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Computer-Aided Design AND APPLICATIONS

Dynamic Display of Ceramic Model Based on Virtual Reality Environment

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Abstract. In order to solve the problem of the complexity and the lack of visual intuitiveness of ceramic CAD modelling, a virtual reality ceramic CAD model dynamic display system based on a physical engine has been developed. The system aims to enable users to dynamically model and display ceramic CAD models intuitively and simply through hand-free interaction, without being limited by physical conditions. In terms of system structure design, a simple and uniform universal cylinder is used for modelling, and Gaussian functions are used to control and fine-tune the deformation of the CAD model, ensuring that the morphological changes of ceramics in the virtual environment are both natural and controllable. In terms of interactive design, this paper successfully realizes the intuitive operation of ceramic CAD models in the virtual environment by combining motion capture technology with virtual reality technology. While ensuring the dynamic controllability of ceramic deformation structures, it greatly enhances the realism and immersion of the experience of the dynamic display system for ceramic CAD models. By comparing experimental data, we have verified the stability and accuracy of the system during the dynamic display process of ceramic CAD models.

Keywords: Physical Engine; Ceramic; CAD; Virtual Reality; Dynamic Display
DOI: https://doi.org/10.14733/cadaps.2024.S28.69-82

1 INTRODUCTION

Ceramics, as a gem of Chinese civilization, has its porcelain-making and ceramic-making skills deeply rooted in China's long history and has been shining brightly for thousands of years. The quality control model proposed by Benbarad et al. [1] has brought innovative solutions to the ceramic manufacturing industry. By combining CAD models with machine vision systems, they have achieved monitoring of the entire process of ceramic products from design to production. Firstly, this project proposes a design process and framework for a virtual experimental platform through theoretical research. Mainly based on the characteristics of virtual reality, summarize the key points of VR design, combine constructivist learning environment elements, and analyze and sort out VR design content based on the five elements of user experience. Afterward, user research methods were used to summarize user needs and complete the functional architecture of the experimental platform. Under the guidance of the proposed design process framework, the construction of a virtual experimental platform was completed, including three stages: construction of experimental content, construction of interactive methods, and creation of practical exploration scenarios. Through design, a truly immersive virtual experimental scenario, interactive feedback of the platform, and a correctly restored virtual experimental experience were achieved. Provided a complete experience process from ceramic production to firing, with a focus on visualizing the firing process. Then, in response to the design difficulty of firing parameters and firing function, the relationship between firing parameters and the glaze effect was summarized through actual firing experiments. The fine glaze effect was presented through the application research of texture technology and UnityShader. Finally, platform optimization and usability testing were conducted to evaluate the experimental platform, and comparative experiments were conducted on effectiveness and satisfaction evaluation. The experimental platform, which was designed based on the process framework, has been validated to have high usability and can serve as a beneficial supplement to classroom teaching [2]. Virtual Reality (VR) technology can utilize computers to create virtual three-dimensional environments. Due to its immersive, interactive, and imaginative nature, it can break through the limitations of time and space, innovate teaching models, and has been widely applied in teaching practice in recent years. The virtual experimental platform is applied to teach various disciplines. Therefore, designing and developing a virtual experimental platform for ceramic product kiln firing based on VR technology can reduce experimental costs and supplement the teaching of ceramic product design courses through virtual simulation experiments. Virtual experiments facilitate repeated practice and help learners proficiently master ceramic production processes and theoretical knowledge. They Can visually display the firing process to help learners understand it intuitively. It can make up for the shortcomings of practical firing and independent exploration and improve students' practical and innovative abilities [3]. Guan et al. [4] applied a virtual reality-based ceramic production method combined with a ceramic CAD model to technical education in a junior high school to explore its impact on student creativity, design thinking, and learning engagement. The students first learn about the production process and key points of ceramics through the teacher's guidance on the basic techniques of ceramics. Next, students simulate the entire process of ceramic making in a virtual environment and experience it. Finally, students reflect on their own works and summarize the experiences and lessons learned during the learning process. Through virtual reality technology, students can intuitively observe and operate ceramic models, thereby gaining a deeper understanding of the principles and methods of ceramic design. The ceramic works they designed are not only diverse in form and creativity but also significantly improved in functionality and practicality. The research results indicate that students who learn using VR combined with ceramic CAD models exhibit excellent creativity.

With the progress of society and the increasing pursuit of spiritual culture, ceramic making is no longer just a kind of craftsmanship inheritance but has gradually evolved into a new way of mass leisure and entertainment. However, traditional ceramic-making processes have extremely high requirements for the environment and equipment, making it difficult for many ceramic experience pavilions to display their exquisite skills fully. From mud material aging, treading, and kneading, to casting and shaping and then to the strict control of high temperatures in the firing stage, every link is full of challenges, which makes the popularization of ceramic-making processes particularly difficult. Faced with this problem, we urgently need to find a convenient and highly immersive method for ceramic ceramic-making experience. In today's rapidly developing informatization, using information technology to re-recognize and interact with things has become a new trend. Many traditional industries have integrated into the wave of informatization, and the ceramic industry is no exception. Hanssen [5] focuses on combining Oculus Rift and clay 3D printing technology with the process of throwing vessels in ceramic crafts. By using Oculus Rift, craftsmen can immerse themselves in virtual ceramic studios, as if they are personally manipulating real clay. Ceramic CAD models provide designers and craftsmen with a digital and precise tool for creating complex vessel shapes and patterns. By combining clay 3D printing technology, these models shaped in VR environments can be immediately transformed into solid 3D printing models, greatly reducing the cycle from design to finished product. Not only does it integrate throwing and pattern making, but it also allows craftsmen to see the real-time presentation effect of the pattern on the vessel during the production process. By analyzing the ceramic CAD model, we can further understand how this new technology improves the efficiency and accuracy of ceramic production.

Although computer-aided technologies such as 3DMax and Maya have been widely used in ceramic product design, various ceramic experience software have also emerged in an endless stream, but these methods still lack immersive virtual reality (VR) environmental experience. In recent years, the rise of VR technology has provided us with new solutions. With its excellent immersion, VR technology, combined with motion capture technology, greatly enhances the user's sense of participation and experience. This provides new possibilities for the inheritance and development of ceramic-making processes. Through VR technology, we can create a virtual ceramic studio, allowing users to feel as if they are present in the scene, experiencing every link of ceramic-making personally, so as to understand better and feel the charm of ceramic culture.

2 RELATED WORKS

Hill et al. [6] delved into the technological platforms that make up 5G, with a particular focus on the key roles of ceramic oxide and nitride materials. Ceramic devices are particularly widely used in mobile phones and base station infrastructure. In wireless telephones, ceramic filters are used to filter out useless signals and improve communication quality. In the 5G era, with the improvement of data transmission speed and the increase of signal frequency, the requirements for material performance are also more stringent. In addition, it will also combine ceramic CAD models to analyze the historical applications of ceramic devices in wireless telephone and base station infrastructure, as well as their potential value in the 5G era. Through precise CAD models, engineers can simulate and optimize the performance of ceramic materials to meet the strict requirements of 5G technology. Ceramic filters have become an indispensable component of 5G smartphones due to their excellent performance and stability. Ceramic RF devices can achieve efficient signal conversion and amplification, improving the overall performance of communication systems. Sample images and line sketches are often used in ceramic product design to explore and meet consumer needs. In order to more accurately capture and predict consumer emotional preferences, Liu and Yang [7] proposed a virtual reality method based on Kansei engineering. Using multiple linear regression analysis and partial correlation analysis methods, the correlation between ceramic product form elements (defined by CAD models) and consumer perception images was thoroughly studied. Combining ceramic CAD models, construct a mapping relationship between formal elements and consumer emotions from four dimensions: overall, unit, interrelationships, and details. This method allows designers and consumers to observe and experience the form of products more intuitively, thereby more accurately capturing consumer emotional reactions. Taking ceramic tea sets as an example, we found that prediction models based on VR and ceramic CAD models exhibit higher accuracy and reliability in predicting user emotional preferences. In the field of mineral processing, accurate image segmentation methods are crucial for real-time measurement of the particle size distribution of raw ore on conveyor belts. Image-based measurement technology is not only real-time, online, inexpensive, and non-invasive but also provides high-precision data support for ceramic design. It can be further expanded and applied to image processing and optimization of ceramic CAD models. The method proposed by Ma et al. [8] can also be used for defect detection and repair in ceramic CAD models. Similar technologies also have broad application prospects in the field of ceramic manufacturing, especially in the processing and optimization of ceramic CAD models. Considering the complex structure and texture details in ceramic CAD models, a mining image segmentation method based on convolutional neural networks and image processing techniques is proposed. For ceramic CAD models, the accuracy of image segmentation will directly affect subsequent design optimization, production manufacturing, and quality control processes.

Augmented Reality (AR) technology provides users with a unique and interactive visual experience by combining graphic information with their physical environment. Marín et al. [9] constructed a theoretical framework that provides a detailed explanation of how users perceive and evaluate the benefits and quality of ceramic CAD models enhanced by AR technology through physical presence. It is crucial to understand the user's perception and evaluation of ceramic CAD models in augmented reality experiences, in order to enhance product display and sales effectiveness. This application allows users to view graphic information of ceramic CAD models placed between them and display devices. The experimental results indicate that the ceramic CAD model can be integrated with the user's environment through AR technology. It makes users feel that their space exists, which has a positive impact on the perceived value of product usefulness and enjoyment. The layered cylindrical model not only provides a basic three-dimensional structure for simulating ceramic, but more importantly, it provides users with an intuitive and easy-to-understand construction framework. The finger manipulation method used by Matsumaru and Morikawa [10] simulates gestures in real ceramic making, allowing users to control the shape of ceramic through intuitive gestures. This interaction method is not only easy to understand and learn but also accurately reflects the user's intention. Ming et al. [11] proposed a virtual experimental platform design process and framework through design theory research. Under the guidance of the proposed design process framework, the construction of a virtual experimental platform was completed, which includes three stages: the construction of experimental content, the construction of interaction methods, and the creation of practical exploration scenarios. We have achieved immersive virtual experimental scenarios, interactive feedback on the platform, and a correctly restored virtual experimental experience through design. It provides a complete experience process from ceramic production to firing, with a focus on visualizing the firing process. Then, in response to the design difficulty of firing parameters and firing function, the relationship between firing parameters and the glaze effect was summarized through actual firing experiments. Through the application research of texture technology and UnityShader, a fine glaze effect was presented. Finally, platform optimization and usability testing were conducted to evaluate the experimental platform, and comparative experiments were conducted on effectiveness and satisfaction evaluation. This platform can seamlessly integrate with ceramic CAD models, providing users with an immersive learning and repair experience.

As a treasure of traditional Chinese culture, ancient ceramics carry profound historical heritage and cultural value and, therefore, play a crucial role in cultural inheritance. Firstly, expert visual methods rely on the meticulous observation and judgment of ceramics by experienced professionals. By comparing the composition of ceramics with the standard database, information such as their age and origin can be accurately inferred. Mu et al. [12] transformed the three main visual features of ceramics - shape, decoration, and inscriptions - into features that can be recognized by machine vision. When ancient ceramic parts are damaged, the similarity of the machine in shape recognition is as high as 96%, which means that even if the ceramic is damaged or deformed, the machine can accurately recognize its original shape. The shape is transformed into the contour information of the object, the decoration is recognized as the texture feature of the image, and the inscription is transformed into a recognition problem of handwritten Chinese characters. In terms of pattern recognition, the Euclidean distance calculated by the machine is only 0.7548, indicating that the machine has high accuracy and consistency in identifying different ceramic patterns. Sun et al. [13] discussed the application of computer-aided tools in ceramic product design, particularly the current status and development of 3D design methods and 3D printing technology in the field of ceramics. Traditional ceramic design often relies on manual drawing and model making, which is not only time-consuming and labour-intensive but also limits the complexity and accuracy of the design. The application of 3D printing technology in the field of ceramics has made significant progress. This technology can directly print complex ceramic structures without the need for traditional moulds or casting processes. The 3D design method allows designers to quickly iterate and modify in virtual environments, greatly improving design efficiency. Through detailed analysis, they can not only understand how these technologies affect the traditional boundaries of ceramic design but also anticipate the new opportunities they bring to ceramic art. Meanwhile, 3D printing technology also allows designers to explore and innovate more in materials, colours, and textures. Through continuous experimentation and adjustment, we have gradually mastered how to use 3D printing technology to create ceramic products that are both beautiful and practical.

During model training, Shi et al. [14] designed a data generator that can extract randomly located sub-volumes from large-scale 3D ceramic models and perform data augmentation. This method not only improves the generalization ability of the model but also enables the model to learn the features of ceramic boundaries better. In order to further verify the universality and practicality of the model, we conducted tests on a real ceramic manufacturing site example. The validation of the dataset on the model testing shows that our method can automatically capture subtle boundary features in 3D ceramic images with little or no need for manual input. These sub-volumes are then input into the network, and we use binary labels generated through specific algorithms as ground truth labels. In summary, 3D image segmentation methods based on encoder-decoder architecture have shown great potential in ceramic boundary recognition. A key challenge in ceramic archaeology is how to effectively combine the geometric characteristics and semantic connotations of archaeological information to create detailed digital twins of ceramic objects and artifacts. Thiery et al. [15] utilized these techniques to extract and correct erroneous information in ceramic models, improving the accuracy and reliability of the data. By using artificial intelligence technologies, particularly decision trees and semantic reasoning, they can achieve personalization and comparison of ceramic features such as patterns, shapes, glaze colours, etc. These rule sets are not only used to guide us in comparing and classifying ceramic features but also to help us understand the meaning and value of ceramics in different historical and cultural backgrounds. By comparing the characteristics of these ceramics, they can not only gain a deeper understanding of their manufacturing processes and historical background but also discover their similarities and differences.

3 TECHNICAL REALIZATION OF CERAMIC CAD MODEL BASED ON THE PHYSICAL ENGINE IN VIRTUAL REALITY ENVIRONMENT

3.1 Unity 3D Modeling Process for Physical Engines

With the rapid development of computer graphics, wide-angle stereo displays, and other technologies, the application of VR technology in the medical field will continue to expand and deepen. For example, in the future, VR technology may be combined with artificial intelligence, big data and other technologies to achieve smarter medical diagnosis and treatment plans; at the same time, VR technology may also play a greater role in remote medical care, virtual reality operating rooms, etc., bringing more innovation and breakthroughs to the medical field. Among them, the combination of Leap Motion and other body sensation technologies has brought new possibilities to the research and application of the VR field. Leap Motion, as a high-precision, high-sensitivity gesture tracking device, can capture the subtle movements of the user's hands and convert them into digital signals. Combined with VR technology, it provides users with a more natural and intuitive operation experience.

Meanwhile, many researchers have explored virtual ceramic modelling. The virtual ceramic modelling training system introduced in this paper, based on Leap Motion and VR technology, further enhances the immersion of virtual interaction and user participation, providing a new solution for the teaching and inheritance of ceramic making. This system uses the Unity 3D engine as a development platform, combined with the Leap Motion device to obtain user's hand movement information, aiming to provide users with an immersive virtual ceramic-making experience. The overall development process covers the following four key steps:

Ceramic Structure Design: First, we need to design the shape and deformation characteristics of ceramics. Given that the model structure made by ceramic casting is most similar to a hollow circular ring structure with a certain thickness on the bottom surface, we can convert the construction of the model into the construction of a hollow circular ring. In Unity, we will not directly import prefabricated models, because such models cannot dynamically change according to user gestures.

Change Detection and Smooth Control: Next, we need to define the user's hand movements and determine these actions. To ensure smoothness during the deformation process of the ceramic model, we will add constraint functions to the deformation process. These constraint functions will ensure that the model can smoothly deform under the user's actions, without sudden transitions or distortion.

Dynamic Data Storage and Retrieval: As users make changes to the ceramic model, the model's grid data will undergo constant changes. At the same time, we also need to ensure that the scene remains smooth during runtime to provide the best experience for users. To achieve dynamic changes in ceramic models following user gestures, we will adopt Mesh programming technology to create custom models. In Unity, all 3D model meshes can be regarded as being composed of meshes (Mesh) of varying sizes. By modifying the coordinates and shapes of these meshes, we can achieve real-time changes in model shapes. Therefore, we will dynamically adjust the mesh data of the ceramic model using the user's hand movement information captured by Leap Motion to achieve dynamic changes in the model. This method not only allows users to control the shape of ceramics through gestures directly but also enables efficient dynamic rendering without sacrificing model quality.

3.2 Ceramic Structure Modeling

Based on the geometric attributes of ceramic CAD models, the three-dimensional structure of ceramics is divided into three parts: the side, the top, and the bottom. Among them, the side can be described as a simple, uniform generalized cylinder with a height of, whose interface is composed of a series of smooth functions defined by two-dimensional circles, which represent the contour curves of ceramics and are contained within a certain range of height in continuous closed intervals. Considering the thickness of ceramics, the side structure is actually composed of multiple hollow circular rings, each ring having an outer radius of at a certain height range and an inner radius of, that is:

$$P_{N,M} = \ h_i, R_i, r_i \ \left| R_i = R \ h_i \ , r_i = r \ h_i \right. \tag{1}$$

$$h_i < \cdots < h_N \in R, N \in R \tag{2}$$

For the rotation in three-dimensional space with the axis of rotation and the angle of rotation being, represented by quaternion, the four vectors are as follows:

$$w = \cos \ \alpha / 2 \tag{3}$$

$$x = \sin \ \alpha / 2 \ n_x = \sin \ \alpha / 2 \ \cos \ \beta_x \tag{4}$$

$$y = \sin \ \alpha / 2 \ n_y = \sin \ \alpha / 2 \ \cos \ \beta_y \tag{5}$$

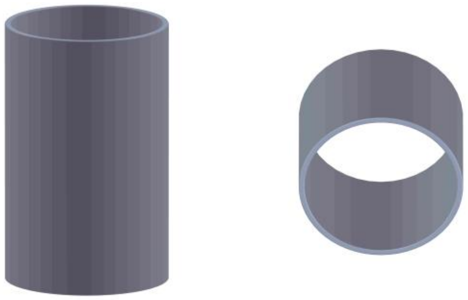
$$z = \sin \ \alpha / 2 \ n_z = \sin \ \alpha / 2 \ \cos \ \beta_z \tag{6}$$

In the formula, the components of the rotation axis are represented respectively.

The top structure of the ceramic is connected to the inner and outer rings of the top annular structure, forming a continuous whole. Detailed structural characteristics will be elaborated in the vertex calculation, including the connection method between the inner and outer rings and any potential complexities. The bottom structure is composed of two circular sections with opposite normal vectors, ensuring the stability and balance of the ceramic. The final structural form is shown in Figure 1, which demonstrates the overall aesthetic appeal and structural integrity of the ceramic.

3.3 Vertex Calculation

Based on the definition of the grid structure of ceramic CAD models, detailed customization was made to the grid attributes such as vertices, normal vectors, and triangle sequences of the CAD models. Based on their distribution positions, vertices can be divided into three types: ⊖ side vertices, ⊜ joint vertices, and ⊛ inner and outer vertices. Among them, the third type of vertices, namely inner and outer bottom surface vertices, as shown in Figure 2, can be obtained by calculating the first type of vertices through a circular ring structure.



(a) Left view (b) Top view

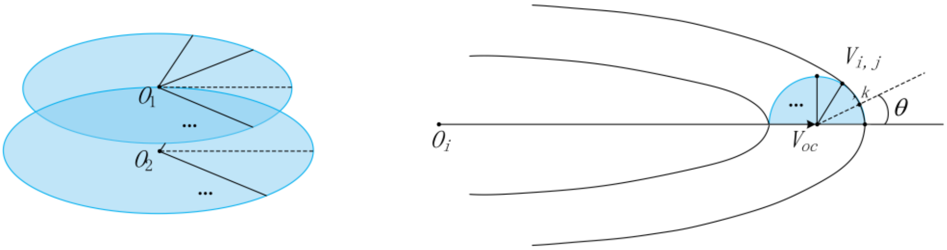
Figure 1: CAD Model Grid Structure of Ceramic.

These detailed definitions and classifications provide an important foundation and direction for further analysis of ceramic structures. To represent the vertex of the ith circle denotes whether the vertex belongs to the inner or outer ring, is the radius inside or outside the ring, is the height at which the ring is located, and the first type of vertex is:

$$v_{i,j,k} = \left[-r_{i,w}\sin\left(\frac{2j\pi}{M}\right), h_i, -r_{i,w}\cos\left(\frac{2j\pi}{M}\right)\right]^T \tag{7}$$

The type ⊜ vertex is connected to the inside and outside of the ceramic CAD grid and only needs to be processed, as shown in Figure 3. Assuming that the slicing angle is, is the th slicing vertex of the th vertex of the th circular ring (the top circular ring), the is the radius of the circular ring, the is the unit vector in the direction of, and the is the normal vector in the direction of, then the type ⊜ vertex is:

$$v_{i,j.k} = v_{oc} + R\cos\ k\theta\ N_{oc} + R\sin\ k\theta\ N_{\perp} \tag{8}$$



(a) Bottom of mesh (b) Top of mesh

Figure 2: Schematic diagram of ceramic CAD model grid.

3.4 Control of Deformation in Ceramic CAD Models

Gesture Definition: This article uses a physics engine to extract and calculate the position, speed, and other information of the hand in each frame in response to the user's intention to change the ceramic CAD model. As shown in Figure 3, the motion vector of the hand in each frame is represented by the vector; and are the horizontal and vertical components of the motion vector, respectively; is the position vector of the hand relative to the ceramic axis, and the angle between them can be calculated using the following formula:

$$\cos\beta = \frac{v_{hx}v_{oh}}{\left|v_{hx}\right|\left|v_{oh}\right|} \tag{9}$$

Set a critical value, when the radius of the ceramic becomes larger; or when the radius of the ceramic becomes smaller; otherwise, the radius of the ceramic remains unchanged. In addition, set a critical value and compare it with the movement speed of the virtual hand in the direction. If, then the height of the ceramic increases; if, then the height of the ceramic decreases; otherwise, the height of the ceramic remains unchanged. To avoid unintentional deformation of the ceramic porcelain and crosstalk between different gestures, this article imposes certain restrictions on and. As shown in Figure 4, the controllable range of virtual gestures is entirely contained within the dashed space. is set as the distance from the virtual hand to the ceramic axis; is set as the height position of the virtual hand; and are respectively the inner and outer diameters of the circle at the height of the ceramic, and are respectively the height boundary of the current ceramic; and are respectively positive offsets of the ceramic model, thus reducing the range of radius and height gesture adjustments to:

$$P_{xz} \in \left[R_i^{in} - off_{xz}^0, R_i^{out} - off_{xz}^0\right] \tag{10}$$

$$P_y \in \left[H_{\min} - off_y, H_{\max} + off_y\right] \tag{11}$$

Similarly, equation (6) represents the range of gestures with increasing radius, where both and are non-negative offsets and satisfy, that is:

$$P_{xz} \in \left[R_i^{in} + off_{xz}^1, R_i^{out} + off_{xz}^2\right] \tag{12}$$

$$P_y \in \left[H_{\min} - off_y, H_{\max} + off_y\right] \tag{13}$$

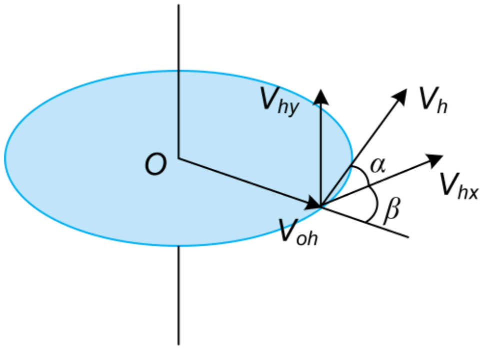


Figure 3: Vector Relation of Hand Movement.

Figure 5 shows the force feedback values received by the fingertips of the thumb when the hand quickly pushes the ceramic (tested every 10 steps). During the process of ceramic making, the mass of the human body is much larger than that of the ceramic, and the ceramic is subjected to a force to rotate upward in space. The ceramic effect diagram is composed of multiple images arranged in chronological order. Due to the interaction of forces, the virtual hand gestures rotate in the opposite direction in a zero-gravity space.

3.5 Smoothing Control of Ceramic CAD Model

In the ceramic art-making experience system, in order to simulate the smooth deformation of the ceramic art contours under user gesture control, we can use a Gaussian function to model the trend of "values getting larger as you get closer to the centre and getting smaller as you get further away from the centre". The Gaussian function is a continuous function widely used in mathematics, physics, and engineering, among other fields. It has a bell-shaped curve, with the highest value at the centre and gradually decreasing on either side.

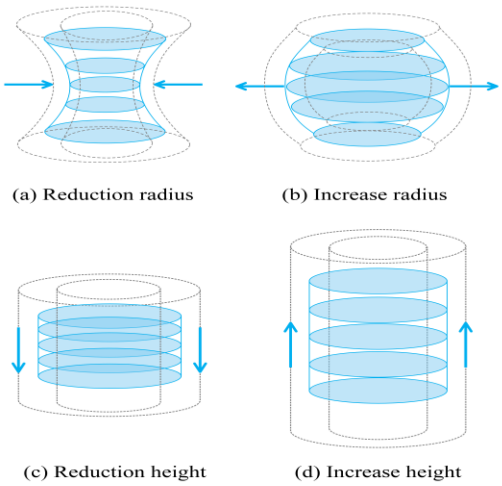


Figure 4: Range of Gesture Interaction.

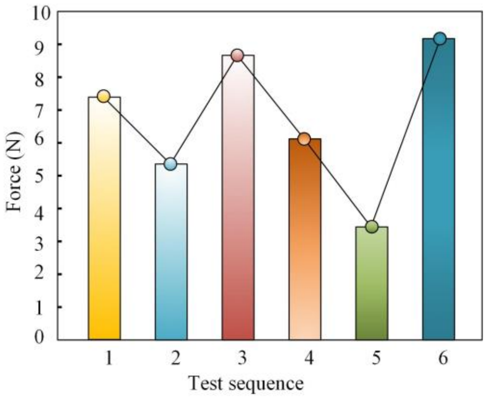


Figure 5: Finger force feedback results based on the physics engine.

Suppose we have a set of vertices of a ceramic contour, as shown in Figure 6. Each vertex has a position coordinate, where the position of the vertex on the two-dimensional plane and the height (or depth) of the vertex are defined. When a user performs a gesture control on a triggering point (or centre point) of the ceramic contour through a Leap Motion device, we hope to smoothly control the deformation of the surrounding vertices with this point as the centre. In the application of ceramic deformation, we can input the coordinates of each vertex into a Gaussian function to obtain the degree of deformation of each vertex relative to the centre point. Then, based on this degree of deformation, we can calculate the new position (or height) of the vertex, thereby achieving a smooth deformation effect. It should be noted that the Gaussian function itself only gives the weight of the degree of deformation, and the specific calculation of deformation (such as the new position of the vertex) still needs to be determined according to the specific logic of ceramic production and user needs. For example, we can use the output value of the Gaussian function as a weight, which is multiplied by the user's input gesture (such as moving distance or rotation angle) to obtain the new position of the vertex. In addition, in order to more precisely control the deformation effect, we can also consider using a superposition of multiple Gaussian functions (i.e., Gaussian mixture model), or adjusting the parameters of Gaussian functions (such as changing amplitude, standard deviation, or centre point position) to adapt to different deformation requirements. Finally, using Gaussian functions for smoothly controlling the deformation of vertices of ceramic contours is as follows:

$$r_i = r_i + k_0 \arctan \ r_{\max} - r_i \ \frac{1}{\sqrt{2\pi}} e^{-\frac{r_i - \bar{r}}{2\delta^2}} \tag{14}$$

$$r_i = r_i + k_0 \arctan \ r_i - r_{\min} \ \frac{1}{\sqrt{2\pi}} e^{-\frac{r_i - \bar{r}}{2\delta^2}} \tag{15}$$

Where, and are the extreme values of the radius; is the radius of the circular ring where the hand control point is located; is the sensitivity coefficient. Meanwhile, to ensure the uniformity of the radius change of the hollow circular ring with the same height above and below the trigger point, the parameter should always be 0. In the experiment, the parameter is adjusted based on experience.

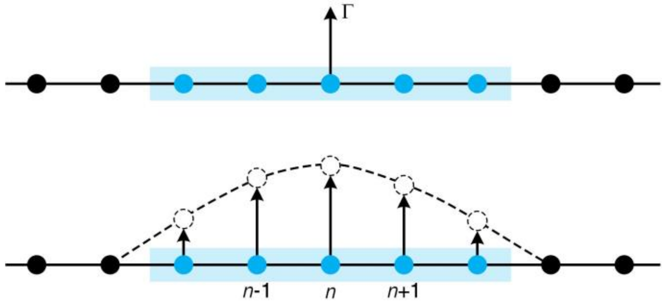


Figure 6: Smoothly changing curve.

4 DYNAMIC DEMONSTRATION OF CERAMIC CAD MODEL IN VIRTUAL REALITY ENVIRONMENT

The design goal of this system is to provide an immersive virtual ceramic-making experience based on Leap Motion and Unity 3D engine. Users will immerse themselves in the virtual scene through a VR headset, using hand movements to control the deformation of ceramic. The system should be able to respond to user gestures in real time and smoothly adjust the shape of the ceramic according to changes in user gestures. In addition, the system should also support users to save or load personalized mesh models through gesture UI interaction, as well as perform game-related operations, such as restarting or quitting the game.

4.1 Interaction of Deformation in Ceramic CAD Model

In the design of interactive deformation, this system mainly uses the Leap Motion device to capture the user's hand movements and then controls the radius and height of the ceramic model in the virtual scene to achieve smooth changes. Through carefully designed interaction logic and algorithms, the system can respond to user gestures in real time, providing users with an intuitive and easy-to-understand experience of ceramic making.

Figure 7(a) is a reference diagram, showing the initial shape of the ceramic. In this state, the ceramic model appears as a hollow circular structure with a specific radius and height. When the user wears a VR headset and starts the system, the system will display this initial ceramic model. Users can capture their hand movements with a Leap Motion device and transmit them in real time to the hand movement control system for processing. When the user's hand stretches outward (inward) from the centre of the ceramic, the system calculates the deformation degree of the circular radius with a corresponding height based on the change of the user's gesture using a Gaussian function algorithm. Then, based on this deformation degree, the system smoothly adjusts the vertex position of the corresponding position on the ceramic model, thereby increasing (decreasing) the radius of the ceramic. At the same time, if the user's hand moves up and down along the side wall of the ceramic, the system calculates the height of the ceramic that needs to be adjusted based on the change of the user's gesture and smoothly adjusts the height of the ceramic model. Figure 7 does not directly show the specific effect diagram after the user's gesture operation, but users can observe in real-time through a VR headset how their gesture-controlled deformation process changes. This process is smooth and natural, allowing users to intuitively feel how their gestures affect the shape of their ceramic model.

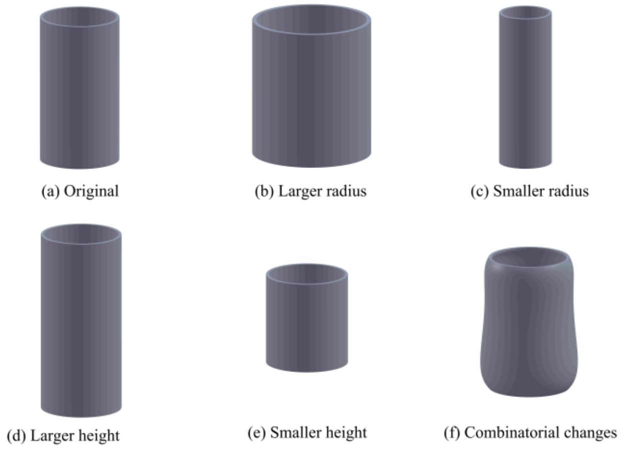


Figure 7: Dynamic display results of ceramic CAD model.

Radius change of ceramic art CAD model: In Figure 7(b), the radius of the circle at the position of the hand (trigger position) gradually increases. This change not only affects the circle where the hand is located but also smoothly spreads to other circles nearby. As the distance of the hand from the trigger position increases, the amplitude of the radius increase gradually decreases, showing a trend of Gaussian distribution. In other words, the radius of the circle that is farther from the trigger position increases more slowly. When the radius of the ceramic circle reaches the preset maximum threshold, the system will automatically stop increasing it to maintain the stability of the ceramic model and the reasonableness of its overall form.

Figure 7(c) shows the scenario where the user's hands are retracting inward. The position of the hands determines the radius of the ceramic ring. The gradually decreasing radius not only affects the ring at the location of the hands but also smoothly affects other nearby rings. As the hands gradually retract inward, the rate of decrease in the radius of the rings gradually decreases, exhibiting a Gaussian distribution pattern. This means that the rings further away from the triggering location have a slower rate of decrease in their radius. When the radius of the ceramic ring reaches a minimum threshold as a result of the inward retraction of the hands, the system will stop further reduction in the radius to ensure that the ceramic model does not undergo excessive deformation, preserving its original aesthetic form and structural integrity.

The height variation of the ceramic CAD model is shown in Figure 7(d), which demonstrates that the virtual hand is placed on both sides of the ceramic CAD model to ensure a close fit with the sides of the ceramic CAD model, and then gradually moves downwards. As the hands move downwards, the height of the ceramic CAD model gradually decreases. This change is smooth and continuous, allowing users to accurately control the height of the ceramic. When the height of the ceramic reaches a minimum threshold, the system will stop further reduction in height to maintain the stability and reasonableness of the ceramic model.

In contrast, the situation is reversed in Figure 7(e). The user again places both hands on either side of the ceramic, but this time ensures that the palms are slightly away from the ceramic, and then slowly moves them upwards. As the hands rise, the height of the ceramic gradually increases. Similarly, this change is smooth and continuous, allowing the user to easily increase the height of the ceramic. When the height of the ceramic reaches a maximum threshold as the hands rise, the system will stop increasing the height to prevent the ceramic model from becoming unreasonably tall.

Combination and variation of ceramic CAD models: After a series of arbitrary combination operations as shown in Figures 7(b)-7(e), the developed system will generate a unique, customized ceramic CAD model for the user, as shown in Figure 7(f).

4.2 UI Interaction of Ceramic CAD Model Dynamic Display System

As shown in Figure 8, this system is developed based on mobile computing technology, cloud computing technology, and touch screen human-computer interaction technology. The system can be deployed on mobile computing devices such as smartphones and tablet computers, as well as on PC terminals. The system carries out the 3D experience design of ceramic artwork CAD models through the following steps.

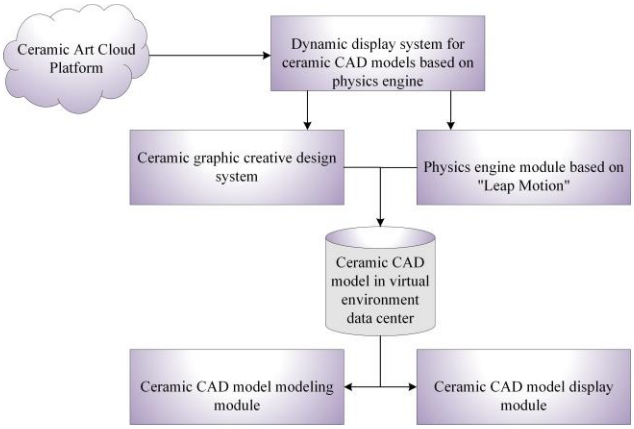


Figure 8: Composition of UI Interaction System.

Feature Selection: Users can select features from a menu by swiping left or right. The options change smoothly as the user swipes until they stop and select an option. Once selected, the user can confirm or cancel the operation by swiping up or down. Swiping up confirms, and swiping down cancels. The data will be saved in OBJ format or another common 3D model format. Upon successful saving, the system will generate an OBJ file in a specified directory, which can be opened and viewed using 3D viewing software like View3D.

Loading feature: When the user selects and confirms the loading option in the main panel, the interface will switch to the loading panel. The loading panel will display a list of ceramic models previously saved by the user. Users can browse and select the previously saved ceramic models in the loading panel through an up/down gesture. The model list on the panel will change as the user's gesture moves smoothly. If the loading is successful, the ceramic in the scene will be replaced with the selected loaded ceramic CAD model, and the CAD model will be displayed in a post-firing state, including possible changes in materials and textures. After the loading is completed, users can also further edit the loaded model or compare it with other models.

System Features: With this virtual ceramic-making experience system, users can fully utilize their imagination and creativity to create ceramic models of various shapes. From adjusting the radius and height to saving and loading models, the system provides intuitive, flexible, and easy-to-understand interactions, allowing users to easily enjoy the joy of creation. The resulting series of customized ceramic models not only showcase the user's unique aesthetic and creative thinking but also become beautiful memories of the user's interaction with the virtual world.

5 CONCLUSIONS

This article presents a dynamic display system for VR ceramic CAD models, developed based on a physical engine. This system allows users to interact with the ceramic in a virtual environment using their hands. Users can control the shape, size, and other parameters of the ceramic through gestures, achieving a dynamic display of the ceramic CAD models. The developed system provides a good user experience. However, the system also encountered some limitations during development. This article will analyze these issues and propose improvement plans.

Absence of tactile feedback: Currently, the interaction between users and ceramic relies solely on the physics engine, resulting in a lack of real tactile feedback during operations, such as shape, weight, temperature, and force. This reduces the immersion of the user experience. Improvement plan: Introduce devices such as force feedback gloves to further provide true sensory feedback and enhance the user's immersion.

Insufficient parameter constraints: Although existing three-dimensional data of ceramic art can be directly used for CAD modelling, it still falls short of the actual requirements of ceramic art. The lack of effective constraints on ceramic geometric parameters during the process of ceramic art creation may lead to ceramic modelling that does not meet the actual process requirements. Improvement plan: Increase parameter constraint function, allowing users to set and adjust key parameters such as the radius and thickness of ceramic during the creation process. At the same time, the system should provide real-time parameter feedback and prompts to help users better grasp and adjust these parameters.

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