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Development and Trends of VR Technology (2022)

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Development and Trends of VR Technology

Abstract

In this paper, it aims to review and analyze the development, application fields, trends and impacts of virtual reality (VR) technology. Based on an overview of basic principles, categories and features of VR technology, current applications and successful cases of VR technology in the fields of gaming and entertainment, education and training, medical care and therapy, industry and manufacturing, architectural design, as well as tourism and culture are analyzed. In addition, the development and trends, and challenges and impacts of VR technology are discussed. Among them, further development, combination and application with other technologies, as well as impacts on human behavior and psychology, and economy and culture are included. Based on the research and analysis of this paper, users can better understand the development and future development direction of VR technology, as well as its impacts and challenges on human society.

Keywords: Virtual reality, VR, development, impact

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1 Brief Introduction to VR

1.1 Concept and Principle of VR

1.1.1 Concept of VR

The full name of VR is Virtual Reality (Virtual Reality), which is a computer technology that simulates real environments and virtual scenarios. By utilizing VR, users can get immersive feelings. They enter a virtual environment, by wearing VR helmets or other virtual reality equipment, where they can explore and interact freely. The emergence of VR technology could be traced back to the 1840s, but it was not until recent years that VR technology was commercialized on a large scale due to the advancement of hardware technology and expansion of application scenarios.

The core of VR technology is the construction of a virtual environment, which requires the use of technologies such as computer graphics and simulated physics, as well as a large amount of data and computing power. By simulating the real world, users can interact with the virtual environment through VR equipment, including touching, moving, and rotating.

VR technology can be applied in many fields, such as games, movies, education, medical care, industry, real estate, etc. In the fields of games and movies, VR technology can provide immersive experiences, making users feel as if they are in the real world. In the education field, VR technology can provide a more intuitive, vivid and appealing learning environment, which is conducive to enhancing learning effects. In the medical field, VR technology can be utilized in surgical simulations, case studies, etc., improving medical levels.

VR technology is a powerful tool that can provide brand-new experiences and interaction methods, expanding users' knowledge and understanding of the real world. With the advancement of technologies and the expansion of application scenarios, the application prospects of VR technology will become increasingly extensive.

1.1.2 Principle of VR

VR is a computer-generated interactive experience that creates immersive environments by simulating sensory experiences in the real or virtual world. Virtual reality consists of software and hardware, where software includes computer programs and algorithms, while hardware includes visualization devices, sound feedback, tactile and force feedback, as well as motion platforms.

In virtual reality, the real-time interaction between a user and a virtual environment is achieved via the relationship between the virtual environment and an avatar (a virtual user), as shown in Fig.1 [2]. This means that the position and motion of the user should be captured in real time to refresh the position and motion of the avatar, allowing consistency between the virtual and the real world to be achieved simultaneously.

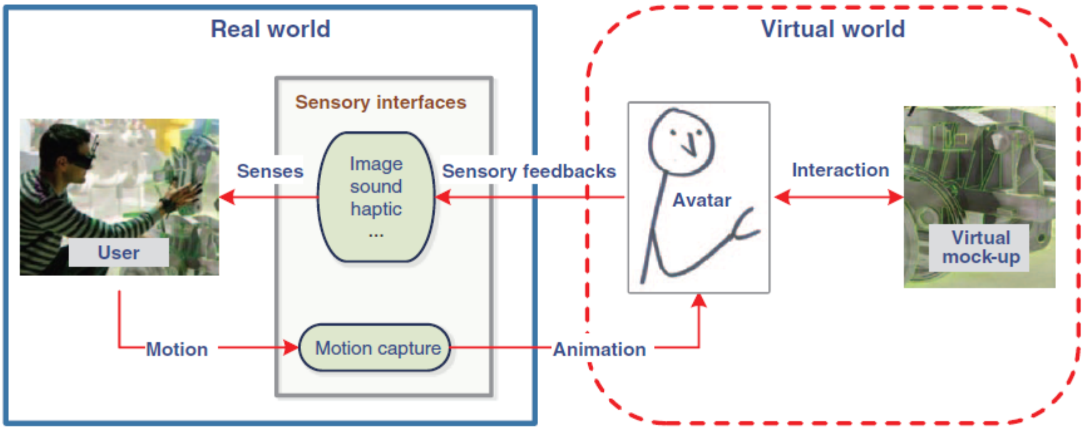

Fig.1 Relationship between a user and a virtual environment

In virtual reality, the concept of assessing users' perception is called the sense of presence. It depends on the way they explore virtual environments, the possibilities for them to interact with the environments, and the multisensory feedback provided by technologies. The sense of presence is largely determined by the participation of users' body in the virtual immersion process. Therefore, virtual reality tends to fully immerse users in the virtual world.

In order to fully immerse users in the virtual world, it requires the support of visual technology, audio technology and interactive technology.

The visual principles of VR involve human vision and image processing technology. When human eyes are watching an object, the left and right eyes receive different images respectively. Thus, binocular parallax is caused, which in turn creates a sense of three-dimensionality and depth. By simulating this parallax effect, virtual reality allows users to experience a sense of reality in the virtual world similar to that in the real world.

For the sake of achieving this effect, VR adopts various imaging technologies, such as stereoscopic imaging, panoramic imaging, spherical imaging, etc. Among them, stereoscopic imaging is one of the most used technologies. It utilizes two cameras to capture different angles of a scene, generating images from two angles of view. Subsequently, the images are presented to users in a synthesized manner. In addition, virtual reality utilizes head-mounted displays (HMD). Images from different angles are projected onto two displays. Then, the images are merged into one image through a lens, allowing users to feel a three-dimensional effect.

In addition to binocular parallax, motion parallax and zoom functions are also key factors for human eyes to produce a sense of reality. Motion parallax means that when users move their heads, the position of objects within their vision will change. This change makes people feel the depth of space. VR dynamically adjusts the angle and position of the image by tracking movements of users' heads, thereby simulating the motion parallax effect in the real world. Meanwhile, virtual reality also simulates the focal length change of human eyes through zoom function, enhancing the sense of reality of scenes.

Moreover, the visual principles of VR also include geometric principle and optical principle. In terms of geometry, virtual reality utilizes three-dimensional graphics technology to model virtual scenes, which can simulate the shape, size and position of objects in the real world. In terms of optics, virtual reality uses optical tracing technology to simulate the lighting, reflection and refraction in the real world, making objects in the virtual world have a more realistic appearance, as well as light and shadow effects.

The principle of audio technology in VR are similar to those of visual technology. It aims to simulate a real audio environment and enhance users' sense of immersion. Audio technology includes three aspects including sound collection, sound processing and sound output.

In terms of sound collection, virtual reality systems usually use microphones to collect it. The system can collect users' voice, the sound of the surrounding environment, etc. In addition, some advanced virtual reality systems can also achieve more realistic sound collection by using devices such as headset microphones.

For sound processing, virtual reality systems usually use spatial audio processing technology, which can stereotype and spatialize sound based on users' position, direction and other information. This allows them to experience the sound coming from different directions of left and right, or front and rear, etc.

In terms of sound output, virtual reality systems usually use audio headphones and other devices for sound output, transmitting stereoscopic and spatialized sounds to users' ears through headphones. This allows users to feel sounds from different directions, enhancing the immersion sense in virtual environments. Some advanced virtual reality systems can even enhance the sense by using vibrators and other devices to transmit sound directly to users' body.

VR interaction is mainly achieved through gesture recognition, audio recognition and head tracking technologies. Among them, the gesture recognition technology converts hand movements into instructions that computers can understand by sensing the movements, thus controlling objects in virtual environments. The technology requires utilization of depth cameras, infrared sensors, optical sensors and other various sensors. These sensors can capture movements of users' hands and convert them into digital signals. After that, computers can judge operations that users want to perform through analysis of these digital signals, and reflect them in virtual environments.

The audio recognition technology realizes the interaction with virtual environments via recognizing users' audio commands. The technology requires to utilize audio recognition software to convert the words uttered by users into instructions that computers can understand. Also, it requires microphones, audio recognition software and other devices. Users can control virtual environments by uttering specific words or sentences.

Head tracking technology achieves the transformation of angle of view in a virtual environment by tracking movements of users' heads. The technology requires to use various sensors, such as accelerometers, gyroscopes and magnetometers, to sense movements of users' heads such as rotation and tilt. Then, these movements will be converted into signals that computers can understand. The computers calculate the position and orientation of users' heads through analyzing those signals, and reflect them in the virtual environment, thereby achieving the transformation of angle of view.

1.2History and Trends of VR

VR could be traced back to 1838, when British physicist Charles Wheatstone[1] proposed the concept of stereo vision. He found that brain processes different two-dimensional images from each eye into a single three-dimensional object. This technique, known as the stereoscopic viewing, can create a deep sense of immersion by viewing two side-by-side stereoscopic images or photographs.

However, it was not until the 20th century that people began to study the stimulation of senses. In 1929, Edward Link designed the world's first commercial mechanical flight simulator which was patented two years later.

This invention marks the concept of VR start to enter the real world. During World War II, the requirements to train pilots prompted the development of VR. More than 500,000 pilots had undergone initial flight training via simulators. The technology then did not only help pilots learn piloting know-how, but also laid the foundation for the later virtual reality technology. In 1930, science fiction novelist Stanley G. Weinbaum proposed an idea in his novel “Pygmalion’s Spectacles”, which said a pair of glasses could allow users to experience virtual environments utilizing holographic images, smell, touch and taste. This idea creates a new direction for virtual reality. Since 1950, the development of virtual reality has entered a new stage. Morton Heilig invented the first real and available VR device, Sensorama. It is huge in size, and equipped with stereo speakers, stereoscopic 3D displays, fans, scent generators and vibrating chairs, allowing users to have immersive experiences. In 1960, Morton invented the first VR HMD. Although it looks considerably similar to modern VR glasses, it only has a stereoscopic display function without a gesture tracking function. When people wear glasses to look left and right, the scene in the glasses will not change. In 1968, Ivan Sutherland and his student Bob Sproull invented the prototype of VR glasses that came closest to the concept of a modern VR device. The prototype was dubbed the “Sword of Damocles” because of its sheer weight and the requirement to be suspended above a person’s head by a robotic arm.

Although the prototype of the “Sword of Damocles” has provided people with more concepts and possibilities of virtual reality, the development of VR has stagnated for a time due to technological limitation. VR technology ushered in a new era till the 1990s, with the rapid development of computer technology, graphics and the Internet.

In the 1990s, virtual reality began to enter the market. In 1985, the first commercial VR device was introduced by Jaron Lanier and his company VPL Research. The device, called EyePhone, is a headset device that allows users to feel and interact with objects in a virtual environment. In 1991, the launch of Genesis, a VR helmet launched by Sega, meant that the commercialization of virtual reality begun.

In addition, the application of VR technology had also begun to expand from military, medical and game fields to various industries. Among them, application in the game industry was the most prominent. In 1995, Nintendo launched Virtual Boy, the world’s first commercial VR game device. Although it was not favored by consumers, it laid a foundation for the development of VR games. Afterwards, VR game devices began to emerge. Head-mounted VR devices, represented by HTC Vive, Oculus Rift and PlayStation VR, brought VR games to a brand-new and higher development stage.

At present, VR technology has developed to a new stage and is becoming a new industry. The application scale of virtual reality is constantly expanding, including but not limited to gaming and entertainment, education, medical therapy, and tourism.

In the future, the development trend of virtual reality has a wide range of possibilities. First of all, the technology of VR hardware and software will continue to advance and improve. With the emergence of a new generation of graphics processors and high-resolution displays, the image quality generated by VR HMDs will be clearer, smoother and more realistic. This is crucial to enhancing the immersion and realism of VR. In addition, with the improvement of sensors and gesture tracking technology, VR hardware will be able to track users' body movements more accurately, making their movements more natural and precise in a virtual environment, which will help create a more realistic virtual experience and improve interactivity of VR applications.

In the second place, the application scenarios of VR will continue to expand. In addition to gaming and entertainment, VR can also be exploited in education, training, medical therapy, virtual tourism and other fields. In the field of education and training, VR can simulate real scenes and scenarios, allowing students or employees to better master knowledge and skills. In the medical field, VR can be used to treat psychological issues and phobias, as well as assist doctors in surgical planning and training. For the virtual tourism, VR can help people explore distant places at home, experience tourist destinations, and promote their travel experiences.

Besides, VR will be combined with other technologies to form more powerful innovations. For instance, virtual reality and augmented reality can be combined to create an augmented virtual experience that merges the virtual and real worlds. In addition, artificial intelligence and machine learning technologies can also be integrated with VR. This will make a virtual environment more intelligent and interactive.

In the end, the social function of VR will be enhanced. Virtual reality can provide a more immersive social experience, allowing users to interact and communicate with others in a virtual environment. For example, users can conduct activities such as voice chatting, gaming and watching movies with friends on a virtual reality social platform at home. This social function will be widely used in fields such as business and education.

Generally speaking, as VR continues to advance and develop, more vivid, immersive and interactive virtual experiences can be expected. In the future, VR will be developing and innovating in terms of image quality, hardware technology, application scenarios, combination with other technologies, and social functions, bringing more convenience and pleasure to users. Even if VR application faces many challenges and difficulties, it is a key direction of future technological development, with unlimited possibilities and potentials.

1.3 Categories and Features of VR

1.3.1 Categories of VR

VR is generally divided into the following categories: fully immersive VR, semi-immersive VR, desktop VR, augmented reality (AR) and mixed reality (MR).

1.3.1.1 VR Fully Immersive VR

Fully immersive VR gives users the most realistic simulation experience, allowing users to interact with virtual users via HMDs, gloves, body trackers and other sensors. Users can see, hear and feel everything in the virtual world as if they are actually there.

The realization of fully immersive VR requires several core components. Firstly, VR HMD is required. It can project high-definition virtual images to users, making them feel they are in a virtual environment. Gloves and body trackers are also required. They can track users' hand and body movements, which can achieve more realistic interactive experiences. Furthermore, sound is quite necessary. VR devices are generally equipped with multiple speakers, which can simulate sound effects in a real environment, improving users' sense of immersion.

The dominant feature of fully immersive VR is that it can bring users an extremely real experience. However, it requires considerable costs for equipment, as well as high requirements for computer graphics processing capabilities and bandwidth.

1.3.1.2 VR Semi-immersive VR

Semi-immersive VR provides users with a partially virtual environment. It will not only give users the perception of being in a different reality when they focus on the digital image, but also allows users to remain connected to their physical surroundings.

Semi-immersive VR requires large screens, projectors, stereoscopic displays and other equipment, projecting scenes in the virtual world onto the screens around users. Users can have virtual experiences via external devices such as controllers or gamepads. However, these devices usually do not provide physical sensations and motion sensing.

Compared with fully immersive VR, semi-immersive VR has lower cost and more user-friendly. Since it does not need high-end HMDs and sensors, it can be more easily accepted and used by the public.

Differ from AR and MR, semi-immersive VR generally does not involve interacting virtual elements with the real world, but focuses more on providing an immersive experience of the virtual world. Therefore, semi-immersive VR is normally regarded as a VR-based platform for entertainment and gaming rather than a technical tool for application fields.

1.3.1.3 Desktop VR

Desktop VR has the lowest cost and is the most user-friendly compared with fully immersive VR and semi-immersive VR. VR experiences provided by desktop VR are achieved by VR apps on the screen of a computer or smartphone. Users require to wear HMDs or use gamepads to interact with virtual environments.

The interaction method of desktop VR is simpler and more intuitive. Users only need to use conventional devices such as mouses, keyboards or gamepads to complete interactions. In addition, desktop VR can also be combined with other technologies including virtual assistants and voice control to enhance interactive experiences.

Due to its limited provision of virtual reality experiences, in some highly immersive application scenarios, desktop VR may not be able to provide a qualified virtual reality experience.

1.3.1.4 Augmented Reality

Augmented reality is a VR-related technology. It combines computer-generated virtual images with physical environments in the real world, so that users can see virtual images in the real world. Unlike virtual reality, augmented reality does not completely replace the real world, but instead integrates the virtual world with the real world to strengthen users' sensory experience.

There are two approaches to achieve augmented reality. One is utilizing mobile phones or tablet computers, and the other is using AR glasses or HMDs. The latter can provide a more immersive AR experience because they can overlay virtual images more accurately on the real world and track users' head and body movements to better adjust the position and size of the virtual images.

1.3.1.5 Mixed Reality

Mixed reality is a technology that interacts virtual elements with objects in the real world. Differ from fully immersive VR and semi-immersive VR, MR allows users to seamlessly switch between virtuality and reality, and perceive the existence of both simultaneously, creating a more realistic virtual experience. Compared with AR, MR can more accurately combine virtual elements with objects in the real world to create new, real and mixed experiences.

Mixed reality utilizes specialized HMDs and sensor devices to interact users' body and gestures with virtual elements and provide high-quality stereo sound and visual effects. Compared with desktop VR and AR, MR may provide more immersive experiences because it can create the virtual world with a sense of space and depth. Users can move freely and interact with virtual elements there. Compared with fully immersive

VR and semi-immersive VR, the experience provided by MR is more natural and comfortable. The reason is that users can perceive the existence of the real world without being completely disconnected from reality. Moreover, compared with AR, MR provides more virtual elements which are more accurately combined with objects in the real world.

1.3.2 Features of VR

As a human-computer interaction technology, VR has the following notable features compared with other forms of computer graphics and interaction methods:

1. Immersive experience: Virtual reality allows users to experience immersive experiences and bring them into the virtual world. They are free to explore virtual environments to gain a more intuitive and in-depth understanding.

2. Multi-sensory interaction: Virtual reality can provide multi-sensory interaction methods, including vision, hearing, touch and smell. Therefore, users can perceive virtual environments more comprehensively and enhance the sense of immersion.

3. Real-time interaction: Virtual reality can respond to users' behaviors in real time. Hence, they can obtain more natural and realistic experiences in virtual environments. Users can have real-time interaction with virtual environments through handles and HDMs, making virtual

environments more vivid.

4. Customizability: Virtual reality can be customized according to different application requirements, including scenes, objects, interaction methods, and response methods in virtual environments.

1.4 Application Value of VR

1.4.1 Innovative Interactive Method

VR provides a completely new method of interaction, which is considerably different from the traditional way of interaction. It provides users with an immersive interactive experience through HMDs, controllers, and sensors. Users can interact with the virtual world via body movements and gestures instead of traditional input devices such as mouses, keyboards or touch screens which cannot provide direct communication and interaction with virtual environments. This limits users' interactive experiences. In contrast, the interaction methods of VR can interact with virtual environments more intuitively and naturally, giving users immersive feelings.

1.4.2 Improve Efficiency and Reduce Costs

VR technology can improve efficiency and reduce costs in many ways. It has been widely used in the medical field. Eleven (48%) relevant papers in 2016 used virtual educational technology for laparoscopic surgery training. Learning was improved using virtual reality in 17 (74%) studies. Twenty (87%) studies reported higher accuracy in medical practice for people trained in VR [3].

Above all, VR technology can reduce demands for physical space. A partial of operations in traditional physical space may require a large amount of physical space and equipment. VR technology can achieve those operations in virtual space without demands for actual physical space, reducing costs and improving efficiency.

Besides, VR technology can also improve the efficiency of remote collaboration. Traditional remote collaboration usually requires to be carried out through telephones, emails or video conferences. However, these methods may have problems such as untimely information transmission and low communication efficiency. VR technology can make remote collaboration more intuitive and efficient by collaborating in virtual space.

Furthermore, VR technology also plays a role in reducing production costs. It can be simulated and tested in virtual space instead of in an actual environment, saving a lot of production costs.

Lastly, VR technology can improve training efficiency. It can provide a more vivid and intuitive training experience by simulating real scenes, improving training efficiency and reducing training costs.

1.4.3 Enhance Users' Experiences

VR technology can provide users with a more immersive experience, enabling them to experience a more real environment and scenario. Therefore, users' sense of participation and experience are enhanced.

In the field of tourism, culture and education, applications of VR technology allow users to experience scenic spots, cultural heritage and knowledge in person, achieving more vivid teaching effects. In the field of games, VR technology can create more realistic and exciting game experiences for players and enhance the entertainment and interactivity of games.

The application of VR technology can promote innovation in various industries, achieving more efficient, more convenient, safer and more ergonomic workflows. For example, in the automobile manufacturing industry, VR technology allows engineers to design and optimize automobile components in a simulated environment. This can greatly reduce errors and costs in actual manufacturing processes, and speed up the launch time of new models. For the medical industry, VR technology can be used to train and educate medical staff, as well as simulate surgery and operation scenarios, improving the accuracy and safety of operations. It can also be used for therapy and rehabilitation to improve treatment effects for patients.

Moreover, VR technology can also promote digital transformation in architectural design, cultural heritage protection and tourism. By using the technology, faster and more accurate simulation, design and display can be achieved in those industries, improving efficiency and experiences. For example, in the field of architectural design, VR technology allow designers and customers to jointly explore and adjust design schemes in virtual space, speeding up project processes and ensuring customer satisfaction with final results.

2 Analysis of Key Technologies and Applications of VR

2.1Key Technologies of VR

The key technologies of VR cover many aspects, including the three-dimensional modeling technology, stereoscopic display technology, human-computer interaction technology and collision detection technology. The continuous development and innovation of these technologies not only brings more realistic visual and auditory experiences to VR, but also makes VR more closely integrated with other technologies.

The stereoscopic display technology is an important part of VR, involving a variety of technologies, such as optics and screens. VR optics has gone through three stages, including the aspheric lens, Fresnel lens and Pancake folding optical path. The Fresnel Lens has advantages of low costs and controllable imaging quality. Its design principle is to remove the part of light that travels in a straight line in the lens, and only retain the curved surface of the lens for refracting light. While retaining the optical characteristics of conventional lenses, the thickness of the lens is greatly reduced to achieve lightweight lenses. However, since this solution needs to place the screen at the near focal plane of the lens, the distance between the lens and the screen is longer, resulting in a larger volume of the entire optical module. In addition, since the Fresnel lens adopts a single-layer lens design, its physical properties lead to problems such as blurred edges of images, easy distortion, and inability to adjust the diopter.

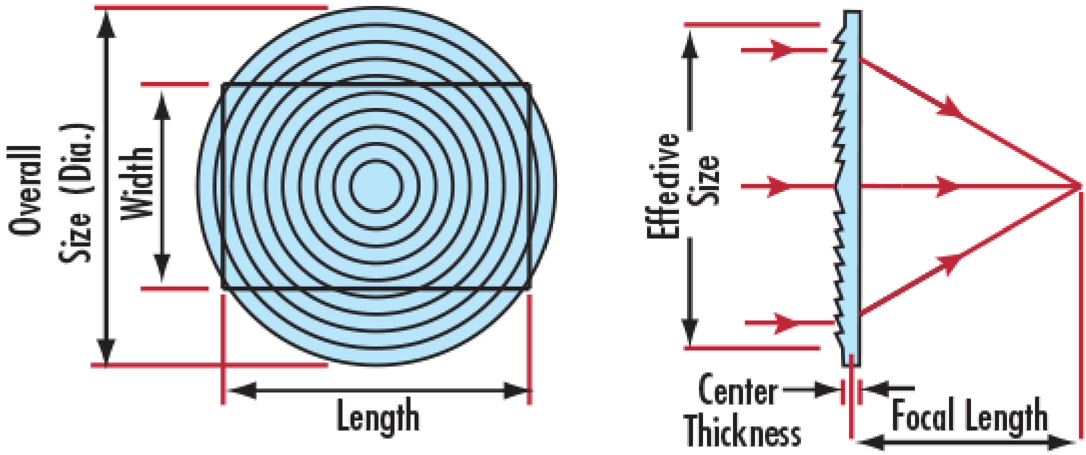

Fig. 2 Schematic diagram of Fresnel lens

In this context, the Pancake optical solution emerged as times require, and has gradually become the development and evolution direction of consumer-grade VR optics. Based on the principle of folded optical path, this solution can not only achieve ultra-short optical focus imaging, greatly reducing the thickness of lenses and the volume of HMDs, but also overcome the edge blur and distortion of the traditional Fresnel lens optical solution, effectively reducing the visual staying phenomenon to achieve a zero-distortion, full-range, and high-definition visual experience. Leading companies represented by Meta, Apple, Pico and Huawei have launched or will soon launch VR HMDs with Pancake as the optical solution. In the next three to five years, Pancake will become the preferred optical solution for consumer VR.

The core design idea of the Pancake optical solution is to fold optical paths through reflection and refraction of polarized light. The Pancake optical solution, also known as the folded optical path solution, is a kind of VR short-focus optical solution. The principle of this solution is that after the image source, emitted by the display screen, enters lenses with the transflective function, light turns back and forth among lenses, 1/4 phase retarder and reflective polarizer, and finally enters the human eye after exiting from the reflective polarizer, as shown in Fig. 3. That is to say, this solution uses folded optical elements to make light travel the same distance in narrower space, “folding” the original optical path, so as to realize the compression of the space between the optical lens and the display screen, and then significantly reduce the size of VR HMD. Through this optical solution, the size of VR HMD can be theoretically reduced to 1/4 in the Fresnel lens solution.

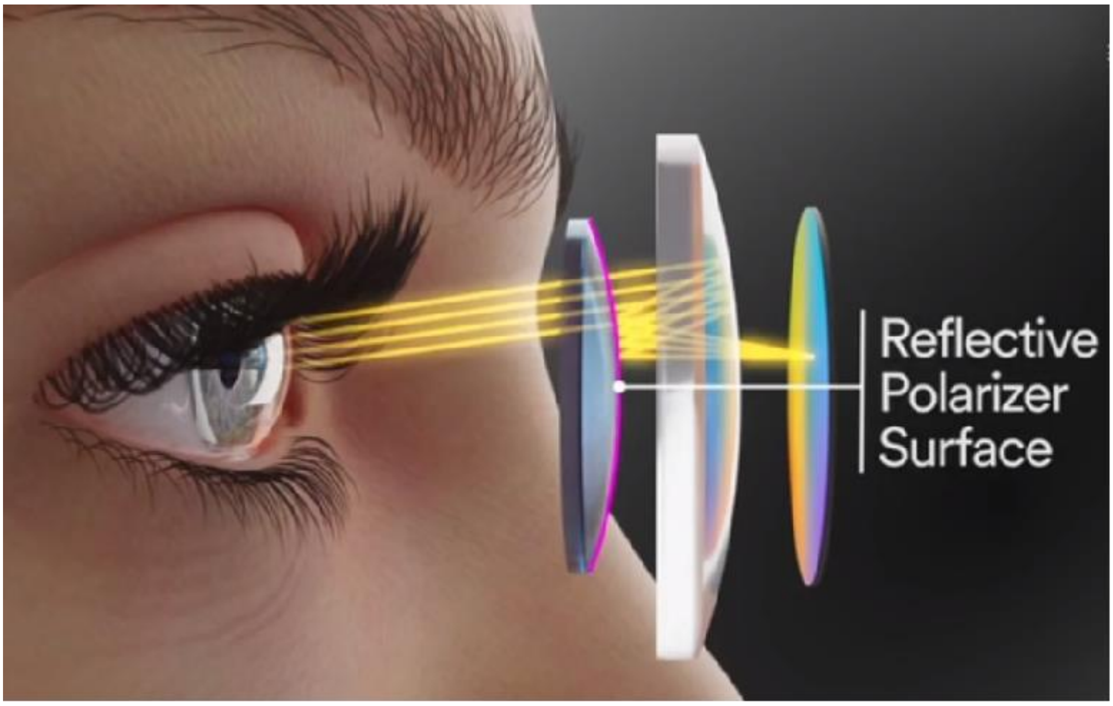

Fig. 3. Pancake optical solution

The biggest advantage of the Pancake optical solution is that it uses multiple foldbacks to expand the total length of the optical path, effectively compressing the distance between the display screen and the optical lens, thereby greatly reducing the weight and volume of the VR HMD, and significantly improving the wearing comfort and usage duration of products. Compared with Fresnel optics, the analytical ability of Pancake optics has been improved by 50%. Besides, it overcomes the blurring and distortion of the edge of the field of view inherent in Fresnel optics, effectively reduces edge glare, and brings a clear experience in the entire visual field.

In terms of the screen, the current mainstream configuration is Fast-LCD superimposing Mini LED backlight technology. It can not only solve the problem of light leakage, but also further improve display performance.

The improved Fast-LCD technology utilizes a new liquid crystal material (ferroelectric liquid crystal material) with overdrive technology to effectively increase the refresh rate to 75Hz to 90Hz. Besides, the response speed has been significantly improved, greatly shortening the distance from the OLED. It also has high mass production stability and yield. However, the color display on screens of Fast-LCD is not as full and bright as that on OLED screens, and it is prone to light leakage. In addition, how to balance power consumption and resolution is another challenge that Fast-LCD requires to face.

As far as the interaction technology is concerned, it still mainly relies on the handle for operation. However, functions such as gesture recognition and eye tracking are also gradually becoming popular, making interaction methods develop in a more natural direction.

At present, there are three solutions for gesture recognition, namely sensors, RGB cameras and three-dimensional cameras. If more accurate and detailed movements of the hands are required, there are glove solutions relying on sensors as well as bare-hand recognition solutions relying on computer vision. For example, the patent of Apple Inc. for "IMU-based gloves" shows that the gloves include multiple IMUs which may include one or more motion sensors that can measure inertial motions of corresponding knuckles. In some examples, in addition to a magnetometer to determine the direction of a geomagnetic field, the gloves may also include a plurality of electrodes for capacitive touch or contact sensing among fingertips.

Quest is a typical solution for computer vision, adopting a black and white first-person camera to track hand nodes, without depth measurement sensors. At that time, monocular RGB cameras using neural network algorithms was a common gesture recognition solution on the market. However, it was difficult to directly recognize three-dimensional gestures, which required utilizing key point regression and real-time attitude algorithms. Besides, it was difficult to achieve coherence and low jitter in terms of time. Therefore, FRL proposed a gesture tracking solution based on four black and white cameras. This solution did not require a depth camera, while demanding less computing power and power consumption. It could run stably under the influence of variables such as dark light and the shape of hands. And, the latency and jitter of the solution are low enough. Besides, it was equipped with four simultaneous VGA wide-angle cameras adopting equidistant projection models. The FOV of each camera could reach 150° (width) * 120° (height) x*175° (diagonal). The parameters of light are determined by the angle between the main axis of the cameras. Therefore, it is more suitable for predicting the distance of hand joint points rather than the depth.

A 3D camera, a camera module including depth information sensors, can effectively improve positioning accuracy and optimize the experience of using a VR HMD. There are three mainstream solutions for 3D cameras, namely structured light, TOF (Time of Flight) and binocular stereo imaging. The common working principle of the three solutions is that an infrared laser transmitter emits near-infrared light. Through reflection, the infrared information is received by a CMOS image processor for infrared light which aggregates the information to image processing chips to obtain three-dimensional data. Therefore, spatial positioning is achieved. The difference among the three lies in the method of emitting near-infrared light to obtain three-dimensional data. The structured light emits speckle, TOF emits surface source, and binocular stereo imaging uses binocular matching to perform the parallax algorithm. TOF is featured with fast response speed, high-accuracy depth information, long recognition distance and large recognition range, as well as high resistance to ambient light. Therefore, it is a feasible solution for 3D vision at mobile end. The structured light is also adopted by some manufacturers due to its mature technology and rich industrial products. Binocular stereoscopic imaging is a relatively new technology. Therefore, there are fewer manufacturers involved. It is more suitably applied in strong light conditions outdoors and high resolution, and is commonly utilized in robot vision and automatic driving.

Eye tracking is a key function of AR/VR HMDs, which can enrich interactions among users. It is also the basis of dynamic foveated rendering technology, enhancing the visual perception of AR/VR. Since the quality of visual information gathered by eyes is the highest in a small area of the field of view (namely the fovea area), vision degrades rapidly beyond this area. Therefore, rendering the central area where a user is looking with high precision and other areas with low resolution can reduce the shading load of GPU and maintain a high frame rate as well, better allocating limited computing resources. Besides, based on the gaze point and gesture recognition, users can interact more accurately with a virtual environment, realizing grasping, typing in the air and other functions. The foveated rendering is divided into fixed one and dynamic one. With fixed foveated rendering, the XR device will preset the central part of a display as the high-quality rendering area. Therefore, the gaze point of users must always be in that area. Their sight is diverted by turning the head. The dynamic foveated rendering captures the gaze point as the eye moves for more accurate real-time rendering. Tobii did a series of benchmark tests on different devices and environments. The test data showed that dynamic foveated rendering could reduce the GPU shading load by two times compared with the fixed foveated rendering, and could more effectively maintain high frame rates and optimize system resources.

The basic principle of eye tracking technology is not complicated. And there is more than one way to achieve the technology. At present, the most common method is the pupillary central corneal reflex (PCCR)[4] adopted by a technology provider Tobii. PCCR mainly includes three modules, including the eye-tracking cameras, illuminators, and model algorithm. The near-infrared light created by the illuminators is reflected by the cornea to form flickering points. The eye-tracking cameras take high-resolution images of the user's eyes, and then locates the flickering points and pupils in real time through algorithm analysis. Finally, the eyes' position and gaze point are calculated using a sophisticated 3D eye model algorithm as shown in Fig. 4.

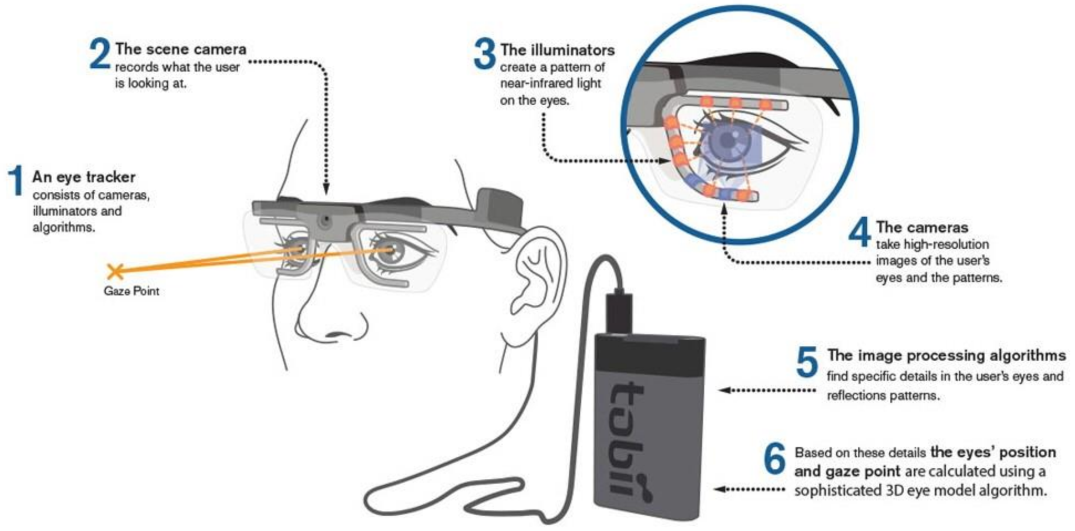

Fig. 4 Eye tracking diagram

The development and advancement of those key technologies has promoted VR continuously, laying a foundation for the wide application of VR.

2.2 Combination and Applications of VR Technology and Other Technologies

VR technology has been widely used in games, education, medical therapy, military, entertainment and other fields. However, VR technology itself has some limitations, such as expensive equipment, single interaction method, and difficult content production. In order to overcome these limitations and improve the performance and experience of VR technology, the combination of VR technology and other technologies has become an important development direction, such as combining with AI, AR and the Internet of Things (IoT).

AI technology, an information technology, that endows technological devices with perception and intelligent behavior. Utilizing AI technology, VR can provide a personalized interactive experience based on users' historical data and habits. For example, it recommends contents such as games, music, and movies based on users' preferences, or provides personalized services based on users' interaction methods and voice commands. Besides, virtual reality scenes can be quickly generated, making VR applications more diverse based on AI. For instance, the deep learning technology can be utilized to automatically extract features from a real environment to generate virtual scenes, improving the realism and interactivity of VR applications. Moreover, virtual characters can be endowed with more intelligent behavior and decision-making capabilities via AI technology. For example, machine learning technology can be made use of to train virtual characters to perform emotion recognition and natural language processing. Hence, they can have a more realistic and humanized performance, enhancing users' sense of immersion. Also, VR can automatically recommend relevant VR contents and experiences based on users' interests, behaviors and locations. For example, based on machine learning and natural language processing technology, it is possible to automatically recommend suitable VR games, applications and experiences based on users' voice commands, behaviors and habits.

AR technology is an information technology that superimposes virtual information on real environments, allowing users to see virtual information there. AR technology can be combined with VR technology to form mixed reality technology, so users can see real information in a virtual environment, vice versa. This realizes the integration of virtuality and reality, and expands users' perception range and interaction methods. Besides, the combination enables users to directly interact with a virtual reality environment in real scenes, such as adding virtual objects in a real room for interaction. AR can realize the collision detection and interaction effect between real and virtual objects. It can also superimpose virtual objects or scenes into the real world, allowing users to feel the existence of virtual objects in real environments, and realizing seamless connection between virtuality and reality. For example, projecting avatars into real scenes, make them appear to be real. Moreover, a more precise navigation experience can also be created. By superimposing virtual information into the real world, more intuitive and accurate navigation information can be provided. For example, using AR glasses to navigate in the city can display the surrounding buildings and road sign information in real time. Also, AR can provide a more intuitive way of human-computer interaction. For example, users can control a virtual environment more naturally via manipulating virtual objects by wearing AR glasses or handheld devices.

The combination of VR technology and blockchain technology is an emerging field that can help VR platforms improve security, as well as efficiency of data sharing and content transactions. Users can use encrypted digital currency to purchase virtual items, digital assets, games and other contents on VR platforms. Blockchain technology can provide secure payment and transaction records. It can also realize a decentralized content market, transforming the ownership and copyright of VR contents into digital assets, and recording all transaction and authorization records on the blockchain. This can help VR content developers better manage and protect their creations. Besides, the technology can help create a fully decentralized virtual reality environment where all interactions and transactions can be recorded and managed through blockchains. This can improve safety and transparency in virtual reality environments. Moreover, blockchain technology can help create decentralized virtual reality social networks where users can exchange personal data, virtual items and digital currencies. This can help users better protect their personal privacy and security.

5G technology is a mobile communication technology featuring high speed, low latency, high reliability, and high connection density. It can provide faster data transmission speed and lower latency, which makes VR applications more interactive and user experience smoother. With the high-speed and stable data transmission of 5G, more users can be supported to enter the same VR scene simultaneously, which will greatly enrich the scenes and contents of VR applications. The combination of 5G and VR technology, a richer and more realistic remote collaboration and education platform can be created, realizing cross-regional and border remote collaborations and education. In addition, the combination enables VR applications to achieve more real-time interactions via high-speed and stable data transmission. Users can interact with other users in a virtual environment in real time. Besides, different virtual scenes and experiences can be customized according to users' interests and habits. Last but not least, 5G technology can provide more efficient and stable network infrastructure for cloud VR. Users can access to cloud VR through terminal devices (such as mobile phones, TVs, PCs, etc.), having a smoother virtual reality experience.

3 Application Fields and Case Studies of VR

VR technology is widely used, and covers a wide range of industries, including gaming and entertainment, education, medical therapy, and industry. As shown in Fig.5, the gaming and entertainment industry takes the largest account of VR applications, reaching as much as 40%. This is followed by the education and training industry, with the percentage of 15. The medical and health industry occupies the least proportion, which is 5. In addition, VR is widely used in architectural design, real estate sales, tourism, aerospace, military and other industries.

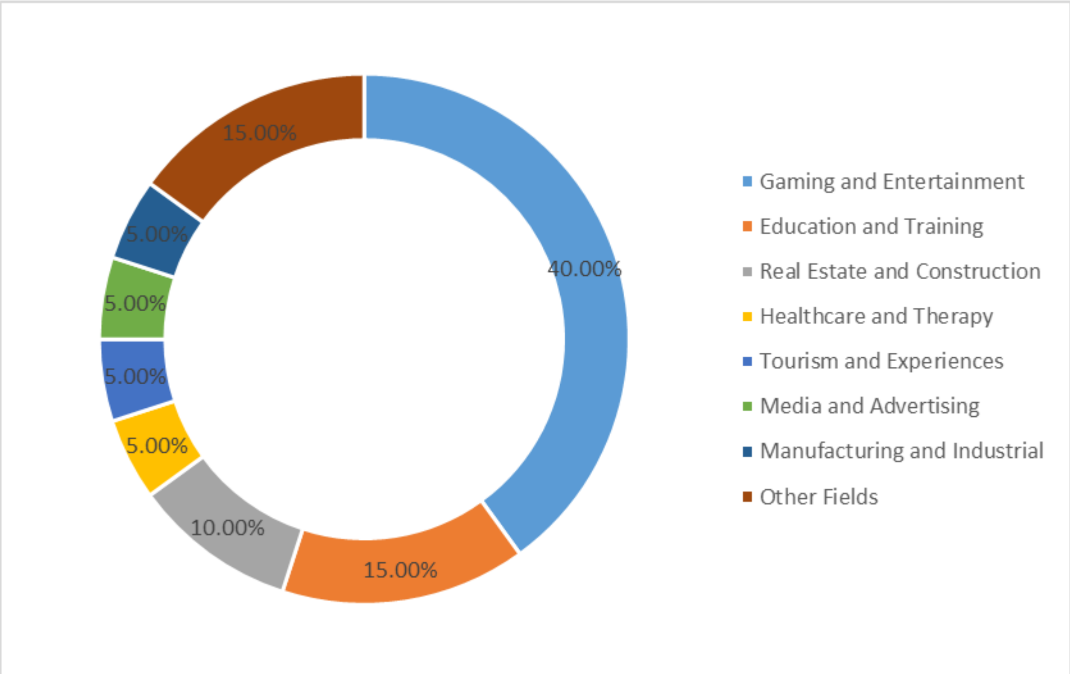

Fig.5 Market share distribution map of VR industries

3.1 Application of AR in Gaming and Entertainment

With the largest proportion in the VR market, the gaming and entertainment industry also has the most extensive VR applications, involving video games, theme parks, and experience halls.

In terms of video games, VR games can provide players with a more realistic and immersive experience than traditional ones. This is due to the features of VR technology. By placing players in a virtual environment, VR technology can simulate realistic visual, auditory, tactile and other sensory experiences, improving the realism and interactivity of games.

Currently, the VR game market is growing rapidly. According to a report released by the market research firm SuperData Research, the global market value for VR games reached $5.26 billion in 2019 and is expected to reach $9.69 billion by 2023. It is obviously to see that VR games play an important role in the game market.

In the field of VR games, many games have successfully utilized VR technology to provide a more realistic and immersive experience. For example, Beat Saber is a rhythm game where players require to use VR headsets and controllers to move their hands to the rhythm of music, and to chop flying blocks. Resident Evil 7: Biohazard is also a very classic VR game. It allows players to experience the horror scenes in a virtual reality game environment, which improves the immersion and interactivity of the game. In addition, games such as Half-Life and Superhot have also launched their own VR versions, allowing players to experience scenes and actions more realistically, and making the game experiences more immersive.

Besides of video games, VR technology is also widely used in theme parks and experience halls. It allows tourists to have a deeper understanding of and participate in the scenes presented by theme parks or experience halls, obtaining more realistic experiences. The utilization of VR technology provides tourists with the immersive experiences different from traditional amusement projects.

For theme parks, VR technology is widely used in the design of various exciting projects, such as roller coasters and flying experiences. Based on VR technology, tourists can experience more real and exciting scenes. It enhances the entertainment and interactivity of the projects, and provides tourists with richer amusement experiences.

For experience halls, VR technology is applied to display various virtual scenes, such as scientific exploration and cultural tourism. Through the application of VR technology, tourists can experience various scenes personally. For example, tourists can explore ancient cultures with the help of VR technology, or experience weightlessness in space. This kind of experience not only enriches the knowledge and experience of tourists, but also enhances their sense of participation and satisfaction. Besides, tourists can obtain richer experiences and knowledge in a short time.

Last but not least, the application of VR technology can bring more revenues and business opportunities to theme parks and experience halls.

Various new projects and activities in theme parks and experience halls can be better promoted utilizing VR, attracting more tourists to visit and experience. Selling VR equipment and related peripheral products will also bring revenues.

3.2 Application of AR in Education and Training

In the field of education and training, the application of VR has increasingly attracted people's attention. It can provide students and employees with immersive learning and training experiences, improving learning and training effects.

In the experiment teaching, VR can provide students with a virtual laboratory environment, allowing them to conduct various experiments without concerned about safety issues. For example, teachers can teach chemistry, biology, physics and other subjects in virtual laboratories, helping students better understand experimental procedures and data results.

In addition, VR can provide a real language learning environment for students to study foreign languages. Students can practice language skills and engage in cultural exchanges by interacting with virtual characters. They can also use VR technology to visit simulated foreign countries, conduct simulated business transactions and participate in cultural activities. This can improve their language skills and boost their selfconfidence.

Besides, VR can provide students and teachers with the opportunity to visit remote places without leaving their homes. For example, students can use VR technology to visit remote museums, natural parks, and cultural sites with zero cost of travel and time. This helps increase the interest and knowledge level of students.

For training employees, VR can simulate real-world working environments, providing employees with training and skill development opportunities. For example, VR can be used to provide virtual training in occupations that involve hazardous equipment, reducing the risk of injury in real-world environments. VR can also be used to simulate complex workflows, helping employees better understand and master task processes.

3.3 Application of AR in Healthcare and Therapy

In recent years, VR has shown great potentials in the healthcare and therapy industry. It has been widely used in medical training, illness experience, pain relief, rehabilitation training, and psychotherapy.

In terms of medical training, VR can provide medical students and professionals with a safe and controlled environment to practice surgeries. VR simulations can replicate real-life scenarios and provide users with instant feedback on their performance. This improves their skills and confidence, and reduces the risks of practicing on live patients.

In terms of the illness experience, virtual reality can help medical students and doctors better understand and experience a patient’s disease. For example, VR can simulate the experience of blindness and help doctors better understand the life experience of blind patients, increasing their attention and sensitivity to blind patients.

In terms of pain relief, VR can distract patients from pain and provide a calming environment. Studies have shown that patients can distract their attention and feelings from pain via VR technology, thereby reducing pain. It is currently used in the treatment of burns to distract patients’ attention during wound care. It is also used in dental offices to reduce anxiety during dental treatment.

In terms of rehabilitation training, VR can provide patients with fun and attractive ways to practice and improve their moving skills. VR games could be used to help stroke patients regain arm and hand movements. VR simulations can also be used to help patients recover from injuries caused by doing exercises or car accidents.

In terms of psychotherapy, VR can provide exposure therapy for people with anxiety or phobias. They can be gradually exposed to their fears in a controlled and safe environment. This can help them overcome their anxiety or phobia. Moreover, VR is being used to treat post-traumatic stress disorder (PTSD), simulating a traumatic event in a controlled environment, allowing patients to confront and process their emotions.

3.4 Application of VR in Industry and Manufacturing

VR is widely applied in the industry and manufacturing sector, which can help enterprises improve efficiency, reduce costs and enhance security.

Above all, VR can be used in design and simulation. Manufacturing enterprises can utilize VR technology to design and simulate the prototype of products. Therefore, they can verify and test the products before manufacturing. This cannot only save time and costs, but also assist enterprises in promoting their products to markets.

Secondly, VR technology can be used to training and operation. Enterprises may provide employees with real virtual operation experience based on VR technology. Hence, employees can master necessary skills and knowledge more quickly. For example, manufacturing enterprises use VR technology to provide machine operators with simulation training so as to improve the efficiency of production lines and reduce error rates.

In addition, VR technology can be applied to real-time data analysis and monitoring. Enterprises may use VR technology to monitor the operation of production lines, the condition of equipment and workers' health status, as well as make timely adjustments and decisions. This can improve production efficiency and quality, and reduce workplace accidents.

Lastly, VR technology can be used to remote coordination and communication. Enterprises may use VR technology to realize remote coordination and communication among employees in different working places. Therefore, they can cooperate better and share resources, saving time and costs, as well as enhancing working efficiency.

3.5 Application of VR in Architectural Design

In recent years, with the development of VR technology, it has been widely used in the architectural design sector, providing architects and designers with a brand-new perspective and tool to better display and present their design concepts. VR can quickly and intuitively convey the information of building models to users. When constructing an architectural model, VR technology fulfills two requirements. First, it achieves parametric modeling. Second, it makes the model more intelligent and convenient when being adjusted and constructed. When making an architectural model, it is not just a simple combination of points, lines, and surfaces, but a three-dimensional model obtained by reorganizing various information. This three-dimensional combination of information provides users with a more intuitive interpretation of information. Using the projection relationship, Users can choose any surface they want to know and operate, so that they can see the section effect of the architectural model. Besides, it can also estimate the required materials according to the doors and windows in the model. As far as the intelligence of model modification is concerned, since the modeling data information is interrelated, other parts of the model will be automatically changed when one part is modified.

Under the traditional education mode of architectural design teaching, architectural design courses are designed by teachers. In order to present more intuitively, teachers will use two-dimensional pictures to carry out teaching. When viewing two-dimensional pictures, a majority of students cannot understand three-dimensional diagrams in detail. So, it is difficult for students to learn three-dimensional knowledge. Therefore, VR and architectural design are combined in current teaching based on VR technology. Utilizing the technology to display the key nodes in design can help students better understand the structure of three-dimensional diagrams. After viewing the animation presentation for dynamic decoration, students can design by themselves, and better master difficult problems. Besides, they can learn knowledge better and faster, and use it to solve practical problems. In the development of social modernization, people’s aesthetic requirements are gradually changing. The teaching of architectural design should be combined with the requirements, and improved based on VR technology. VR technology is used to realize the flexible transformation of teaching, so students can understand the application of architectural design more intuitively. In addition, colleges and universities can use VR technology to promote the development of teaching work.

In addition to its role in architectural design, VR technology creates more and more possibilities in heritage conservation. Using VR to display architectural heritage, while ensuring the authenticity as much as possible, has many outstanding advantages. It can reduce damage to architectural heritage, which may be caused by natural or human factors. Besides of that, when it is inconvenient for people to travel long distances to appreciate beautiful buildings, VR can be used to achieve this. This increases the frequency of architectural heritage in people’s vision, which is of great benefit to the protection and inheritance of architectural heritage.

VR technology has made a great contribution to building construction. It can simulate the operation sequence and steps at the construction site, allowing managers to supervise and guide more intuitively, discover and solve problems in time, and ensure that everything is normal at the site. In addition, VR technology makes the construction process be presented to users in a more subtle way. This allows operators to have a certain understanding of the site before construction, so as to improve the working efficiency. When people are at the construction site, they can better understand the importance of safety and be more alert to the occurrence of danger. Moreover, VR can be used to test building components to ensure safety.

3.6 Application of VR in Tourism and Culture

VR technology is widely applied in the sector of tourism and culture.

It can be used to create virtual travel experiences, allowing users to explore different locations, cultures and landscapes through VR devices without actually traveling. In addition, the technology can help the tourism industry to achieve better promotion, allowing tourists to experience the atmosphere and characteristics of scenic spots in advance, thereby improving their interests. Moreover, VR can be used in cultural and artistic sector. For instance, it can create virtual exhibitions and artwork browsing, allowing users to appreciate artworks and cultural heritage around the world at home, providing users with richer cultural experiences.

In addition to applications in consumers, VR technology can be applied in scenic spot planning, museum exhibition design and other professional applications. In terms of scenic spot planning, VR technology can be used to visualize and simulate the planning and construction of scenic spots, helping planners and designers better understand and evaluate different design schemes, thereby optimizing planning and design. In terms of museum exhibition design, VR technology can be used to create virtual exhibitions, allowing visitors to browse museum collections and exhibits without visiting the museum in person. Besides, the technology can be used for visualization and simulation of exhibition design, helping designers to better understand and plan the exhibition layout and design effects.

3.7 Analysis of Successful Cases

3.7.1 Oculus VR

Oculus is leading the global VR HMD market. Its main product is the Oculus Rift VR HMD. Initially, Oculus crowdfunded through the Kickstarter website. In March 2014, the blueprint of VR industries outlined by Rift DK1 was favored by Meta CEO Mark Zuckerberg who acquired Oculus VR by $2 billion. Later on, with the strong support of Meta, Oculus spent tens of billions of dollars in 7 years completing the evolution from the Oculus Rift developer version, SDK, to the consumer version, and then to update versions such as Go, RiftS, Quest and Quest2. Therefore, Oculus became the benchmark for VR HMD. In 2022, Meta launched products over $1,000 for the first time, distinguishing mid-to-low-end models.

In terms of contents, Meta has formed an ecological closed loop among the content generation, technological change, and terminal release, as shown in Fig. 6. The software contents of OculusVR include two platforms: QuestStore and AppLab. QuestStore is a VR content distribution platform, targeting professional VR game practitioners including independent studios, game studios, and distribution companies. AppLab is based on player communities and focuses more on cutting-edge contents. Its applications are not displayed in the QuestStore. Developers can only share them with users through existing distribution channels by links, such as SideQuest. (The SideQuest platform mainly accepts games that are not launched in QuestStore). Horizontalworlds welcomes creators to build a virtual world. It is a social network where content creators and users interact synchronously, forming a spreading effect.

Since released in 2019, QuestStore has exceeded $1 billion in revenue. As of February 2022, the total number of applications in QuestStore surpassed 400, 60% of which were games. Among them, eight surpassed 20 million in revenue, 14 surpassed 10 million, and over 120 surpassed 1 million, while only over 60 surpassed 1 million in February 2021.

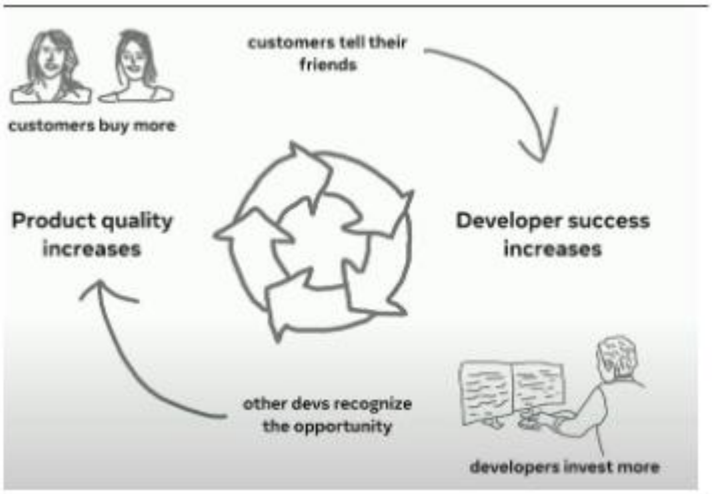

Fig.6 Underlying logistics of Meta ecology

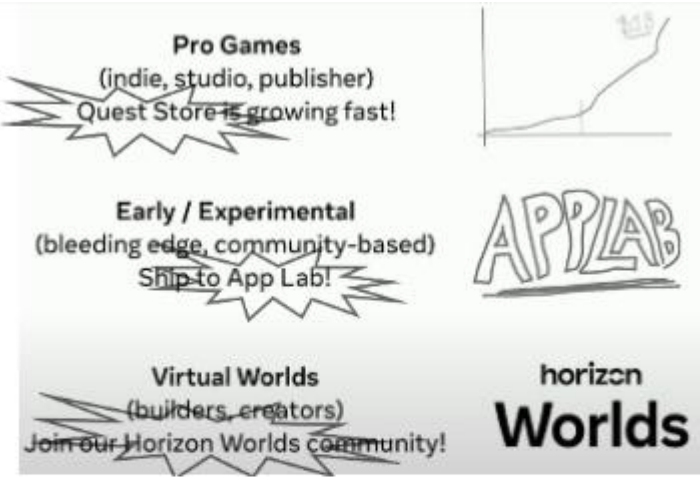

Fig.7 Three platforms of Meta for form construction

There are several key factors for the success of Oculus VR. First of all, founders of the company uphold their belief in VR technology, firmly believing that the technology will become increasingly popular and important in the future. Secondly, many of the company's team members have rich experience in game and software development, which provides solid technical support for product development. Lastly, Oculus VR is committed to working closely with developers and partners to ensure that its products and services work seamlessly with a variety of different VR applications and scenarios.

The success of Oculus VR also lies in its attractive product design. By adopting high-resolution display and excellent head-tracking technologies, Oculus Rift HMD can provide authentic and smooth VR experiences. Besides, the HMD has a comfortable fit and ergonomic design, allowing users to wear it comfortably for a long time.

Lastly, the success of Oculus VR is due to its excellent marketing strategies. The company has adopted bold marketing strategies when releasing its first product, which include raising funds via Kickstarter, and present its products in game exhibitions. Those initiatives have helped Oculus VR win increasing attention and support, laying a solid foundation for its subsequent product launches.

3.7.2 Google Earth VR

Google Earth VR, a virtual reality application, is developed by Google. It allows users to explore any place on earth in virtual reality space. Users can fly freely anywhere in the world, and view cities, ranges, rivers, buildings and landmarks in astonishing clarity.

The design of Google Earth VR aims to provide users with an immersive experience by utilizing techniques including high-definition images, 3D models, 360-degree panoramic photos and satellite images, making them feel as if they are really on the surface of the earth.

The success of Google Earth VR is due to following factors:

1. Innovative user experience: Google Earth VR creates brand-new experiences for users, allowing them to immersively explore scenic spots and landmarks around the world so as to satisfy their curiosity for tourism and exploration. Based on advanced VR technology, users can explore earth in person by wearing VR helmets and handle controllers, bringing them astonishing visual experiences.

2. Rich resources: Google Earth VR is equipped with rich data and resources of earth, covering millions of places and attractions in the world which include historical monuments, scenic spots, natural scenery and other landmarks and attractions. The resources provide users with unlimited space for them to explore and discover, allowing them to know the world better.

3. User-friendly interface design: The interface of Google Earth VR is quite user-friendly as users only need to wear VR helmets and handle controllers to explore anywhere on earth. It adopts intuitive gesture operation and icon design, allowing users to move, rotate and zoom maps easily, which facilitates users' experiences.

4. Strong sociability: Google Earth VR has strong sociability. Users can communicate and share their earth exploration experiences with other VR users via the Internet. The social nature makes Google Earth VR not just an application software, but a large-scale virtual community where users can interact with people around the world.

4 Impacts and Challenges of VR

4.1 Impacts of VR on Human Behavior and Psychology

The impact of VR on human behavior and psychology is one of the hottest topics in recent years. By providing immersive experiences and interactive methods, VR technology can make users feel everything in virtual scenarios, which brings them unprecedented sensory experiences and cognitive methods. Therefore, the impact of VR on human behavior and psychology has become a hot issue for scholars and researchers to study.

In terms of behavior, VR technology allows users to actively participate in the virtual world, and provides them with more authentic experiences. This has great application value for tasks that are hard to complete in the real world, such as risk education, training and medical treatment. In the medical sector, VR technology can be utilized to simulate surgical operations, mental treatment and rehabilitation training, allowing patients to take safer and more effective treatment. In the education sector, VR technology can be utilized to simulate experiments and real-world scenarios, so students can understand better about courses, improving their study efficiency.

In terms of psychology, VR technology can bring considerably real sensory experiences, impacting emotion and cognition of users. Studies show that, in a virtual reality environment, users' sensory experiences for virtual objects will impact their behaviors and attitudes. Moreover, VR technology can be used to provide psychological treatment, such as helping people alleviate anxiety and pressure via a virtual reality environment.

However, VR will cause some negative impacts. As VR can bring users a considerably realistic feeling, they may be addicted to it, and ignore tasks and responsibilities in real life. Besides, users may prefer to stay at home because VR can simulate all kinds of environments and experiences, which may cause long-term health problems. Moreover, wearing HMD for a long time may cause visual problems.

Therefore, VR technology is positively applied and promoted in many sectors, but users need to avoid its potential negative impacts when using it.

4.2 Impacts of VR on Economy and Culture

VR technology has extensive applications and impacts over economy and culture.

In terms of economy, VR technology is promoting the innovation and development of many industries including tourism, real estate, entertainment and education. Based on VR technology, enterprises can provide more realistic and immersive experiences to attract more consumers, improving the sales and market share of products. Besides, the technology can reduce costs of enterprises, such as reducing travel and transportation costs through VR conferences, or reducing training costs through VR training. Therefore, VR technology cannot only bring better experiences for users, but also higher economic benefits.

In terms of culture, VR technology is changing people’s ways of cultural consumption and creation. Based on VR technology, people can experience different cultures as if they are on the scene, such as visiting exhibitions via VR museums, and exploring different culture backgrounds via VR games. Besides, creators have broader creative space utilizing VR technology. For example, they can create more complex and immersive scenes by shooting VR films, or provide multi-dimensional music experiences by creating VR music. Therefore, VR technology can not only bring a more realistic cultural experience, but promote the innovation and development of cultures.

4.3 Challenges Faced by VR and Solutions

Although VR is developing rapidly, it also faces various challenges.

In terms of the display device, the mainstream VR display device used currently is the HMD. The main parameters of a HMD include viewing angle, resolution, and refresh rate, the current technological level of which cannot achieve the true visual angle of the human eye and the clarity of the retinal screen. It also puts high requirements on the power supply and computing power of computing units.

For the interactive device, slow development of gesture tracking devices has limited the popularization of VR. At present, there is a few VR devices that can be used to track the position of hands and bodies. Besides, most of them interact through handles. The interaction contents are simple and inconsistent with people's inherent habits, and the interaction methods require diversity, while interactive experiences should be more natural.

For the software, VR requires rich contents. However, there are quite a few high-quality VR contents on the market. A large number of startups choose to start from the hard software sector, while ignoring development and innovation of contents.

Lastly, VR always has the dizziness issue, which is the biggest problem for the virtual reality experience. It is a discomfort caused by the inconsistency between virtual and real scenes felt by the human eye and brain. This issue involves multiple factors, including screen refresh rate, optical distortion, display delay, positioning accuracy, and asynchronous motion.

Some effective solutions have been proposed for the above challenges.

For the issue of display devices, a solution is to utilize optical technologies to achieve a bigger viewing angle and a higher resolution. One of the optical technologies is FOVeated Rendering[5] which can be used to optimize VR rendering performance. It can not only ensure the quality of images, but also improve the frame rate and stability of VR applications. FOVeated Rendering utilizes the visual characteristics of human eyes to distinguish the high and low-resolution areas of an image. In VR application, head movements will cause users to pay different attention to areas in a scene, while FOVeated Rendering can render high-resolution areas in the focus area and low-resolution areas beyond the vision in accordance with users' focus of sight, reducing unnecessary rendering efforts and improving frame rates.

For the interaction issue, the solution is to add new sensor devices to VR devices, such as optical sensors and ultrasonic sensors. Those sensors enable more accurate and natural pose tracking. In addition, interaction devices based on gesture recognition and neural technology are under developing, such as the gesture recognition technology based on electronic electromyography (EMG) signals. EMG is a technique for measuring muscle electrical activity which can recognize gestures by detecting muscle electrical signals in arms and fingers. By integrating EMG sensors to VR devices, users can interact via natural gestures without utilizing handles and other external devices.

For issues in the software, efforts from multiple parties are required. First of all, policy guidance and investment support are required. Governments should increase investment in VR-related industries, and encourage innovative companies to invest more resources on content development by policy guidance and incentive mechanism, promoting the construction of content ecology. Secondly, an open platform is required to involve more developers and content providers to jointly create a rich and colorful VR content ecology. Besides, community construction is of great importance. Community communication and interaction can inspire more innovation and ideas to promote the development of VR contents. Also, AI technologies can be utilized to optimize content creation and recommendation, bringing them more convenience and efficiency, such as generating scenes and roles in a virtual world, and analyzing users' behaviors to better meet their demands. Last but not least, cooperation among industries is required. As VR is a multi-disciplinary field, it requires coordination and cooperation among industries to promote content development. For example, game development companies can cooperate with film production companies to move scenes and roles in a film to virtual reality, creating more realistic virtual experiences.

For the dizziness issue, there are many solutions. One solution is a prediction algorithm, proposed by Ripan Kumar Kundu et al., to reduce system delay[6]. The algorithm is LSTM (Long Short-Term Memory), bidirectional LSTM, and convolutional LSTM based on time series. It is used to predict head and body movements, and reduce motion to photon delay in VR devices. Combining the algorithm with deep learning can further reduce the errors caused by curve fitting and effectively alleviate the dizziness caused by system delay.

5 Conclusions and Visions

VR technology has developed rapidly and been widely applied in the past few years. Because it can provide users with immersive experiences, improve learning outcomes, reduce risks, and enhance medical efficiency, it has specific applications in gaming and entertainment, education, medical care and therapy, industrial manufacturing, building design, as well as tourism and culture. At present, the technology is not perfect, facing with high device costs, technical limitations, social acceptance and other challenges.

With the continuous innovation and development of VR technology, it is believed that VR will become one of the mainstream technologies in the future. Through more refined and professional technological research and development, VR technology will present more realistic and refined immersive experiences, providing more efficient and high-quality services. In addition, the application of VR technology will also be more extensive, bringing more convenience and innovation to people’s lives and work. Lastly, with the widespread application and popularization of VR technology, the impacts of it on human behaviors and psychology, as well as how to ensure the development of technology while ensuring human health and safety should be noticed.

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