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Computer-Aided Design AND APPLICATIONS

Artistic Reproduction of Wood Carving: Virtual Simulation of 3D and Human-Computer Interaction

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Abstract. Amidst the swift evolution of contemporary society, the age-old art of wood carving is encountering unprecedented obstacles. Powerful model rendering and detail construction were achieved using precise 3D contour details. You can see the rendering results of the complex features of the wood carving works. This article utilizes HCI-based 3D computer culture wood carving art digitization to construct an accurate model of 3D heritage wood carving. By analyzing the shape, texture, and subtle features of CAD, a 3D art woodcarving digital virtual simulation has been created in the field of digital art. The precise features of this woodcarving technique provide a more scientific platform for constructing textures. At the same time, the integration of user needs and HCI technology has created the charm of woodcarving culture and user interaction in virtual simulation spaces. By exploring the virtual influence space of intangible cultural heritage, the audience's participation and immersive experience have been increased. Created user interaction results for intangible cultural heritage woodcarving. Therefore, the seamless integration of intangible culture and virtual model simulation of wood carving into a new perspective and cutting-edge technology has been achieved.

Keywords: Intangible Heritage; Wood Carving Technology; Artistic Reproduction; CAD; Human-Computer Interaction
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1 INTRODUCTION

The intricate production process of traditional wood carving, requiring exceptional skills, has made its transmission and acquisition a formidable challenge [1]. Cultural heritage is not only a precious witness of the past but also the crystallization of art and wisdom that has been passed down to this day. Through advanced technological means, gain a deeper understanding of the structure and materials of these cultural heritage sites. The texture, texture, colour, carving techniques, depth, and smoothness of wood directly affect the final effect of wood carving works. And these details are the key to the charm of woodcarving art. Among them, woodcarving, as a unique art form, occupies an extremely important position in cultural heritage. Some scholars have elaborated on the CAD design or reverse engineering surface reconstruction of 3D sculpture computer models. And apply examples to verify the feasibility and superiority of this large-scale sculpture block-forming technology based on CNC progressive forming. The process route for producing large sculptures using CNC progressive forming technology for large-scale sculpture assembly. The entire production process of sculpture products, including CAD model scaling and segmentation, adding process auxiliary surfaces for sculptural surface patches, and progressive sheet metal forming. Reverse engineering methods can also be used to measure three-dimensional data of pre-formed mud moulds, wood moulds, etc. After processing the measured data, import it into reverse engineering software for measurement data processing and surface reconstruction to obtain a CAD model. Computer-aided design software can be applied to design three-dimensional sculpture shapes and obtain CAD models of sculptures. Scale the constructed surface model in 3D CAD software according to the required sculpture size [2]. Then, based on the size and shape of the sculpture, the machining stroke of the CNC progressive forming machine, etc., the scaled sculpture model is segmented into several free-form surface pieces.

In CAD software, project the boundary lines of each surface patch vertically onto the selected reference plane and then output the projected closed curve diagram in the plane engineering drawing. To ensure the continuity of progressive forming machining, it is necessary to add a process auxiliary surface connecting the boundary of the curved surface and the reference surface so that subsequent progressive forming machining can proceed continuously. The process of constructing surface patches in CAD software is to assist in the 3D model of surface segmentation, and the boundaries of each part of the surface patches obtained are generally not on the reference plane. You can create a line segment on the reference plane that is similar to the boundary curve of the surface patch and then insert a mesh surface passing through these two curves between the two to add the process auxiliary surface of the surface patch. Input the NC code into the sheet metal CNC forming machine to perform progressive forming on the sheet metal and form the required formed parts. Because sculptural surfaces are generally complex, it is best to use the forward stretching method for progressive forming [3]. CNC progressive forming technology is based on the geometric information of the workpiece shape and controls the forming tool head on the CNC equipment to perform local plastic processing on the sheet metal along a specific trajectory, gradually forming the sheet metal into the desired workpiece. According to the complexity of the surface, select the appropriate forming tool head. The forming tool head starts from the specified position, processes from the highest layer (first layer) of the sheet metal, and moves downwards according to the cross-sectional contour to process the required formed parts layer by layer. In the actual forming process of sheet metal, the CNC machining program for machining the curved surface is determined by the CAM module of the 3D machining software. First, mill out a simple substitute wood support, place the sheet metal on top of the milled substitute wood support model, fix the sheet metal with an edge pressing device, and use the CAM module to generate the machining trajectory of the forming tool head. Through online teaching, case analysis, interactive discussions and other methods, students can have a deep understanding of the artistic characteristics and technical requirements of wood carving technology. The design, development, debugging, and deployment of this creative teaching model are all carried out in the same working environment, greatly improving the coherence and efficiency of the development of the teaching model. In the selection of backend databases, Microsoft SQL Server 2010 was used to ensure data stability and security. Through the online platform, students can access learning resources anytime and anywhere, participate in course discussions, submit assignments and work, and achieve personalized and autonomous learning. Guided by the principle of modular design, this teaching mode adopts the MVC three-layer architecture mode based on B/S mode to ensure the efficiency and scalability of the system. In the study of woodcarving art, group cooperation can not only promote communication and interaction among students but also work together to complete complex woodcarving works through division of labour and cooperation, improving students' teamwork and practical skills [4].

With the deepening exploration of art and the continuous sublimation of people's aesthetic concepts, the understanding of "beauty" and the reverence for "nature" have been deeply integrated into every detail and decoration of interior design. Especially in the field of cultural heritage woodcarving art, its unique charm and profound cultural heritage bring a new perspective and inspiration to interior design [5]. Integrating wood carving techniques into interior design is not only a way to inherit and promote traditional culture, but also an innovation and expansion of modern aesthetics. Woodcarving, as an ancient and exquisite art form, not only reflects the ingenuity and skills of craftsmen but also carries rich historical and cultural connotations. Display, also known as frame sculpture, is an indispensable part of interior design. Taking wooden landscape sculptures as the main body can fully expand the scope and possibilities of display. In the expression of landscape sculpture, woodcarving techniques endow it with characteristics such as commemorative, thematic, decorative, functional, and decorative [6]. The application of woodcarving technology makes landscape sculpture more vivid, delicate, and infectious in expression. Through practice and innovation, wood carving technology is applied to various aspects of interior design, such as furniture, partitions, wall decoration, etc., allowing wood carving technology to be fully demonstrated and inherited in interior design. On this basis, it is necessary to conduct in-depth research on the compatibility between wood carving and interior design and find the best way to integrate the two [7]. By introducing modern design concepts and technological means, we can break the limitations and constraints of traditional wood carving techniques, and achieve innovation and breakthroughs in form, materials, technology, and other aspects of wood carving. Through careful design and arrangement, woodcarving landscape sculptures can showcase the artist's thoughts, style, feelings, personality, etc. in a larger space, creating a unique cultural atmosphere and artistic atmosphere for indoor spaces. At the same time, it is also necessary to pay attention to social changes and market demands and adjust and update design concepts and methods promptly to meet people's constantly changing aesthetic needs and lifestyles [8].

More and more designers and artists are creating dynamic installation art that enriches urban landscapes and attracts tourists from all over the world. Mainly focusing on the challenges encountered in the design process of a type of dynamic sculpture with continuous changes in form. Kinetic Sculpture is representative of this type of dynamic product, which has an avant-garde aesthetic and ornamental value [9]. At present, there are few design theories for tool software, and to design a reasonable tool software product, user experience designers lack systematic guidance during the design process. The design of such wooden sculptures requires designers to spend a lot of time and effort creating digital models and product animations, which limits the creativity of artists and lacks effective auxiliary design tools to help designers reduce their workload [10]. By summarizing the characteristics of dynamic sculpture, some scholars have proposed a design method based on curve-constrained form, which is more in line with design habits. Under the guidance of a systematic tool software design model introduced, the author designed a high-fidelity prototype interface for the entire tool system. A complete parameterized design process was designed using computer graphics (CG) and computer-aided technology (CAD). Through user experiments, we found that KINETIIST performs well in terms of user experience in terms of effectiveness, interactivity, and learning habits, and has practical value. Users can quickly generate a three-dimensional model and simulation animation of a wooden sculpture with simple operations and defining a few parameters [11].

There are the following innovative points in the research:

1. This article proposes a parameterized design method based on the principle of skeleton, which helps designers quickly construct dynamic wood sculpture digital prototypes from a morphological perspective. This design method simplifies the design process into four simple steps: sketch design, skeleton generation, unit allocation, and motion simulation.

2. This article proposes a dynamic sculpture design method that utilizes curve-constrained shapes and develops a dynamic sculpture prototype design tool for use in browsers. Users can quickly generate 3D models and computer animations of dynamic sculptures by drawing curves and adjusting parameters.

3. Currently, there are relatively few design methods and theories for computer-aided design tool software, making it difficult to design such products. This article validated its effectiveness through practical experience in the later stage of interface prototype design.

Section 1 of this article elaborates in detail on the integrated application of 3D CAD and HCI technology, by combining these two technologies. Section 2 of this article successfully constructed a virtual simulation system for intangible cultural heritage woodcarving. This system not only achieves high-precision replication and virtual display of woodcarving works but also provides users with a rich interactive experience. Section 3 provides a detailed introduction to the design and implementation process of the system, including data acquisition, model construction, interaction design, and other aspects. In Section 4, we tested and evaluated the performance and effectiveness of the system to ensure its stability and practicality.

2 RELATED WORK

Li et al. [12] elaborated on the innovative artistic and cultural integration methods of interactive robots in the process of wood carving feature characterization. The device cleverly integrates four core components. Firstly, there is an audience interaction design that allows viewers to interact with the device intuitively and interestingly, sharing their dreams and visions. It can intelligently parse the audience's input and transform it into patterns in woodcarving art. The precise communication with the industrial robotic arm ensures that the patterns generated by the software can be accurately carved through the robotic arm. This device utilizes advanced artificial intelligence (AI), KUKA industrial robots, and cutting-edge interactive technology to bring viewers a brand-new artistic experience. Liu and Yang [13] use intelligent driven multi-colour drawing software to interpret and transform the audience's hidden dreams into exquisite collective painting in the form of woodcarving art. Viewers can interact with devices through sound, and their words are transformed into concrete woodcarving works. With the help of modern technology, traditional woodcarving techniques have been revitalized and presented to the audience in a more dynamic and interactive form. This process not only showcases the new applications of robot technology in the field of art but also greatly enriches the audience's sense of participation and artistic experience.

As a unique and precious traditional craft, the inheritance and development of wood carving culture face many challenges and opportunities. Nortvig and Petersen [14] proposed a gesture recognition method based on a dual channel region convolutional neural network (CNN) and explored its potential application in the inheritance of woodcarving cultural heritage craftsmanship and art. However, due to the complexity and diversity of gestures, traditional gesture teaching methods are difficult to teach apprentices comprehensively and accurately. In the wave of the digital age, how to combine wood carving art with modern technology, improve its inheritance efficiency, and expand its influence has become a topic worth exploring. The CNC progressive forming technology of sheet metal is currently an emerging technology for wood carving sheet metal forming internationally, which does not require specialized moulds. Trek [15] established a calculation formula for the wall thickness and thinning rate of CNC progressive forming workpieces by studying the forming mechanism of sheet metal CNC progressive forming technology. Based on CNC progressive forming technology, a large-scale sculpture block forming technology based on CNC progressive forming is proposed, which establishes the 3D wood sculpture CAD modelling, wood sculpture model scaling and segmentation. It is possible to process sheet metal parts with large forming limits and complex shapes through CNC equipment, which is suitable for small batches, multi-variety, and complex woodcarving sheet metal products. At the same time, the positions of electrode wires and threading holes, the selection of wire-cutting routes, and the technical details of cutting and removing raw materials in actual wire-cutting operations were discussed. And proposed the principles of surface segmentation for sculpture models, as well as a detailed method for constructing process auxiliary surfaces in CAD software. A comprehensive analysis was conducted on the impact of various factors on the wood carving forming process in the CNC progressive forming process, and a complete method for optimizing these factors was proposed. Two different methods were studied for the establishment of sculpture models: using 3D CAD software for design and using reverse engineering to reconstruct CAD wood sculpture surface models. Detailed research has also been conducted on the combination technology of various woodcarving plastic parts, providing a series of feasible technical solutions. The production technology route for the entire CNC progressive forming woodcarving sculpture product from adding process auxiliary surfaces of curved patches, progressive forming processing, trimming raw materials to final combination forming. You and Li [16] used portraits as an example to make wooden sculptures, verifying the feasibility and superiority of this CNC progressive forming-based sculpture-making technology, and providing a reliable example for the production of such sculpture products. Through digital technology, Zhang [17] can more accurately control the size, shape, and texture of wood carving components, improving the production accuracy and quality of work. In parametric manufacturing, designers can change the form and details of work by adjusting parameters, achieving a more flexible and personalized design. In the artistic inheritance and development of woodcarving cultural heritage craftsmanship, the exploration of new technologies and materials is crucial. Designers are searching for new types of wood or composite materials with better performance to enhance the physical properties and durability of wood carving.

3 OVERVIEW OF ICH WOODCARVING TECHNOLOGY

3.1 Development History

The art of ICH wood carving boasts a profound heritage that dates back several millennia. This craftsmanship was prevalent in ancient China, spanning diverse domains like architecture, furniture design, and religious artefacts, thereby occupying a pivotal position in the country's traditional cultural landscape. With the changes of the times, woodcarving techniques are constantly developing and innovating, forming distinctive regional schools and styles. From the early rough and bold to the later meticulous, ICH woodcarving technology has made remarkable progress in skills and styles. Table 1 shows the representative works of ICH woodcarving technology in different historical periods and their characteristics.

Historical Period	*Representative Works*	*Craftsmanship Characteristics*	*Stylistic Features*
Pre-Qin Period	Altars, Tables	Simple carving, bold lines	Simple and natural, focusing on practicality
Qin-Han Period	Palace Woodcarvings, Coffins	Elevated carving skills, beginning to focus on details	Solemn and serious, reflecting imperial dignity
Sui-Tang Period	Buddhist Statues, Religious Items	Further development of carving skills, the emergence of relief and openwork carving	Smooth lines, focusing on the expression of spirit
Song-Yuan Period	Furniture, Decorations	Skills reaching the peak, emergence of multi-layer openwork and 3D carving	Intricately detailed, pursuing artistic conception
Ming-Qing Period	Imperial Woodcarvings, Garden Woodcarvings	Balancing inheritance and innovation, the emergence of various schools and styles	Gorgeous and intricate, focusing on decorative and artistic value

Table 1: ICH woodcarving technology in different periods.

3.2 Artistic Feature

ICH wood carving technology attracts people's attention with its unique artistic characteristics. First of all, wood carvings usually use hard and fine-grained wood, such as rosewood and boxwood, which not only has high hardness and stability but also can present unique texture and colour, adding a unique charm to wood carvings. Secondly, ICH woodcarving technology pays attention to the expression of detail and charm. Sculptors carve wood into various lifelike images of animals, figures, and flowers through exquisite skills, and at the same time, they pay attention to the expression of artistic conception and the charm of the works, which gives the works high artistic value. Finally, ICH wood carving presents diversity in style. The woodcarving works of different regions and schools have their characteristics in style, such as Longan woodcarving in Fujian, Dongyang woodcarving in Zhejiang, and Chaozhou woodcarving in Guangdong, all of which attract people's attention with their unique technical characteristics.

3.3 Inheritance and Development Status Quo

The inheritance and development of ICH woodcarving technology are facing many challenges. On the one hand, the process of modern industrialization and urbanization makes the traditional handicraft market shrink gradually, and the inheritance and development of woodcarving art are seriously threatened. On the other hand, the production process of traditional wood carving technology is complicated and the technical requirements are extremely high, which makes its inheritance and learning face many difficulties.

To meet these challenges, many woodcarving artists and institutions began to explore new inheritance and development models actively. They attract more people to pay attention to and participate in the inheritance and development of ICH wood carving by opening studios, holding exhibitions, and carrying out education and training. Furthermore, they also actively use modern scientific and technological means, such as 3D CAD technology and virtual reality technology, to inject new vitality into the progress of ICH wood carving technology.

3.4 Accuracy and Efficiency Improvement

As a complex dynamic installation art product, if we want to transform the design process of wooden sculptures into inherent logical relationships in computer language. Firstly, the mathematical logic for parameterized design of dynamic sculptures must come from the first abstraction based on empirical models, which requires collecting a large number of related works for observation and organization. Secondly, its dominant mode needs to be between the dominance of form and the dominance of structural mechanics because, in terms of the artistic quality of installation art products, it is undoubtedly necessary to prioritize the already formed form. However, considering the properties of its device, if the prototype design completely disregards assembly and basic structural constraints. The designed prototype loses its value as a substitute for real projects for designers to refer to. Table 2 outlines the diverse applications and compelling advantages of 3D CAD technology in woodcarving design.

Application Stage	*Advantages Description*
Design Modeling	Quickly builds 3D models and supports complex shapes and detailed designs.
Rendering Display	Realistic rendering effects showcasing the appearance and texture of woodcarving works
Comparison and Optimization	Provides comparison and optimization functions for multiple design options, selecting the best solution
Processing and Manufacturing	Provides precise 3D model data, supporting automatic cutting and carving functions

Exhibition and Promotion	Presents 3D models to users for interaction and experience through virtual reality technology, improving user satisfaction

Table 2: Application and Advantages of CAD.

In conclusion, 3D CAD technology holds a pivotal position in the perpetuation and advancement of ICH woodcarving techniques. Beyond enhancing the precision and efficiency of design, it introduces unprecedented convenience and prospects for woodcarving production and exhibition. As technology and its applications continue to progress, 3D CAD is poised to assume an even more crucial role in safeguarding and evolving ICH woodcarving traditions.

4 METHODOLOGY

4.1 Scanning of Target Object

In the inheritance and innovation of ICH woodcarving technology, when introducing 3D CAD technology and hand-held scanning equipment, a key challenge is encountered: the detector of hand-held equipment cannot directly identify the laser reflected by the woodcarving work to be detected in some cases. This is because some areas of wood carving, especially those with smooth surfaces or less texture, may not provide enough reflected signals for the scanner to capture. To solve this problem, it is needed to carry out special pretreatment on the wood carving to be detected before scanning, that is, to paste it on its surface to provide a clear reference point for the scanner.

The patch process needs careful operation to ensure the accuracy and efficiency of scanning. First of all, we should choose the areas with complex textures and uneven surfaces on the wood carving for pasting, because these areas can provide more obvious feature points, which is beneficial to the identification and positioning of the scanner. Furthermore, special attention should be paid to avoid sticking in a straight line, because the sticking points arranged in a straight line may not provide enough information to build an accurate 3D model.

As shown in Figure 1, the pasted woodcarving works are ready for scanning. In the scanning process, the handheld scanner needs to identify at least four patch points to successfully establish the coordinate system and calculate the distance. If there are less than 4 detected points, the red line of the scanner will stop, and the progress bar on the right side of the screen will turn green, prompting the user to make necessary adjustments or add more patch points.

After patch — Intermediate results — Final results

Figure 1: Scanning objects.

At the beginning of scanning, users are advised to scan one side of the wood carving slowly so that the scanner can collect enough point cloud data to establish a stable coordinate system. With the accumulation of data, the scanner will gradually speed up the scanning speed, and users can quickly scan other parts of the wood carving at this time. However, if you scan from the beginning, it may lead to confusion of data scanned to different surfaces and affect the final model quality.

During scanning, the progress bar on the left side of the screen will remain green, which means that the current scanning quality is good. For some woodcarving parts with delicate or fine textures, users should scan slowly along the grain direction to avoid destroying the original grain and details of woodcarving.

The scanning process is usually divided into two stages: rough drawing and fine drawing. Firstly, a rough drawing is carried out to quickly capture the general shape and outline of wood carving; Then, make a detailed description and scan the key parts and details more carefully. If insufficient patches or poor scanning results are found in the scanning process, users can add more patches or adjust the scanning strategy at any time to ensure that the final 3D model can accurately and completely reflect the artistic charm of woodcarving works.

4.2 Artistic Representation of ICH Woodcarving Technology

As an important part of traditional culture in China, ICH wood carving has its unique artistic charm and cultural value. However, with the changes of the times and the progress of science and technology, traditional wood carving technology is facing the dual challenges of inheritance and development. As an effective means of protection and inheritance, artistic reproduction can show the charm of traditional wood carving techniques to the public more intuitively and vividly. High-definition scanning is the first step of artistic reproduction. The woodcarving works are scanned from all directions and angles by a high-precision scanner to obtain detailed information such as surface morphology, texture and colour. After the scanning is completed, the scanned data is imported into the computer and digitized by image processing software. In the process of processing, the image can be denoised, enhanced and repaired to improve the image quality.

Assuming I denotes the comprehensive pixel set of the entire woodcarving imagery, and $I_{c\,i}$ signifies the subset of pixels that possess the specific hue $c\,i$, the depiction of colour interconnectedness can be portrayed as follows:

$$\gamma_{i,j}^{k} = \underset{P_1\in I_{c\,i},P_2\in I}{P_r}\left[\left|p_1 - p_2\right| = k\right] \tag{1}$$

In this context, $i,j\in\ 1,2,L,N\ ,k\in\ 1,2,L,d$ signifies the spatial separation between pixels designated as p_1,p_2, while $\left|p_1 - p_2\right|$ denotes a distinct measurement of the distance between these same pixels. When taking into account the correlation between numerous colours, the colour correlation diagram tends to become exceedingly intricate and extensive. A streamlined alternative is the colour autocorrelation graph, focusing solely on the spatial interplay between pixels sharing identical hues. Figure 2 shows the learning process of woodcarving features in the simulation.

CAD not only displays the output images of woodcarving works in a full-screen way so that designers and audiences can feel the details and beauty of the works in the most intuitive way but also realizes the deeper reproduction of woodcarving works through its powerful image processing function. In the CAD system, the resolution of the output image usually matches the resolution of the display, which ensures the clarity and realism of the image when it is displayed. When the user finishes drawing the wood carving pattern structure, the CAD software will accurately calculate and record the polygon area where each pixel is located in the output image.

In the process of transforming a 2D plane scene into a 3D scene, CAD technology first accurately projects the object from the 2D plane into the 3D space by using the perspective projection principle according to the distance relationship of the depth of the object in the scene. This step requires not only accurate geometric calculation but also a detailed simulation of visual elements such as light, shadow, and materials to ensure that the final 3D scene has realistic visual effects.

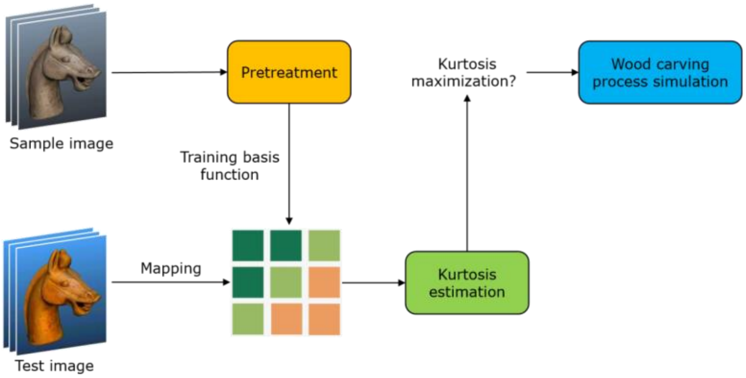

Figure 2: Feature learning process.

After the 3D scene is built, CAD software will further project the 3D scene onto the 2D plane according to the position relationship of the virtual viewpoint. In this process, the software will take into account the position, direction, focal length, and other parameters of the viewpoint, as well as the shading effects of objects in the scene, so as to generate a 2D image that can accurately reflect the 3D scene. Determine the depth-related data for each pixel within the imagery of the real-world scenario:

$$Z=\frac{Z_{\min}-Z_{\max}}{255}d+Z_{\max} \tag{2}$$

The given equation d signifies the grayscale intensity of the image's depth data, which undergoes a linear mapping to the actual scene, spanning a range from 0 to 255. The farthest elements in the imagery correspond to the lowest depth value, labelled $Z_{\min}$, while the closest elements correspond to the highest depth value, labelled $Z_{\max}$. Z Represents the depth value of the current pixel in the real-world scenario.

In the digital reproduction process of intangible cultural heritage woodcarving technology described in this article, Gaussian filters are applied to the preprocessing steps of depth images. Since depth images often contain noise and errors generated by measurement equipment, these noises may cause distortion of depth information in the image, thereby affecting subsequent virtual rendering and visual display.

Gaussian filters use their unique Gaussian kernel function to weigh and average each pixel in the depth image, thereby achieving noise suppression and image smoothing. By adjusting parameters such as the size and standard deviation of the Gaussian kernel function, targeted processing of noise of different degrees and types can be achieved. Defined in 2D space, the formula is expressed as follows:

$$G\ u,v\ =\frac{1}{\sqrt{2\pi\sigma^2}}e^{-\ u^2+v^2\ /\ 2\sigma^2} \tag{3}$$

The filtering radius is denoted as $r^2=u^2+v^2$, while σ signifies the standard deviation of the normal distribution.

Consider the set $X=\left[X_1,X_2,\cdots,X_n\right]$ comprising elements for classification, where each element possesses s indicators $X_j=\left[x_{j1},x_{j2},\cdots,x_{js}\right],j=1,2,\cdots,n$. Given c classification categories, the degree of membership for each element can be represented by a $c\times n$--dimensional matrix U:

$$U=\begin{bmatrix} u_{11} & u_{12} & \cdots & u_{1n} \\ u_{21} & u_{22} & \cdots & u_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ u_{c1} & u_{c2} & \cdots & u_{cn} \end{bmatrix} \tag{4}$$

The function formulated for ambiguous classification aims to achieve the following objective:

$$J_m(W,Z)=\sum_{i=1}^{n}\sum_{j=1}^{c} w_{ij}^{m} d_{ij}^{2}(x_i,z_j) \tag{5}$$

Where $Z=(z_1,\cdots,z_n)$ and z_j stand for the centroid of the $j\ (j=1,2,\cdots,c)$ cluster; m signifies the weighting factor; and $d_{ij}(x_i,z_j)=\left\|x_i-z_j\right\|$ denotes the Euclidean distance between the sample point x_i and the centroid z_j.

Restrictions imposed on the clustering objective function:

$$\sum_{i=1}^{c} u_{ik}=1,\forall_k \tag{6}$$

The defined error function is expressed as:

$$\cos t(u,v)=\left\|u-v\right\|\times\max_{f\in T_u}\left\{\min_{n\in T_{uv}}\left(1-f\cdot normal\cdot n\cdot normal\right)\div 2\right\} \tag{7}$$

The given formula $\left\|u-v\right\|$ signifies the distance between two points u,v, T_u denotes the set of all triangles adjacent to u, and T_{uv} represents the collection of triangles with uv as an edge.

Consider the plane P traversing the centroid $P^{'}$ of the nearest points K, where the normal vector n fulfills the condition $\left|n\right|=1$. Consequently, the eigenvector associated with the smallest eigenvalue M serves as the normal vector for point P_i:

$$M=\sum_{i=1}^{K}\left(P_i-P^{'}\right)\left(P_i-P^{'}\right)^{T}/K \tag{8}$$

The normal vector direction derived through the aforementioned method might be inverted relative to the actual normal vector, necessitating its adjustment. Additionally, not all qualifying edges necessitate shrinkage. Shrinking an edge encompassed by a concave polygon might induce a reversal in the surface's normal; therefore, selective shrinkage is advisable. To maintain consistency, the normal variation of the triangular surface is regulated to a specified threshold, ensuring that the angle formed between the triangle's normal and the original mesh's normal N_{ini} stays beneath the threshold ε:

$$\arccos\left(N_{new}\cdot N_{ini}\right)\leq\varepsilon \tag{9}$$

5 ANALYSIS OF EXPERIMENTAL RESULTS

To thoroughly evaluate the proficiency of the real-time rendering algorithm presented in this paper, specifically in addressing artistic reproductions of ICH woodcarving techniques, and the performance of the woodcarving's 3D reconstruction algorithm, a comprehensive experimental study was undertaken. In this study, several wood carving scenes with different complexity and characteristics are selected as test objects, and the performance of the real-time rendering algorithm is verified by comparing the rendering speed. Experiments are carried out in the same hardware environment to ensure a fair comparison. The parameter settings of rendering tasks are consistent to ensure the accuracy of comparison. As shown in Figure 3, the algorithm shows a good performance in rendering speed and can maintain a fast rendering speed even when dealing with complex scenes, which proves the efficiency of the real-time rendering algorithm in dealing with artistic reproduction of ICH woodcarving technology.

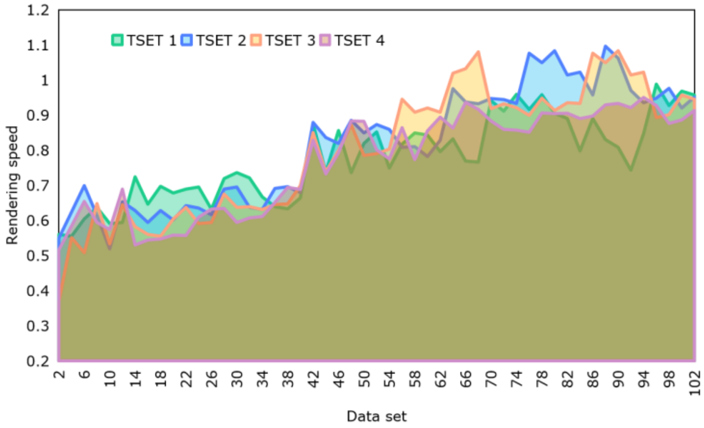

Figure 3: Comparison of rendering speed of algorithms.

To evaluate the performance of the woodcarving's 3D reconstruction algorithm, a comparative analysis of recall and accuracy was conducted in this study. The algorithm was trained using an identical training dataset, both before and after optimization. Subsequently, the algorithm was executed on a test dataset to generate 3D models of woodcarving works. Figures 4 and 5 illustrate a marked improvement in recall and accuracy of the enhanced algorithm proposed in this paper, thereby validating its superior performance in the realm of woodcarving generation.

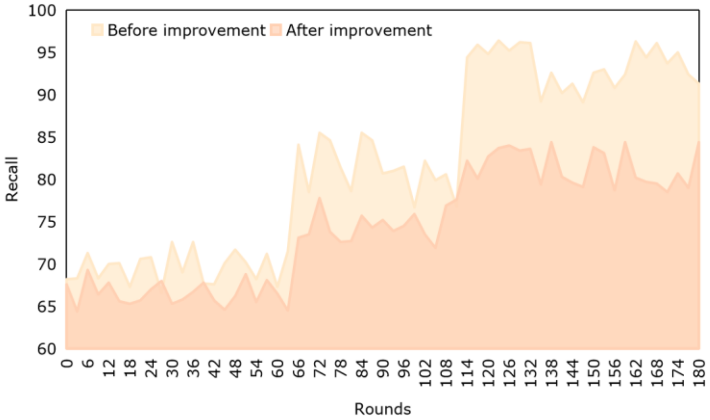

Figure 4: Comparison of recall of woodcarving 3D reconstruction.

In terms of woodcarving feature detection, the methodology introduced in this article is benchmarked against the renowned SIFT algorithm. Utilizing an identical dataset of woodcarving images, the performance of the proposed algorithm is gauged through a comparative analysis of the congruency in feature detection outcomes. As shown in Figure 6 and Figure 7, the feature points detected by this method are more consistent with the actual results, which proves the superiority of this method in woodcarving feature detection.

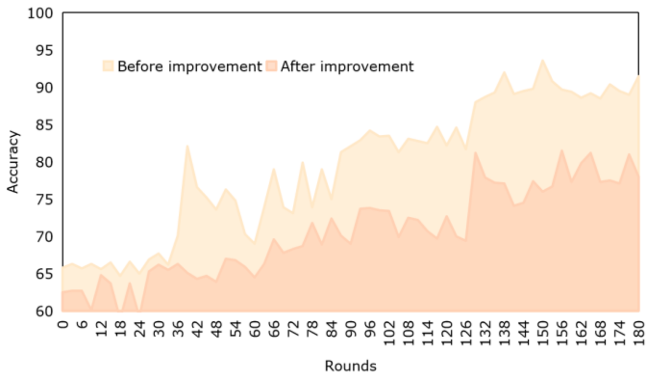

Figure 5: Comparison of accuracy of 3D reconstruction of woodcarving.

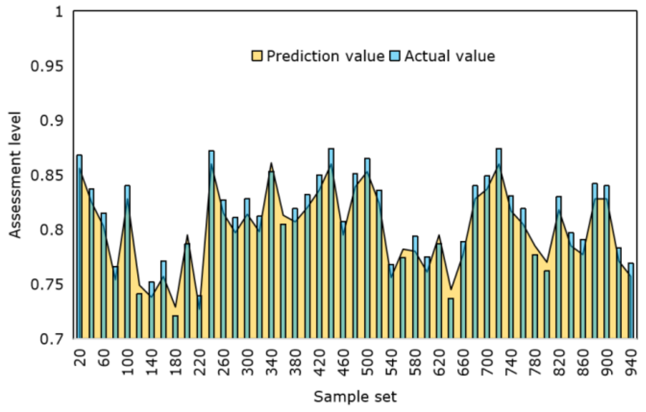

Figure 6: Detection performance of the method in this article.

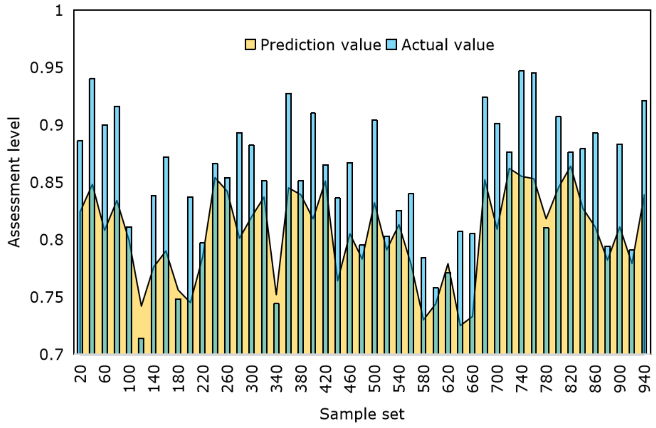

Figure 7: Detection performance of sift algorithm.

Based on the preceding experimental validation, the real-time rendering algorithm presented herein exhibits remarkable proficiency in the artistic reproduction of ICH woodcarving technology. The 3D reconstruction method for woodcarving demonstrates impressive recall and precision, while the woodcarving feature detection algorithm likewise showcases good accuracy.

The advent of 3D laser scanning technology has introduced paradigm shifts across industries due to its non-contact active measurement capabilities. This technology not only facilitates the direct acquisition of high-precision 3D data, but it also significantly reduces time and cost, making the digitization of intricate objects effortless. Through this technology, we can swiftly capture and reconstruct a 3D model that closely resembles the shape, dimensions, texture irregularities, and orientation of an object, as exemplified in Figure 8(a). To ensure the model's precision, the measurement functionality offered by 3D laser scanning allows for accurate distance verification, as shown in Figure 8(b). This feature guarantees dimensional accuracy and provides a robust foundation for diverse applications.

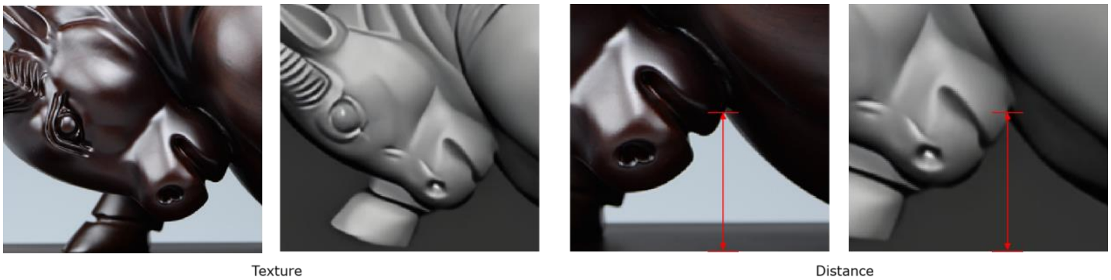

Figure 8: Comparison between physical objects and 3D models.

According to different fields and application requirements, the model generated by 3D laser scanning technology can output a variety of data formats. For example, you should be able to output DXF files supported by AutoCAD for CAD design and drawing; For the 3D printing industry, we can output files in *.stl format to meet the needs of various 3D printing devices. For users who use general 3D professional software such as 3Dmax, files in *.obj format can be provided to realize seamless docking of models in this software. In addition, it also supports the output of PDF and other formats that can be recognized by popular readers, which is convenient for users to carry out on different platforms.

6 CONCLUSIONS

In this article, the efficient and accurate artistic reproduction of ICH woodcarving technology is realized by combining 3D CAD technology and the HCI virtual simulation method. Through a series of experiments, the real-time rendering algorithm, 3D reconstruction algorithm of woodcarving and woodcarving feature detection algorithm proposed in this article all show superior performance, which provides strong technical support for the inheritance, display and research of ICH woodcarving technology.

The efficiency of the real-time rendering algorithm guarantees seamless and prompt visualization of woodcarving techniques in a virtual simulation setting. Irrespective of the simplicity or intricacy of woodcarving scenarios, the algorithm maintains swift rendering rates, offering users an immersive encounter. CAD numerical control progressive forming technology can shorten the production time of woodcarving products compared to traditional sculpture production methods. Moreover, it saves materials and greatly reduces the cost of wood carving production. It also has the advantages of precise forming and the ability to produce in small batches. The sculpture technology based on CAD progressive forming is a new sculpture production process technology and sculpture expression mode. The application of CNC progressive forming technology in sculpture production has opened up a new field of CNC progressive forming application. There is still little research on sculpture technology based on progressive forming both domestically and internationally. This technology is in the initial stage of formation and needs to be further developed and improved based on exploring the mechanism of progressive forming.

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