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Exploring Digital Art Design Methods Based on Virtual Reality Technology and Their Application in Interactive Experiences

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Abstract Digital media art design is an important development direction in the field of contemporary art creation. By leveraging digital technologies, it has achieved the digitization, intelligence, and interactivity of artistic creation. This study combines virtual reality (VR) technology with digital media art design to construct a VR-based digital media art design system. It introduces an improved gesture interaction recognition method using Leap Motion to implement interactive functions within virtual scenes. A gesture library for landscape interaction was designed, achieving an average gesture recognition accuracy rate of 97.93%, outperforming the gesture recognition method built into Leap Motion in terms of recognition speed and accuracy. In experiments on digital art design for gardens, the user experience was satisfactory, enabling users to select plants and construct garden landscapes using gesture interaction within virtual scenes. The gesture set generated by the system designed in this study is intuitive, easy to execute, and memorable, effectively completing design tasks and contributing to improving the interaction methods and user experience in landscape layout design.

Index Terms virtual reality technology; Leap Motion; gesture interaction recognition; digital art design

I. Introduction

In the era of rapid technological advancement, new forms of artistic expression have entered a phase of diversified development, showcasing their comprehensive, interactive, and dynamic visual characteristics [1], [2]. Technological empowerment not only extends the temporal and spatial boundaries of traditional art but also transforms cultural memory into a contemporary language that can be perceived and participated in through emotional interaction and cross-disciplinary technological collaboration [3]-[5]. As science and technology continue to advance, artistic expression has become increasingly diverse, with ever-richer forms of presentation [6]. Among these, virtual reality technology, as a cutting-edge scientific achievement, has shown remarkable development potential when integrated with digital media art design [7], [8]. The characteristics of virtual reality technology, such as 3D spatial perception, dynamic environmental simulation, and multi-sensory stimulation, provide digital media art designers with a broader creative platform [9]-[11]. Through this technology, they can transform their imaginative ideas into immersive artistic experiences, meeting the modern audience's demand for novel, unique, and deeply engaging artistic works, thereby exploring a new path for the high-quality development of digital media art design and reshaping the interactive relationship between art and the audience [12]-[15].

In previous media art design, designers were often constrained by factors such as time and space, making it difficult to realize bold creative ideas [16]-[18]. By integrating virtual reality technology with digital media art design, designers can freely express their imaginative ideas and optimize and adjust digital media art design content through intuitive and clear presentation forms [19]-[22]. Compared to traditional media art design scene construction, the application of virtual reality technology is simpler. Designers only need to use computers and related equipment to create immersive, multi-dimensional interactive experiences [23]-[25]. Therefore, it is necessary to analyze the application value and characteristics of virtual reality technology in digital media art design and propose specific innovative application strategies.

This paper is based on VR technology. Through an introduction to VR technology and digital media art design, a digital media art design system with relatively good performance and comprehensive functionality is designed. This system consists of two major modules: software and hardware. Subsequently, the Leap Motion method is introduced for the development of an interactive immersive system. Addressing the issue of unstable recognition in the edge areas and finger-obscured regions of Leap Motion gesture recognition, a hierarchical correction method for Leap Motion gesture interaction is proposed. This method analyzes Leap Motion recognition errors through real-time threshold comparison and employs a hierarchical correction algorithm to correct hand position, thereby addressing recognition instability during human-hand interaction. Finally, we sequentially design gesture interaction experiments, digital media art design system simulation experiments, and landscape digital art design experiments to explore the digital art interaction experience effects under the proposed method.

II. VR-based digital art design experience

II. A. Digital Media Art Design

II. A. 1) Digital Media

In the context of the information age, many new forms of media have gradually emerged, with digital media being one of the more common types. Digital media refers to the effective integration of various digital technologies into the design of media content, based on cultural and artistic design methods, to better promote and disseminate relevant content. In the modern internet field, with the rapid development of information technology, digital media has become more mature and sophisticated. Under the impetus of digital media, it has provided strong support for the development of other fields.

II. A. 2) Digital Media Art Design

As people's living standards continue to improve, there is an increasing demand for higher standards in artistic forms. To design artworks that align with modern tastes, it is essential to enhance the application of digital media art design. This involves using digital technology as the core, media communication technology as the primary means, and tailoring designs to specific artistic objectives. Such approaches not only enhance the abstract nature of artworks but also endow them with virtuality, interactivity, and integration, thereby improving their aesthetic appeal and providing viewers with a more enjoyable visual experience.

II. B. Digital Art Design System Based on VR Technology

II. B. 1) Overall Design

When virtual reality technology is in operation, it uses a computer to simulate an environment and transmits the simulated information to terminal devices to display the simulated environment, thereby constructing a specific three-dimensional virtual world for users. Users can not only hear sounds in the environment and observe its specific conditions but also experience a relatively realistic sense of touch, immersing themselves in the virtual environment. This paper utilizes VR technology as its core to design a digital media art design system, providing support for digital media art design. In this system, the core processor uses the TMS320C6657 chip for data computation and analysis, providing support for the construction of virtual scenes. In terms of circuit design, corresponding DSP circuits are designed based on the different functions of each component to drive the operation of individual components and the entire system. Considering the characteristics of VR technology and the specific circumstances of the existing digital media art design system, appropriate optimizations are made to each component to enhance the system's overall capabilities. Additionally, to control the system's operation, a corresponding software system must be designed. During software development, the MapInfo platform was selected to achieve better visual effects for artistic design works. Specifically, its overall structure is shown in Figure 1.

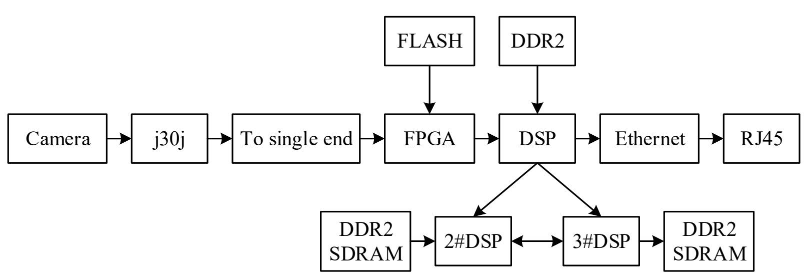


Figure 1: Digital media arts design system based on VR technology

II. B. 2) Hardware Design

In terms of memory, a pyramid-shaped structure is used, meaning that the lower layers of memory have a larger capacity than the upper layers. The entire memory module consists of four layers:

(1) The top layer is on-chip SRAM, which is the slowest but has the highest capacity.

(2) The second layer is off-chip DRAM, which has a slightly higher storage rate than the top layer and a larger capacity.

(3) The third layer is Flash memory, which is the slowest in terms of speed but has the highest capacity within the module.

(4) The bottom layer is web-based distributed storage, i.e., remote storage, used to store remote data information.

Within the SRAM inside the module, there is a cache function, while the DRAM outside the module has a block RAM function. For Flash memory, it serves as a program bootloader, capable of transmitting the actual image data collected by the sensor to the upper-level storage module for storage.

II. B. 3) Software Design

(1) Image Plug-in

Used to draw various virtual images. This plug-in was developed using the MapInfo platform and includes specific OpenCV library functions within its functional controls to enable the drawing of virtual images.

(2) Video Plugin

During system operation, data or video information is collected via on-site installed cameras. Subsequently, the corresponding video plugin processes this data. First, leveraging VR technology, the image information is comprehensively searched. Based on the search results, the system retrieves video sources stored internally and constructs the corresponding CvCapture object, specifically reading frame information from video files.

(3) Sound Plugin

Sound data collection is primarily implemented by BASS. The principle behind this functionality is as follows: in the sound section, the BassLoader control is used as the primary tool to transmit sound into the system, with input parameters as the main path for collecting audio data from the collected information; output parameters are used as handles to display normalized floating-point numbers.

II. C. Gesture interaction recognition based on Leap Motion

Whether it is body movements, gestures, eye movements, voice commands, or other forms of interaction, motion sensors are required as a medium for human-computer interaction. For example, Leap Motion sensors can be used for gesture interaction, eye trackers can be used to capture eye movement and gaze focus information, and Kinect can be used to obtain body movement information [26]. From a technical perspective, motion capture essentially involves measuring, tracking, and recording the movement trajectory of an object in three-dimensional space.

II. C. 1) Basic Principles of Leap Motion

Leap Motion is a motion controller released by Leap, a motion controller manufacturer, in 2013 for PCs and Apple Mac computers. The Leap Motion controller mainly consists of two high-definition cameras, optical sensors, and three infrared LED lights. Leap Motion employs binocular vision principles to accurately measure hand distance. By capturing images from different angles using its built-in cameras, it simulates human stereoscopic vision to determine the positional information of gestures in three-dimensional space. Leap Motion tracks hand movements at over 200 frames per second. Its detection range spans a inverted tetrahedron-shaped area from 25 millimeters to 600 millimeters above the sensor, with precision reaching up to 1/100 millimeter.

II. C. 2) Leap Motion Basic Data

Leap Motion uses a recognition technology based on computer vision principles, and the measurement method applied to stereoscopic vision is called triangulation. It has a wide range of applications, from small devices such as Kinect to high-precision work environments such as aircraft assembly. Currently, the most representative application is Leap Motion's gesture recognition technology, which is also used in Microsoft's mixed reality head-mounted display, HoloLens. Leap Motion's API provides developers with a series of snapshot data points tracking hand movements. In the official documentation, these regularly sent updates about hand movements are referred to as “frames.” Each frame contains a series of basic binding data from Leap Motion, including lists and information about all detected palms, all fingers, all tools (defined as long, straight objects longer than fingers, such as a pen), and all targetable objects—i.e., lists and information about all fingers, tools, and gestures. A diagram illustrating the data hierarchy contained within the frame data is shown in Figure 2.

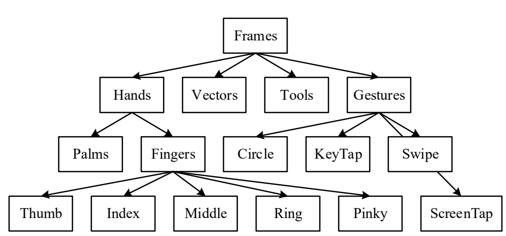


Figure 2: The data hierarchy contained in frame data

II. C. 3) Leap Motion Gesture Recognition Method

Whether used in exhibition halls or as an auxiliary teaching tool in classrooms, the system's interactive methods must employ innovative approaches to capture the attention of visitors or students. Additionally, the displayed content should be closely aligned with real-life scenarios and easily understood by the majority of users, regardless of whether the content is intended for educational or aesthetic purposes. Therefore, this system primarily focuses on showcasing a “flower sea,” allowing users to customize gestures to control the growth and display of flowers, thereby highlighting the diverse characteristics of the flower sea. In terms of innovation, the system chooses to present flowers in a digital media format, making them more abstract and tech-savvy. This approach not only meets the need for eye-catching exhibitions but can also be used in daily commercial exhibitions and other activities to enhance user engagement. The core interactive functions of the system design are shown in Figure 3.

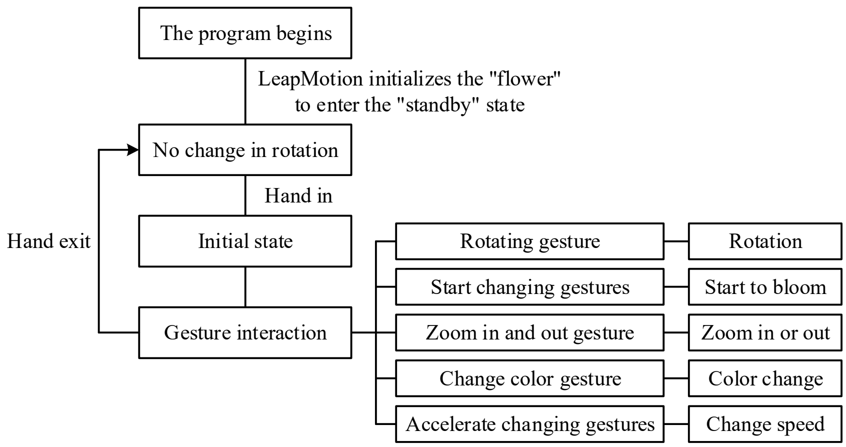


Figure 3: Core interaction

During the process of calculating hand gesture positions using LeapMotion devices, multiple mathematical formulas and technical descriptions are required. These formulas involve fields such as computer vision, coordinate transformation, and geometric calculations. LeapMotion uses dual cameras to capture hand positions, so it is necessary to transform points from the camera coordinate system to the world coordinate system.

Points in the camera coordinate system (x_c, y_c, z_c) can be transformed into points in the world coordinate system (x_w, y_w, z_w) using the camera's projection matrix P, as shown in Formula (1):

$$\begin{pmatrix} x_w \\ y_w \\ z_w \\ 1 \end{pmatrix} = P \begin{pmatrix} x_c \\ y_c \\ z_c \\ 1 \end{pmatrix} \tag{1}$$

The projection matrix P can usually be expressed as formula (2):

$$P = K[R \mid t] \tag{2}$$

In equation (2), K is the camera's intrinsic matrix, R is the rotation matrix, and t is the translation vector.

LeapMotion uses stereoscopic vision technology to determine depth information through the parallax of two cameras. Assuming that the optical axes of the two cameras are parallel and the baseline distance between the cameras is B, the depth z can be calculated for the corresponding points (x_L, y_L) and (x_R, y_R) of the left and right cameras, as shown in Formula (3):

$$z = \frac{f \cdot B}{x_L - x_R} \tag{3}$$

In formula (3), f is the focal length of the camera, and $x_L - x_R$ is the horizontal disparity between corresponding points on the two cameras. The depth value z calculated from the disparity can be used to convert the point (x, y) on the camera plane to the point (X, Y, Z) in three-dimensional space to achieve three-dimensional reconstruction, as shown in formula (4):

$$X = \frac{x \cdot z}{f}, Y = \frac{y \cdot z}{f}, Z = z \tag{4}$$

In addition to position information and 3D reconstruction, LeapMotion can recognize finger posture and motion trajectories. Assuming the 3D position of the finger joint is $p_i = (x_i, y_i, z_i)$, the direction vector d_i of the finger skeleton can be expressed as formula (5):

$$d_i = p_{i+1} - p_i \tag{5}$$

To identify different gestures, the angle between the direction vectors of the finger bones can be calculated. Assuming that the angle θ between two vectors d_1 and d_2 is calculated using formula (6):

$$\cos\theta = \frac{d_1 \cdot d_2}{\| d_1 \| \| d_2 \|} \tag{6}$$

In equation (6), denotes the dot product, and $\| d \|$ denotes the magnitude of the vector.

In summary, the LeapMotion device captures hand positions using dual-camera stereoscopic vision technology. Points in the camera coordinate system are transformed to the world coordinate system via the camera's projection matrix, and then the depth values of the fingers are determined through parallax calculation and reconstructed as points in three-dimensional space. During hand pose recognition, the direction vectors of the skeleton are calculated using finger joint positions, and different gestures are identified based on the angle between the vectors. This series of mathematical calculations and algorithms provides the LeapMotion device with high-precision gesture recognition capabilities, significantly enhancing the user's interactive experience.

II. D.Gesture Hierarchical Correction Algorithm

II. D. 1) Manpower Structure Model

The human hand is a crucial medium for human-computer interaction. In gesture-based interaction systems, nearly all operations are performed through a virtual hand. Therefore, the structure of the hand model forms the foundation of human-hand interaction. The human hand consists of the wrist joint, finger joints, and phalanges between the joints. A normal human hand has five fingers, each of which is composed of a fingertip (Tip) and three finger joints. Based on their proximity to the wrist, the finger joints are classified into distal interphalangeal joints (DIP), proximal interphalangeal joints (PIP), and metacarpophalangeal joints (MCP) (the thumb has two finger joints and no distal interphalangeal joint). During continuous movement, the phalanges can be regarded as rigid bodies. The connection between the phalanges and finger joints follows the constraints of hinge motion, meaning they can rotate relative to each other but cannot move. The phalanges can rotate around the finger joints with angular restrictions, and the rotational state determines the posture of the fingers.

II. D. 2) Virtual hand position error judgment

Using LeapMotion, you can obtain the coordinates p_i of a specific finger joint in the 3D world for a given frame, as well as the positions p_{i-1}, p_{i+1} of the two adjacent joints of the same finger. (For the metacarpophalangeal joint, the adjacent joints are the palm position and the proximal interphalangeal joint position; for the distal interphalangeal joint, the adjacent joints are the proximal interphalangeal joint position and the fingertip position.) Let the proximal interphalangeal joint be p_1, then the schematic diagram is shown in Figure 4.

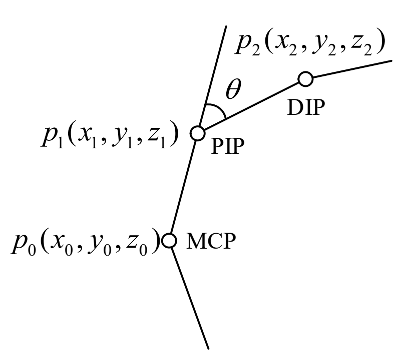


Figure 4: Knuckle model

This joint angle θ is:

$$\theta = \arccos \frac{p_1 p_0 \cdot p_1 p_2}{| p_1 p_0 \square p_1 p_2 |} \tag{7}$$

When hand gestures move to the edge of the LeapMotion recognition area or fingers obstruct each other, the stability of LeapMotion recognition decreases. This often manifests as drastic changes in virtual hand posture, i.e., drastic changes in finger joint angles. Therefore, before drawing each frame of the hand model, compare the angles of the finger joints in the previous frame to obtain the angle change of the finger joints θ_Δ, i.e.:

$$\theta_\Delta = \theta_i - \theta_{i-1} \tag{8}$$

Here, i represents the frame sequence.

If the joint movement angle $|\theta_\Delta|$ is greater than the joint movement threshold λ, it indicates that the hand posture has changed dramatically, which is considered an error in LeapMotion recognition. This joint is considered an error joint, and the system will correct the pose of this problem joint:

$$\begin{cases} \text{if } |\theta_\Delta| < \lambda, \text{Correct joint recognition} \\ \text{if } |\theta_\Delta| \geq \lambda, \text{Incorrect joint position} \end{cases} \tag{9}$$

Among these, the magnitude of the joint movement threshold λ affects the determination of problem joints in the system. If the joint movement threshold is too large, the system will have difficulty identifying LeapMotion recognition errors; if the threshold is too small, the system will produce misidentifications, affecting the system's operational efficiency.

II. D. 3) Virtual Hand Hierarchical Correction

When an error is detected in the LeapMotion recognition information, the system deletes the erroneous data from the current LeapMotion body sensor and performs position correction on the problematic joint. During gesture interaction, excluding LeapMotion recognition errors, the movement process of the gesture can be regarded as a uniform change from one hand posture to another. The movement of the hand posture should be natural and smooth, with the angles and directions of the finger joints not undergoing sudden changes. Therefore, when performing hand posture correction, the system uses the angle change θ of the problematic joint in the previous frame as the movement angle of the problematic finger joint in the current frame, and uses this to perform the next posture correction. That is, the incorrect posture is replaced with a corrected posture centered on the problematic joint, with the rotation angle of the lower joint being θ, thereby achieving virtual hand position correction.

Assuming that the position of the erroneous joint δ in the $i(i \geq 1)$ polar coordinate system is $p_\delta^i(x_n, y_n, z_n)$ and the position of the lower joint $\delta+1$ in the $i+1$ level coordinate system is $p_{delta+1}^{i+1}(x_{n+1}, y_{n+1}, z_{n+1})$ The rotation angle of the error joint is θ, and the rotation matrix $R(\theta)$ is obtained. Then, the position of the lower joint $\delta+1$ after rotation in the i th coordinate system is:

$$p_{\delta+1}^i = p_{\delta+1}^{i+1} * R(\theta) + p_\delta^i \tag{10}$$

When drawing virtual hand poses, it is necessary to obtain the world coordinates of the finger joints. Therefore, the $i(i \geq 1)$-level coordinates of the problem joint after rotation must be converted to world coordinates. If the problem joint is simultaneously the metacarpophalangeal joint, proximal interphalangeal joint, and distal interphalangeal joint, and their rotation angles are $\theta_{mcp}, \theta_{pip}, \theta_{dip}$, respectively, the rotation matrix can be derived. That is:

$$\begin{cases} R_{mcp} = R(\theta_{mcp}) \\ R_{pip} = R(\theta_{pip}) \\ R_{dip} = R(\theta_{dip}) \end{cases} \tag{11}$$

The adjusted world coordinates of the metacarpophalangeal joint are W'_{mcp}, the world coordinates of the proximal interphalangeal joint are W'_{pip}, the world coordinates of the distal interphalangeal joint are W'_{dip}, and the world coordinates of the fingertip are W'_{tip}. Then:

$$W'_{mcp} = p^0_{mcp} \tag{12}$$

$$W'_{pip} = p^1_{pip} \cdot R_{mcp} + p^0_{mcp} \tag{13}$$

$$W'_{dip} = (p^2_{dip} \cdot R_{pip} + p^1_{pip}) \cdot R_{mcp} + p^0_{mcp} \tag{14}$$

$$W'_{tip} = ((p^3_{tip} \cdot R_{dip} + p^2_{dip}) \cdot R_{pip} + p^1_{pip}) \cdot R_{mcp} + p^0_{mcp} \tag{15}$$

The world coordinates of each finger joint are calculated using a hierarchical correction method to drive the computer to draw a virtual hand.

II. D. 4) Calibration error analysis

While correcting joint posture, the system continues to calculate the problematic joint angle data identified by LeapMotion, subtracts the correction angle θ from the actual calculated angle θ', and obtains the correction error θ'_Δ, that is:

$$\theta'_\Delta = \theta - \theta' \tag{16}$$

The error analysis steps are as follows:

(1) Set the correction error threshold λ'. Compare the correction error θ'_Δ with the correction error threshold λ' to determine whether the correction was successful.

(2) If the correction error is less than the correction threshold, it is considered that LeapMotion has identified correctly, and the virtual hand is synchronized with the actual hand pose. The correction is stopped. Otherwise, the pose correction continues.

(3) If the correction data still cannot be synchronized with LeapMotion after 1 second, the system correction fails, and a correction failure message is displayed on the interface. The user is prompted to move their hand out of the recognition area and perform the human hand pose recognition operation again.

Therefore, the correction error threshold affects the correction effectiveness of problem joints in the system. If the threshold is too high, the virtual hand correction will differ significantly from the actual hand, rendering the hand pose correction ineffective; if the threshold is too low, the correction results are prone to failure, affecting the user experience.

III. Analysis of Interactive Experiences in Digital Art Design

III. A. Gesture Interaction Experiment Results and Analysis

This section conducts experiments on the aforementioned improved multi-feature fusion hierarchical gesture recognition algorithm. Ten participants were invited to perform the defined 10 gestures in sequence (Gesture 1: Browse, Gesture 2: Open Menu, Gesture 3: Close Menu, Gesture 4: Work Interaction, Gesture 5: Page Jump, Gesture 6: Rotate, Gesture 7: Switch, Gesture 8: Flip Forward, Gesture 9: Flip Backward, Gesture 10: Pause), with each gesture performed 20 times, resulting in 1,925 valid data samples, which were used to construct the gesture dataset GD. First, to obtain the third-layer feature similarity threshold E, 20 inputs from each gesture were randomly sampled, and their average distance was calculated. The gesture similarity results are shown in Figure 5, with the highest gesture similarity threshold being 77.

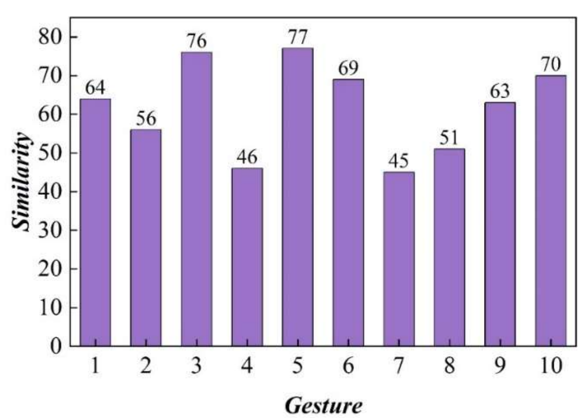


Figure 5: The result of the gesture similarity

In addition, we calculated the Euclidean distance distribution of the two types of gestures (known samples and interference gestures) during the recognition process as the number of samples increased. Figure 6 shows the line distribution of the Euclidean distance of the gestures. It can be seen that the lines do not intersect, further verifying that when the distance threshold E is set to 80, the two can be effectively distinguished.

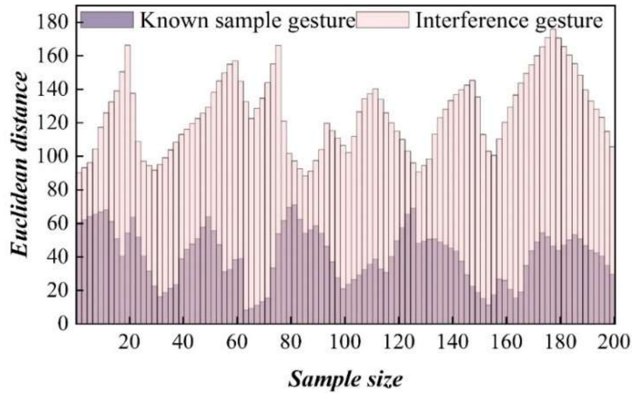


Figure 6: Broken line distribution of gesture Euclidean distance

Statistical calculations were performed on the acquired gesture data, and the gesture recognition results are shown in Table 1. As can be seen from the table above, the improved hierarchical gesture correction algorithm has a high recognition accuracy rate, with an average recognition rate of 97.93%. Gestures 9 and 10 are similar in overall shape but differ slightly in the degree of finger joint bending. The algorithm also performs well in recognizing such highly similar gestures.

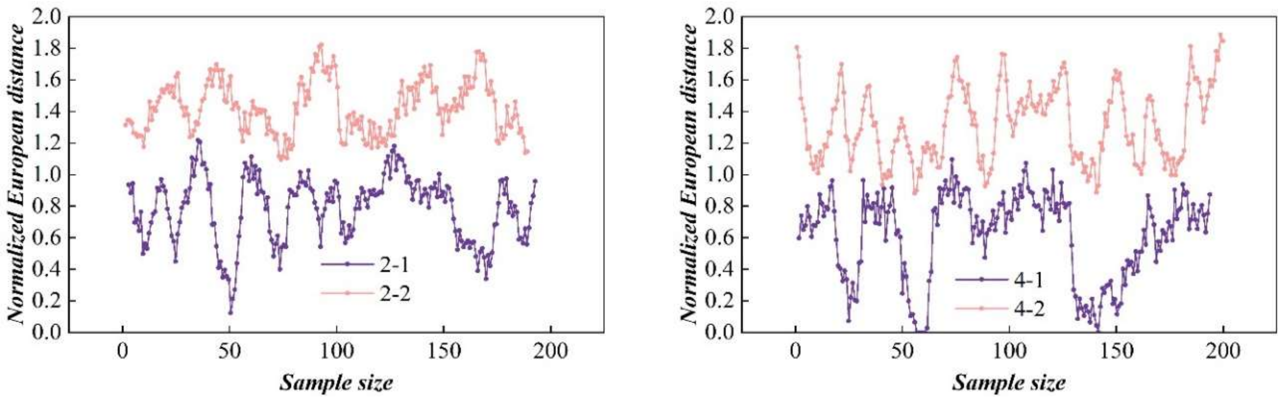
Table 1: Experimental results of gesture recognition

Gesture type	Effective sample size	Correct number of times	Recognition accuracy
Gesture 1	192	188	0.9792
Gesture 2	193	187	0.9689
Gesture 3	191	185	0.9686
Gesture 4	188	186	0.9894
Gesture 5	195	191	0.9795
Gesture 6	197	192	0.9746
Gesture 7	186	183	0.9839
Gesture 8	196	192	0.9796
Gesture 9	194	191	0.9845
Gesture 10	193	190	0.9845

The layered strategy distributes gesture features across different layers for matching, using whether the palm undergoes displacement changes as the first-layer identification criterion, thereby directly narrowing the scope of judgment for matching with template gestures. For example, if displacement changes occur, the first layer can restrict the target gesture to either Gesture 6 or Gesture 7, two dynamic gestures, eliminating the need to perform matching calculations on static gestures 1–5. Subsequently, the two are distinguished based on matching calculations in subsequent layers. The second layer counts the number of fingers, dividing the four static gestures with two or four fingers into two subcategories, each containing only two gestures. The layered strategy simplifies the multi-classification problem into a binary classification problem. Figure 7 shows the classification results for gestures with two or four fingers, with the Euclidean distance normalized using formula (17):

$$\| X,Y \|_{nor} = \frac{\| X,Y \| - \| X,Y \|_{\min}}{\| X,Y \|_{\max} - \| X,Y \|_{\min}} \tag{17}$$

Among them, $\| X,Y \|_{nor}$, $\| X,Y \|_{\max}$, $\| X,Y \|_{\min}$ represent the normalized value, maximum value, and minimum value of the Euclidean distance between the gesture to be measured and the template gesture, respectively.



(a) The number of fingers is 2 (b) The number of fingers is 4

Figure 7: The number of gestures is the normalized Euclidean distance of 2 and 4

To enhance the robustness of the gesture dataset, 10 participants performed 20 undefined gestures. The final dataset GD comprises 1,953 sample data points. Figure 8 shows the confusion matrix of the improved gesture recognition algorithm after hierarchical correction. The coordinates on the axis represent, in order from 1 to 10: roaming, opening the menu, closing the menu, interact with the work, page jump, rotate, switch, flip forward, flip backward, and pause. The value 0 represents the interference gesture category. The horizontal axis indicates the predicted category of the input gesture, while the vertical axis indicates the true category of the gesture. Each value indicates the probability that the input gesture of category n is predicted as the template gesture of category m. The values on the diagonal represent the probability of correct recognition. All gesture recognition accuracies exceed 92%.

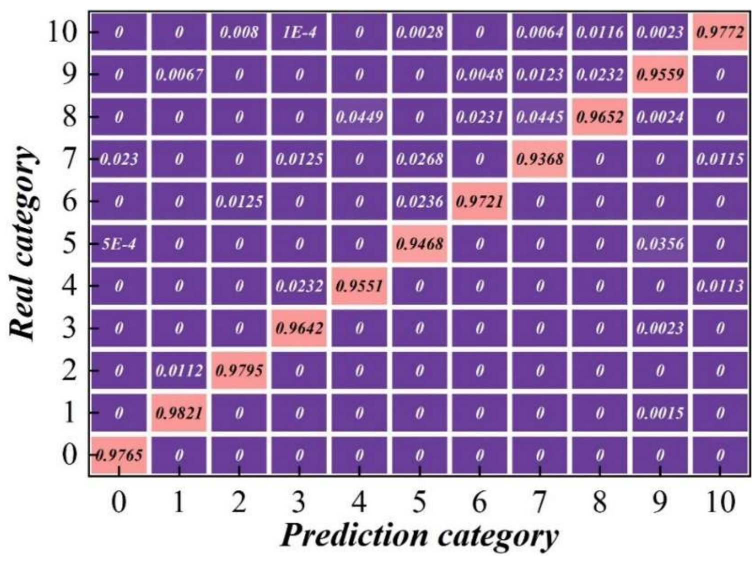


Figure 8: The confusion matrix identified after the gesture stratification correction

In addition, experiments have shown that the method described in this paper has a good fault tolerance rate. Even when the palm orientation and finger bending degree differ from the template gesture within a certain range, correct recognition is still possible. The palm orientation can deviate up to 16 degrees above or below the template gesture, and the finger bending degree can deviate up to 1.1 degrees above or below the template gesture.

III. B. Simulation of a VR-based digital art design system

III. B. 1) Experimental Environment

To make the experiment illustrative, a numerical comparison method was used to compare the computational time of the traditional digital media art design system with that of the system described in this paper. Various measurement instruments were used in the experiment to obtain a wealth of experimental data, providing a reference basis for subsequent work. The core of the digital media art design system based on virtual reality technology is the TMS320C6657 processor. The TMS320C6657 processor primarily handles the reception of image data and the aggregation of computational results. Upon receiving an image, the DSP controller transmits it to DSP 2 and DSP 3, where it is split and then uploaded to the corresponding locations. Based on the aforementioned test environment setup, an image plugin was used to continuously send 10 or more image data sets. Through data interface transfer, the test results were uploaded to the system.

III. B. 2) Experimental Results and Analysis

Experimental tests were conducted to measure the computational time required by the two systems for digital media art design during the debugging process. The test results are shown in Table 2. The test results indicate that the system described in this paper runs faster, performs target detection tasks correctly, and can be completed stably, meeting the system's high-performance requirements. In contrast, when using the traditional digital media art design system to detect targets, four errors occurred (Image-1, Image-5, Image-7, and Image-9), and the process took longer.

Table 2: System runtime comparison

Number	Data size/B	Target number	Traditional system		This system	
			Time	Results	Time	Results
Image-1	512×300	10	14.225	Inaccuracy	11.233	Accuracy
Image-2	512×300	3	2.225	Accuracy	1.185	Accuracy
Image-3	512×300	8	8.585	Accuracy	6.439	Accuracy
Image-4	512×300	10	10.456	Accuracy	8.821	Accuracy
Image-5	512×300	3	3.512	Inaccuracy	1.785	Accuracy
Image-6	512×300	5	5.589	Accuracy	2.246	Accuracy
Image-7	512×300	5	11.288	Inaccuracy	9.455	Accuracy
Image-8	512×300	7	10.585	Accuracy	8.763	Accuracy
Image-9	512×300	5	7.228	Inaccuracy	5.215	Accuracy
Image-10	512×300	3	3.678	Accuracy	1.221	Accuracy

III. C. User Experience Test Results

To evaluate the system's interaction efficiency and usability, this study designed a user trial for landscape architecture digital art design. Participants were required to complete plant layout tasks using five different plant layout patterns, with plant types including coniferous trees, deciduous trees, and various other plant models of different sizes. This task can be used to validate individual features as well as assess the entire workflow of environmental creation. A total of 20 participants (aged 20–22) were invited to experience the system and provide feedback, including five landscape architecture students. Among the participants, four had prior experience with virtual reality, while the remaining 16 had no prior experience.

Participants completed the plant design task in the specified scene using either a mouse or Oculus Quest gestures. The time required to complete the task was recorded and compared. The time required for users to complete the experiment is shown in Figure 9. Participants were also asked to complete a corresponding questionnaire after the task to assess their satisfaction with the system compared to traditional keyboard and mouse systems, as shown in Table 3.

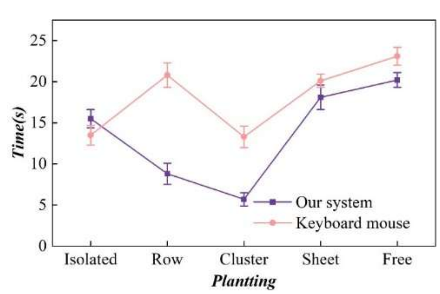


Figure 9: The user needs time to complete the experiment

Table 3: User satisfaction survey: our system vs. keyboard & mouse

Indicator	Our system				Keyboard & mouse			
	Satisfied (0)	Somewhat Satisfied (1)	Somewhat Dissatisfied (2)	Dissatisfied (3)	(0)	(1)	(2)	(3)
Comfort	2	15	3	0	3	17	0	0
Immersion	19	1	0	0	2	5	13	0
Ease of use	18	0	2	0	15	5	0	0
Intuitiveness	18	1	1	0	16	2	2	0
Learning curve	17	1	2	0	16	1	3	0
Operation Variety	19	0	1	0	16	2	2	0
Response Time	18	1	1	0	15	1	4	0
Layout Accuracy	17	2	1	0	13	3	4	0

Through comparative experiments, this system requires slightly more layout time than keyboard and mouse operations in the solitary planting mode, but is faster than keyboard and mouse operations in the row planting, cluster planting, patch planting, and free layout modes. The average time required to complete design tasks using this system is 511 seconds, while the average time required using a mouse and keyboard is 588 seconds. In terms of actual user experience, a small number of participants reported feeling uncomfortable and experiencing dizziness, and also mentioned minor delays in trajectory recognition. Most participants believed that designing plants in this system's environment was more immersive and intuitive compared to keyboard and mouse operations, allowing them to think while designing. All participants successfully completed the interaction tasks. Compared to traditional mouse and keyboard operations, the system designed in this study can more efficiently complete tasks in virtual landscape layout and provides a more immersive and intuitive interaction experience.

IV. Conclusion

A digital media art design system based on virtual reality technology is the result of the cross-disciplinary integration of virtual reality technology and digital media art, representing a new direction for the development of the digital creative industry. This system enables gesture recognition based on Leap Motion for interactive experiences in digital media art design. The study analyzed the causes of virtual hand movement errors and low gesture recognition accuracy during gesture interaction using Leap Motion, and proposed a hierarchical hand posture correction method to address recognition challenges caused by occlusion and poor edge detection capabilities in the optimal recognition area. Experimental results indicate that the proposed method effectively enhances the user's interactive experience when using Leap Motion-based gestures. Landscape architecture art design experiments indicate that completing design tasks using this system takes less time on average. In terms of actual experience, only a small number of participants reported feeling uncomfortable or experiencing dizziness, and also mentioned minor delays in trajectory recognition. Most participants believed that plant design in this system environment is more immersive and intuitive compared to keyboard and mouse operations, allowing them to design and think simultaneously. All participants successfully completed the interactive tasks.

Overall, Leap Motion technology and its related applications have opened up new prospects for digital art design exhibitions and hold vast potential for development. With the continuous advancement of technology and deeper application, digital art design exhibitions will undoubtedly usher in a brighter future, making greater contributions to the preservation and dissemination of cultural heritage.

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