Research on the interaction design of VR plant installation under the perspective of embodiment

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ABSTRACT

Based on the theory of embodied interaction and multi-modal sensory design, this study constructs an immersive plant experience model integrating virtual reality technology, and explores the effect of the integration of multiple senses, such as visual, tactile, and olfactory, on the enhancement of user immersion and participation. By integrating software and hardware technologies, an interaction scene containing dynamic rendering, wind sensation simulation and odor feedback is designed, and the effectiveness of the model is verified through user experiments. The experimental results show that the multi-modal interaction design significantly enhances the user's immersion and emotional connection, and provides a new direction for the application of virtual reality in cultural, ecological and educational fields. The study also analyzes the current technical limitations of multi-modal design and proposes future optimization solutions and application expansion possibilities.Place your ‘full paper’ abstract here. You do not need to have this in an ‘extended abstract’ or other paper formats.

Keywords

embodied interaction, virtual reality, multi-modal design, immersive experience, sensory extension

INTRODUCTION

In recent years, with the rapid development of Virtual Reality (VR) technology, its application in multiple fields has been expanding, especially in interaction design and immersive experience shows great potential. Virtual Reality enables users to immerse themselves in perceptually rich digital environments by simulating real-life scenarios

and creating interactive virtual spaces. However, most current VR designs rely too much on visual effects and the multi-modal integration of other senses is still insufficient, which limits the comprehensiveness and deep extension of immersive experiences.

Embodied Interaction Theory provides an innovative design approach that emphasizes the central role of body perception and movement in the user experience. By combining physical behavior with virtual scene interaction, Embodied Interaction can significantly enhance users' perception and emotional connection to the virtual environment[1]. In recent years, this theory has received extensive attention in the field of immersive design, providing theoretical support for enhancing multi-modal sensory experience in virtual environments. The virtual design of interaction scenes related to ecology and environment is of great social significance. By simulating the natural environment, virtual reality can help users understand nature more deeply and stimulate their awareness of environmental protection[2]. However, at present, the design of most virtual nature scenes still remains in shallow visual presentation, lacking multi-sensory and multi-modal interaction design methods, which makes it difficult to realize the deep emotional connection between users and virtual nature[3].

Based on the above background, this study aims to explore the potential application of virtual reality technology in natural thematic interaction from an embodied perspective through multi-modal interaction design[4]. This study not only supports the theoretical development of virtual reality interaction design, but also opens up new practical paths to enhance users' immersive experience and emotional resonance.

LITERATURE REVIEW

Embodied interactions

As the technology of virtual reality (VR) becomes popularized and developed, the boundaries between the real world and that virtual confusion are already blurred beyond clarity. Users 'demand for virtual experiences is increasing. Traditional methods of virtual experience can no longer meet the demands of users.In this context, the idea of "Embodied Interaction" is getting more and more attention[5].

"Embodied Interaction" means the process in which the user interacts with a computer system through body movements. It emphasizes the direct link between user body and interaction system; with user's body seen as part of interaction to improve user experience and interaction effect. Embodied Interaction typically consists of technologies such as body perception, motion recognition, gesture interaction, among others, that enable users to interact in a more natural and intuitive way[6]. Presented like this, the interaction process is more cheerful and natural. In virtual reality and augmented reality, the methods of embodied interaction are popular because technique can condition users in this way to be both absorbed in and active participants as they are drawn through three-dimensional experience[7].

In Merleau-Ponty's Phenomenology of Perception, life is put primarily in terms of bodily sensations and movement. He says the process of perceiving is inseparable from one's own body – and from the world outside it[8]. This has planted seeds for the philosophy of embodied interaction to grow. In the practice of embodied interaction, users can interact with virtual environments or devices by means of body perception, motion recognition, and gesture interaction. Such interaction goes beyond the

traditional way of operation, gives a subtler link between person and material object: interaction experience becomes more natural and at the same time more engrossing. When applied to virtual reality (VR) and related fields, embodied interaction can greatly enhance the user's sense of being drawn into the action. Through gesture control, Motion feedback and haptic simulation people can interact with the virtual world more like they did with reality[9].

Virtual Reality (VR) and Multi-Sensory Experiences

Virtual reality technology uses multi-sensory experiences, such as simulations of vision (pictures), hearing (sounds) and touch (force feedback), to create an all-around sensory input for the user.Examples include It’s got everything: sight, sound, touch. It's core features includes multi-sensory, immersion, interactivity and autonomy.Multi-sensory perception makes it possible for users to gain comprehensive knowledge of the virtual environment by combining various sensory cues; immersion allows users to disregard the outside world and become fully integrated into a virtual space being presented on their high-definition monitors; interactivity refers to interactions in real-time between users and virtual environments (for instance controlling virtual objects with joysticks or gestural devices); and autonomy means that users get personalized experiences as well as physical independence[10].There is still room for the improvement of the sensory feedback in VR. For example, the sense of touch -- essential to any truly immersive simulation was not at all studied. The new project is aimed at researching this subject thoroughly and making it possible for people to come into direct contact with things as they 'feel'[11].For example, even after years of trying to make it work, smell and taste simulators have not yet reached maturity; haptic devices such as gloves or body suits do not address the sense of texture on a surface well enough[12]. The researcher dealt with these unsatisfactory points by means of odor generators and high-precision haptic feedback devices, while environmental simulation devices such as fans and heaters were employed in order to heighten the realism and immersion experienced by users of a given virtual scene[13].

The Practice of Embodied Interaction in VR

The application of embodied interaction in VR is mainly reflected in the following aspects:

technical application	Functional Description
Body perception and motion tracking	Capturing the user's head, hand, and body gestures through VR devices allows the user to achieve behaviors in the virtual environment that are consistent with the real environment. For example, users can manipulate virtual objects or trigger events through gestures.
haptic feedback	Utilizes a vibrating handle or haptic glove to simulate the user's sense of contact with a virtual object, providing

	realistic haptic feedback such as the texture, weight and softness of the object.
environmental simulation	The user's immersion is further enhanced by fans, heat sources and vibration equipment that simulate the wind, temperature and ground texture of a natural environment.
Emotions and interactions	In VR, embodied interaction strengthens the user's emotional connection with a virtual character or environment. For example, by experiencing the process of plant growth or the sensation of interacting with nature through motion simulation, users are able to build deep emotional resonance.

The major VR titles currently on the market include Nostos (Homeland), Monkey King Hero is Back VR, Resident Evil 4 VR, Beat Saber VR and FRAME-Lab(figure 1). These titles undoubtedly provide users with a sense of immersion through strong auditory and visual impacts, and users can gain corresponding dominance over the control of their grips to perform flexible operations. However, there is always a big difference between the behavior of the avatar and the actual behavior of the user. Users can only use their eyes, ears and fingers to experience the game, while their sense of touch, smell and other parts of the body are ignored, so the user is not participating in the game as a full human being, and his or her physical senses and experiential environment are restricted[14]. Nostos is a VR multiplayer online open world game developed by NetEase that allows users to freely explore and survive in an open world with an oriental animated movie style. This game has a dynamic weather system with delicate feedback and a fresh and healing painting style, allowing users to experience a relatively realistic environment. However, in order to prevent dizziness, in the design of the VR camera, Nostos adopts a headset to control the facing direction, and the direction of the buttons to determine the direction of the panning direction, and users control the character's panning or smoothing by manipulating the buttons on the VR joystick in which they can run the map, excavate relics, do quests, and explore treasure. Monkey King Hero is Back VR, on the other hand, tends to allow users to follow the adventures of the Monkey King Hero from a spectator's point of view, incorporating animations of traditional cultural elements to attract users, with the Monkey King Hero resembling the role of a tour guide, leading users around the VR world. Resident Evil 4 VR changes the most basic logic of combat and interaction to a somatosensory style suitable for VR, with two modes of full-motion movement and teleportation movement, and changes the user's perspective to a first view in order to observe the surrounding environment as well as cranking the joystick for somatosensory operations, making the experience more realistic. Beat Saber VR" is a rhythmic beat class music VR game, the user along with the music rhythm waving the hand of the red and blue lightsaber chopping or dodging the oncoming cubes, although it is still the use of the handle to play the game, but chopping and dodging the interactive mechanism cleverly allows the user to dance all over the body, the body's degree of utilization and extension compared to the previous examples of the game are higher. FRAME-Lab, on the other hand, breaks away from the user's reliance

on a controller and provides a new way for the user to interact with the virtual reality environment. The traditional controller is replaced by a physical frame that allows the user to explore a variety of worlds and features. Users can creatively use their bodies to interact naturally through the window frames, either by maintaining the balance of the frame, drilling their heads into the frame, or fanning and striking with the frame.

At least half of the works exemplified above modeled plants in VR environments; however, the plants are mainly present in the user's experience in the form of environmental backgrounds, which are visible everywhere but do not participate in the main interactions; the plants are objectified within these VR works, and the users rarely feel their own resonance with the plants and usually tend to treat the plants as static objects with no feedback ability, instead of being treated as equals. rather than as equal and worthwhile beings to be learned from. Works that use plants as subjects of interaction are emerging, such as We Live in an Ocean of Air, a groundbreaking multi-sensory virtual reality installation by Marshmallow Laser Feast, which explores the invisible connection between plants and humans through breath, allowing the viewer to interact with the entire ecosystem around the Giant Sequoia Tree, the largest living organism on the planet. the largest living individual organism on Earth.

Nostos | Monkey King Hero is Back | Resident Evil 4 VR | Beat Saber VR | Beat Saber VR

Figure 1: Current main VR games

In short, with the fuselage of interactive VR, users can interact with virtual scenes more quickly and naturally.Because it can perceive user 's physical movements and stance, users in the virtual environment can move freely and observe their surroundings from different angles or directions without really even thinking about itIn the virtual environment thus virtually experiencing scenes and events vicariously as if one were present on the scene oneself, rather than simply viewing through some electronic box such as television screen or monitor.This direct physical participation not only increases the user 's sense of immersion, but makes his connection between him and virtual world more immediate and his feeling participation in it more intense.

RESEARCH METHODS

Research framework

Building on the theories proposed by embodied interactions and multi-modal designs, this paper's research is directed at creating new kinds of virtual reality (VR) plant devices--interaction models which adjust to touch, sight and smell in different ways. The research framework tries to increase users' immersion feeling and their emotional resonance with the work through multi-modal interaction design. First, the interaction goals of the virtual natural scene are clarified through user demand analysis: what users expect from visual reality, how they should feel a plant, and what kind of smell it emits. Second, Speed Tree is employed to fine model the plants, while Unity is used to animate evolving plant ecology besides create scenes in which these plants reside. Third, the Arduino platform and odor-generating device are integrated. Finally, we test for user feedback to optimize design results and iterate the mode of

interaction through testing; only in this way can we bring our design into line with the wishes of its users.

Experimental design

The research's experimental part has two key activities: Construct virtual scenes and achieve interactive functions. In virtual scene construction, the Unity engine will be used to establish a dynamic plant growth scene; and the SpeedTree tool can be utilized for creating a natural tree and an entire set of shrubs, which imitates true natural light and shadow as well as landscape seasonal changes so as to enhance the realism with environment ambiance. With regard to interactive features, holistic tactile interaction is achieved through a hardware that uses Arduinos; it blasts people with an artificial Allium odor and at the same time sends vibrations on the hand as one would receive if they were touching an actual plant In addition, the design solution brings in motion capture technology so that users can control virtual plants using their natural body language, for example pressing on leaves or causing a composition to grow plants, embodying the essence of interaction.

Experimental design also pays particular attention to the dynamic feedback of interactive behavior. For example, when touching a plant: the tactile device will thus simulate the feel and flexibility of the plant surface; when close to some specific plants: the odor device takes your ride gear for all of them; and when the user is near a particular potherb, aroma that only such greenery puts out but it cannot possibly replicate, all of these helps create a stronger bond between them there. A breed of multi-modal integration design, it provides the technical basis for studies which seek to create a feeling of immersion in natural environments.

User research

This study uses a mixed research method of questionnaire survey and user behavior data analysis to examine the efficacy of multi-modal interaction design. First, a questionnaire survey measured users' subjective experiences along dimensions such as immersion, emotional connection and interactivity to gather data on external factors like video dynamics, haptic feedback, and the olfactory experience of the plant; this was followed by an investigation into whether one could produce an immersive emotional response inside the scene itself. Second, the user's operations in the virtual environment were recorded via behavioral data analysis methods. This included how often they interacted with the plant and for how long, as well as response times after triggering specific actions. By analyzing these data, we can describe and quantify the characteristic use patterns of users - so it is possible to assess concretely what effects on users' immersion experiences and their emotional bonding come from this design.

For this project, in order to investigate the state of affairs regarding human relationships with trees, we conducted field observations in places where there are local trees and used Figure 2-1 user observation materials to analyze and derive points for design innovation. Observations show that groups having interaction with trees are generally local people living in the area for a long time, seldom new comers who are young. Because trees might be distant, people's direct exchanges with them are but a few: mostly lying in its shade, walking dogs under the tree, entertaining-noise amplification of shows under trees, and bringing children tipi-tentsunder the trees.

These exchanges are of short duration, not deep, and the trees continue their existence as background.

In the same way, the study also makes comparisons of interaction effects between different combinations of modal. For example, it examines to what extent the effects on user experience are different according to a single visual mode, visual and tactile bimodal modes, visual/touch/and smell multimodalization combinations? At the same time, this will help locate where multi-modal design advantages lie in terms of interaction effect, which can serve as a basis for future optimization efforts. Finally, combining the results from user feedback and behavioral data the study will further optimize the multimedia interaction design of the virtual natural scene, ensuring that its visual realism and emotional interaction experience are both balanced and improved.

What memories do you have with what kind of tree? What characteristics of the tree evoke your memories (smell, touch - the five senses)?	Recall the specific location and environment description, what are the elements of surrounding area?
I got a spicy sting on the poplar	Zhejiang Road primary school
When I was in primary school, I raised silkworms and looked for mulberry trees everywhere. I still remember the shape of the leaves.	Very hot summer pale green chubby silkworm weekly record in this observation diary
Rubbing on dry trees	School playground old residential building demolished when I was a child the village has a lot of piles of steel and cement waste, I born
Small loquat tree, leaves feel fluffy, much like before and friends to draw blind box to draw the flocking small hand	The red brick in front of the house, like lying on the edge of the alley next to a black cat
My home house has not been renovated, there is a very old ginkgo tree in the yard, my childhood followed...	Old house, three floors, there is a not too small yard, there is a big flower bed in the middle, there are grandma's vegetables, by training
Grandma planted a pomelo tree in front of the house, which will bloom and bear fruit around October, fragrant	In the doorway
There is a big camphor tree, in the summer of memory grandma always brew a pot of hot tea and sit under the camphor tree slowly,...	In front of the tree is my grandmother's yard, behind the tree are pieces of farmland and low low tea
A camphor tree blown crooked by the wind, after being blown crooked, he never stood up again. Me...	The old three-story residential house has a vegetable garden beside the tree, and the car always hides under the tree for shade, and there are many neighbors during the day
No, it's huge. Yellowhorn tree. On the primary school playground in spring, the sky is full of green buds, and the autumn soybean is big	Under the tree, the kind of oozing bricks that rain easily becomes assassins of floor tiles squeeze out the narrow living space of the whole tree, but it is not square

Figure 1-2: Survey Research Results

In conclusion, the elucidation of the "Memory Tree" five senses is to reflect one's deep experience and emotions pertaining to nature.This realization & experiential knowledge of the five senses is not just recognition for the environment at an intuitive level, also it brings back people's beautiful memories and emotional ties to nature. By these ways, people's perception and understanding of nature are deepened and changed. So in creating a VR product experience, we will start from the user's feelings and experience of nature, and take the five senses as the source of our creation. In this way our work can more closely approximate users' natural behavior and sense experience and draw on their existing experience in order to indue them with more direct feelings about plants,thus producing a more realistic and emotionally-satisfying experience.

MULTI-MODAL INTERACTION DESIGN

Visual Interaction Design

Used as a part of dynamic rotational acceleration and scatter technique, In the present instance, scene modeling technology is put into use to construct a vital scene with plant life through the combination of Unity and SpeedTree.Such dynamic changes in the plant model involve the process of growth (e. g., leaf expansion, flower blooming), the external environmental response (e. g. plant swaying in a breeze, light's effect on the color of plant material), and real-time feedback triggered by the user's operation (e. g., when a withered stem recovers).Increasing the user's sense of presence also requires the visual design to include light and shade shading with real-time elemental effects in scene modeling. An example: around the plant the system adjusts light intensity and how shadows are depicted when nearby objects interact with the plant; when the user performs a watering action, growth of the plant's roots sucking up water is shown dynamically and naturally, realising a vivid ecological scene.

Haptic Interaction Design

By linking a simulated virtual tree and a physical rope (imitating that tree 's banyan-like aerial roots), we create haptic link between the two. This means that users can manipulate the rope with both hands and still feel what they are doing. Arduino assists in the direction of the haptic feedback; it controls a vibration motor to give different tactile sensations dependent on user strength, speed and rhythm. When gameplay includes such things as rope tautness (a feeling of its length) or restrictions from branches in a gusty wind swirling over the countryside, there is also an intimate relationship between actual and virtual life for these children of nature—what they learn here is likely applicable to other areas of experimental work. Also, the floor environments while participants walk include things like alternating soft and hard ground. By this genuine feeling people receive an ever deeper impression of nature's surroundings.

Olfactory Interaction Design

The sound design are synchronised with visual and sensuous feedback to create a complete multi-sensory experience.From the sound of the wind, the sound of falling leaves, the lively sound effects of energy transfer, to their ultimate mood music with animals chirping and butterflies fluttering, these things have been incorporated subtly and cleverly into what could otherwise be considered by most patients-and even critics!

Auditory Interaction Design

The sound design actually includes an odour-producing kit designed to naturally heighten your enjoyment and comfort. The quite fresh aromas of plants (such as flowers' scent or that from damp earth) can be reproduced.

TECHNICAL REALIZATION

Visual Interaction Design

SpeedTree has been used to construct the ficus tree's intricate structure and to restore the form of the aerial roots. We also have a highly detailed approach which brings out dangling examples at their most robust, in terms of mass and proportion. For Smoothness of morphological realism and adjustability, we come to branch, leaf, and slab root hierarchies with a process that was procedurally generated. Moreover, the techniques of showing point clouds are combined with Unity's dynamic tree in visual style, so that with real-time rendering and a particle system to go along, viewers can watch from start to finish as energy is captured and flows through this process. Players benefit from such an expressive visual experience.

Haptic interaction and physical feedback

On the Arduino platform, a rope control system that is able to record changes in appearance of person was designed. By pressure sensors and position tracking, the player's hands motion what are the data points this sensor outputs into VR world is simulated in real-time. For example, if the players hands are split apart, a simulation of energy is made; and when these two parts come together, again energy output takes place as well. Meanwhile the vibration equipment at once provides force feedback, so that users can feel tension and current of rope flow in real life.

Integration of olfactory devices

With help from miniature odor generators and a combination of Unity scene triggers,a great diversity of smells can be released directly into your face. For example, when the player approaches a tree, they will get the light scent of flowers; when the rain ends, the smell is that of damp earth. According to Arduino synchronization with Unity operation logic--being sure to match both the sense of touch and what you see in images--this controlling factor should be discovered. Its loudness and temporality can be adjusted as necessary for any given situation.

Game flow and interaction mechanism

Game interaction design is divided into three stages as shown in table 1 and figure 3.

Interaction initiation: Players learn the core interaction mechanisms through initial contact with the tree, for example through ropes that simulate connections to the roots. Fans simulate gusty winds, and particle systems represent the collection and transfer of energy.

Work with the tree: Players control the flow of energy through rope movements to defend the tree from harsh environments and maintain its health. The particle visual dynamics of the energy flow is closely linked to the user's movements.

Natural Recovery: Players enter the final stage, which visually shows the miracle of recovery with blossoming flowers and birdsong, while the olfactory device releases the scent of flowers, creating a natural atmosphere full of vitality.

point	thrust	physical interaction	virtualization
Opening - Interactive Departure	This module teaches animation and interaction to understand the background of the story, and a novice tutorial to familiarize yourself with the core interaction mechanisms.	Step into the experience area decorated as a forest and hold the rope as an external fan simulates the effect of a gusting wind.	In the VR scene, both the user and the tree are represented as particles. Wind gradually disperses these particles and energy particles, which flow according to the wind's direction and strength. The rope serves as the tree's aerial root, with its central area designed to capture and transport the energy of the particles.
Process - Working with Trees	Players need to use branches to form a capture net to receive particle energy and channel it to maintain the damage caused by broken branches and damaged roots.	The player establishes a connection with the tree by grasping solid ropes (branches of the tree), and when the player opens his arms he collects energy, and when he combines his arms he outputs energy.	When the gale comes, gain yourself while maintaining the tree, consolidate the player's own particles, strengthen the connection with the branches, and gain the branches to increase the speed of the player's energy delivery. At the same time, the busier the tree branches, the stronger the resistance, the larger the net that captures energy, and the more efficient the collection of energy.
The End - Natural Recovery	In the final stage of the game, the player experiences the process of transformation from darkness to	The fan stops and an external olfactory device sprayer simulates the scent of flowers,	As players break free of the darkness, they hear more sounds and see more sights, including mirror images of flowers in

	light as everything comes back to life.	immersing the player in the scent of everything.	bloom, butterflies fluttering, and birdsong. Eventually, the darkness turns to clear and vibrant.

Table 1: Game interaction design stages

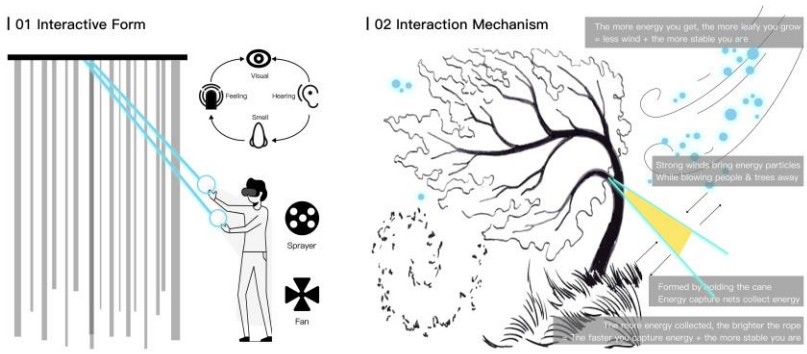


Figure 3 : Interaction Mechanism

multi-modal integration and optimization

The research centers on real-time data synchronization and makes good use of the communications protocol between Unity engine and Arduino to ensure combining visual, tactile and olfactory senses in synchronization: At the same time, given the complexity of multi-modal interaction, GPU acceleration and multi-threading parallel processing are applied to optimize system performance by reducing delay and thus enhance the user experience.

Through deep integration of visual, tactile, olfactory and other multi-modal design, this study has successfully achieved a unique new type of virtual natural interaction experience Players can experience the growth and change of trees through novel point cloud vision in rich sensory feedback. They can also feel the deeply emotional connection between man and nature in interaction. This design will be an important reference and guidelines for future virtual ecosystems and immersive educational applications.

DESIGN CASE STUDIES

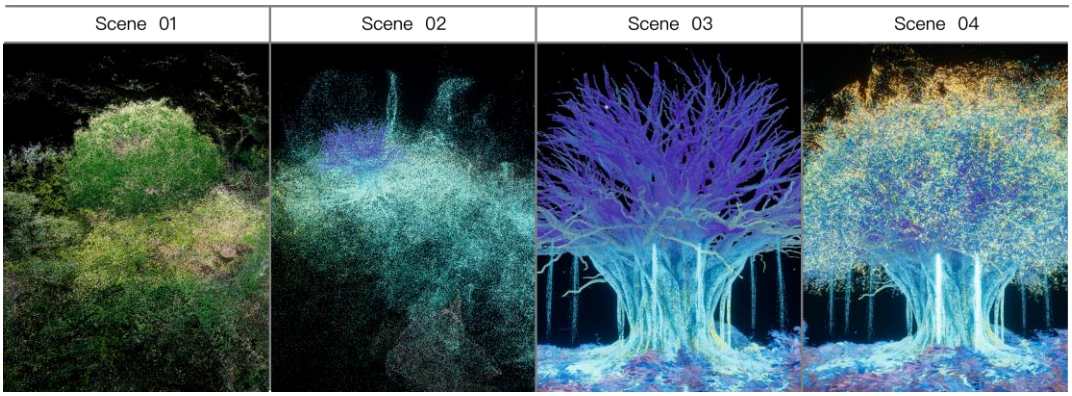
Scenography

This work creates an immersive VR scene bestowing reality of garden through the Unity engine (visual, tactile, olfactory, auditory multi-modal).For the visual, Shader Graph technology is used to achieve dynamic changes in light and shadow as well as detailed texture effects; while SpeedTree combined with PBR materials makes realistic imagery of plants themselves.At present, the 3D sound function of Unity can adjust in real-time the direction and strength of sounds such as birdsong and water murmuring sources to create a natural auditory immersion in our scene.To achieve

the sense of smell and the tactile feel, hardware such as fans and misters is integrated into the system. For example, when the user gets close to a tree, breeze blown by fan makes more vivid and at the same time there is a scent of grass sprayed by them enhancing realism.In addition, using interactive design allows the user to directly interact with the virtual environment. For example, touching leaves on trees causes dynamic particle effects, plucking grass affects the overall sound-scape, and all other aspects create an extremely high level of interactivity.

User experiments

The test was set up inside a university exhibition hall with 30 participants invited to experience the test. The participants were assigned to two groups: the experimental group had multi-modal-based VR scenes, and the control group had traditional VR scenes with visual and auditory elements. These tests contained user interaction tasks with the scene (e.g., discovering hidden elements) and questionnaire assessment of immersion, engagement, and satisfaction. The study tracked user behavioural patterns in terms of action frequency and subjective feedback to measure the actual impact of the multi-modal design.



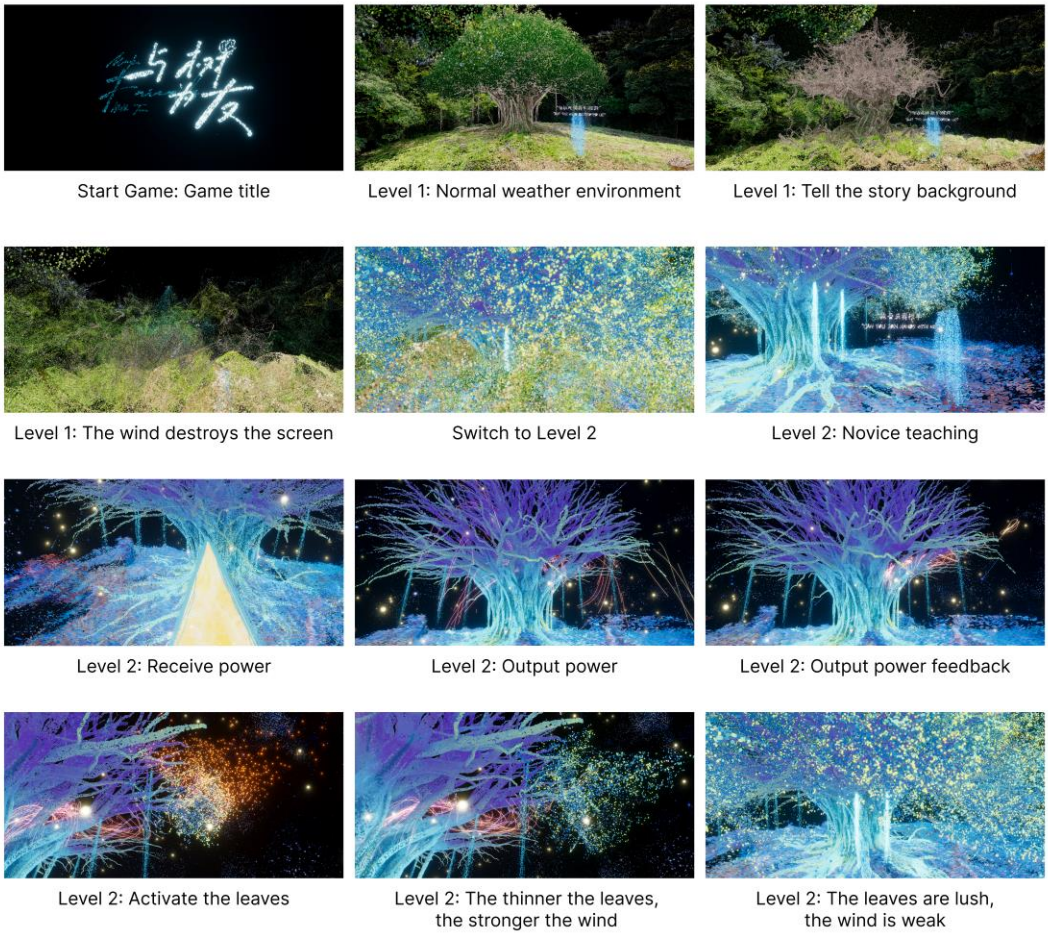


Figure 4-5 : Interaction effect presentation

RESULTS AND DISCUSSION

Experience feedback

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Technical limitations

Although multi-modal design significantly improves user experience, its hardware cost and scene complexity become the main limitations. High-precision dynamic rendering requires high device performance, and slight lagging occurs in some scenes. In addition, the lack of portability of the fan-and-sprayer device limits the generalizability of the scheme in a wider range of applications.

Figure 6 : Interaction experience experiment

CONCLUSION AND DISSCUSION

Grounded in the theory of embodied interaction, this research proposes this immersive VR plant human–plant entity experience model through the spatiotemporal sequence of multisensory design (vision, touch, and smell). More specifically, the findings demonstrate that, while the typical experience of VR tends to overlook the non-visual senses, a more multi-modal design provides a strong enhancement in browser immersiveness and app engagement. The experiment proves the hardware and software coupled multi-modal extension method proposed in this paper worth, and provides a feasible path for the innovative application of virtual reality in the area of cultural display, environmental education and ecological design.

While this study showed the merits of a multi-modal design approach, there are still tradeoffs for adopting improvements in hardware cost, device convenience, and technology optimization. These results lead us to believe that future work will pay attention to (1) Developing light and low retrofitting hardware equipment (such as portable fans and micro-misting equipment), (2) optimizing dynamic scene rendering technology (including LOD optimization and AI tuning algorithm), (3) improving the operation efficiency of the device while ensuring the visual quality. At the same time, immersive application scenarios (such as urban greening education, disaster environment simulation, and nature healing experience) will provide users in various fields with new direction of demands. We will also develop more personalized interactive model and adapt immersive experiences with the usage of the user data which can stimulate the deep integration of virtual and reality and provide premium ground for multi-model design to be widely used in virtual reality domain.

The multimodal immersive VR plant experience constructed by this research institute also has profound significance in the social and educational aspects. By integrating multiple senses such as vision, touch and smell, we simulated a "symbiosis" scenario between humans and plants, allowing participants to experience genuine care and responsibility for the ecosystem in a virtual environment. After users completed the interactive tasks, the questionnaire feedback indicated that they were more willing to participate in activities such as tree planting and environmental protection volunteer services in real life. Meanwhile, teaching experiments also show that this VR simulation can serve as an effective tool for ecological education in primary and secondary schools or community science popularization, stimulating teenagers' sense of environmental responsibility and willingness to act, thereby promoting the

transformation of the human-nature relationship from "objectification" to "co-protection by subjects".

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