction and conceptual design activities. Based on analyzing existing technologies, not only have geometric representations (such as parameterized or polygonal models) and interaction methods been classified, but their application in product AR design has also been given special attention. To gain a more specific understanding of these issues, an experimental section was also designed, inviting users from different backgrounds to participate. Xu and Zheng [18] conducted a qualitative discussion using sketches drawn by visual contrast testers and conducted in-depth analysis based on user survey information before and after the experiment. Although AR systems provide a more intuitive and immersive experience, users can express their design ideas more naturally. However, some users have reported that prolonged use of VR systems can lead to physical fatigue, which is a problem that traditional 2D sketching processes do not encounter. They were asked to use traditional methods (i.e. pen and paper) and two AR-based applications (focusing on 3D sketching and 3D carving respectively) to draw conceptual sketches of computer mice. Although immersive 3D technologies such as virtual reality (VR) are widely available and reasonably priced, many designers still prefer to use pencils, paper, or digital counterparts to draw preliminary ideas on a 2D plane in the conceptual design process. In addition, although the sample size is not sufficient to provide statistically significant evidence, these results provide valuable insights into the current level of technical readiness of AR technology as a conceptual design tool.

3 CNN MODEL

CNN, a deep learning algorithm, excels in image recognition and processing, playing a pivotal role in the design and presentation of AR products. Firstly, CNN facilitates the rendering and display of 3D product models. Through convolution and feature detection, it produces high-quality, lifelike 3D images, heightening the realism of virtual products. The convolutional layer convolves the input features and passes the results to the next layer, which is similar to how cortical neurons in the biological world respond to stimuli. Each cortical neuron can only process information about its receptive field layer size. Although fully connected feedforward neural networks can also extract features and classify data, this structure is not suitable for large image data. On the contrary, convolutional layers have the characteristics of local perception and weight sharing, which can reduce computational complexity, allow for deeper network structures, and consider the spatial relationships between different features. As the number of layers and receptive fields in the network model increases, low-level features are gradually concatenated into high-level features. Because each pixel is a related input feature, it requires a lot of "neurons". This is not a simple combination, but a powerful visual hierarchy that provides more possibilities for processing image features.

Relu (Corrected Linear Unit) activation function, also known as linear correction unit, is widely used in tasks such as computer vision. In practical use, the Relu activation function converts all negative values to 0, while keeping positive values unchanged. This operation is called unilateral inhibition, which gives neurons in the neural network sparse activation. It reduces the interdependence between parameters, thereby enabling the model to better mine relevant features and fit training data. Currently, the Relu activation function is the most widely used in convolutional neural networks. The gradient of the Relu function has only two values, 0 and 1. When the input is less than Å, the gradient is 0 and the gradient stops propagating from that position. When the input is greater than 0, the gradient is 1, and the gradient remains unchanged to continue forward propagation, keeping the convergence speed of the model in a stable state, effectively avoiding overfitting problems. As shown in Figure 1, the typical structure of CNN is shown.

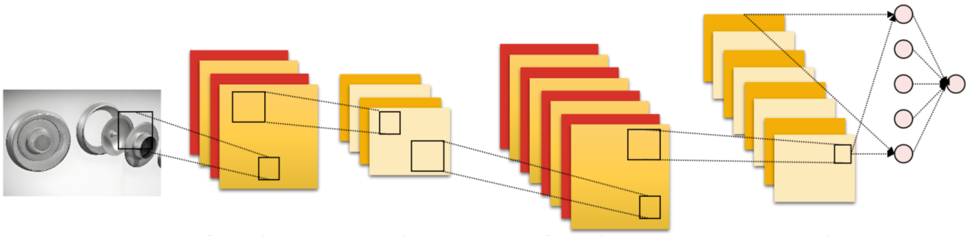

Figure 1: CNN structure.

4 COMBINATION OF CAD AND AR TECHNOLOGY

With the widespread application of image technology, the evaluation of image quality has become a crucial issue. Compared to other forms of information, images have unparalleled advantages, so accurate evaluation of them has very important application value. In addition, scenarios such as remote on-demand and video conferencing also require real-time online monitoring of image quality, and continuous adjustment to overcome transmission errors and network delays and meet user needs. Specifically, in image recognition, the quality of the collected images directly affects the accuracy and reliability of the recognition results. Therefore, accurate evaluation of image quality is crucial for improving the effectiveness and reliability of various applications. In the military field, the quality of photos collected by aerial photography equipment such as drones directly affects the judgment of battlefield monitoring and strike effectiveness. Therefore, it is necessary to adopt an objective and unified standard to evaluate the reconstructed images. At present, the evaluation of image quality is mainly divided into two categories: the first category is based on whether the participants are human, which are subjective evaluation criteria and objective evaluation criteria. At present, people usually evaluate the quality of images based on their visual perception, and this evaluation result is greatly influenced by subjective factors.

As depicted in Figure 2, the style-transferred image, refined through Poisson editing, seamlessly integrates the target style while retaining the source's core content. Where: u represents the source image; v is the gradient field of the source image; Ω is the covered area in the merged target image; $\partial\Omega$ represents the boundary; S is the merged image. Let f represent the image in Ω area, and f^* represent the merged image outside Ω area.

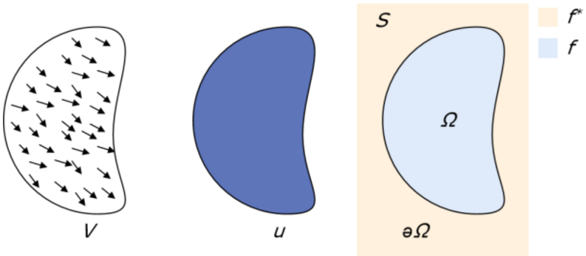

Figure 2: Schematic diagram of Poisson image editing.

In the early stage of product design, designers can create virtual prototypes of products through CAD software and present them to users by using AR technology. Users can directly view the virtual image of the product in the real environment and interact with it in real time. This virtual prototype display can help users understand the appearance, size, and functional characteristics of products more intuitively and put forward more targeted feedback and opinions. Furthermore, designers can also optimize product design in time according to users' feedback and opinions.

The goal of image synthesis is that the merged image is as smooth as possible without obvious boundaries; that is, the gradient change in the region is as small as possible. In addition, it is necessary to ensure that the source image can keep its texture information while ensuring that the region is as smooth as possible, so the optimization problem under this constraint is:

$$L^{*} = \min_{f} \iint_{\Omega} \left\| \nabla f - v \right\|^{2} \tag{1}$$

At this point, the integrand function is:

$$F = \left\| \nabla f - v \right\|^{2} = \left\| \nabla f - \nabla u \right\|^{2} = \left(f_{x} - u_{x} \right)^{2} + \left(f_{y} - u_{y} \right)^{2} \tag{2}$$

Then apply the Euler Lagrange equation, where:

$$\frac{d}{dx}\left[\frac{\partial F}{\partial \left(f_{x} - u_{x} \right)^{2}} \right] = \frac{d}{dx}\left[2\left(f_{x} - u_{x} \right) \right] = 2\left(\frac{\partial^{2} f}{\partial x^{2}} - \frac{\partial^{2} u}{\partial x^{2}} \right) \tag{3}$$

Then, we can obtain:

$$\frac{\partial^{2} f}{\partial x^{2}} + \frac{\partial^{2} f}{\partial y^{2}} = \frac{\partial^{2} u}{\partial x^{2}} + \frac{\partial^{2} u}{\partial y^{2}} \tag{4}$$

The Laplace operator, viewed through the lens of divergence, is formulated as the divergence of a gradient:

$$\Delta f = div \left(\nabla f \right) = \nabla \cdot \left(\nabla f \right) = \nabla^{2} \tag{5}$$

So, the 2D space is expressed as:

$$\Delta f = div\left(\frac{\partial f}{\partial x} i, \frac{\partial f}{\partial y} j \right) = \frac{\partial^{2} f}{\partial x^{2}} + \frac{\partial^{2} f}{\partial y^{2}} \tag{6}$$

Equation (6) can be written as the following Poisson equation:

$$\Delta f = div \left(\nabla u \right) = \nabla^{2} u \tag{7}$$

Where Δf is the Laplace operator; div is the divergence operator. The desired composite image can be obtained by solving this Poisson equation.

The combination of CAD and AR technology can also help create customized exhibition schemes. Designers can create personalized product models through CAD software according to users' needs and preferences and present them to users by using AR technology. Users can directly view and experience personalized product effects in the real environment and make adjustments according to their own needs.

In this article, the quick selection tool of Photoshop software is used to segment the image, and the cabinets, tables, chairs and other objects of the product image are divided into approximate frames, and the mask colour is used to mark them. Different objects use different colours, such as the market segmentation map shown in Figure 3.

Represent the gray function of a 2D discrete image of $m \times n$ with $f(x,y)$, and define its $p+q$ moment as follows:

$$m_{pq} = \sum_{x=1}^{m} \sum_{y=1}^{n} x^{p} y^{q} f(x,y) \tag{8}$$

Figure 3: Homestyle segmentation.

The position of the grey gravity centre of the image is represented by two first-order moments, denoted as m_{10}, m_{01} .

The original image $N \times N$, denoted as $f(x,y)$, undergoes processing via the neighborhood averaging method, resulting in the image $g(x,y)$:

$$g(x,y) = \frac{1}{M} \sum_{(m,n) \in S} f(m,n) \tag{9}$$

In this context, S represents the neighborhood centred around (x,y) , while M denotes the total count of coordinate points contained within the set S .

Image binarization involves setting a threshold, denoted as T . Pixels with a grey value greater than or equal to T are assigned a value of 1, while those with a grey value less than T are given a value of 0. This process results in a black-and-white image consisting only of the grey values 0 and 1. The rules for grey image binarization are outlined below:

$$g(x,y) = \begin{cases} 1, & f(x,y) \geq T \\ 0, & f(x,y) < T \end{cases} \tag{10}$$

The value of the original pixel is denoted as $f(x,y)$, $f(x,y)$ represents the binarized pixel value, and $f(x,y)$ serves as the threshold.

In product design, let $p(i)$ represent the histogram probability of the image, i denote the grayscale value and $0 \leq i \leq L$ be a given parameter. The histogram potential function can be expressed as follows:

$$P_H(k) = \frac{1}{P_{\max}} \sum_{i=0}^{L} \frac{P(i)}{1 + \alpha (i-k)^2} \tag{11}$$

$$P_{\max} = \max \left\{ \sum_{i=0}^{L} \frac{P(i)}{1 + \alpha (i-k)^2} \right\} \tag{12}$$

With α serving as the parameter, let $I = [f(x,y)]_{m \times n}$ represent the product design array, described as follows:

$$x \in \{0,1,2,3,\ldots,m-1\} \qquad y \in \{0,1,2,3,\ldots,n-1\} \tag{13}$$

The grey value of the pixel located at the image array (x,y)'s position is represented by $f(x,y) \in \{0,1,2,3,\ldots,G-1\}$, while G signifies the maximum grey value of the image I. The histogram function for the image I is defined as follows:

$$h(i) = \sum_{x=0}^{m-1}\sum_{y=0}^{n-1}\delta\left(f(x,y)-i\right) \qquad i \in \{0,1,2,3,\ldots,G-1\} \tag{14}$$

With $\delta(0)=1$ and $\delta(i \neq 0)=0$, $h(i)$ designates the count of pixels possessing the grey value i that occur within image I.

5 RESULT ANALYSIS AND DISCUSSION

To verify the applicability of AR technology in product design displays for different styles and product types, this article selects four typical product design scenarios: electronic products, household goods, industrial equipment, and outdoor equipment. In each scene, different mainstream design styles were selected for display. As shown in Figure 4, from left to right corresponds to the original product design, target design style, and fusion effect presented through AR technology.

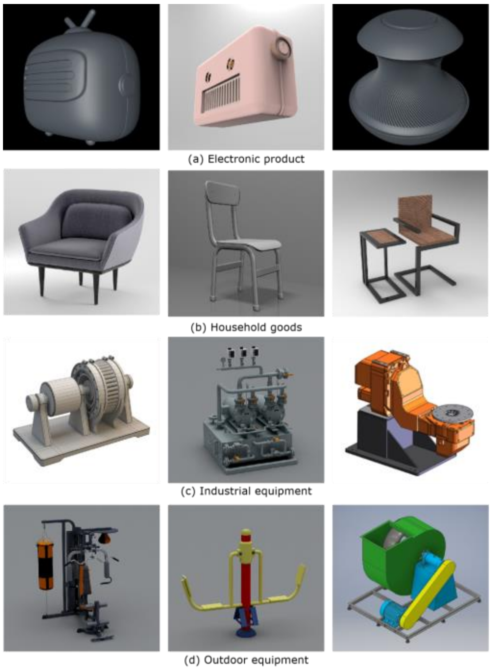

Figure 4: Fusion effect diagram.

As depicted in Figure 5, a comparative analysis of the success rates among various product design feature detection methodologies is presented. This evaluation underscores the remarkable performance of the product feature detection approach proposed in this article, attaining a success rate exceeding 90%. This significant outperformance surpasses other benchmark methods. In practical applications, this methodology not only enhances the efficiency of the design process but also deepens designers' understanding of the intrinsic principles governing product design. Moreover, it offers robust technical underpinnings for the intelligent and automated evolution of product design.

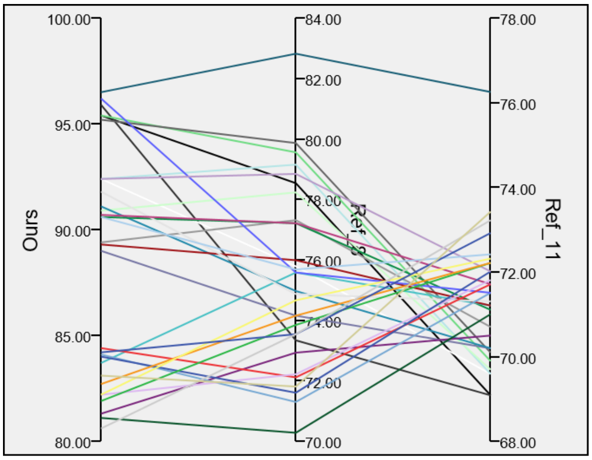

Figure 5: The success rate of design feature detection.

The comprehensive outcomes depicted in Figures 6 and 7 convincingly demonstrate the superiority of the 3D reconstruction method for product images introduced in this article, exhibiting enhanced reconstruction precision and user satisfaction over the feature detection techniques documented in References [8] and [11]. This achievement not only benefits from our carefully designed algorithm framework but also lies in the careful polishing of key technologies.

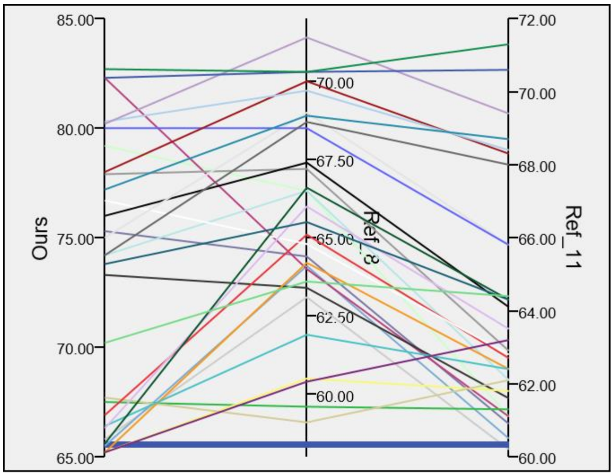

Figure 6: Comparison of reconstruction accuracy.

In the process of exploring 3D reconstruction technology in depth, we carefully introduced regularization terms into the loss function, which is an innovative measure aimed at effectively managing the complexity of the model and significantly reducing the risk of overfitting. A model that performs well only on training data may fail due to its inability to adapt to complex and ever-changing test data. Regularization technology, as a key strategy in the field of machine learning, aims to prevent models from overly focusing on the details of training data and neglecting the learning of wider data distribution by constraining model parameters. Therefore, by cleverly adding regularization terms to the loss function, it is ensured that the model not only focuses on fitting the training data during the training process but also pays attention to the simplicity of the model structure and its adaptability to unknown data. This progress is not only reflected in numerical indicators but also in visual effects. This balanced thinking is not only reflected at the technical level but also reflects profound thinking about the future development of 3D reconstruction technology. When dealing with complex and ever-changing product images, the method demonstrates an excellent ability to capture complex image features, laying a solid foundation for achieving more accurate feature matching and 3D reconstruction. By comparing and analyzing the image-matching results before and after improvement, it is clear to observe the significant accuracy improvement brought about by the introduction of regularization terms. It is worth mentioning that the introduction of regularization terms does not simply add a mathematical formula, but rather provides a profound understanding and modification of the model learning mechanism. It makes us realize that while pursuing high precision, we cannot ignore the generalization ability and stability of the model.

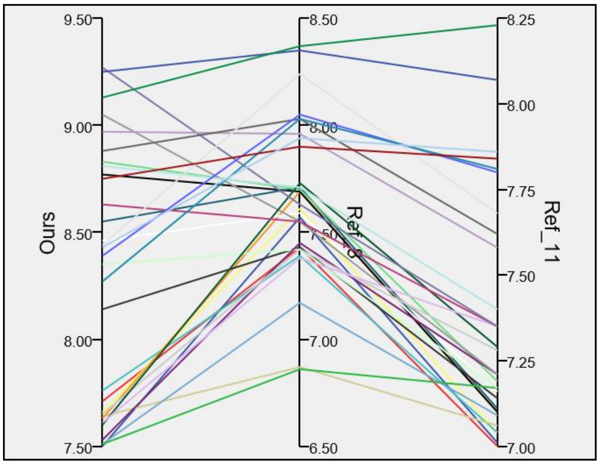

Figure 7: Comparison of user satisfaction.

Regarding product design quality, the proposed method leverages precise feature detection and efficient 3D reconstruction to capture the shape, structure, and intricate details of the product, thereby guaranteeing the precision and credibility of the design solution. This ensures a superior design output that not only aligns with user requirements but elevates the overall product quality. Additionally, from a visual perspective, the integration of optimized algorithms and advanced image processing techniques renders the design outcomes more realistic, vivid, and captivating. This excellent visual expression can not only attract users' attention but also enhance users' interest in products. The degree of user satisfaction is often closely related to the usability, convenience of operation and user experience of products. Therefore, in the process of developing this method, we always pay attention to the improvement of user experience.

In the experimental setup, six image sets were initially designated as test samples. However, during the preprocessing phase, we identified distortion issues in two of these sets. To uphold the credibility of our findings, we opted to exclude these distorted sets and confine our analysis to the remaining four. Figure 8 offers a visual comparison of the image-matching outcomes, both before and after optimization. Before enhancement, the matching error rate hovered at approximately 10%, indicative of a significant number of mismatched instances, thereby compromising the overall accuracy. Nevertheless, following the introduction of a regularization term to refine the model, the error rate underwent a substantial reduction, stabilizing within the range of 3% to 5%.

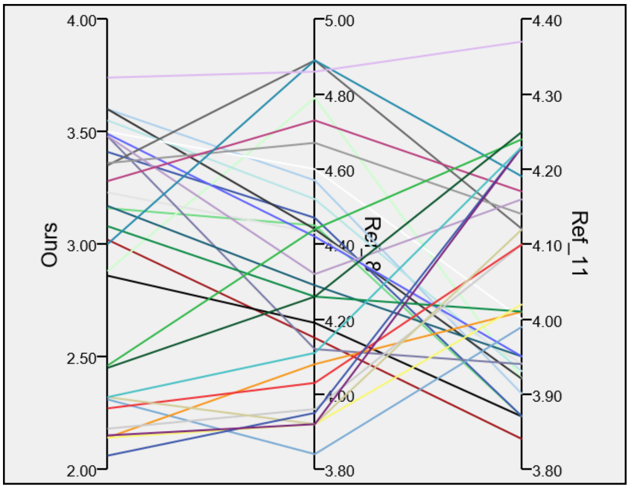

Figure 8: Image matching error rate.

Further analysis of the data in Figure 8 shows that the lowest error rate before improvement is 9%, while the highest error rate after improvement is only 4.5%. Even in the case of relatively poor matching results, the improved method can still maintain a low error rate, far below the lowest level before improvement. By adding a regularization term to the loss function to reduce the complexity of the model, the error rate of image matching is successfully reduced and the accuracy of matching is improved. This improvement has not only achieved remarkable results in numerical value but also has important significance in practical application.

6 CONCLUSIONS

The emergence of AR technology undoubtedly injects new vitality into product design and exhibition fields, opening up an unprecedented field of possibilities. In today's increasingly mature CAD technology, we can accurately construct and display three-dimensional models of products. However, the introduction of AR technology has made this display method more vivid and interactive. It cleverly integrates virtual elements into the real world with its unique charm, constructing a breathtaking immersive interactive space. This unprecedented product experience allows users to have a more intuitive and in-depth understanding of the product, greatly enhancing the attractiveness of the product and user satisfaction. In this space, users are no longer passive observers, but participants who can participate in real-time and directly interact with virtual products. The implementation of AR technology not only further enriches and personalizes the presentation of products, but more importantly, it greatly enhances the convenience of human-computer interaction.

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