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Human Computer Interaction Based Cao's Kite Craft Experience in Virtual Reality

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Abstract **-** Cao's Kite craft was generated in 18th century and now becomes one of the representative Chinese national intangible cultural heritage items. Cao's kite craft includes four basic skills and we focus on the skill of tying the framework in this paper. Especially, in the step roasting bamboo strips of tying the framework, we improve the mesh deformation algorithm to achieve better effects. In the interactive realization of virtual kite craft, we implement all three steps of tying the framework. By the human computer interactive design in this paper, the immersion and engagement of the experiencer are further enhanced in virtual reality.

Keywords**:** Cao's kite craft; virtual reality; human computer interaction; mesh deformation

1. Introduction

Cao's kite craft is an important expression of Chinese traditional culture and one of the representatives of China's intangible cultural heritage. Due to changes in the times and population, the inheritance and protection of Cao's kite craft face some challenges [1-2].

With the widespread use of Internet media, government departments are guiding the inheritance and development of Cao's kite craft actively. The Cao's Kite Museum have been established and various internet media platforms have been utilized to publicize the kite culture. However, the current display and communication methods are too simple, and the information on the museum's official website is mostly presented in the form of text and pictures, which may not be attractive to those who like fun and entertainment. At the same time, the text and pictures can only allow the audience to watch from a third-person static perspective, making it difficult for them to truly put themselves in the shoes of the inheritors [3-4].

Therefore, virtual reality (VR) technology can play a positive role in the inheritance and protection of Cao's kite craft. Combined with VR technology, the production process, historical background, and culture of Cao's kite craft can be digitized, three-dimensional, simulated, etc. Comprehensive and in-depth display and dissemination of connotations [5].

Cao's kite craft includes four basic skills: tying the framework, pasting the paper, drawing the pattern, and flying. In this paper, we concentrate on the skill of tying the framework. For tying the framework, there are three steps including, cutting bamboo strips, roasting bamboo strips and twisting cord. Especially, in the research of the process of roasting bamboo in the tying process, the kite frame needs to be deformed. The traditional mesh deformation and free-form deformation (FFD) algorithms cannot meet the needs of this process well. Therefore, in the process of bending bamboo strips, the original algorithm needs to be redesigned and improved. And it can meet the demand of controlling the overall deformation based on a single point finally.

The whole experience system is exploited by Unity. The system guides the experiencer to experience the kite making process, and the experiencer will interact with the basic steps of kite making according to the operation prompts. All the experiences are designed by human computer interaction to achieve better effects.

2. Research on Mesh Deformation Algorithm in Virtual Reality

This section focuses on the improvement of mesh deformation algorithms based on VR technology. Traditional mesh deformation algorithms may face computational inefficiency when dealing with complex numerical models. To address this limitation, the improved algorithms aim to enhance the performance of the deformation process while maintaining high quality deformation results. The VR technology allows for a more intuitive and natural interaction, thus enabling users to manipulate and edit 3D models more easily. In addition, the improved algorithm will be combined with the existed FFD algorithm in order to achieve a balance between local and global deformation, and also increase the flexibility and accuracy of model editing. In the experimental design and result analysis section, the performance of the traditional mesh deformation algorithm and the improved algorithm in different scenarios will be compared to verify the effectiveness and superiority of the improved algorithm.

2.1. 3D Modeling and Deformation Algorithm

Currently, common modeling methods include direct modeling, polygon mesh modeling, point cloud modeling, and spline modeling [6-8]. In the interaction platform exploited in this paper, the key model is modeled by mesh modeling method. The mesh model is composed of elements such as vertices, edges, triangular faces, polygonal faces, etc., as shown in Fig. 1. Its main advantage is that it can classify and select various types of elements for editing and modification, and it can also split and separate the selected geometric models to obtain the model of the desired shape.

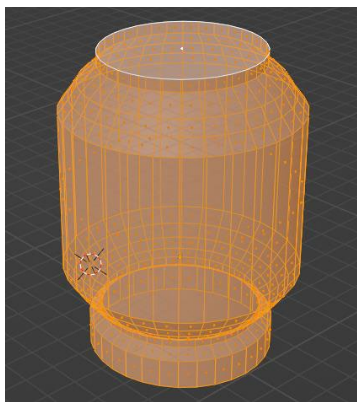

Fig. 1: Mesh model.

In recent years, the research difficulty of deformation algorithms has gradually shifted to the field of 3D geometric model deformation. Common 3D geometric model deformations include mesh deformation, FFD, skeletal animation, physical simulation, etc. Among them, mesh deformation and FFD are closely related concepts. Among them, mesh deformation and FFD are closely related concepts. Mesh deformation usually refers to the process of editing and deforming the vertices and faces of a 3D mesh model to get a new mesh model. It can be implemented either by manual editing or by program algorithms. The method is usually localized, i.e., only some parts of the model are deformed while other parts remain unchanged. For example, a simple mesh deformation can be achieved by selecting certain vertices or facets on the model and then performing operations such as translating, rotating, scaling, etc.

2.2. Free Form Deformation Algorithm

FFD usually refers to a more advanced mesh deformation technology, which was first proposed by Sederberg. It does not deform the object directly, but deforms the space in which it is embedded, and can globally adjust the local deformation effect [9-10]. FFD usually requires predefined shapes (e.g., spheres, cubes, etc.) to control the deformation effect of the model. Users can drag control points on these shapes and the whole model will be deformed according to the deformation effect of the shape. FFD is usually used to realize character animation, character deformation, simulation and other effects. The mathematical principle is as follows:

- Construct the X_0-STU coordinate system and embed the desired deformation of the model into the rectangular.
- Assign a fixed grid parameter coordinate to each point inside and outside the rectangle as well as on the boundary, as shown in Fig. 2.

• By moving different control points, the object is deformed.

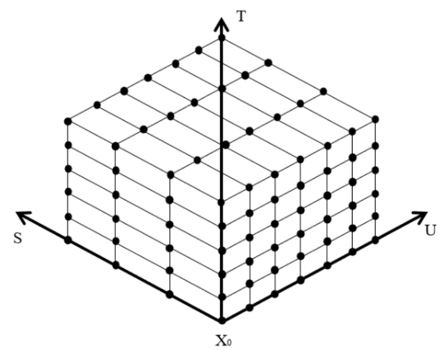

Fig. 2: Construction of a coordinate system and a framework for FFD control.

As shown in Fig. 2, X_0 is the origin of the coordinate system and S, T, U are the axes. As shown in (1), taking any point in this coordinate system with coordinates $X_{(s, t, u)}$, we have:

$$X(s,t,u) = X_0 + sS + tT + uU \tag{1}$$

The calculation formula for the grid, as shown in (2):

$$s=\frac{T\times U(X-X_0)}{T\times U\cdot S}, t=\frac{S\times U(X-X_0)}{S\times U\cdot T}, u=\frac{S\times T(X-X_0)}{S\times T\cdot U} \tag{2}$$

For X_0 at any point of the coordinate system, there are $0 < s < 1$, $0 < t < 1$, $0 < u < 1$.

As shown in Fig. 2, the rectangle is uniformly divided into $l \times m \times n$ small lattices so that a three-dimensional network is formed, and the vertices of each small lattice become the control vertices for FFD [11]. And the control vertex grid $P_{i, j, k}$ is labeled in the rectangle, where i = 0, 1, ..., l; j = 0, 1, ..., m; k = 0, 1, ..., n. The control vertices are uniformly distributed in the interior and on the surface of the rectangle, and thus the control vertices satisfy (3):

$$P_{i,j,k}=P_{0,0,0}+\frac{i}{l}S+\frac{j}{m}T+\frac{k}{n}U \tag{3}$$

In 3D deformation, the model is driven to deform by moving the control points. The new coordinate position of any point coordinate $X_{(s, t, u)}$ after deformation is shown in (4):

$$X_{(s,t,u)}=\sum_{i=0}^{l}\sum_{j=0}^{m}\sum_{k=0}^{n}P_{i,j,k}B_{il}(s)B_{jm}(t)B_{nk}(u) \tag{4}$$

In summary, the mesh deformation technique mainly realizes deformation by manipulating the points of the 3D mesh, which allows for a more precise adjustment of the geometry. The FFD technique, on the other hand, can realize more natural deformation by deforming the whole model, simulating the elasticity and softness of natural objects. Therefore, the combination of the two methods can improve the flexibility of operation and achieve different shape changes while maintaining the details of the model to meet the diverse modeling needs.

2.3. Improved Mesh Deformation Algorithm

In the VR environment, the response interaction is mainly accomplished by the virtual hand in the immersed space, so it needs to be designed and improved from the aspects of user's habit and the limitation of VR hardware equipment. For the consideration of users' daily habits, in the process of roasting bamboo in reality, usually both hands need to grasp two points before bending. Therefore, it is necessary to realize the deformation of the required part based on the position of a single point, and the change of the position of the hand needs to be consistent with the degree of bending of bamboo strips. Due to the grasping characteristics of the virtual hand, most users cannot control the virtual hand accurately through the VR handle, and in the process of grasping the bamboo strips for bending, it will simultaneously generate offsets in the three coordinate axes, which will have an impact on the flatness of the bamboo strips, and therefore it is necessary to make the deformation occur in the same plane [12].

2.3.1. Bending deformation

In order to control the deformation of the model, it is necessary to calculate the bending radius and FFD of the vertices. The first step is to calculate the bending radius of the mesh R. According to the pre-determined bending range, determine the length of the mesh in the given axis L and the angle θ to be bent, and calculate the bending radius R according to the relationship between the arc length and the radian $R=L/\theta$.

Based on the specified deformation region, a 4×4 transformation matrix is generated, for which translation and rotation and scaling operations are performed. The formulas are as follows.

The transformation of the rotation θ around the z-axis is shown in (5):

$$R_z=\begin{bmatrix}x'\\y'\\z'\end{bmatrix}=\begin{bmatrix}\cos\theta & -\sin\theta & 0\\ \sin\theta & \cos\theta & 0\\ 0 & 0 & 1\end{bmatrix}\begin{bmatrix}x\\y\\z\end{bmatrix} \tag{5}$$

Translate t_x on the x-axis, t_y on the y-axis, and t_z on the z-axis, with the transformations shown in (6):

$$T=\begin{bmatrix}x'\\y'\\z'\\1\end{bmatrix}=\begin{bmatrix}1 & 0 & 0 & t_x\\ 0 & 1 & 0 & t_y\\ 0 & 0 & 1 & t_z\\ 0 & 0 & 0 & 1\end{bmatrix}\begin{bmatrix}x\\y\\z\\1\end{bmatrix} \tag{6}$$

For any point (x,y,z), the scaling factors are S_x, S_y, S_z, and its coordinates after the scaling transformation are (x',y',z'), as shown in (7):

$$S=\begin{bmatrix}x'\\y'\\z'\\1\end{bmatrix}=\begin{bmatrix}s_x & 0 & 0 & 0\\ 0 & s_y & 0 & 0\\ 0 & 0 & s_z & 0\\ 0 & 0 & 0 & 1\end{bmatrix}\begin{bmatrix}x\\y\\z\\1\end{bmatrix} \tag{7}$$

With the above three matrices it is possible to represent any combination of the various transformations in space, as shown in (8):

$$M=S\cdot R\cdot T \tag{8}$$

For grid points that are not in the region, no bending process is performed, and for grid points that are in the region, bending is performed along the axial direction according to the coordinates of the point. Finally, the deformed grid points are recalculated back to the coordinates under the original coordinate system, and the process is shown in Fig. 3.

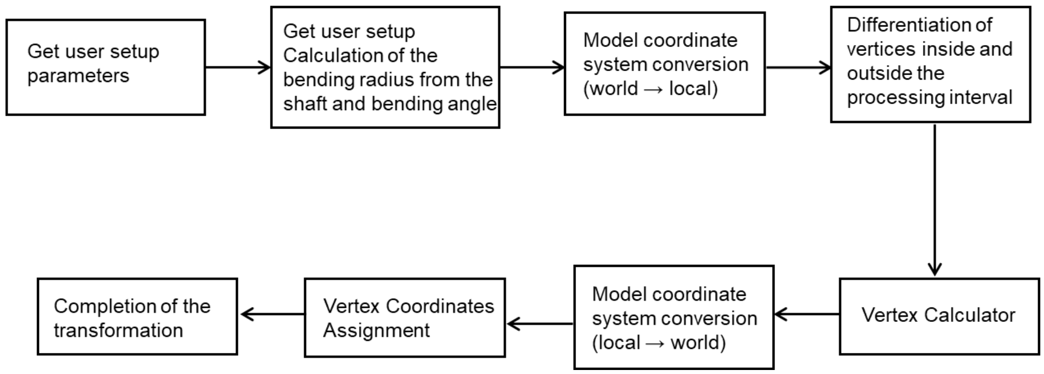

Fig. 3: Transformation flowchart.

In a nutshell, the bending effect is achieved by projecting each vertex on the model onto the xoz plane, and then using the projected point as the center of the circle, and the points on the arc with the radius of the bend as the new vertex positions.

2.3.2. Single point control deformation

Controlling deformation requires obtaining the angle between two points and thus determining the degree of bending. In this paper, the intersection point between the virtual hand and the bamboo strip is set as P. By calculating the vector between the intersection point P and the deformation point Q, the angle θ_1 is calculated, and the value of θ_1 is assigned to the bending angle θ in the transformation to derive the bending radius R, which controls the subsequent model transformation, and the process is shown in Fig. 4.

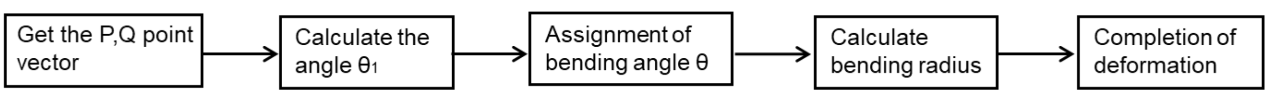

Fig. 4: Assignment flowchart.

2.3.3. Coordinate axis locking

Most of the skeleton of the kite needs to be in the same plane, however the virtual hand will inevitably go out of plane to make the material distort as it interacts in three dimensions, so the transformation needs to be confined to the same plane. To accomplish this, you need to use the transform.localPosition property in Unity, which gets or sets the local coordinates of a game object relative to its parent. By creating a new Vector3 object, the z-axis of the game object is constrained to position 0, so that the object can only move in the plane xoy. The function of the entire script is to control the range of movement of the game object, thus enabling a more fine-grained game interaction experience.

3. Experiments and Results of The Improved Algorithm

In conjunction with the previous section on the deformation algorithm, in order to verify the applicability of the algorithmic improvement for this system, the experimental results of the improved algorithm are compared and analyzed in this section.

3.1. Experiments for Bending Deformation

This experiment is based on bending deformation to make the image change in translation, rotation and scaling. The accuracy and usability of the method is examined by deforming the model in different degrees during the experiment, and the analysis results are shown in Table 1. The experimental results show that the deformation method is controllable to change the model and can change the shape and position of the model without affecting the quality of the model. At the same time, the method can control the deformation of 3D shapes better, thus realizing a more natural and smooth deformation effect.

Table 1: Analysis of bending deformation experimental results.

Position of the kite	Pattern	Result
Head		
Wing		
Tail		

3.2. Experiment for Single Point Control of Deformation

The experiment is based on the study of previous step, and the synchronized positional deformation of the model with the virtual hand is achieved by changing the morphology of the model through a single point of control of the 3D model transformation matrix. The degree of synchronization between the model and the hand is verified by the position change of the virtual hand during the experiment, and different control cases are compared, as shown in Fig. 5. The experimental results show that the single point control is able to locally deform the model after the bending test at different angles, and the single point control model deformation algorithm can achieve the deformation of the model in a more natural way and can control the degree of deformation. By adjusting the position of the control point and the external force applied, different deformation effects can be obtained. At the same time, single point control is practical in realizing the virtual hand to interact with the object, morphology adjustment and so on.

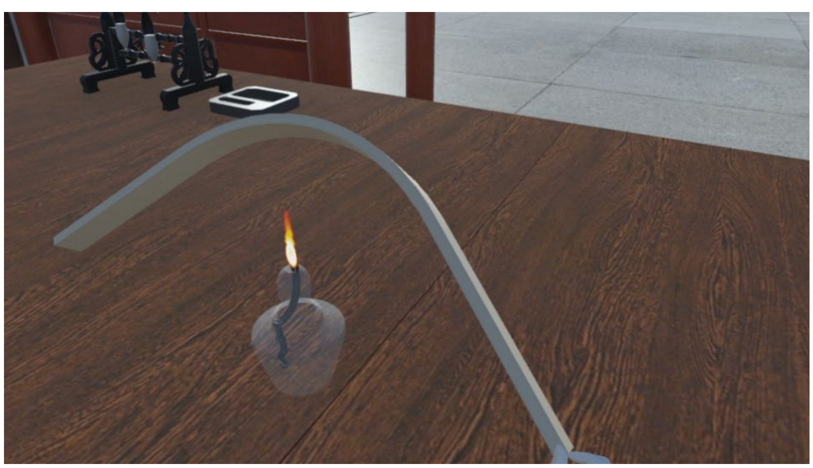

Fig. 5: Single point control deformation application results.

3.3. Experiment for Coordinate Axis Locking

The experiment was conducted by locking the coordinate axes of the coordinate points in a plane so that the model being controlled would not be affected in other directions when transforming in that plane. By comparing the experiment with the operation of the control points without coordinate locking, the improved points are more in line with the process requirements in reality. The experimental results show that through the flexible use of the coordinate axis locking technique, the coordinate axis locking can make the model more convenient and precise when transforming in a certain direction, and also avoid the accidental deformation due to misoperation.

4. Interactive Realization of Virtual Kite Craft

In the design and realization of the interaction of virtual kite making process, considering that some actions of kite tying are more complicated in reality, some steps are simplified in order to avoid the confusion of the experience user's operation in the scene. The main interaction points are realized as follows.

4.1. Cutting Bamboo Strips

During the VR interaction, the experiencer can interact with the bamboo strips in the scene. First, the saw is found in the right toolbar and picked up using the handle. When the bamboo strip interaction is activated, a line highlight will appear on the bamboo strip, and then the bamboo strip can be cut in the highlighted part. When the saw blade touches the bamboo strip, the strip will be split into two parts, as shown in Fig. 6.

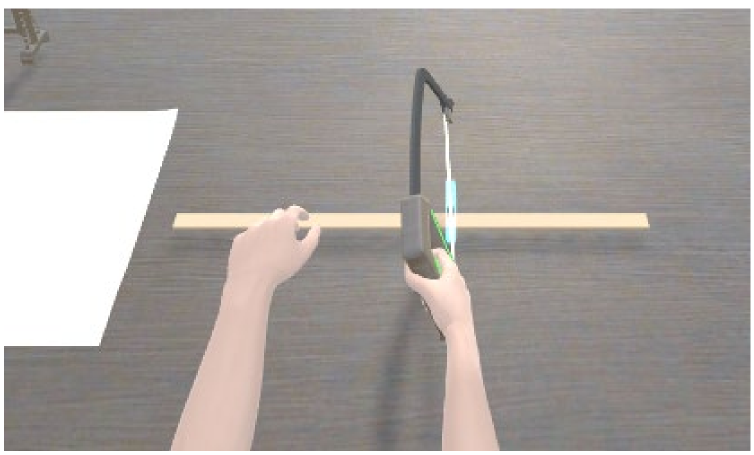

Fig. 6: Bamboo strip cutting interaction.

4.2. Roasting Bamboo Strips

In the roasting bamboo interaction step, the experiencer can interact with the previously cut bamboo strips in the next step. First, the user needs to take out the lit alcohol lamp from the right toolbar. Then, using the handle, the bamboo strips are placed on the flame for roasting. In order to provide a more realistic visual effect, the improved mesh deformation algorithm mentioned in Section 2 is used in this step. The visual effect is enhanced by utilizing a grid model deformation algorithm. This interaction design further enhances the immersion and the involvement of the experiencer in the VR scene.

4.3. Twisting Cord

In this interactive step, the experiencer can follow the instructions to splice the roasted bent bamboo strips and use the handle to twist the cord around the strips. In order to realize the core of this function, it is necessary to traverse all points on the sub-path in a loop, calculate the direction of the path and the perpendicular vector between the path direction and the reference direction based on the current point and adjacent points firstly. Secondly, calculate the mesh vertex, corresponding vertex position, normal and texture coordinates at each point, and add them to the vertex, normal and texture coordinate arrays. Finally, generate triangles for the mesh model according to the vertex index and add add them to the triangle array. The result is shown in Fig. 7.

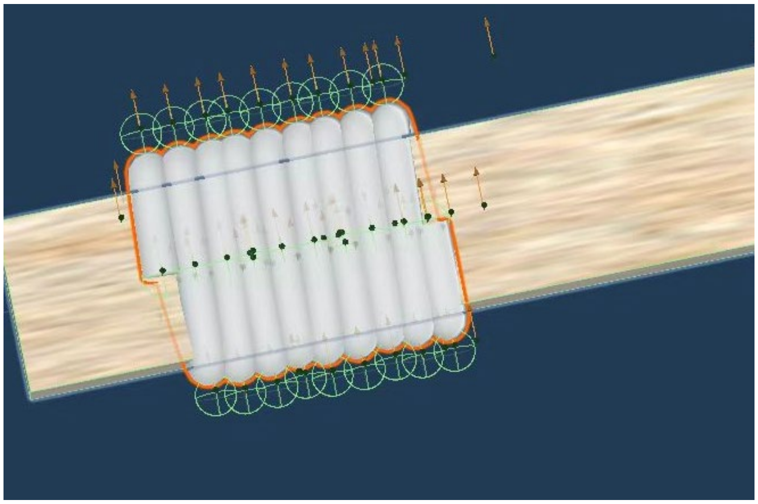

Fig. 7: Twisting cord interaction.

4. Conclusion

In this paper, we have a brief explanation of Cao's kite craft firstly. The significance of the digital protection of Cao's kite craft is discussed according to its current situation, and the necessity of the combination of VR technology and Cao's kite craft is discussed. Secondly, we research the key technologies of Cao's kite craft. The operability of virtual kite craft production is enhanced with the help of mesh deformation and other methods, and the experimental design is carried out to analyze the experimental results. Finally, the interactive realization of virtual kite craft is implemented to achieve a better human-computer interaction.

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References

[1] Y. Hou, S. Kenderdine, D. Picca, M. Egloff, and A. Adamou, “Digitizing intangible cultural heritage embodied: state of the art,” *ACM J. Comput. Cult. Heritage*, vol. 15, no. 3, pp. 1–20, Sep. 2022.

[2] Y. Yu, H. Ren, “Innovative Application of Virtual Reality Technology in Digital Display of Intangible Cultural Heritage,” *Proceedings of SPIE - The InternationalSociety for Optical Engineering*, vol. 13063, 2024.

[3] H. Zhong, L. Wang, and H. Zhang, “The application of virtual reality technology in the digital preservation of cultural heritage,” *Computer Science and Information Systems*, vol. 18, no. 2, pp. 535–551, 2021

[4] A. Acker, “Emulation practices for software preservation in libraries, archives, and museums,” *J. Assoc. Inf. Sci. Technol.*, vol. 72, no. 9, pp. 1148–1160, 2021.

[5] Q. Zou, H. Feng, and S. Gao, “Variational Direct Modeling: a framework towards integration of parametric modeling and direct modeling in CAD,” *J. Technol. Comput. Aided Des. TCAD*, vol. 157, p. 103465, 2023.

[6] L. Diazzi and M. Attene, “Convex polyhedral meshing for robust solid modeling,” *ACM Trans. Graphics*, vol. 40, no. 6, pp. 1–16, 2021.

[7] H. S. Seah, B. Tandianus, and Y. Sui, “Modeling and Rendering with eXpressive B-Spline Curves,” *Computer Science Research Notes*, 2023.
[8] R. Hao, Z. Wei, X. Hu, K. Zhu, J. Wang, J. He, and L. Zhang, “Multistage adaptive Point-Growth network for dense point cloud completion,” *J. Remote Sens.*, vol. 14, no. 20, p. 5214, 2022.
[9] N. Wang, Y. Zhang, Z. Li, Y. Fu, H. Yu, W. Liu, X. Xue, and Y. Jiang, “Pixel2Mesh: 3D mesh model Generation via Image guided deformation,” *IEEE Trans. Pattern Anal. Mach. Intell.*, vol. 43, no. 10, pp. 3600–3613, 2021.
[10] P. Zheng, Q. Liu, J. Lou, C. Lian, and D. Lin, “A free-form surface flattening algorithm that minimizes geometric deformation energy,” *IET Image Proc.*, vol. 16, no. 9, pp. 2544–2556, Apr. 2022.
[11] Y. Fang, M. Li, C. Jiang, and D. M. Kaufman, “Guaranteed globally injective 3D deformation processing,” *ACM Trans. Graphics*, vol. 40, no. 4, pp. 1–13, 2021.
[12] X. Yang, X. Han and H. Wan, “A Virtual Grasping Method of Dexterous Virtual Hand Based on Leapmotion,” in *Lecture Notes on Data Engineering and Communications Technologies*, vol. 104, pp. 163-176, 2022.