EXPANDING THE METHODS OF HUMAN-VR INTERACTION (HVRI) FOR ARCHITECTURAL DESIGN PROCESS

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Abstract. The emergence of virtual reality technology now brings the possibility of new design methods. Virtual reality technology allows architects to feel space better and express design ideas more intuitively. With the interactive perception equipment and VR glasses, geometric shapes can be created and modified in a virtual environment, replacing the mouse and keyboard to complete the creation of space in the early stage of the design process. At present, the application of virtual reality in the architectural design process has some problems include unnatural interaction, low accuracy, high work cost. This paper will summarize the interactive methods of virtual reality technology in various current cases and compare the input and output of the device by analyzing the matrix method. We can explore interactions that are beneficial to architectural design. Using these interactive methods, we can expand the interface relationship between humans and the virtual environment.

Keywords. HCI; HVRI; Interaction; Digital Architecture Design; Virtual Reality.

1. Introduction

With the advancement and development of computer technology, virtual reality technology began to appear and apply in various fields. Virtual reality is a simulation in which computer graphics is used to create a realistic-looking world (Burdea & Coiffet, 2003).The characteristics of virtual reality are immersion, interaction, and imagination. Virtual reality technology breaks through the way people perceive the world in the past. It turns people's dreams of creating and experiencing virtual space into reality. In this context, using virtual reality technology in the architectural design process will be more effective. Virtual reality technology allows designers and users to immerse themselves in the virtual architectural space. It is conducive for the designers to improve the quality of architectural space.

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2. The development of Human - VR interaction for architectural design process

2.1. THE APPLICATION OF VIRTUAL REALITY TECHNOLOGY IN THE ARCHITECTURAL DESIGN PROCESS

The introduction of design concepts used virtual reality at first. Virtual reality technology allows architects to express their designs freely (Schnabel et al. 2008). Virtual reality is a technology that adds immersion and interaction to the three-dimensional computer model. It can show the world that cannot express in traditional forms (Burdea & Coiffet, 2003). Therefore, VR is a powerful tool that can surpass reality.

The use of virtual reality technology can increase the collaboration of teams. By analyzing and evaluating two technologies, the 3D virtual world of remote design collaboration and the tangible user interface combined with AR. VR has increased the cooperation between design teams (Gu et al., 2011).

VR helps to understand the concept of space. VR-based 3D sketching interface can improve spatial cognition in the conceptual stage (Rahimian & Ibrahim, 2011). VR can also be used for three-dimensional interactive creation, modeling in design work. Users can experience the created space directly (Schnabel et al., 2008).

The combination of VR and BIM can lower the barrier of use. The technology allows users to interact in real-time and experience the virtual environment. It makes users experience a designed environment. It can have the function of simulating physical dynamics (Yan et al., 2011).

At present, VR has various applications in the field of architectural design, but there is a lack of further exploration in interactive methods. Due to the limitation of interactions, the application efficiency of virtual reality technology in the architectural design process is not high.

2.2. THE DEVELOPMENT OF INTERACTION FOR ARCHITECTURAL DESIGN PROCESS

Before the use of computers in architectural design, the way of architectural design was to draw drawings with paper and pen. At this time, people design buildings with the interaction of hands, drawing, and pen. In the 1970s, due to the development of computer hardware, specialized CAAD software was born. Architects used it for two-dimensional drawing work. Then from the mid-1980s to the 1990s, three-dimensional architectural model software began to appear. After entering the 21st century, parametric 3D design software has also started to use in the architectural design process. At this time, the process of architectural design bases on human-computer interaction. Architects use the mouse and keyboard to input parameters and design buildings on the computer. The emergence of virtual reality has expanded the way of architectural design. In the future, architects can no longer rely on the mouse and keyboard. Using perception devices, architects can design buildings in virtual reality with a variety of interactive methods.

2.3. RESEARCH OBJECTIVES

Due to the abstract and professional nature of traditional two-dimensional drawings, the communication between professionals and customers is impeded. Virtual reality technology can solve these problems. Virtual reality technology breaks the previous two-dimensional architectural design mode, and avoids the disadvantages of graphic design. The design can be constantly improved in the process and the virtual technology can make the design more perfect. At the same time, the immersion, interaction and imagination of virtual reality also provides convenience for users to participate in design. At present, interaction is one of the key problems of virtual reality in architectural design. This study attempts to find a natural interaction by sorting out different interaction modes. Improving the interaction mode of virtual reality technology in the architectural design process can make the architectural design process easier to be understood by people. As a result, it can reduce the communication barriers between professionals and non-professional users. Using virtual reality technology, non-professional users can participate in the design process, making the final building more suitable for use.

2.4. THE ADVANTAGES OF VIRTUAL REALITY TECHNOLOGY IN INTERACTIVE METHODS

Virtual reality technology can satisfy the natural interaction mode and reduce the difficulty of using the computer. It is still difficult for many non-professionals to use computers because of the cost of learning basic principles and operating skills. Better human-computer interaction will make computers easier to use, more enjoyable for users, and more productive. Ideally, people would be able to talk to the computer and control it in a more natural way than the current window, icon, menu, pointer (WIMP) interface. Using virtual reality to conduct human-computer interaction can make the computer easier to use. With virtual reality technology, the operation of the computer can be more in line with people's natural habits, and improve efficiency. Virtual reality technology can solve the problems the problems existing in the process of architectural design. In virtual reality, architects can feel the space and get more real feelings. Besides, architects can also get a multi-angle visual experience. The interaction between humans and the virtual environment can be more diverse and use body language. In short, virtual reality technology allows architects to experience the space they design. It can help architects to improve the quality of design.

2.5. THE PROBLEMS OF INTERACTION BETWEEN HUMAN AND VIRTUAL REALITY IN THE CURRENT ARCHITECTURAL DESIGN PROCESS

Virtual reality technology can enable users to better understand design, help to improve users' participation in design, and realize collaborative design. However, there are still some problems with using virtual reality in architectural design.

- Due to the difficulty of interacting with virtual objects, architecture visualization in VR system is limited (Camacho et al., 2019).
- Virtual reality technology equipment is not mature enough, and some people

will appear simulator sickness (Kreutzberg, 2014).

- In order to create a realistic digital environment, designers need to put more effort into defining objects in virtual reality (Lo & Gao, 2020).
- Multi-person interaction and long-distance collaboration in virtual reality are still being studied (Ishikawa et al., 2020).

All these problems increase the workload of designers and limit the application of virtual reality technology. It is necessary to reduce the cost of the designer's work and make it easier for the designer to operate in the virtual world. The improvement of the interaction is conducive for the popularization and application of technology.

3. Interactive methods of Human - VR interaction (HVRI)

At present, the main interactions of virtual reality technology are as follows.

3.1. THREE-DIMENSIONAL INTERACTION

Three-dimensional interaction refers to the operation of mapping spatial information or buttons of an input device into a virtual space to complete specific interactive tasks. According to different input methods, there are two types of mapping.

Direct mapping is mainly to input the spatial information of the hand or device directly. Ray casting uses virtual light. The virtual hand is a way of mapping by constructing the user's hand in the virtual world to achieve the purpose of interaction. Virtual hands have insufficient grasping accuracy. Based on the rules of threshold self-adaptation (TSA), virtual hands can achieve more accurate grasping (Zou et al., 2019) (Figure 1). Indirect mapping is mainly to map input information into gestures with the device. The users use these gestures to complete interactive tasks. In the WIM (world in miniature) system, users can control the mini-space. The change of the mini-space will affect the objects in the scene (Stoakley et al. 1995). Besides, the user can project three-dimensional space onto a two-dimensional plane and use the image plane to manipulate objects in three-dimensional space (Pierce et al., 1997).

There are three problems with 3D interactive technology. The space range is too small that it is difficult for the virtual hand to grasp the distant objects accurately. The three-dimensional interactive device provides more degrees of freedom, but it is hard to control. Interactive technology is lack multiple methods. In response to these problems, we propose to integrate existing technologies and develop new interactive methods. Besides, people's body language needs to be fully utilized, such as the use of hand interaction.

Figure 1. Virtual hands based on TSA rules (Zou et al. 2019).

3.2. GESTURE AND BODY INTERACTION

Gesture and body interaction refer to track the parts of the human body with the trackers or computer vision methods. The information in the real world is the input information of the virtual world, and then the recognition algorithm is used to analyze and give feedback. Gesture and body interaction is one of the current mainstream virtual reality input methods. Kinect uses computer vision recognition algorithms to analyze video and parse out gestures (Zhang, 2012) (Figure 2). The accuracy of recognition has been improved greatly. Leap Motion uses binocular visual recognition to collect user data and uses algorithms to analyze human body movements. The PS4 handle can obtain the movement information of the hand with the sensor worn on the hand. It recognizes the change of the spatial position and gets feedback. Google Project Soli uses radar to monitor air gestures and identify movement changes by transmitting and receiving feedback signals.

The problem of gesture and body interaction is that there are still problems with the recognition accuracy of gesture interaction. At present, only click gestures are recognized better. When using gestures, you need to stay for a certain time to switch the functions. The memory of gestures is complicated. To solve these problems, gesture interaction can first use click gestures to complete a series of operations before the accuracy meets requirements. The switching of gesture actions can be done with the help of a virtual interface.

Figure 2. Kinect's body recognition (Zhang, 2012).

3.3. HANDHELD MOBILE DEVICE INTERACTION

Figure 3. Compared with the VR scene rendering of FURION and other mobile devices, the FURION on the right has a better light perception (Lai et al. 2017).

With the development of the mobile device, people have begun to apply the three-dimensional interactive capabilities of these handheld smart devices to the field of virtual reality. The idea of the interaction between handheld interactive devices and virtual reality is to calculate the relative position of the device and superimpose the marked digital information on the captured image. Then the operations are on the 2D level. Currently, it is widely used in location navigation and collaborative games. FURION is a system architecture that can use wifi to support high-quality VR applications on smartphones (Lai et al., 2017) (Figure 3).

At present, the interactive mode of handheld mobile devices has problems that

the display screen is too small and the computing power of the device is limited. When performing virtual reality operations on mobile devices, new interaction methods should be developed to adapt the restrictions.

3.4. VOICE INTERACTION

Voice interaction refers to the interactive mode in which users request the system to perform specific functions by voice commands. This way releases the hands. It can input a large amount of text accurately, and the interaction is very natural. Voice interaction has been applied to many smartphones. The voice recognition software is very diverse and has reached high accuracy. Google glasses, wearable devices, and Xiaomi speakers have integrated voice assistants to achieve voice interaction. Besides, creating virtual characters in the virtual world and performing voice interaction can also relieve anxiety (Yang et al., 2016) (Figure 4).

The problem with voice interaction is that when the voice interface needs to perform complex interactive tasks, the vocabulary is very demanding. When operating in virtual reality, if both hands are occupied, voice can be used as an auxiliary input to execute some simple commands.

Figure 4. Voice interaction system with virtual human (Yang et al.2016).

3.5. TACTILE INTERACTION

Figure 5. CLAW VR controller realizes tactile interaction (Choi et al. 2018).

When used as an input device, a tactile sensing device can capture user actions. When used as output devices, they can provide users with tactile experiences. With the widespread use of touch screens, tactile feedback technology has made fast progress in recent years. There are many applications on general touch screens and touch gloves. The CLAW VR controller provides force feedback and realizes the interaction of motion and touch (Choi et al., 2018) (Figure 5).

Tactile interaction is a mature method. However, in virtual reality, gloves and other equipment may be required, which has certain usage restrictions.

3.6. MULTI-CHANNEL INTERACTION

Multi-channel interaction refers to an interaction method that integrates two or more input channels. Multi-channel interaction makes full use of people's

senses, making the interaction more natural and effective. Users can input information with gestures, voice, and so on. It improves the efficiency of input and the naturalness of interaction. MSVT system uses speech recognition and gesture input to complete the visualization of scientific data (LaViola, 2000). Multi-channel interaction can combine vision and touch. The portable visual-touch fusion VR software framework uses gloves and head-mounted devices to combine the sense of touch and vision, making interaction methods more diverse (Guo et al., 2020). Besides, the fusion of hearing, vision, and touch can further increase the immersion of virtual reality (Jadhav et al., 2017) (Figure 6).

Multi-channel interaction has some problems. First, we need to develop varied semantic models for specific operations. Second, it is difficult to organize different interactive devices. Finally, the information of different interaction channels should be fused.

Figure 6. Interaction that combines hearing, vision and touch (Jadhav et al. 2017).

4. Comparison of input and output of different interaction methods

Different interaction methods have different results of input and output. Firstly classify the input terminals in the form summarized above and add some interactions. Input methods divide into controllers, gestures, motion capture, voice, tactile, eye tracking, face recognition, brain waves, and multi-channel input. According to the various human senses, the output is classified into vision, hearing, tactile, body perception, and smell. Adding the different interaction methods mentioned above into the table, we can see that there are still many vacancies in the current interactions of virtual reality (Table 1). The main input focuses on gestures and speech and the main output is vision. Because of the characteristics of current virtual reality interaction methods, improvements can be made from four aspects.

- Use multiple sensory channels. Sometimes a single channel cannot accurately express the intentions of users, and the multi-sensory interaction can convey information more accurately.
- Operation in three-dimensional space. Operations in virtual reality should be based on three-dimensional. The operation in the space is more in line with the human natural operation mode.
- Two-way interaction. Interactive input and output can be carried out in both directions like eye-tracking and visual feedback, tactile input and tactile feedback, three-dimensional auditory localizer, and sound feedback. Two-way interaction can maximize the use of the senses and bring new experiences to people.
- The naturalness of interaction. A good interaction model should make people

unaware of the existence of an interactive interface. The user can naturally operate the virtual world. For example, users will naturally focus on things of interest in the virtual world.

Table 1. Comparison of different interaction methods.

Output \ Input	Controller	Gesture	Motion capture	Voice	Tactile	Eye tracking	Face recognition	Brain waves	Multi-channel input
Vision	Ray casting、WIM、Image plane、HTC VIVE	Virtual hand、Kinect、Leap motion、Google Project Soli、Google Glasses	Kinect、Leap motion、	Voice recognition software、Google Glasses	Smart phone touch screen	HTC VIVE PRO EYE			MSVT system、Portable Vision-Touch Fusion VR Software Framework
Hearing				Voice recognition software、Mi Speaker					
Tactile			Exoskin coat		Touch gloves、CLAW VR controller、Smart phone touch screen				Portable Vision-Touch Fusion VR Software Framework
Body perception			Exoskin coat						
Smell									

5. The direction of the interactive mode of virtual reality technology in the process of architectural design

This article summarizes the various interactive technologies of virtual reality. The methods need to be selected according to the needs of architectural design. There are three requirements in the field of architectural design.

- The way of interaction needs to be natural enough. If designers rely too much on a certain medium when performing operations, the thinking will be limited. For example, with too much use of the mouse, keyboard, and screen nowadays, it is difficult for architects to perceive the building space through the screen. The real feeling of the designed buildings will be biased.
- There must be a certain degree of accuracy. Architectural design has high requirements for scale. It is necessary to be able to input values accurately to control space design. Therefore, in the interaction of virtual reality, attention should be paid to the function that can define the value.
- Interactive learning and work costs need to below. If the time of learning is too long, the technology will be hard to promote and apply. The current design process schedule is very tight and it is difficult for designers to spend a lot of time learning new technologies. Therefore, to facilitate the application of virtual reality technology, it is necessary to make the interaction of virtual reality easy to study and close to nature.

In response to these three needs, combined with the advantages of various interaction methods summarized before, we propose three strategies.

- In the way of interaction, the interaction can use gestures as much as possible. The use of voice interaction can assist in the operation. This kind of method is the most natural. Switch gestures can use the function buttons of the virtual interface. Voice interaction can be used when both hands are occupied. Multi-channel interaction helps architects improve design efficiency.
- The accuracy of the interaction can be precisely controlled by inputting values through the three-dimensional virtual interface.

- We can consider using a graphical interface to represent the parameterized data logic. We can even control the model parameters by inputting body language directly. In the future, we can use natural interaction to realize parametric modeling and design work.

By analyzing the various existing interactive methods, we can see that there are some problems in the current virtual reality interactive methods. When virtual reality technology is used in the field of architectural design, it is necessary to change the interactions according to the needs. In the process of architectural design, we can use the device to capture gestures on the virtual reality interface to complete the creation of three-dimensional geometric objects. With the buildings created in this way, architects can directly roam inside the building to get a more real experience. The operation interface innovation of virtual reality will be a direction that can be improved.

Because virtual reality is multi-perceptual, immersive, and interactive, it is very effective to apply virtual reality to the communication between designers and users. In high-density urban areas, the development of residential buildings has three characteristics. First, to accommodate more people, the scale of residential construction projects is getting bigger and bigger. Second, the customer's needs are becoming increasingly diversified and the market is changing fast. Third, the industrialization of building components reduces production costs. Open architecture can meet such needs, but it requires users to participate in the preliminary design work. Using virtual reality technology can reduce the cost of communication between designers and non-professionals. Non-professionals can intuitively feel the residential space in virtual reality and put forward their own diversified needs. For designers, the participation of the user can improve work efficiency and reduce useless work. For developers, the participation of users can better meet the needs of customers and residential products have a higher competitive advantage. After non-professionals use virtual reality technology to intervene in the design process, the final product can be adapted to various needs while reducing costs.

6. Conclusions

This paper sorts out the various applications of virtual reality technology in the field of architectural design and analyzes the development process of human-computer interaction. It summarizes the advantages and problems of virtual reality technology in the architectural design process and analyzes the existing virtual reality interactions. The matrix compares the existing interactive methods of virtual reality. Finally, it is proposed that in the field of architectural design, gestures can be used as much as possible in virtual reality. The use of voice interaction can assist in the operation. The three-dimensional virtual interface can help to control the values accurately, and the interactive method can be improved to achieve easier parameterized construction and design work. Finally, the paper suggests that virtual reality technology can be used in the process of participatory residential design, allowing non-professionals to participate in the design process, improving design efficiency and meeting the diverse needs of users.

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