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Virtual Flower Visualization System Based on Somatosensory Interaction

Liu Long[1], Huai Yongjian[1]*

1. School of Information Science and Technology, Beijing Forestry University, Beijing 100083

88204277@qq.com, Huaiyj@163.com

Abstract: Somatosensory interaction has already become a research focus with the rapid development of virtual reality technologies, which has widely applied in the field of computer vision. However, the task is very challenging because of the serious penetrating phenomena in the process of interaction and the high complexity of the gesture recognition problem. For these issues, we present a feasible solution that solves the problem of finger penetration in virtual flower interaction process, which including the details of virtual hand position mapping, object collision detection, and finger position optimization. After analyzing the requirements associated with hand gesture in virtual flower interaction, we propose a finger gesture-based method to recognize the custom gestures, which utilized Particle Swarm Optimization algorithm to optimize the trajectory of fingertips and joints. In addition, a prototype of virtual flower somatosensory interaction system has designed and implemented for forestry interactive application, and the prototype evaluation has given through the user experimental. Experimental results show that the proposed methods can effectively solve the problem of finger penetration during grasping, and accuracy identify the custom gestures, and provide a more natural, intuitive and efficient user experience compared with the traditional interaction.

Keywords: virtual flower visualization; Leap Motion; somatosensory interaction; precision grasping; gesture recognition

1 Introduction

Virtual Reality (VR) technology is composed of three elements (interaction, immersion, and imagination), which aims to build virtual scenes to be manipulated by the user through input devices, and the user can feel high immersion during the interaction [1]. Additionally, somatosensory interaction referring that the user interacts with the surrounding environment through their body movements directly by sensors. This technology aims to build a more natural interaction environment, which simulates the user's behavior to manipulate a three-dimension (3D) virtual model [2]. Combining virtual reality technology and the use of somatosensory devices makes it is possible for users to feel the real scene and the reaction of interact, which almost like they were in the real world. Due to the intrinsic properties of the above technologies, they are rapidly becoming powerful tools in the fields of medical visualization, Computer Aided Design (CAD), and virtual assembly, providing a new dimension experience for users and changing the traditional way of interaction [3-5].

Virtual plant refers to simulating plant growth process on the computer [6]. Currently, some researchers are devoted to applying VR technology in the field of virtual plant visualization, and developed many visual tools and applications. At the same time, many somatosensory interaction-based methods use new input/output device to implement the virtual human control interface, which makes full use of human perception ability to express the control intention in a natural way [1]. However, few visualization systems offer adequate functions to achieve immersion and interactivity for forestry visualization research, it would be more productive and innovative if models can been saw in a real 3D environment and modify or make adjustments using hand gesture instead of mouse manipulation. Therefore, we will develop a visualization interactive system for virtual flower interaction, which users can visualize the whole project in a virtual 3D world and interact with them via gestures.

In recent years, the miniaturization and portability of the VR visual devices have promoted the development of the VR industry extensively, there are many kinds of head-mounted display (HMD) and somatosensory devices in the market, such as Oculus Rift, HTC vive, Kinect and Leap Motion, etc.. [1]. Many scholars have investigated and evaluated the properties of such consumer hardware [7-9]. According to their research, we decide to use Oculus Rift as the virtual reality device and Leap Motion for gesture recognition in the system. However, there are two major technical challenges in this application. First, it is possible generate serious penetration phenomena in the process of grasp interaction. Second, flower-manipulating gestures are usually fast and complex, involving high complexity of the interactive gesture recognition.

In this work, a prototype of virtual flower somatosensory interaction system has designed and implemented for forestry interactive application. The objective of this article is to tackle these technical challenges, which arise during implementation of our system. The contributions of our study can be summarized as follows:

(1) This study proposed a visualization interactive system to support the structural function analysis of plants and use of somatosensory interaction-based operation instructions improve the researchers for manipulating plants interaction process.

(2) This study present a feasible solution that to tackle the problem of finger penetration in virtual flower interaction process, which including the details of virtual hand position mapping, object collision detection, and finger position optimization.

(3) This study propose a finger gesture-based method to recognize the custom gestures, which utilized a Particle Swarm Optimization (PSO) algorithm to optimize the trajectory of fingertips and joints.

The remaining parts of this article are organized as follows: Section 2 discusses previous research related to visualization of virtual flowers and its application. Section 3 introduces the functionality goal and somatosensory interaction method of virtual flower visualization. Section 4 presents the virtual hand precision grasping process and the gesture interaction based on Leap Motion. Section 5 discusses prototype system and user test. The final section offers conclusions and future research directions.

2 Related Work

2.1 Visualization of Virtual Flowers

Virtual flower visualization is one of the hot issues in recent years. Its main research direction is divided into two aspects: on the one hand is the visual model of flower plants, on the other hand is the application of interactive technology in virtual flower visualization. In the aspect of flower model, there are mainly graph-based and image-based methods. In the literature [10], based on the different arrangement of petals, the stochastic perturbation function is added, and the automatic generation system of the flower model is established by the extended L-system. Finally, realized the three-dimensional model of the rose, lily and tulip. In the literature [11], a common simulation method is presented for herbaceous flower. By combining image information and bi-cubic Bezier surface simulation of organ morphology, and the use of Logistic equation simulation of flower organ growth process, the author realizes the model and simulation of tulips, carnation and jasmine. The above literature mainly focuses on the real sense rendering of the overall appearance of the flower model, and does not simulate the different components of the flower.

On the other hand, in the literature [12], a 3Gmap L-system application for flower model with growth simulation is proposed. The user can intuitively control the shape of the final model and take into account the internal structure of the flower. Through the interactive manipulation of different modules, the model and rendering of dandelion and hyacinth are realized. In the literature [13], a training system for the Japanese art of flower arrangement is implemented, which used to simulate the different flower arrangement, and can generate force feedback when users insert flowers into the pinholder. But the system interaction is complex, the device is not easy to move. The above system inevitably has some flaws, such as the structure function is single, lack of immersion, the interactive way is not natural and so on. The work of this paper will focus on these shortcomings, and improve the visualization of virtual flowers by introducing new interactive methods and designing reasonable structural functions.

2.2 Flower Application Based On Somatosensory Interaction

With the continuous progress of natural human-computer interaction technology and the popularity of interactive devices, somatosensory interaction breaks the traditional way of the interaction and brings a completely new interactive experience to users. The detailed account of the differences between somatosensory interaction and traditional interaction is shown in Table 1. In the process of interaction, users do not need to have direct contact with the object, which reduces the constraints for the user, while enhancing the immersive human-computer interaction, so that the interaction process more natural [14]. Especially the introduction of new generation of somatosensory devices, such as Kinect and Leap motion, has driven the enthusiasm of a wide range of developers and scholars to develop a variety of applications in medical, music, business, and robotics [15-19]. However, the use of somatosensory interaction technology to develop visualization systems for virtual flowers is rare, and there is very little research literature available. In the literature [20], a visualization system for creating a flower model is proposed. First, Kinect gestures are used to interact with the model parameters. Then, the commands are received via 3Gmap L-systems. Finally, create the model and output the files that can be used in Unity3D. In 2014, Leap Motion officially launched a V2 Playground application, through the virtual hand picking petals from the flower, the user can freely interact with virtual flowers [21]. In 2016, the Australian Energy Plant Biology Laboratory launched a virtual reality educational application of "Virtual Plant Cell". Users can observe the chloroplasts, mitochondria and DNA of plant cells through the Google Cardboard, and explore the effects of environmental conditions on genes [22]. The above study uses a single somatosensory interaction device to achieve the interaction between people and flowers, and its function is not comprehensive enough. Some of them can only control the model interaction, which lack simulation of specific details; while others focus on visualization display, which lack human-computer interaction operation. Therefore, this paper will combine the Leap Motion and Oculus Rift to realize construction of virtual flower visualization system.

Table 1 The differences between somatosensory interaction and traditional interaction

Label	Somatosensory interaction	Traditional interaction
Interface mode	Natural user interface (NUI)	Graphical user interface (GUI)
Input device	Kinect, Leap Motion, etc.	Mouse/Keyboard, Glove, etc.
Interactive accuracy	Low	High
Interactive immersion	High	Low
Interactive imaginative	High	Low
Interactive feedback	Vision, Auditory	Vision, Physical
Physical fatigue	Worse	Better
Interactive experience	3D	2D

3 Virtual Flower Visualization Interactive System

The somatosensory interaction-based system means that the high immersive visual output devices and intuitive input devices are employed in the system. Due to the Oculus Rift provides high resolution (960 x 1080 pixels per eye) stereoscopic images with 100° field of view (FOV) and widely applications in different field [4], since it is well integrated with Unity and its handful Software Development Kit (SDK) support for multiple platforms, we decide to use Oculus Rift as our output device. The Leap Motion supports detail hand structures like fingers and joints and provides better interaction functionality. It also provides a unique ID tag, when hand are detected. According to the evaluation of Leap Motion's effectiveness in 3D environments, we chose it as the input device for recognizing gestures.

3.1 System Design Goal and Functions

The visualization system developed in this article addressed two major design goals: (1) Giving the user a basic understanding of the structural function analysis of plants; (2) Giving the user a basic understanding of how the researchers for manipulating plants interaction process. The system is comprised of three primary components: (1) User Interface (UI) and relevant events. It includes initial interface, help interface and all UI elements in the system. (2) Scene system. This study used 3ds Max and Unity3D to create the virtual model and scene of the virtual flowers and plants. (3) Operational interface. The function goal of an operational interface is able to meet the requirements of visualization interactive, including two aspects: It enables user to directly select and accurately manipulate model with hands in real time, and observe the structure in a flexible multi-dimensional viewpoint; It will provide immersive 3D visualization of flowers and plants and good user experience.

3.2 Somatosensory Interaction-Based Method of Virtual Flower Visualization

In this paper, the virtual visualization interactive control framework is shown in Figure. 1, which is divided into three parts: user gesture recognition, somatosensory interaction control and visualization. Gesture recognition part: we obtain user interaction gesture data from the Leap Motion controller, then the user gesture information is processed by the algorithm, and the corresponding function operation is recognized. Somatosensory interactive control part: First, we create a virtual interactive scene in the Unity3D engine, in order to show the three-dimensional model of flowers and botanical information; Secondly, it analysis the incoming message through the virtual interaction scenario control interface, then gives the corresponding interactive control instruction to implement the operation of virtual flowers. Visualization Part: the effect of real-time interaction in a virtual scene is rendered to the screen via the Oculus Rift head mounted display.

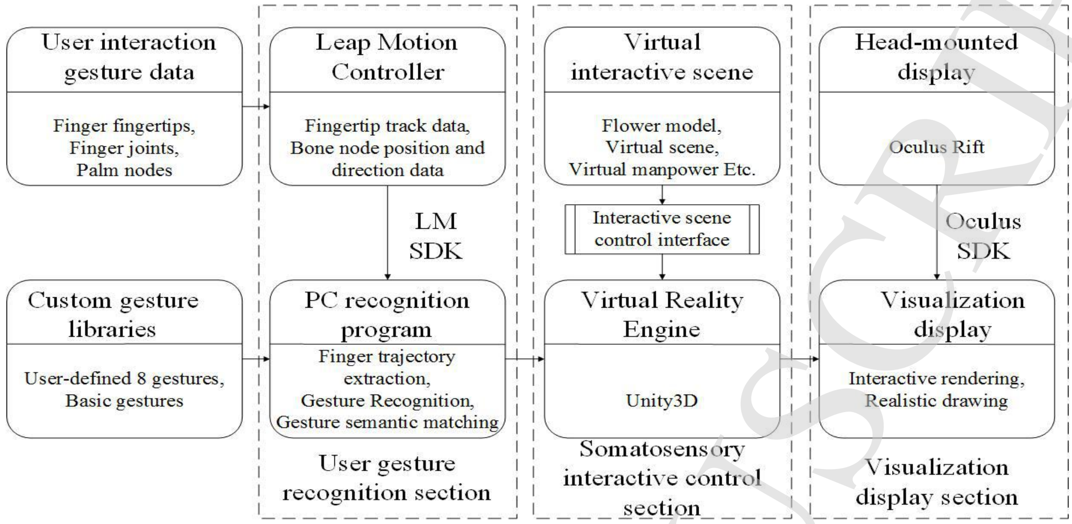


Figure. 1 Interactive control framework

4 Algorithm Description

4.1 Virtual Hand Precision Grasping Processing

One of the purposes of building a virtual flower visualization interactive system is to achieve the interaction between virtual hands and virtual flowers. One of the most important issues is the precise hand grab operation of the virtual hand. Unnatural, unreal, unstable grasping can easily lead users to fatigue, so that users can't observe and operate for a long time. Virtual hand precision grasping processing is divided into three steps: virtual hand position attitude mapping, virtual hand and object collision detection and virtual hand grab penetration problem optimization. The processing of this paper will be described in detail below.

4.1.1 Virtual Hand Position Attitude Mapping

The system is based on somatosensory interactive devices to start the study in the Unity3D game engine platform. Therefore, there is a difference between the Leap Motion coordinate system (right-hand coordinate system) and the Unity3D coordinate system (left-hand coordinate system), as shown in Figure. 2. For each frame of data, its coordinates must be converted, as a result of virtual hand gesture mapping. The Leap Motion coordinate axis direction in Unity3D coordinate system are represented by u'_x, u'_y, u'_z, there are $u'_x = (1,0,0)$, $u'_y = (0,1,0)$, $u'_z = (0,0,-1)$. The origin of the Leap Motion coordinate system corresponds to the origin of the Unity3D coordinate system. Then, the position of the virtual hand [23] in the Unity3D coordinate system is determined according to the formula (1).

$$\begin{cases} (x,y,z) = \rho \cdot (x',y',z') \cdot T \\ c = c' \cdot T \end{cases} \quad (1)$$

Where, (x,y,z) and c represent the coordinates and directions of each block (palm or finger) transition to Unity3D coordinate system, respectively; (x',y',z') and c' represent the coordinates and directions of each block collected by Leap Motion, respectively; ρ is the scaling factor, which used to characterize the scale transformation of coordinate transformation. T is the coordinate transformation matrix:

$$T = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{bmatrix}$$

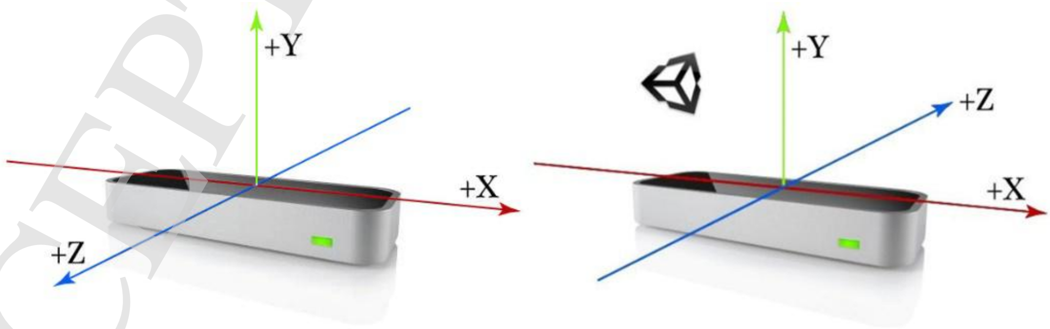


Figure. 2 The mapping of the Unity3D coordinate system on Leap Motion

4.1.2 Virtual Hand and Object Collision Detection

The difference between virtual grabbing and real fetching is whether the hands and objects have physical contact, and the relationship between them is mainly feedback to users in visual form. Collision detection is the basis and precondition in the process of virtual hand grasping. Accurate and efficient collision detection method can enhance the real sense of interaction, and enable users to experience better in the virtual environment. In this paper, a fast collision detection method is proposed. First, the pre-collision detection is carried out by ray collision detection, and then the collision detection is completed by OBB (Orient Bounding Box) collision detection method. The basic idea of the algorithm is: first, to determine whether the ray emitted by the fingertip can collide with the object, and then to construct OBB surround box for accurate collision detection of the object and the fingertip.

In the pre-collision detection phase, according to the definition of rays in the three-dimensional vector space [24]. Assuming that the known ray start point P_0, the ray direction α, and the vertices of the triangle are A, B, and C, respectively. It is necessary to determine whether or not the ray intersects the triangular plane. If it intersects, the center of gravity coordinate (u, v) of the intersection point and the distance d of the ray start point to the intersection point R are calculated. Here:

$$\begin{cases} R = A + u \cdot (B - A) + v \cdot (C - A) \\ R = P_0 + d \times \alpha \end{cases} (2)$$

Formula (2) can be written:

$$P_0 + d \times \alpha = A + u \cdot (B - A) + v \cdot (C - A) (3)$$

According to the formula (2), (3):

$$R - A = \begin{bmatrix} -\alpha & B - A & C - A \end{bmatrix} \begin{bmatrix} d \\ u \\ v \end{bmatrix} (4)$$

When $d > 0$, $0 < u$, $v < 1$, $0 < u + v < 1$, the coordinates of the intersection point are inside the triangle. Solution formula group, let $\beta = B - A, \gamma = C - A, L = R - A$, formula (4) can be written as:

$$\begin{bmatrix} -\alpha & \beta & \gamma \end{bmatrix} \begin{bmatrix} d \\ u \\ v \end{bmatrix} = L (5)$$

According to cramer's rule:

$$\begin{cases} d = \dfrac{1}{|-\alpha \quad \beta \quad \gamma|} |L \quad \beta \quad \gamma| \\ u = \dfrac{1}{|-\alpha \quad \beta \quad \gamma|} |-\alpha \quad L \quad \gamma| \\ v = \dfrac{1}{|-\alpha \quad \beta \quad \gamma|} |-\alpha \quad \beta \quad L| \end{cases} (6)$$

In our algorithm, the starting point P_0 of the ray is set as the coordinates of fingertips, and the point of intersection of the fingertips and objects is P_v. We determine the virtual finger movement direction by the size of d, assuming that the length of the ray in the current frame is d_c, the length of the previous frame is d_p. If $d_c < d_p$, represent virtual hands close to the object, if $d_c > d_p$, then the opposite. In this paper, we set a distance threshold d_0. When $d_c = d_0$, it is consider that the distance between the virtual hand and the object is close enough. Then, it prevents the fingertip from moving in the positive direction of the z-axis of the three-dimensional space, and starts the accurate collision detection module.

In the process of accurate collision detection, the method of constructing an OBB is as follows: Let the vertices of the i-th triangles be p^i, q^i, r^i, and the number of triangular patches of the bounding box is n. The center of the bounding box is:

$$m = \frac{1}{3n} \sum_{i=1}^{n} (p^i + q^i + r^i) (7)$$

The covariance matrix element is:

$$C_{jk} = \frac{1}{3n} \sum_{i=1}^{n} \left(\bar{p}_j^i \bar{p}_k^i + \bar{q}_j^i \bar{q}_k^i + \bar{r}_j^i \bar{r}_k^i \right) \quad 1 \le j, \ k \le 3 (8)$$

Where, $\bar{p}^i = p^i - m$, $\bar{q}^i = q^i - m$, $\bar{r}^i = r^i - m$, each is a 3 × 1 vector.

As the human hand belongs to the irregular shape, we use a small cube instead of fingertips, and the local coordinate system is established on the cube. The origin of the coordinate is the center of the palm, the direction of the middle finger is the x-axis, the direction of the thumb perpendicular to the x-axis is the y-axis, the z-axis is determined by the right hand theorem. And then determine the oriented bounding box in the direction of the border, consistent with the boundaries of the fingertips and objects. In the method of reference [25], the collision detection in this stage is the intersection test between two OBBs, and the intersection test is performed according to the separation theorem. Assuming that A is the point where the intersection may occur on the model, B is the point on the tangent plane of the finger, BA is the vector from B to A, N is the normal vector of the tangent plane, D is the distance from point A to tangent plane. The error range allowed for collision detection is [-a, a] (a = 0.1mm). So the formula is:

$$\begin{cases} BA = B(x,y,z) - A(x,y,z) \\ D = \dfrac{N \cdot BA}{|N|} \\ D \le a, \text{Collision}; D > a, \text{No collision} \end{cases} \quad (9)$$

In this paper, the main algorithm flow (see Figure. 3) is as follows: Setting the surface contact mark of the rays and objects emitted by the fingertips is false. In the frame loop obtained by Leap Motion, the direction of movement of the virtual finger is judged by the change in the length of the ray between the current frame and the previous frame. When the virtual hand is close to the object, if the contact mark becomes true, it means that the grab operation is performed. When the distance size satisfies the set threshold, the exact collision detection module is activated. Then, according to the separation axis theorem, we can determine whether the virtual fingers collide with the object. If a collision occurs, the virtual finger is prevented from moving forward, and convert to judge grasping condition. If no collision occurs, return to the pre-collision detection process for the next judgment.

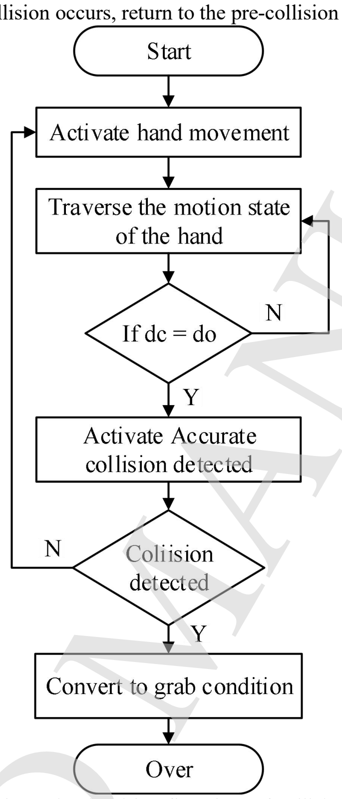


Figure. 3 The main algorithm flowchart of collision detection

4.1.3 Virtual Hand Grab Penetration Problem Optimization

In the process of virtual hand grasping, the position and attitude of the finger should be optimized, in order to prevent finger and model penetration, and ensure the authenticity of grasping. According to the characteristics of virtual hand grasping operation, the attitude optimization goals mainly include the following points: (1) When optimizing, each finger joint should satisfy the constraint requirement. (2) After the optimization, the position of the finger first contact with the object is always maintained on the surface of the object. (3) After the optimization, the bending degree of finger should be reduced. After the collision detection is realized, the inverse kinematics method can effectively adjust the posture of the finger in the environment and avoid the serious penetration between the virtual hand and the object. Based on the improved Cyclic Coordinate Descent (CCD) algorithm in [26], this paper proposes an optimization algorithm of finger attitude adjustment. First, we preliminary adjust the posture of the finger in contact with the object, and then introduce another virtual agent hand model for kinematic optimization, which can ensure a true and stable grasping operation.

The comparison effect of the virtual hand before and after the precision grasping process is shown in Figure. 4. In Figure. 4(a), the virtual hand stably grabbed the object, but there was a serious finger penetration phenomenon. After it has been processed by the above-mentioned method, we can get a more realistic grasping effect, as shown in Figure. 4(b).

(a)

(b)

Figure. 4 Comparison of before and after the precision grasping process. (a) Before the precision grasping process. (b) After the precision grasping process.

4.2 Gesture Interaction Based on Leap Motion

4.2.1 Gesture Definition

The gesture definition is the foundation of gesture recognition, and therefore must be reasonable planned. Although Leap Motion can better predict the positions of fingers and hands that are not clearly in view and provide some stationary gestures, we should pay attention to avoiding complex hand poses. According to people's handedness, the use frequency and flexibility of right hand is much higher than the left, and when we design gestures, we try to use our right hand to convey information. Different from the general gesture operation, in the process of flowers and plants interaction, we need each gesture to correspond to different operation, thus achieving overall interactive control. In summary, in defining the gesture library of the system, it should be consistent with the daily life of human interaction habits, and gestures should not be too complicated, and each operation should correspond to the interaction of flowers and plants.

In order to realize the natural interactive control of the virtual flower visualization system, this paper defines the gesture interaction mode as navigation and manipulation. Navigation refers to the operation of the natural interface, such as the function button selection. Manipulation refers to the operation of the virtual floral model, such as anatomical virtual flowers. This paper mainly designed the gesture database under the manipulation mode, gestures in the navigation mode using the basic gestures defined by other researchers. According to the system requirements, eight gestures are defined to interact with the flower plant model, as shown in Figure. 5. In Figure. 5(a), according to the direction and position of the finger, we learn that the user did the grab action, then the virtual hand grab the entire virtual flowers. When the user's hand makes the action as shown in Figure. 5(b), the virtual hand pinch the different organ models of the flower. In Figure. 5(c), when the user's left hand is facing to himself, there will appear a function selection interface, the user using the right hand click on the different buttons to view the specific information on the flowers. When the user makes a gesture as shown in Figure. 5(d), the entire flower model will be decomposed. In Figure. 5(e), the user's palm is down, and the index finger and middle finger remain straight, when the hand moves to the six directions of the space, the flower model also made the appropriate movement. In Figure. 5(f), when the user makes the action of clenching and opening the palm of the hand, the floral model is scaled. In Figure. 5(g), the palm of the user is upward, and when the user's hand moves up quickly, the flower plant grows. When the user's hands clenched, and palm is down, reset the flower model, as shown in Figure. 5(h). In combination with practical requirements and ease of operation, this paper has abandoned the more complicated gesture design, the definition of each gesture and the specific functions shown in Table 2.

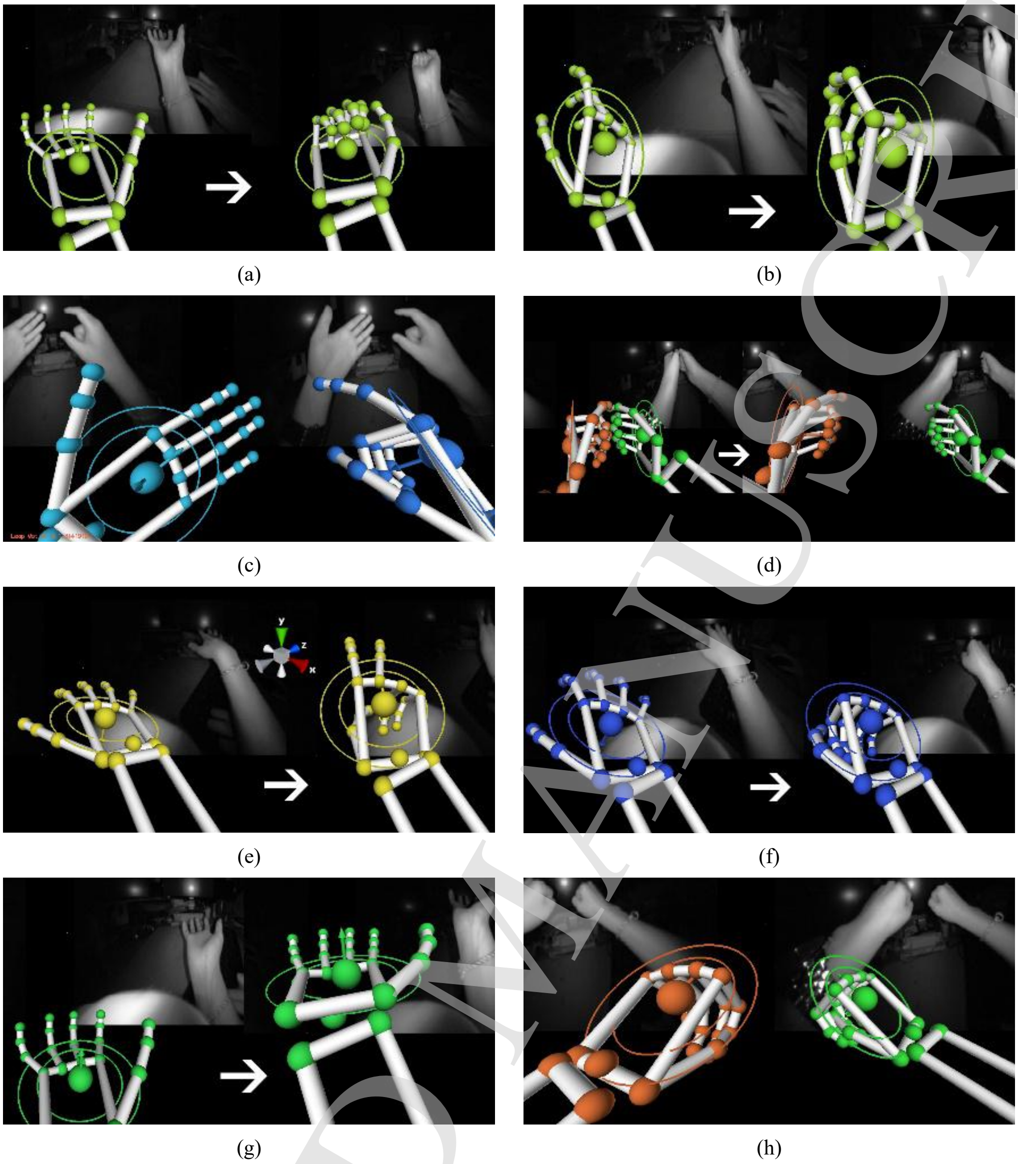


Figure. 5 Virtual hand interaction mode. (a) Grab the entire model. (b) Pinch different organs. (c) Show specific information. (d) Decompose the whole model. (e) Six-direction movement model. (f) Scale the entire model. (g) Control flower growth. (h) Reset the entire model.

Table 2 Gesture definition and specific function

Label	Gesture definition	Specific function
a	Five fingers move towards for the center of the palm at the same time	Grab the entire flower model
b	Two or three fingers move toward for the center of the palm	Pinch different organ of flower
c	Left hand face to the user, and stretching the fingers, right hand click to choose	Show the organ information of flower
d	Two hands relative, move in the opposite direction, and open the palm	The flower model is decomposed into specific organs
e	Right palm down, the index and middle finger remain straight, and move in the space in six directions	When the two fingers move left or right, the model rotates around the y axis; when moving up or down, the model rotates around the x axis; when moving forward or backward, the model translates in the z axis

f	Right palm down, clench palm or open palm	When the palm is clenched, the model shrinks; when the palm is open, the model is enlarged
g	Right palm up, open the palm and waving up	Flower growth animation control
h	Hands clasped and palm down	Reset flower model

4.2.2 Gesture Recognition

Take the grasping operation as an example. According to the gesture requirement of the interactive system, the number of fingers and finger grasping posture need to be identified. Therefore, we need to make attitude estimate of all the finger joints, and the fingertips should be tracked and detected. In the process of interaction operation, there is an angle problem between the hand and the somatosensory device, so it has a problem of mutual occlusion between the fingers, which will lose some of the data, and causes that cannot correctly identify the defined gestures. Therefore, this paper is based on swarm intelligence algorithm to optimize the fingertips and the trajectory of the bone to achieve precision grasping gesture recognition. The following is a brief description of the process. The specific flow chart is shown in Figure. 6.

(1) We use Leap Motion to obtain the fingertip and direction vectors, then collect the position data for each finger segment and map it to the virtual hands model.
(2) Define the angle constraint between finger joints according to the mechanical properties of stable grasping. In this paper, most of the models that need to be interactive are irregular objects, and the virtual fingers may appear different degree of deformation, the kinematic model of virtual fingers is realized by using the forward kinematic algorithm based on constraint.
(3) After pre-processing the data, the particle swarm optimization algorithm is used to optimize the joints of each bone, until the joints of the virtual fingers reach the constraint condition.
(4) Depending on the change in the distance of the fingertip position of the optimized virtual finger, it matches the defined gesture template library to identify a particular gesture of operation.

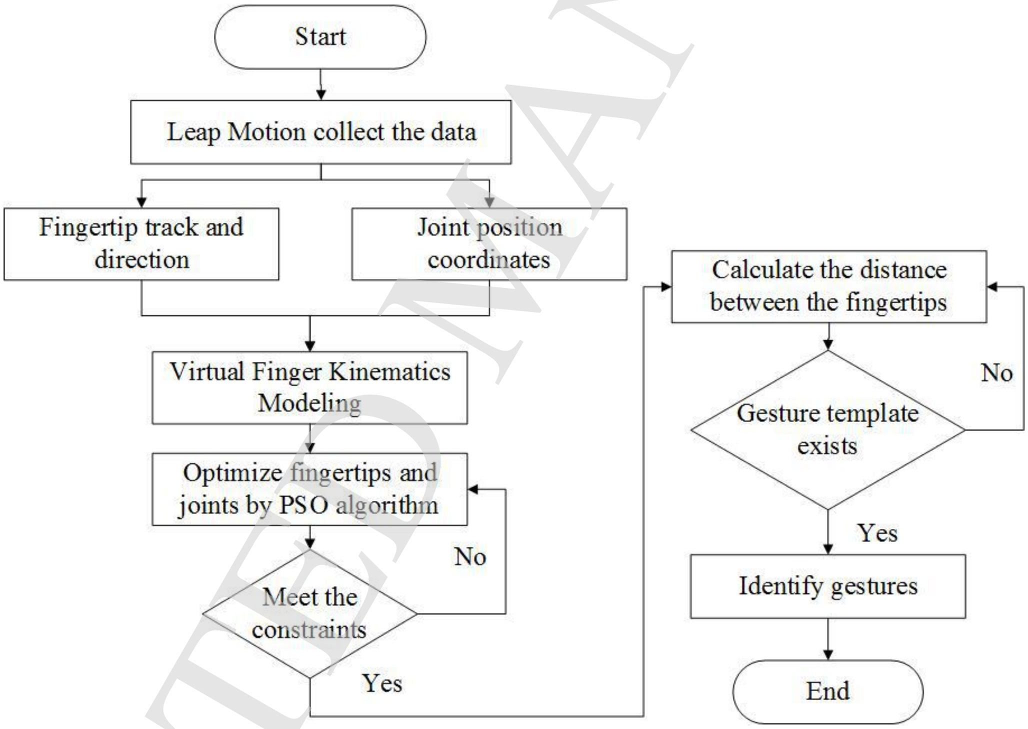


Figure. 6 Gesture Recognition Process Based on Swarm Intelligence Algorithm

A large number of investigations have found that in the fine interaction process between user's hands and objects, the main role is the thumb, index finger and middle finger. From the comparison of the gestures defined in the previous section, there is a significant difference in the degree of bending and the change in fingertip position. The frame data of each joint of the finger obtained by Leap Motion can be mapped to the virtual hand model to simulate the different degree of bending of the virtual finger. By calculating the fingertip position and the degree of finger flexion between the thumb and the other fingers, we can determine the current gesture state to achieve the purpose of identifying the different gestures.

5 Experiments and Discussions

In this paper, we use Leap Motion and Oculus Rift somatosensory device to build hardware system. Our platform is developed with Unity3D, and the system prototype is realized by C # programming language, with Visual Studio 2015, Leap Motion SDK and Oculus Rift SDK as the development environment. The system was tested on Windows 7 Ultimate 64-bit system, with an Inter (R) Core (TM) i7-3770 CPU @ 3.40 GHz processor with 4GB of RAM. The user can interact with the flower plants in real time and smoothly through the operation of grab and waving.

5.1 User Test Design

5.1.1 Quantitative Test

The efficiency and feasibility verification of our visualization interactive system includes both gesture recognition test and manipulation accuracy and comfort test. We invited twenty testers (eight women) to participate in the system validation, including five forestry-related professionals (three males and two females) had more than one year of experience in floral plants. Ten computer-related professionals (six males and four females), most of whom have contacted with somatosensory device and have more than one year of gaming experience. Five people who do not have forestry and computer-related knowledge (three males and two females). After detailing the definition of gestures, the operation of our system, test items, and with 15 min training, the test began.

(1) Gesture recognition test. To evaluate the proposed algorithm we performed a set of experiments applying. The set is comprised of 12 gesture performed by the 20 testers. The first third of the 12 gestures are the navigation gesture (Circle, Swipe, Pause, ScreenTap), and the other two-thirds are the manipulation gesture (see Table 1). Each gesture has been performed 10 times resulting in 120 samples, and the total number of samples is 2400.

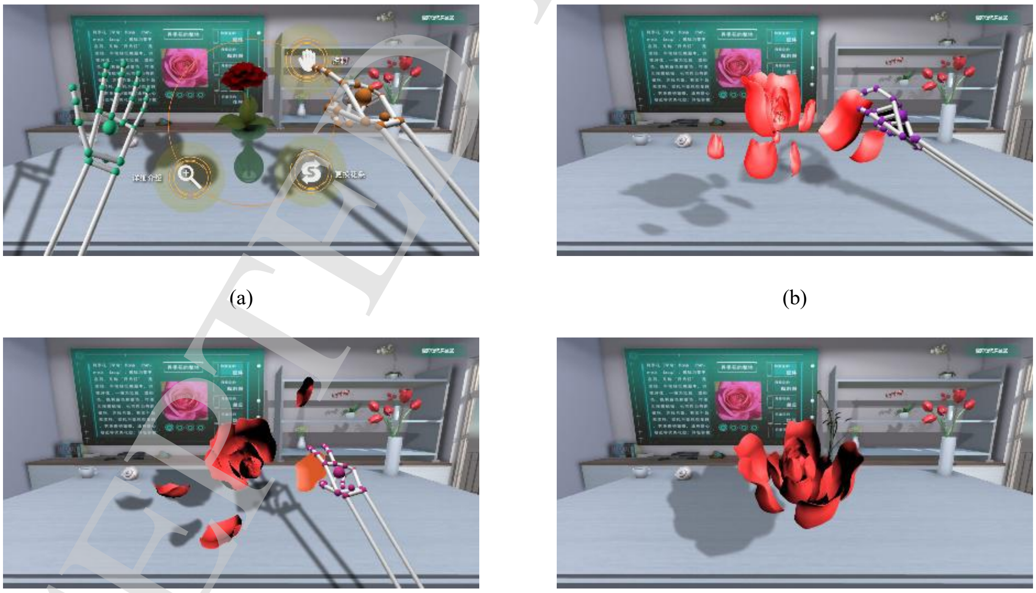
(2) Manipulation accuracy and comfort test. It describes the accuracy and comfort of our system with time and comprehensive error. Accuracy tests were designed to control the movement, scaling, growth and anatomy of the virtual rose. Five interactive tasks were designed for our system, and the specific requirements are as follows: (1) Rotate the flowers in the 3D space to the specified position and shift to the designated position. (2) Pinch the selected parts of the flower and rotate it to the specified position for observing. (3) Select a part of the flower and perform the zoom operation of the specified location. (4) Control flower growth with defined gestures and rotate to the specified angle for observing. (5) Perform an anatomical operation on flowers of the specified Angle and position and display the corresponding information from multiple angles. All test items were conducted with the comparative test of mouse/keyboard and gesture. Comfort test was designed to measure the time consumption of the process and the fatigue strength of testers.

5.1.2 Qualitative Test

This study designs a set of user experience subjective evaluation result questionnaire according to several evaluation indexes of interactive experience in virtual reality. In this paper, the ten points system was selected to evaluate and corresponding to the five levels of satisfaction, of which 1-2 scores correspond to "very dissatisfied", 3-4 scores on behalf of "less satisfied", 5-6 scores means "general", 7-8 scores represent "more satisfied", 9-10 scores is "very satisfied". In order to get more accurate user feedback, different satisfaction corresponds to two scores. For example, the user chose 6 scores, representing his evaluation of this content, that between the "general" and "more satisfied", but in fact slightly inclined to "more satisfied." The test was carried out after quantitative test, and included five questions: (1) System overall performance; (2) Real-time performance of interactive operations; (3) The sense of immersion and realism of the system; (4) The natural degree of interactive gestures; (5) The simplicity and aesthetics of the system interface.

5.2 System Prototype Application

Taking the anatomy of the virtual rose flower as an example, the user operates according to the experimental procedure, and finally the whole model is decomposed into different organs. The experimental results are shown in Figure. 7. As shown in Figure. 7(a), after the user enters the virtual scene and perform a custom gesture c, then the selection interface appears, using the right hand click on the replacement flower button to select the rose flower model for interactive operation. As shown in Figure. 7(b), when the virtual hand is detected to collide with the model, the user performs a custom gesture b, selects different organs for pinch operation, the Figure shows that the user succeeds in pinching the petal model. We see from Figure. 7(c) that the user chooses a petal model and then controls the model to move in six directions in space by the custom gestures e. Repeat the selection, movement and other operations to the virtual rose model until the whole flower anatomy is completed, as shown in Figure. 7(d).



(a) (b)

(c) (d)

Figure. 7 Virtual flower anatomical interactive control. (a) Choose the flowers for anatomy. (b) Pinch the petals for anatomy. (c) Move the selected petals. (d) Final anatomical results.

5.3 Result and Discussion

The recognition rate of proposed method for 12 gestures is shown in Figure. 8. For example, Gesture-a mainly mistakenly identified as Gesture-f, which may be caused by the inherent similarities of trajectory. Some gestures recognition rate can achieve 100%, because we use both hands to define gestures. The research results show that the accuracy of gesture recognition algorithm is 97.3%, which can be used to control the virtual flowers quickly and naturally, using the somatosensory interaction control method and the optimization algorithm proposed in this paper.

All participants successfully completed the designated interactive tasks, the total interaction time of our system was 294s, with an average comprehensive error of 6.5%. The total interaction time of mouse/keyboard was 368s, with an average comprehensive error of 8.6%. From the Table 3, we know that our system performed better than the mouse/keyboard in task 3, task 4, and task 5. The mouse is slightly better than our system in the space rotation (task 1), which is due to the human physiologic constraints, and it still need to be done in fractionation for large-angle rotations. In other multi-degree-of-freedom tasks that only require a small angle adjustment gesture, the user can quickly and continuously adjust to the specified gesture and can switch back and forth between the interaction tool and model by using a gesture, thus greatly improving the interaction efficiency. In terms of precision, with the mouse being a discrete precise input device, three of the five tasks have a slightly higher precision than our system. However, the mouse is not suitable for manipulating the movement of objects in 3D space, so it is difficult for the user to quickly adjust to the specified posture when the degree of freedom of operation is increased to 9. After testers experienced our system, they were asked a question to evaluate whether the five somatosensory interaction-based tasks produced a high degree of fatigue. The results are more positive, the user experience of gesture-based interaction was great and surpassed tester's expectations.

As shown in Table 4, in the system interface and interactive gestures in the natural degree, the user satisfaction is higher, the average score of 9 scores or more, indicating that this system can be very friendly interoperability. And for the overall performance of the system and immersive experience, only a few tester give the general evaluation, most of the participants are satisfied with the system. For some of the tester with relevant knowledge, the highest given 9 scores. Relative to the real-time performance of interactive operations, because Leap Motion will be repeated recognition of human hand, affecting the real-time interaction, so there are individual users to give 6 scores, the final average score of only 7.5 scores, indicating that the system needs to continue to improve in real-time.

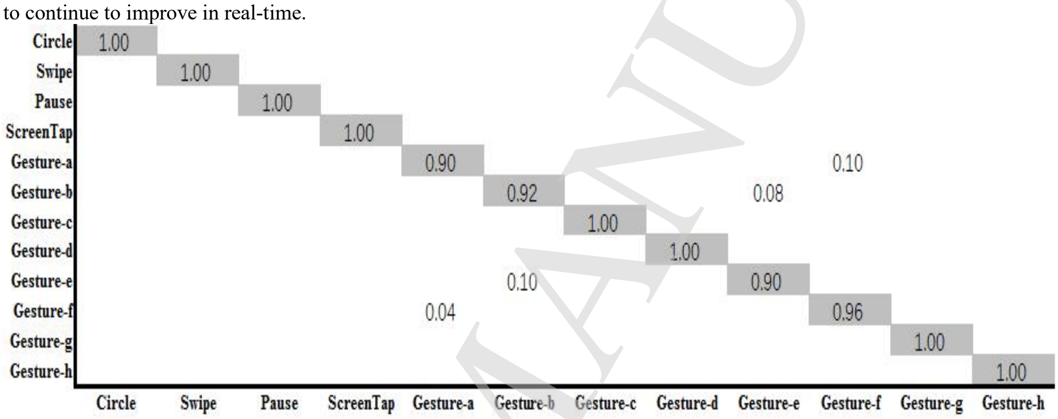


Figure. 8 The confusion matrix for gesture recognition test

Table 3 Result of manipulation accuracy and comfort test

Task	Tester	Input method	Time (s)	Comprehensive error
1	20	Mouse/Keyboard	71	0.01
		Leap Motion	93	0.05
2	20	Mouse/Keyboard	48	0.045
		Leap Motion	57	0.09
3	20	Mouse/Keyboard	93	0.285
		Leap Motion	62	0.12
4	20	Mouse/Keyboard	81	0.02
		Leap Motion	52	0.035
5	20	Mouse/Keyboard	75	0.11
		Leap Motion	30	0.025

Table 4 Subjective Evaluation results of user experience

Evaluation index	Tester	Lowest score	Highest score	Average score
System overall performance	20	7	9	8.2
Real-time performance of interactive operations	20	6	9	7.5

The sense of immersion and realism of the system	20	7	9	8.6
The natural degree of interactive gestures	20	8	10	9.2
The simplicity and aesthetics of the system interface	20	8	10	9.1

By comparing the test experience with the testers and the statistical analysis of the questionnaire, the following positive feedback and negative feedback are obtained. Positive feedback: (1) Testers on the overall performance of the system have a good evaluation, and consider that the interaction between flowers and plants is basically realized. (2) Testers can quickly learn the hand gestures defined in this paper and complete the interactive operation tasks. Most of the testers believe that interactive gestures are simple and consistent with daily usage habits. (3) Most of the testers consider that the interface is simple and beautiful, which has a good sense of immersion and realism experience, and the system can provide real-time feedback to users. Negative feedback: (1) Some users suggested that the specific details of flowers and plants are not rich enough, and lack of voice prompt and explanation. (2) The relevant professional testers proposed that the feedback motion simulation of the plant after the model operation was not realistic enough. (3) Some testers think that the lack of interactive interaction between hands reduces the experience effect. We also found that men tend to accomplish interaction tasks more easily and quickly than women, probably because most men are more adaptable to 3D space.

6 Conclusions

This article designs and implements a visualization interactive system of flowers and plants based on somatosensory interaction, which developed for the purpose of giving users a simple and natural method for visualizing a flower model. To demonstrate the system the Oculus Rift and LMC provided an interface to the virtual world. This study present a feasible solution that to tackle the problem of finger penetration in virtual flower interaction process, which including the details of virtual hand position mapping, object collision detection, and finger position optimization. Then, we propose a finger gesture-based method to recognize the custom gestures, which utilized a PSO algorithm to optimize the trajectory of fingertips and joints. The system has two specific capabilities: (1) the ability to describe detail information of flower plants in 3D space for forestry visualization; (2) the ability to support the structural function analysis of plants and use of somatosensory interaction-based operation instructions improve the researchers for manipulating plants interaction process. The example scenarios presented in this study demonstrate the implementation feasibility of the proposed system in the virtual plant visualization. A major limitation of the proposed system is the lack of the physical feedback of flowers and plants during interaction process. The physical feedback would be very helpful in flowers and plants visualization to improve the user realistic experience.

We plan to further improve the proposed system in several directions. First, it would be useful to increasing physical feedback simulation in the process of interaction. Second, there is a need to increase the diversity of gestures and to define more instructions, and improve the accuracy of gesture recognition by developing the recognition of combined or two-hand gesture. Also it would be valuable to extend the system to different platform.

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Long Liu is currently working toward the Ph.D. degree in the School of Information Science and Technology of the University of Beijing Forestry University, Beijing, China. His research interests are in forestry virtual reality technology, virtual reality and virtual landscape and somatosensory interaction technology.

Yongjian Huai received his Ph.D. degree from Northwestern Polytechnical University of School of Electronics and Information, Xi'an, China, in 2002. He is now a Professor with Department of Digital Media, School of Information Science and Technology, Beijing Forestry University, Beijing, China. His research interests are in virtual reality and virtual landscape, data visualization, virtual reality technology and somatosensory interaction technology. He has published more than 8 papers in international journals and conferences.