中国移动 China Mobile | 研究院 CMRI

Development Trend of 6G Holographic Communication Service （2022）

China Mobile Research Institute

Content

Foreword

The development of 6G technology in the future will provide a more robust communication network, gradually making the development and application of holographic communication services possible. The white paper conducts research and analysis on the technological evolution, application scenarios, network requirements, and industrial development of holographic communication. In holography technology, three development stages of 2D, 3D, and ideal holography are proposed through the analysis and research of the existing technology. Seven typical scenarios of holographic communication services under the future 6G network are constructed, and the corresponding network requirements are preliminarily analyzed. Through the analysis of the industry market, the structure of the holographic communication industry chain is sorted out, and the development of the holographic communication business under the network is the prospect.

China Mobile will work with the industry to promote the development of holographic communication technology, expand new application scenarios, promote the maturity of the industry chain, and jointly promote the development of holographic communication services with the industry.

1. Overview of Holographic Communication Technology

1.1 Background of holographic technology

"Holography" means "all information." This concept was first proposed in 1947 and was invented by British-Hungarian-born physicist Dennis Gabor, for which he won the Nobel Prize in Physics in 1971. Holographic technology uses the principles of interference and diffraction to record the reflection of an object, the amplitude, and phase information in the transmitted light wave, and then reproduce the actual three-dimensional image of the object. It has close links with physics, computer science, electronic communication, and human-computer interaction.

1.1.1 Academic Research Field of Holography

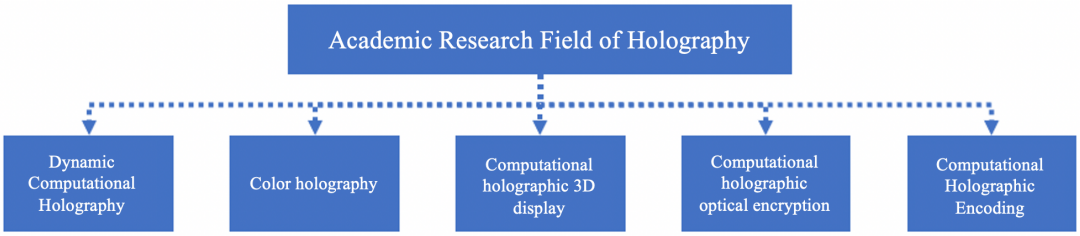


Figure 1 Holography academic research direction

With the maturity of computer technology, people have expanded the fields of dynamic computational holography and its operations, color holography, computational holographic three-dimensional display, computational holographic optical encryption, and computational holographic coding. Researchers are working hard to break through the constraints of computing power, equipment, and algorithms and develop the ideal holographic three-dimensional display.

1.1.2 Derivative fields of holographic technology

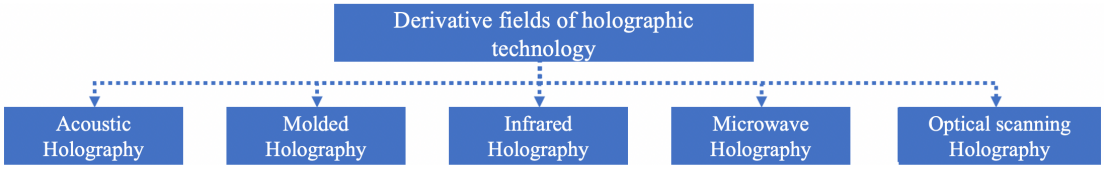


Figure 2 Derivative fields of holographic technology

The proposal of holographic technology is not only the invention of technology but also the proposal of an idea. With the technical principle of holographic technology, the concept of recording object information through the superposition and interference of object waves and reference waves has been applied to many other fields. Some similar areas have been derived; the more representative ones are acoustic holography, molded holography, infrared holography [1], microwave holography, and optical scanning holography [2], and so on.

1.1.3 Holographic Imaging Technology

According to the different imaging principles and presentation effects, holographic imaging technology is divided into 2D holography, 3D holography, and ideal holography. 2D holography refers to relatively simple reflection, refraction principles, or visual residues to create naked-eye three-dimensional effects with limited viewing angles. Includes air imaging, rotating fan screens, fog screens/fog screens, and stereo raster displays. 3D holography is the current holographic display technology closest to the ideal holographic display effect. The technologies mainly include holographic light field, point cloud, ionized air, optical tweezers, acoustic tweezers, and volume holography technology. The ideal holography is natural narrow holography based on computational holograms, and the holographic display of 3D objects is completed through the production and reproduction of computational holograms.

1.2 Development stage of holographic technology

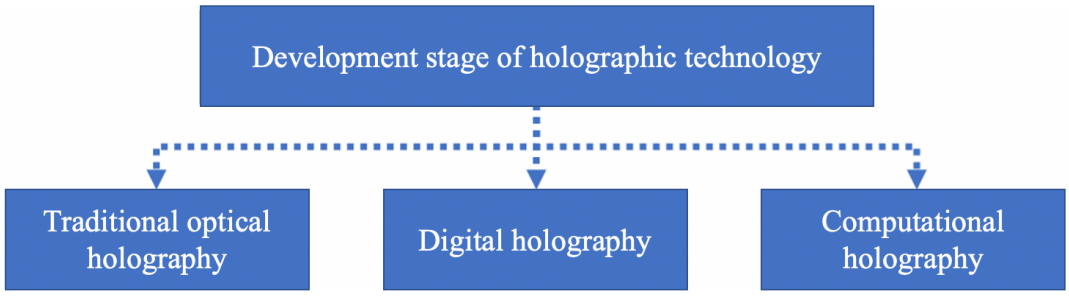
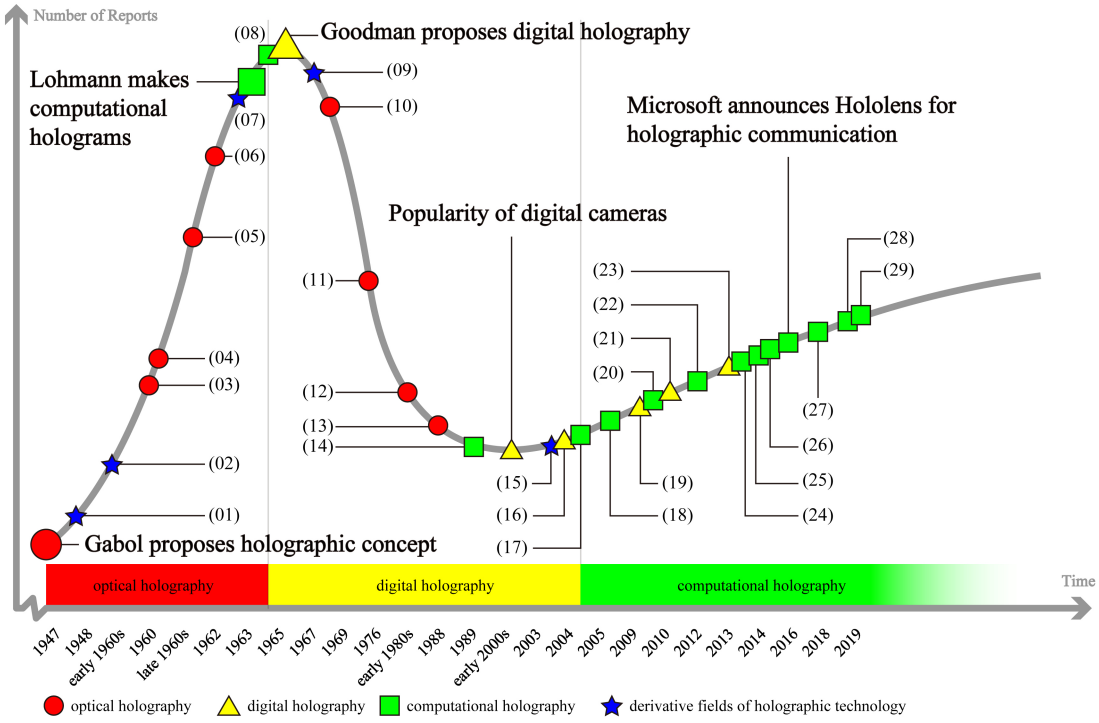


Figure 3 Development stage of holographic technology

The development of holography has gone through three main stages: traditional optical holography, digital holography, and computational holography. As shown in Figure 4, the first laser came out in the late 1960s. At this time, holography technology inspired many derivative fields and reached its peak when digital holography was proposed. However, due to the immaturity of CCD and computing equipment, the research of digital holography has fallen into a low ebb. With the popularization of digital cameras and the maturity of computer technology in the early 21st century, the

branch of computational holography emerged in digital holography. Because it does not rely on physical objects but uses computers to simulate the optical distribution of things to make holograms, it has quickly become a hot research topic.



(01) Gabol proposes acoustic holography

(02) Research on microwave holography

(03) Holographic light source changed to laser

(04) Invention of the first laser

(05) Leith and Upatnieks propose laser holography

(06) Leith and Upatnieks propose off-axis holography

(07) The first microwave hologram completed

(08) Paris applies Tukey's fast Fourier transform algorithm to computational holography

(09) Simpson and Deeds propose infrared holography

(10) Benton proposes rainbow holography

(11) Denisyuk creates reflection hologram that reproduces 3D image with white light

(12) Molded laser holography

(13) China applies molded holography in the field of anti-counterfeiting

(14) Smalley makes first holographic projection display system

(15) Hesselink and Orlov take first infrared hologram

(16) Huebschman completes holographic dynamic projection display system with DMD chip

(17) Shiraki realizes 3D true color holography with LCD

(18) Michalkiewiczyoga showing holographic projections of 3D objects to satellite LCOS

(19) Eliminate the effects of zero-order diffraction

(20) Digital Reproduction Technology of Computational Hologram

(21) Hongzhen Jin Complete color holographic display algorithm

(22) Digital Image Encryption Method Based on Fourier Computational Holography

(23) A SOPC algorithm is proposed to solve the dynamic holographic display problem from the perspective of hardware

(24) A multi-computational holographic digital watermarking technology based on tomography is proposed

(25) Summarize the improved algorithm of spatial computational holography 3D imaging technology

(26) Improve the Boqi coding method to eliminate the aliasing of the conjugate image and the original image

(27) Data Compression Coding Technology for Computational Holographic 3D Display

(28) An improved split table lookup algorithm is proposed

(29) The ultimate goal of 3D display is to realize the dynamic display of the hologram

Figure 4 The development history of holographic technology

1.3 Holographic communication business

We believe that the holographic communication business is an overall application solution for data collection, encoding, transmission, rendering, and display of highly immersive, multi-dimensional interactive application scene data based on naked-eye

holography technology. It includes the entire end-to-end process from data collection to multi-dimensional sensory data restoration. It is a highly immersive and interactive business form.

2. Application scenarios and network requirements of holographic communication

6G technology will support human beings to have a deeper understanding and perception of the physical world, help human beings build a virtual world and a virtual real world, so as to expand human activity space; At the same time, it supports the interconnection of a large number of agents, so as to extend the level of human physical fitness and intelligence. Combined with 6G technology, holographic communication vision and future communication technology development trend, taking expanding activity space and extending physical intelligence as the baseline, expansion and mining can obtain relevant 6G holographic communication scenes and business forms, including digital twins, high-quality holography, immersion XR, new smart city, global emergency communication and rescue, intelligent factory, networked robot, autonomous system and so on, which fit the vision of 6G, Reflect the perfect cooperation of "man machine object environment".

According to the difference of depending on technology and giving user experience, in the future 6G era, the application scenarios of holographic communication will fall into seven categories: bandwidth remote management, low delay precision assistance, super intelligent information network, multi-dimensional interactive experience, high-quality portrait interaction, on-site full information display and immersive holographic image. As shown in Figure 5:

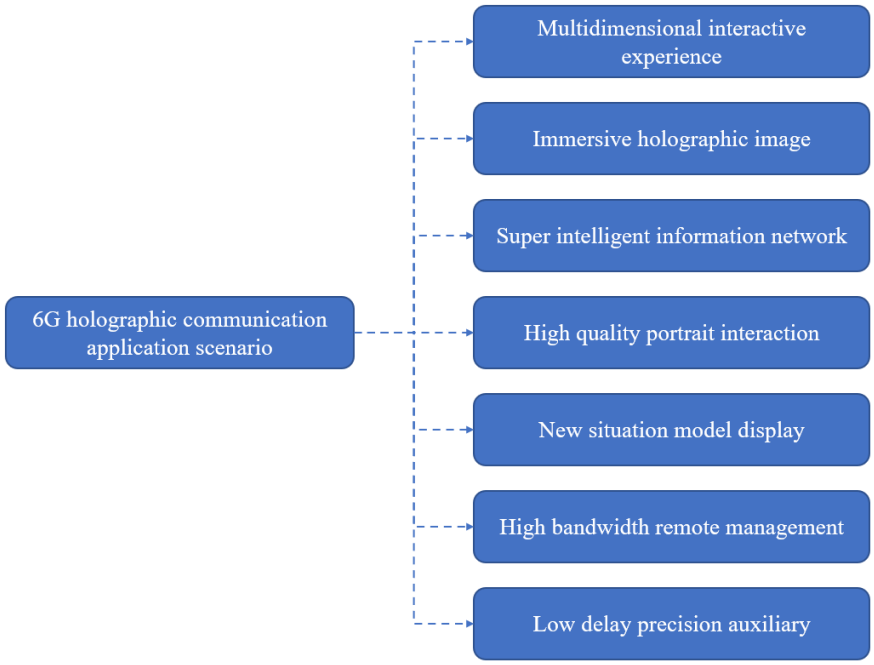


Fig. 5 general diagram of 6G holographic communication application scenario

2.1 Multi-dimensional interactive experience

For a long time, people have been pursuing the realization of more realistic and participatory display technology and experience effect. In the future 6G era, the communication network transmission performance will be greatly improved so that holographic technology and multi-mode interaction technology can be implemented. Empowered by these technologies, users can experience richer interaction channels and more real interaction effects. In the multi-dimensional interactive experience scene, the full data from objects and environment can be collected, and holographic technology can be applied to construct the experience scene for users to deeply participate in the interaction, so as to enrich the immersive multi-channel interaction means and provide rich and novel interactive experience.

Multi-dimensional interactive experience scenarios are mostly used for experience-enhanced businesses, which require high-performance transmission of collected environment and item data to construct immersive scenarios. Therefore, higher requirements are required for communication network bandwidth and traffic density support capability.

In multi-dimensional interactive experience scenes, the display end can generate more immersive and interactive imaging effects, bringing richer sensory experience to users. Therefore, the multi-dimensional interactive experience scene can be widely used in pan-entertainment, cultural education and other fields. By constructing rich multi-dimensional interactive display effects, holographic entertainment, holographic cultural education and other services can be provided to users. In the 6G multi-dimensional interactive experience scene, home XR entertainment uses virtual reality, channel interaction and other technologies to establish a display scene with high display quality and high interaction degree, so that users can play home games, virtual sports and other entertainment projects with high immersion. In addition, the 6G communication network also makes it possible to watch holograms. Users can watch holographic pictures with a high degree of three-dimensional sense and authenticity, and interact with the device through multiple channels, so as to reap a better viewing experience.

2.1.1 Holographic games

The fourth game revolution -- holographic games are developing at a high speed, leading the real optical revolution. Although holographic game is the most widely used scene and has the longest development time, it has not yet applied holographic technology and realized interaction. Currently, there are no holographic games on the market. The combination of game and holographic technology will make the fidelity of game environment and player's game experience reach the peak. The application layout of holographic game is shown in Figure 6:

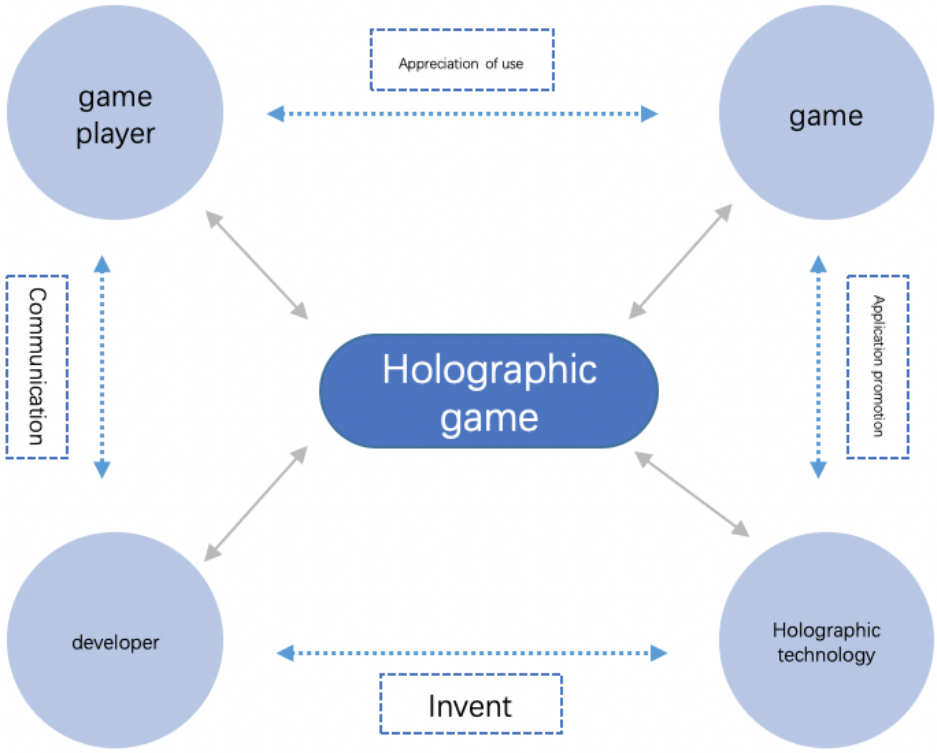


FIG. 6 Hologram game application layout

2.2 Immersive holograms

At present, the immersive experience mode is virtual reality or augmented reality or the combination of the two, and due to problems such as display accuracy and scene data download rate, augmented reality experience has not reached the standard of commercial use. In the 6G era, the shackles will be broken. Users can create full scene effects through naked eye holography, providing users with a completely immersive experience.

Only in a relatively fixed system environment can the ultra-low delay and ultra-high bandwidth communication bring users the ultimate experience. Therefore, the requirements for transmission are high, and the requirements for interaction are also more demanding in order to enhance the immersion of experience. At the same time, it will be an unprecedented challenge for the carrier and media of display to achieve naked eyes, and only the ultimate can achieve immersive experience.

Through the use of 6G technology and naked eye 3D display technology, immersive holographic image will greatly improve the user experience, and is widely used in life and entertainment scenes. Typical scenes include holographic service and sales, holographic news and stage choreography, holographic cinema, holographic sports, demonstration of real estate model rooms and immersive theme restaurants, as shown in Figure 7:

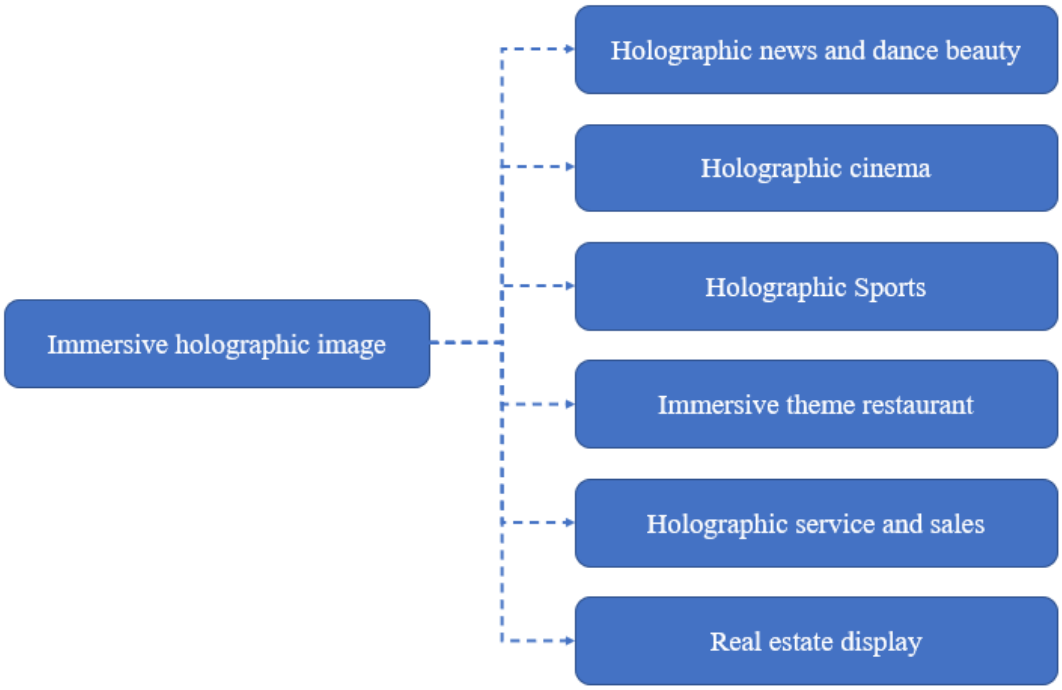


Figure 7. General picture of immersive hologram scene

2.2.1 Holographic news and choreography

Holographic news and stage design are currently mainly applied in news retransmission, exhibition presentation and stage design to create realistic and fantastic media effects for the audience and give the public a brand new media visual experience. The lifting screen projection technology or 45 degree phantom imaging film is mainly adopted. Its application layout is shown in Figure 8:

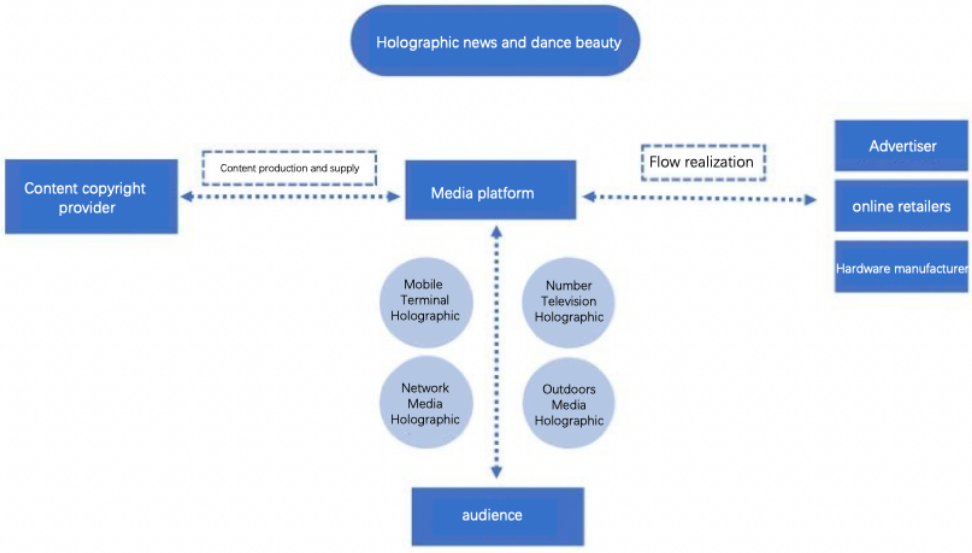


FIG. 8 Application layout of holographic news and stage choreography

2.2.2 Holographic cinema

The development of holographic projection, VR and other display technologies has provided a good support for the growth of the audience's demand for "multi-screen", "ultra-wide perspective" and "immersive" three-dimensional viewing. At present, the holographic projection form that can completely avoid the "halo 3D" phenomenon has not yet emerged, and the most suitable projection form for holographic viewing still needs further research and investigation. The application layout of holographic cinema is shown in Figure 9:

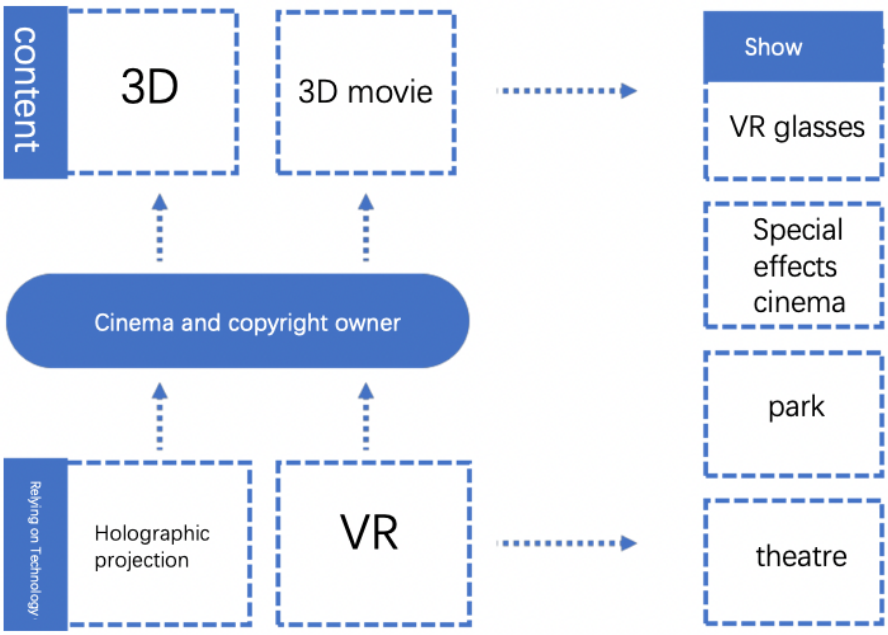


Figure 9 Application layout of holographic cinema

2.2.3 Holographic sports

Holographic projection technology gets rid of the tedious steps of computer programming simulation design, overcomes the defects of computer plane 3D simulation design, and has the stage effect of three-dimensional imaging more real and closer to the actual rehearsal, providing better choreography technology and innovation for the performance of large-scale events, opening and closing ceremonies. The key points of this technology are timely processing and projection content, convenient projection content design, etc. As shown in FIG. 10, the interaction of holographic projection technology will bring significant changes to sports training and physical education, and the rival virtual image training generated by holographic projection technology will become possible.

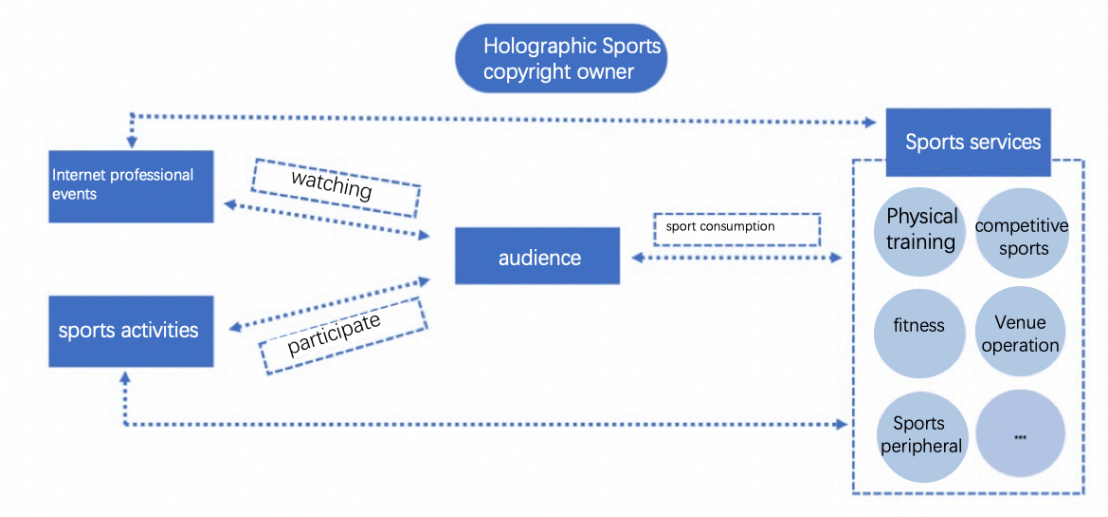


Figure 10 Layout of holographic sports application

2.2.4 Immersive themed restaurant

Holographic projection technology, naked eye 3D ring screen and lighting effects can jointly create a holographic restaurant, creating an immersive experience of ordering, waiting and the whole dining process. In addition, according to the needs and preferences of users, customized exclusive theme banquet hall, improve user experience.

2.2.5 Holographic services and sales

Holographic service company has the independent research and development of the holographic content library, contains the projection of the scene, display model, virtual character such as a full range of content, also supports personalized custom services, holographic internal related technical support service platform at the same time, can maintain all application scenarios, and the ability to constantly upgraded platform within the holographic content. The application layout of holographic advertisement is shown in Figure 11:

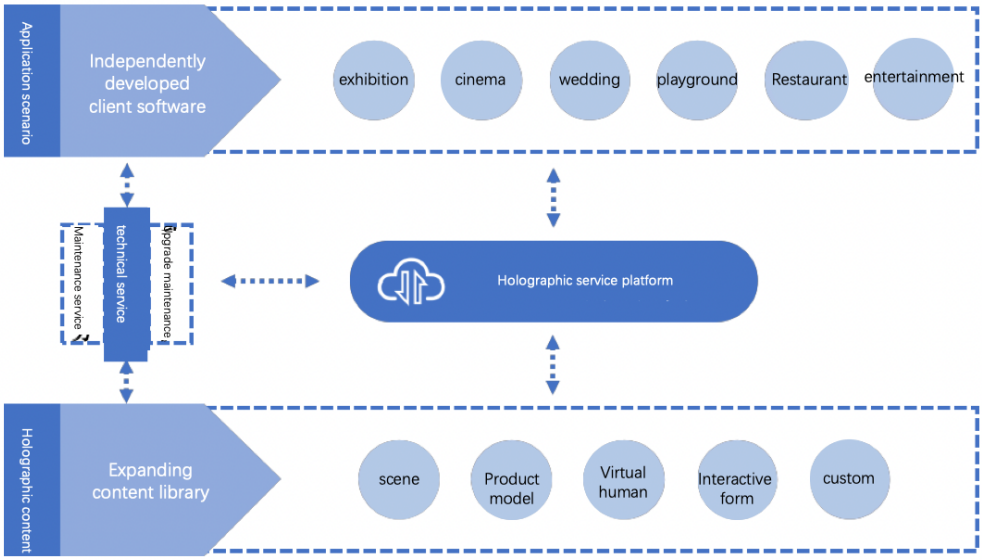


Figure 11. Layout of holographic advertising application

2.2.6 Real estate, sample room display

Holographic technology is combined with solid sand table, and holographic 3D images can be presented above the sand table area, presenting details such as residence, square and landscaping in a holographic way. The more novel 3D real estate display is in three walls through the combination of screen 3D display. 3D holographic projection provides intuitive and clear display and analysis of real estate data through holographic imaging, sound and light fusion, and portrait interaction, providing buyers with a smoother experience.

2.3 Super intelligent information network

With the advancement of the research and application of artificial intelligence, intelligence has long been the goal pursued by various fields. In the super-intelligent network scenario, the large bandwidth, low delay and wide connection characteristics of 6G communication network enable the collected large-scale data to be uploaded and comprehensively processed and analyzed by combining big data and artificial intelligence technologies, enabling 6G to be fully intelligent and realizing the close combination of AI, digital twin and 6G network.

Super-intelligent information network scenarios generally need to collect environment and scene data, and have high network adaptability and situational awareness ability, and even in-depth application of artificial intelligence technology. Therefore, such scenarios require high transmission bandwidth, strong network situational awareness and adjustment ability, and high DEGREE of AI intelligence integration for communication networks.

With the integration of 6G and ARTIFICIAL intelligence technology, the huge amount of data and high-performance data transmission generated by the acquisition end will provide a solid data layer foundation for ARTIFICIAL intelligence processing and analysis and solution. Artificial intelligence will be able to perceive more multidimensional and comprehensive data and improve data transmission processing speed and remote data interaction ability. Therefore, super-intelligent information network scenarios can be applied to areas closely combined with ARTIFICIAL intelligence, such as automatic driving and intelligent robots, so that ARTIFICIAL intelligence can "think quickly" and "be able to touch the sky". Super intelligent information network can provide digital management of natural environment and urban environment. By collecting multi-source and multi-dimensional data such as traffic and public security in the city, the agent can realize intelligent real-time monitoring and analysis based on comprehensive urban data, allocate urban resources, and alarm abnormal conditions. It can also obtain massive data by collecting vehicle peripheral information and other vehicle information, and provide automatic driving services after the analysis and decision of the agent.

2.3.1 Holographic driving

The application of holography technology in car driving is mainly aerial stereoscopic imaging, which projects the original physical keys into the virtual environment and observes the road conditions while observing the information, reducing the pressure of attention distribution and ensuring driving safety. The key point of the application of this technology lies in the timely transmission of road information and scientific and convenient interaction mode. The holographic driving application layout as shown in Figure 12 integrates voice interaction, gesture interaction and 5G communication technology into more modern mobile functions, such as in-car office.

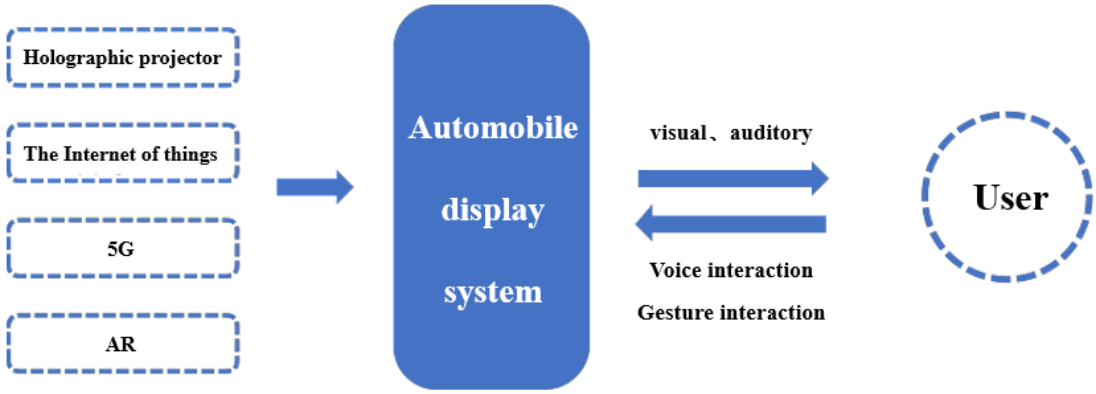


Figure12 Hologram driving application layout diagram

2.3.2 Holographic surveying and mapping

The construction of intelligent mine is an important topic for theoretical and practical research of mine construction in the future. The system research and

development and industrial application exploration based on "5G + remote control" carried out in China is a good application case. Combining the mine surveying and mapping information management system with holographic image can provide more vivid and accurate visualization data, which is convenient for users to use and improve users' experience.

2.4 High quality portrait interaction

Will bring new ways of communication and experience, make communication more real zero distance, across space and time. Through natural and lifelike visual reduction, the three-dimensional dynamic interaction of people, objects and their surrounding environment will be satisfied, and the communication needs of users for people, people and objects, people and the environment will be realized.

High quality like interactive scenario put forward higher requirements for information communication system, need to do people, objects and environment of high quality data collection and transmission and multimodal interaction under the three dimensional, so would need high precision data acquisition transmission collection equipment and fast enough holographic image transmission ability and strong ability of space three-dimensional display. At the same time, in order to let users enjoy the ultimate immersive experience, it will be a big challenge for the way of interaction in three-dimensional mode.

The wide application of the holographic communication can make between people communicate with each other and meeting will take on a variety of rich form, a holographic communication can be used for remote training and education application, to provide students participation and interaction ability, and have more interactive, make the person is in this mode is better to memory and learning, realize in the true sense to real-time communication across space. It can also realize cross-temporal interaction. By inputting the body data of deceased relatives and cooperating with AI technology, cross-temporal companionship can be realized.

2.4.1 Medical teaching

The application of holographic technology in medical teaching is mainly to make doctors more familiar with the internal structure of the human body through the virtual 3D image of the human body. At the same time, doctors can also simulate the operation process through the virtual image of the equipment.

2.5 New Situation Model Showcase

The current holographic projection scene is relatively fixed and the equipment is cumbersome, and there are certain requirements for ambient lighting, so the scene is relatively limited. Under the background of 6G technology, light field holography of

small scenes can be realized. The display of light field 3D models can enrich our daily life and improve the efficiency of our work, thereby reducing operating costs and enriching the interactive experience.

The scale of the new situation model display scene is small, so the data transmission volume is small, and the required data quality does not need to be very precise, but this scene focuses on the interaction between the user and the scene model, because the three-dimensional data information is richer and more meaningful than the two-dimensional. At the same time, users can obtain information more intuitively and accurately.

The new situation model display scene can perfectly combine reality and holography. The scene does not need to be grand, but the interaction or display is more realistic. Although the three-dimensional information acquisition is more convenient, the content requirements are more stringent than the current stage. Users can use physical Sensors interact with the model through gesture interaction or somatosensory interaction. The typical application scenarios are holographic culture, holographic education, popular science teaching and digital interactive experience restaurant, as shown in Figure 13:

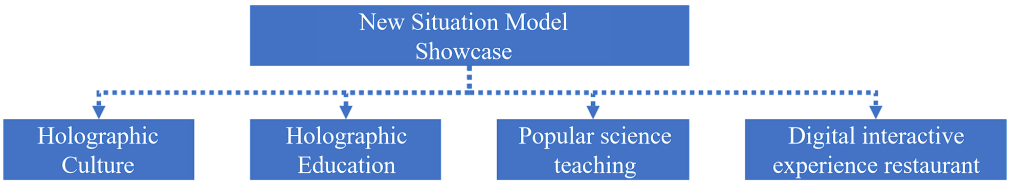


Figure 13 General view of the new situation model display scene

2.5.1 Holographic Culture

The application of holographic display technology in the cultural construction of many museums and science and technology museums can more comprehensively display the details of the collections and the culture behind them, allowing visitors to observe the details of the collections and deepen their understanding of the meaning of the collections. Its application layout is shown in Figure 14.

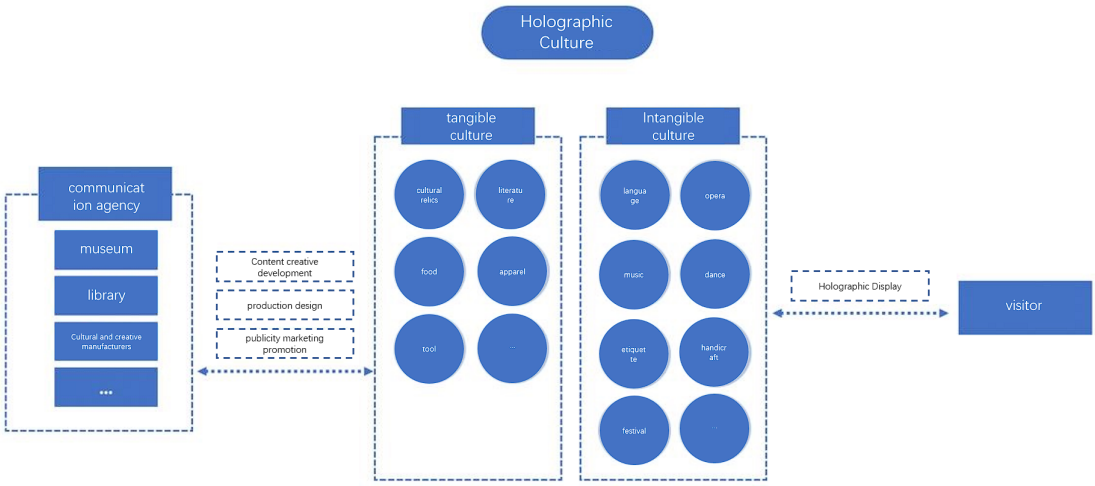


Figure 14 Layout of holographic culture application

2.5.2 Holographic Education

Holographic education comprehensively applies holographic display, interactive technology and cloud technology, integrates various innovative display methods such as holography, 3D, AR, etc., and provides various functions and technologies for the production, use, learning, assessment, management and other teaching links of interactive teaching courseware. means. As shown in Figure 15:

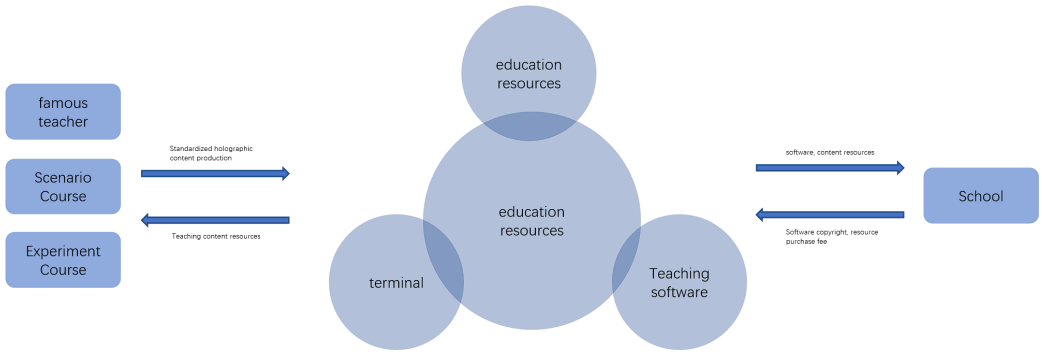


Figure 15 Layout of holographic education applications

2.5.3 Popular science teaching

Popular science teaching refers to the use of holographic technology to show the public the operation process of the industry and transfer scientific knowledge. Due to the high imaging conditions of virtual imaging technology, multimedia equipment such as projectors, LED displays, spherical screens, and ring screens are required, and there are certain requirements for funds and venues. Therefore, virtual imaging technology is mostly used in botanical gardens, natural museums, etc. large venues.

2.5.4 Digital interactive experience restaurant

The interactive table made by the interactive projection system has the functions of entertainment and ordering, turning the table into a display platform, showing the production methods of dishes, drinks, desserts and other foods in the form of interesting animations. The realization of this function mainly relies on naked-eye 3D holographic projection technology and gesture interaction.

2.6 High-bandwidth remote management

With the continuous advancement of the informatization process of production and life, more and more real objects will be mapped into the digital world to realize multi-directional monitoring and perception. In high-bandwidth remote management scenarios, acquisition and monitoring devices such as sensors will generate massive amounts of data for use by remote business parties. At that time, 6G will provide long-distance data transmission services with ultra-large bandwidth, helping users to obtain remote real-time data, obtain holographic situation information, and conduct large-scale remote data transmission, processing and presentation.

The prominent feature of high-bandwidth remote management scenarios is that the volume of data transmission is large and requires long-distance data transmission. Therefore, the large-scale data transmission characteristics of high-bandwidth remote management scenarios require the communication network to have large transmission bandwidth and high throughput capabilities, and to maintain good stability under ultra-long-distance transmission.

After the 6G communication network is applied to road monitoring and other situational collection operations, the large bandwidth and low latency of the 6G network will greatly improve the efficiency of situational monitoring, allowing staff to view remote monitoring without leaving home through technologies such as holographic presentation. Comprehensive information about an object or scene, improving the work experience. Therefore, high-bandwidth remote management scenarios are widely distributed in industries such as industrial and agricultural operation monitoring and special environment exploration. For example, in the mining industry, after the collection end in the mine collects multi-dimensional environmental information in the mine through multi-directional sensors, it can transmit massive full-true data to the remote central control room for presentation, assisting the on-site staff to grasp the underground environmental information. Identify the abnormal conditions of the underground environment, and conduct a comprehensive detailed inspection of the accident points. In addition, in the crop planting industry, multi-source information such as the growth status of crops and the surrounding environment is collected by sensors and transmitted remotely, and processed and presented in the central control room, allowing agricultural experts to comprehensively control the situation information of crops and target crops. Questions are given remote guidance.

2.6.1 Agricultural remote control

In the agriculture, forestry, animal husbandry and fishery industry, farms, forest farms, pastures and fish ponds are usually large, which brings inconvenience to the management and operation of staff. The holographic technology is used in the agriculture, forestry, animal husbandry and fishery industry for remote management, and the remote display of crops, livestock, forests and fish will reduce the operation cost of agriculture, forestry, animal husbandry and fishery in remote areas and improve efficiency.

2.6.2 Remote control of mining industry

The remote control holographic image can accurately replicate the real-time situation of the mine in 360°, and the staff can realize the remote control of the equipment according to the transmitted holographic image, which provides a great guarantee for the personal safety of the miners. The process is also more humane.

2.7 Low delay and precise auxiliary

The inherent data communication delay of traditional communication network will be greatly reduced in 6G network. The extremely low delay of 6G network will make the data transmission quality between end-to-end higher and the connection closer. Therefore, under the scenario requiring high real-time data transmission, 6G network can realize high-quality synchronization of remote data, promote the improvement of communication efficiency and resource allocation efficiency, and truly realize the interconnection of all things.

The outstanding feature of low delay and precise auxiliary is the urgent demand and high transmission quality. Some sub scenes apply high-resolution display technology, which requires higher immediacy and reliability of end-to-end data transmission. Therefore, the low delay and precise auxiliary scenario puts forward the requirements of high data transmission uplink and downlink rate, low air interface delay and strong network stability for 6G network.

By giving full play to the low delay advantage of 6G network, the security and stability of communication network will be greatly improved. Therefore, low delay precision auxiliary scenarios will be widely used in medical, manufacturing and other fields. In this scenario, 6G network makes the implementation of telemedicine possible. With the power of high-performance communication network, hospital specialists can remotely inquire and interact with the patients by tactile, visual and other multidimensional data. In addition, through the 6G communication network, the staff can transmit hand movement data in safe places and meanwhile manipulate the robots in the laboratory to carry out high-risk chemical experiment operations, which improved the safety of operation in special places.

2.7.1 Auxiliary surgical display

The combination of holography and actual surgery is mainly to see the internal structure of the patient's body through radioactive materials and generate virtual three-dimensional images. This technology can help doctors more intuitively understand the situation in patients and increase doctors' intuitive understanding of the relationship between anatomical space and tissue and blood vessels. Based on the data received from standard CT scanning and three-dimensional ultrasound system, creating a spatially accurate three-dimensional interactive medical hologram, so that doctors can interact directly and accurately with the dynamic hologram of the patient's real anatomy.

2.7.2 property management

The contactless concept spawned by the epidemic also affects the application direction of holographic technology. Now, contactless elevator keys based on holographic technology and contactless intelligent door locks have also been born. The contactless button uses the air imaging technology to project the digital screen in the air, which can be operated conveniently and safely. However, the accuracy of air imaging technology needs to be improved. The introduction of 6G technology is expected to improve the interaction sensitivity, achieve millisecond delay, and bring a new use experience.

2.8 Holographic communication network requirements

Holographic high-precision display and dynamic interaction effect also put forward corresponding requirements for holographic communication, including ultra-high bandwidth, ultra-low delay, network computing power, synchronization and network security, as shown in Figure 16:

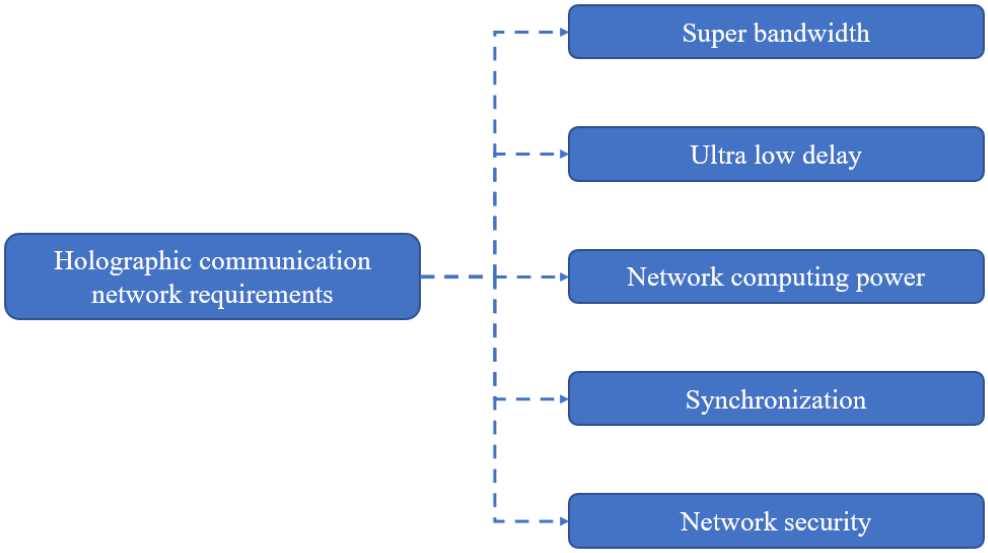


Figure 16 holographic communication network requirements

2.8.1 Ultra high bandwidth

Compared with traditional HD and 3D virtual video, the streaming media transmitted by holographic communication will have a demand for network bandwidth of Mbit/s. Camera sensor (such as Microsoft kinectforwindowsv2) can output 1080p image. Each pixel of 1080p image has 4byte color data, and the resolution of depth image is 512dpi×424dpi, 2byte depth data per pixel, equivalent to 70.4mb original data per frame. Moreover, with the increase of the number of sensors and viewpoints, the network bandwidth will be higher at higher resolution and frame rate.For 70 inch display screen, holographic communication requires about 1tbit/s network bandwidth.

Using more efficient image compression technology and encoding and decoding scheme (such as h.266) can alleviate the bandwidth demand of holographic communication to a certain extent. However, the future network still needs ultra-high bandwidth. The research on millimeter wave, terahertz, visible light and other higher operating bands shows that the user experience rate of future network can reach 100gbit/s, and the peak speed exceeds 1tbit/s. At the same time, the development of these new spectrums also poses greater challenges to the antenna and RF technology.

2.8.2 Ultra low delay

Similar to the requirements of strong interactive immersive applications such as AR/VR, holographic communication requires that the network must provide an end-to-end delay of less than 1ms in order to make users feel immersive.

The emergence of RDMA (remote direct memory access) technology has solved the delay caused by data processing between client and server in network transmission. It transfers data directly from the memory of one computer to another computer without

the intervention of both operating systems. Compared with the traditional TCP/IP communication mode, RDMA allows network communication with high throughput and low delay. This technology can further reduce the network transmission delay and has great development potential in the future network application scenarios.

2.8.3 Network computing power

The process of realizing holographic communication can be described as follows: first, the object information is obtained through the acquisition terminal equipment, generating the hologram by calculation, then transmitted through the network after coding and compression. Finally, the hologram of the object is reconstructed and displayed after decoding at the terminal. Owing to the huge amount of information and data contained in the hologram and the long computing time, it will not only bring great bandwidth burden, but also cause a large MTP (motion to photos) delay. In order to meet the user's immersive experience of strong interactive applications such as AR/VR, the MTP delay is required to be within 20ms, while for holographic communication, it is required to be 10ms or less.

With the rapid development of cloud computing and MEC (mobile edge computing) technology, the future network can solve the computing power needs of holographic communication through the rapid deployment of cloud and edge.

2.8.4 Multi dimensional information synchronization

The generation and transmission of holograms contain multi-dimensional information, which derives from video, audio, touch, smell, taste and so on. Only when the information of each dimension is kept strictly synchronized can it give users an immersive feeling.

Therefore, in the transmission process, the simultaneous media streams of holograms generated by objects from different sensors and different angles need to keep quite strict synchronization. How to intelligently manage these concurrent flows is a great challenge and test for the future network.

2.8.5 network security

The hologram transmitted through holographic communication contains a large amount of information data, including sensitive information such as facial features and sounds, which requires the network to provide absolute security. However, the use of existing security technologies will increase the end-to-end delay. Therefore, the Compromise between delay and security is one of the difficult problems for future networks.

3. Industry Chain

At present, holography has made great application in military, education, exhibition and medicine fields. The number of enterprises which are engaging in the field of holography in China has grown from a dozen to more than a thousand, and the market capacity has risen to the level of 10 billion. With the progress of science and technology and the breakthrough of various technical bottlenecks, a new round of development of holography will come. In the near future, holography will be widely used in various fields such as industry, commerce, medicine, education and defense. Holography will generate huge economic and social benefits and have a subversive impact on the history of human civilization.

The industry chain of holography is divided into three parts: upstream, midstream and downstream. They represent the basic layer, enterprise layer and product application layer of holographic industry respectively.

(1) Upstream base layer

The upstream base layer mainly includes holographic material developers and manufacturers, holographic device parts manufacturers, holographic technology servers and holographic chip manufacturers. Upstream industries provide support in various aspects such as sensors, chips and servers according to the different needs of the back-end of the industry chain.

(2) Midstream enterprise layer

As the part of the holographic industry chain with the longest service coverage and the most diverse service contents, midstream enterprise layer mainly includes holographic content companies, equipment manufacturing companies and comprehensive service companies. Holographic content companies provide holographic games, holographic theaters, holographic advertising and other content services. Equipment manufacturing companies are responsible for manufacturing holographic projection products, holographic displays and other service carriers. Comprehensive service companies provide the whole process from technical support, content cooperation to actual deployment services.

(3) Downstream application layer

Downstream application layer covers most of the practical application scenarios of holographic technology in the market. It is the part of the whole industry chain with the strongest user perception. The products are in various forms, including glasses, 3D screens, air imaging, holographic storage and holographic computing products, etc.

The hierarchical structure of the holographic industry chain is shown in Figure 17.

Figure 17 The hierarchical structure of the holographic industry chain

3.1 Upstream functions and structures

3.1.1 Upstream functions

The upstream of the holographic industry chain is dominated by servers, semiconductors, materials and parts enterprises. It provides basic hardware services for midstream and downstream enterprises. It mainly includes cloud computing, cloud servers, server hardware equipment, chips, circuit components, optical devices, organic materials, signal processing equipment, and professional instruments.

The arithmetic support in the whole industry is provided by cloud computing, cloud servers and server hardware equipment, including image acquisition, processing, transmission coding, etc. Chips or micro integrated circuits are the core processing and control logic units of all devices. Circuit components and optical devices are the support to complete the holographic business. Signal processing equipment is used to connect different parts, transmitting signal between the links in the whole business logic. The clarity of hologram acquisition and presentation effect are determined by professional instruments, such as lenses, projection screens, materials, parts, etc.

The composition of upstream structure is shown in Figure 18.

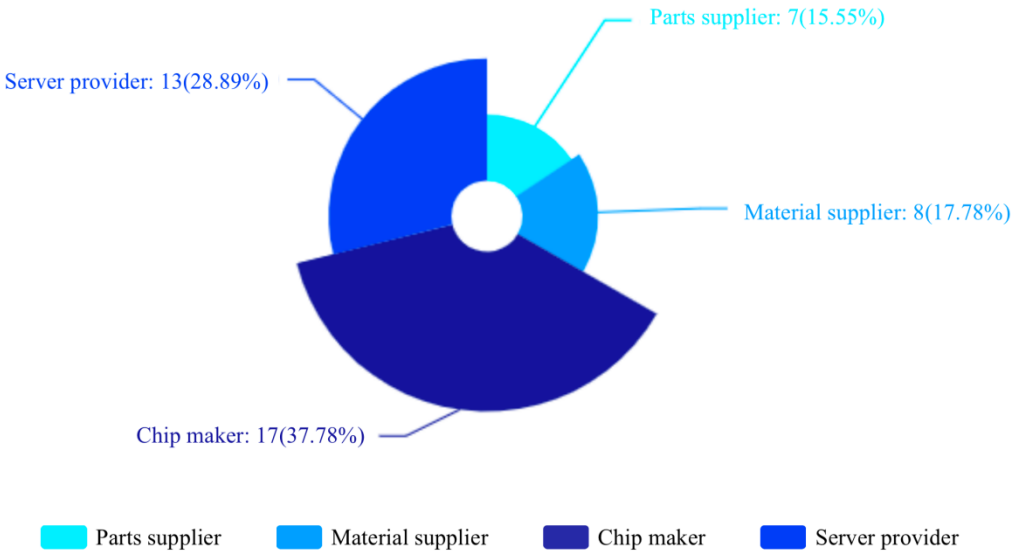


Figure 18 Upstream structure

(1) Head-mounted display field

The upstream mainly provides computing, storage, connection chips, small display panels, various sensors including head tracking visible light sensors, eye tracking infrared sensors, depth sensors, IMU sensors, and batteries. The small display panel is responsible for presenting the image in the head-mounted device to the human eye. And the various sensors are mainly used for information acquisition, transferring external signals into the device and converting them into a digital form that can be processed.

(2) Naked eye 3D screen field

The upstream provides LED intermediate materials, holographic film, high-speed visual sensors, holographic raster, and display chipset, LCD panel, power supply module, etc. Various intermediate materials and holographic film are in the material category. The naked eye has more stringent requirements for the display of 3D effects, requiring the use of higher precision sensors, such as liquid crystal panels, holographic gratings, etc.

(3) Air imaging field

The upstream mainly provides optical devices such as equivalent negative refractive index flat lenses. The convergence of light in space is the biggest difference between the air imaging field and the first two fields. The air imaging field focuses more on the processing of light, so more refractive, reflective and other optical devices are needed.

3.1.2 Industry maturity

In addition to industry giants like Microsoft and Sony, the holographic industry chain is also widely populated with young innovative companies, relying on technological innovation and invention to explore new paths. They make the whole industry chain to be full of vigor, vitality and opportunities. Upstream companies are the source of the industry chain and can already provide the necessary guarantee in basic materials and core technologies, especially in the field of head-mounted display. In the field of head-mounted display, high-precision sensors and connection chips that can realize signal acquisition, input and processing have already exist. However, in the field of naked-eye 3D and air imaging, there are still many difficulties in materials and technology that need to be overcome by all enterprises, because of the extremely strict requirements for the 3D effect of the display.

3.2 Midstream functions and structure

3.2.1 Midstream functions

The whole product vendors, integration service providers and content designers are in the midstream of the holographic industry chain. Based on the actual scenario-oriented needs, they provide various types of services such as the whole product sales, full-link services and holographic product content design, modeling and presentation with the support of upstream technologies and services.

The composition of the midstream structure is shown in Figure 19.

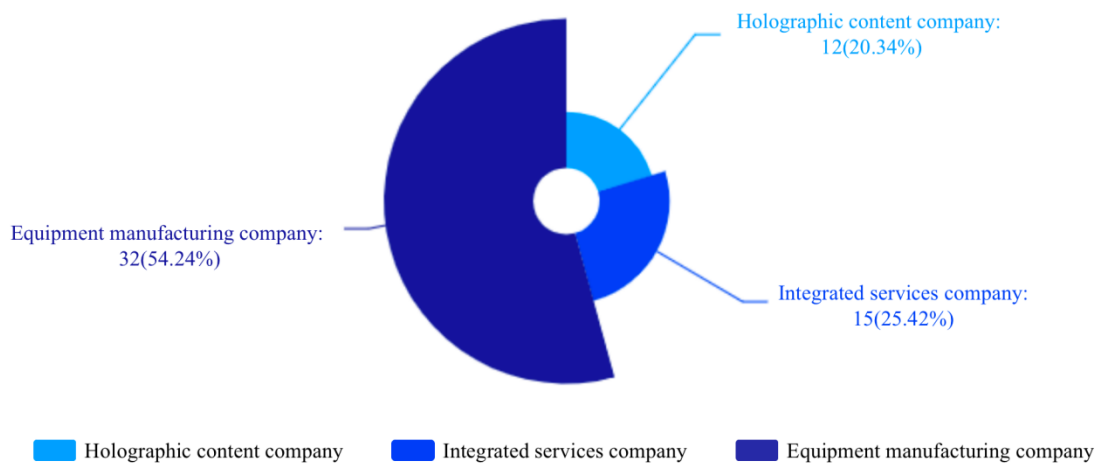


Figure 19 Midstream structure

(1) Complete machine products field

Midstream companies mainly provide sales and maintenance services for holographic projection products, holographic display products, holographic AR products and holographic laser products.

(2) Integration service field

Various companies of the midstream provide holographic solutions, covering many scenarios such as leisure and entertainment, shopping experience, video calls, etc. From demand mining of holographic applications, scenario research to deployment and maintenance of holographic products, various companies in the field of integrated services open up the whole chain of holographic applications, providing a complete holographic experience for multiple user groups such as enterprises and individuals.

(3) Holographic content design field

The midstream companies mainly provide the most intuitive holographic content to the public. Due to the many differences in end-users and scenarios, the positioning of each company in content design also varies greatly, mainly involving holographic advertising, holographic theater, holographic weddings, holographic games, holographic idols and other common areas.

3.2.2 Industry maturity

Midstream enterprises distribute in different segments, such as content producers, holographic integration service providers, holographic laser manufacturers, holographic collection manufacturers, and holographic display equipment manufacturers. On the whole, midstream enterprises have been relatively complete in providing complete products and services. Combined with upstream and downstream enterprises, the whole holographic industry chain structure is more abundant. However, because holography has not really come into the life of the public, there still exists a lack of content design and interactive experience, which is the most important direction to be studied in the future development of holography.

3.3 Downstream application and industry layout

3.3.1 Air imaging market

Air imaging is a display technology, which use the optical principle to show image in the air in three-dimension. Air imaging is gradually changing from the early stage of displaying three-dimensional content with undertaking mediums like fog screens towards the direction of changing the nature of air through ionizing air, acoustic tweezers, optical tweezers, and other technologies. Air imaging products can be divided into two categories.

The first category is the air imaging that needs undertaking mediums, such as fog screen imaging, rotating fan air imaging, etc.

The second category is the air imaging which doesn't need undertaking mediums. These holographic products are difficult to implement and have poor practicability. Most of them remain in the conceptual stage and have not achieved mass production. For example, the representative of ionized air imaging technology company Aerial Burton, the representative of optical tweezer holographic display technology team Arthur Ashkin, the representative of acoustic tweezer holographic display technology team from the University of Sussex in the UK, and the refraction flat half lens panel represented by Asukanet's ASKA3D Plate and Dongchao Technology. These products have certain applications in medical treatment, elevator virtual buttons, exhibition and other fields through light field reconstruction technology. With mature motion sensing equipment, interactive air holography can be realized.

(1) Fog screen projection equipment

Fog screen stereo imaging system technology is also known as air imaging, fog screen imaging. The principle is that the air screen system can create a fog wall formed by water vapor, the projector will project the picture on the above, due to the air and the molecular vibration of the fog wall is not balanced, can form a hierarchical and three-dimensional sense of the image.

Fog screen projection equipment includes a proprietary projector and basic components, the system forms the image mainly using air as well as a small cabinet, does not use special chemicals.

(2) Rotating LED fan projection equipment

Rotating LED fan projection takes advantage of the visual transient phenomenon of human eyes and adopts rotating LED light strip for air imaging. Rotating LED fan projection is widely used in exhibitions, advertising media, stage performances and other scenes, its advantages are cheap and easy to realize.

(3) 360° holographic projection system

360°holographic projection system is also known as 360°holographic, 360°holographic imaging or 360°holographic projection. It is a four-sided cone made of transparent material, and the projector is projected at 45° to the holographic membrane so that the viewer's eye can penetrate it from any side. Through surface mirrors and reflections, four video transmitters beam light signals to special prisms in

the cone, which are pooled together to form a three-dimensional image with real dimensional space.

(4) Holographic display stereoscopic screen

Holographic display stereoscopic screen mainly uses laser rotary projection technology. However, laser rotary projection technology is not widely used because of noise and insecurity.

(5) Interactive holographic air imaging panel

By changing the microscopic structure of glass or resin and using the principle of light field reconstruction, the interactive holographic air imaging panel allows the light to oscillate, reflect and refract many times in this microscopic structure, and re-converge the divergent light into a real image in the air. This air imaging technology projects images and objects in the sky as real images, so it can be called a true hologram.

(6) Ionized gas imaging

The Japanese company Science and Technology uses the mix gas of nitrogen and oxygen in the air to a searing slurry that creates a transient 3D image in the air. This method is mainly achieved by continuous small explosions in the air.

Aerial Burton's ionized air imaging method uses a 1KHz pulsed laser that is reflected and focused to an exact location in the air above by a 3D scanner to transmit the laser. The laser ionizes the air molecules in that position and displays the entire hologram through a scintillation of light composed of each point.

Holovect 3D hologram projector uses self-developed technology to control the refractive index of the air in the cubic area according to the phenomena of light reflection, refraction and diffusion, so that the laser can produce reflection and refraction at specific locations. By adjusting the refractive index of the laser and the air in different areas, Holovect can draw 3D images based on the spatial information of the light.

(7) Optical tweezer/acoustic tweezer air imaging

Optical tweezer imaging has better security than ionized air imaging technology. One of the highlights of this application is that it supports tactile feedback and tactile interaction. The disadvantages are low resolution, stable environment and low brightness. In 2018, Arthur Ashkin's team used optical tweezer to control particles in three dimensions using a concentrated laser beam.

The team at the University of Sussex in the UK used a "multi-mode acoustic tweezer display" device, which uses ultrasonic waves released by an array of speakers to cause air to oscillate in three dimensions, creating a rapid change in air pressure over time. The change in air pressure creates acoustic radiation forces that drive the particles.

(8) Industry maturity

Holographic fog screen, LED fan holographic projection, and 360° holographic projection technology have low difficulty in achieving and overall high maturity. Therefore, they have been put into mass production and applied in advertising, media, and other fields. Technologies such as holographic air imaging panels, optical tweezer/acoustic tweezer air imaging, and ionized air imaging are currently limited to the realization of technology, cost, and other issues that have not achieved mass production, so the maturity is relatively low.

From the perspective of the development direction and demand market of the holography industry, because of the lower maturity, the air holography technology without screen is more promising at present and is the main target development direction of various manufacturers.

3.3.2 Stereoscopic display market

Holographic space projection screen is a new generation of display equipment, with many advantages such as high clarity, strong light resistance, ultra-thin, anti-aging and so on.

The preparation and processing technologies of this screen include nanotechnology, material science, optics, polymer and other multidisciplinary achievements. This screen uses the molecular level of nano-optical components, holographic color filter plate crystal as the core material, organic materials, inorganic nano powder, and fine metal powder as raw materials. The 3D stereoscopic display screen includes stereoscopic display technology based on binocular parallax effect, multi-view stereoscopic display technology, and light field holographic display technology based on eye-tracking. Among them, naked-eye 3D stereoscopic display mostly adopts the imaging principle of column lens grating 3D technology, the light pointing 3D technology and slit grating 3D technology.

· Column lens grating stereoscopic display

The stereoscopic display based on the 3D technology imaging principle of column lens grating has the advantage of nondestructive brightness and can be formed as a cylindrical lens, trapezoidal lens, triangular lens, and other forms. However, this display has higher processing accuracy requirements of 3D design. The process is also more complex which need to separate mold.

· Light pointing stereoscopic display

Based on the imaging principle of light-pointing 3D technology, the light pointing stereoscopic display is realized through a 120Hz backlight combined with a special 3D film, which leads to high image resolution. The disadvantage is that the light source needs to reach 120Hz, and the screen is generally thick, which is only suitable for small and medium-size.

· Slit grating stereoscopic display

The stereoscopic display based on the 3D imaging principle of slit grating has the advantages of simple technology and is generally used for technical verification. The disadvantage is that the maximum transmittance is only 50%, the backlight needs to be brightened. And it also has high energy consumption. The normal screen models of this kind of display on the market are 24, 28, 32, 46, 50, 65 and 85 inches.

(1) Polarizing 3D display - glasses are required

Passively polarized glasses have a layer of polarization guiding film on the screen, and staggered each line of light polarization direction to do direction torsion.

Polarizing 3D uses the principle that light has a vibration direction to decompose the original image. Firstly, dividing the image into two groups images of vertically

polarized light and horizontally polarized light, and then using different polarization directions of the polarized lenses on the two sides of 3D glasses. By doing so, people's two eyes receive two sets of images and synthesize stereo images through the brain. The downside of polarized 3D is that it requires two video output devices, one for each eye.

(2) Stereoscopic display based on column lens grating technology - naked eye

Column lens grating is composed of many cylindrical lenses with the same structure arranged in parallel. One side of the grating is planar, and the other side is periodically arranged cylindrical lens. It is composed of display panel and column lens grating. By using the refraction of the column lens array on the light, the light of different parallax maps is refracted to different directions to form viewpoints, which are respectively provided to the left and right eyes of the viewer. After brain fusion, stereoscopic images with depth are generated. In 3D display, the function of column lens is to transform 2D information presented by planar pixels into 3D information containing directional information, and form viewpoint rays with specific intensity, color and directional Angle.

Column lens grating has high light transmittance and light energy utilization, which can realize high brightness 3D display. However, the light control method based on refraction principle of cylindrical lens grating will produce aberration, and the cost is much higher than that of slit grating. The disadvantage is that the aberration affects display quality, high production cost.

(3) 3D display based on pointing backlight technology - naked eye

This display is accomplished by combining a 120Hz backlight with a special 3D membrane, which has high image resolution. The disadvantage is that the light source needs 120Hz, and the screen is generally thick, which is only suitable for small and medium-sized. The representative enterprises include Mide Technology, which independently developed the 3D display FD2410 in 2017.

(4) 3D display based on slit grating 3D technology - naked eye

The advantage is simple technology so that it's generally used for technical verification. The disadvantage is that the maximum transmittance is only 50%, the backlight needs to be brightened. And it also has high energy consumption. The normal screen models of this kind of display on the market are 24, 28, 32, 46, 50, 65 and 85 inches.

(5) Monocular stereoscopic display - deep 3D

Monocular depth information is related to the focal length of each lens, and the difference of depth information can be seen through the degree of blur. Binocular parallax can be regarded as basic 3D or shallow 3D, while monocular depth information display can be deep 3D. Different from the above stereoscopic display, the light-field holographic display can focus on any image depth at any angle or even with only one eye, realizing the natural and real 3D display to a certain extent. A real holographic display can display light in all directions of the optical scene.

(6) Other stereoscopic display systems requiring glasses

In addition to the above naked eye 3D display, in the early market, there are also many 3D display eyeglasses and supporting display products such as chromatic

aberration 3D glasses, polarized 3D glasses and shutter 3D glasses. Chromatic aberration 3D glasses are based on the principle of color splitting and can be viewed by wearing color separation glasses. However, red and blue color matching will make users uncomfortable, and the stereoscopic effect is not good. Polarizing 3D glasses need to be used in conjunction with a display and projector that support the corresponding technology. The content is converted through a polarizing light converter without the need for picture correction. They are suitable for both cinema and home use. Shutter 3D display refers to the time sequence alternating left and right parallax images displayed on the display screen. Viewers can see the 3D images by wearing synchronous timing shutter glasses, which has a relatively excellent depth of field effect. However, the viewing experience is limited due to the problems such as image interruption, drastically reduced brightness and flickering.

(7) Industry maturity

Different technologies lead to different display methods, among which the development of laser display changed from the concept stage in the 1960s to the limited development stage now, with slow progress.

Polarized 3D displays are already commercially available, but they require specific glasses and have limited potential. Column lens grating technology, 3D display based on pointing backlight technology and slit grating to backlight technology is more suitable for the future needs of users, is directly by the naked eye to watch.

Although these display methods are admirable, they are limited by the refraction principle, which leads to control of the light way and will produce aberration. In the meantime, the content production and hardware mold will also cost high, In the future, more research can be carried out on the way of light control. After all, the display content is dependent on the display effect.

3.3.3 Stereoscopic glasses market

The development of holo-glasses has gone through four stages: laboratory AR, mobile AR, wearable AR and mixed reality MR. In 1966, the father of computer graphics and augmented reality, Turing award winner Ivan Sutherland, developed the first augmented reality system, which is the first AR device implemented by humans, named Sword of Damocles. It also was the first virtual reality system. This system uses an optical fluoroscopic head-mounted display with two 6D trackers, a mechanical one and an ultrasonic one. Subject to the processing power of the computers at the time, the system placed a display device on the ceiling above the user's head and connected to the headset by a connecting rod, capable of converting a simple wireframe into a 3D image. Since then, it has opened the exploration of virtual reality, augmented reality and mixed reality.

(1) Shallow 3D glasses

HMD (helmet mounted display) uses two relatively independent display screens to provide left and right images to the viewer, so that the viewer is completely immersed in the displayed scene, with a strong sense of presence. HMD generally consists of a

micro display screen, optical imaging system, circuit control system and counterweight device. Some professional HMD also need to be equipped with a head tracking system. Those parts are tightly and precisely fastened to a helmet-like device. HMD was first proposed by Sutherland of Harvard University in 1968 and designed the SWORD of Damocles, which uses CRT as a micro-display screen. Its principle is to make images generated by small micro-display screen magnified by the optical system for viewers to watch. The HMD needs to be light and small because it is fixed to the viewer's head. With the advent of small, lightweight, high-resolution micro screens, HMD has developed rapidly and entered various applications.

In recent decades, there are three main reasons for the poor development of binocular parallax/shallow 3D. The first is the lack of bandwidth and content, including the ability of equipment encoding and decoding and network transmission. Secondly, the image display performance is generally, the key factor is that many 3D display devices are derivatives of 2D display technology.

(2) Deep 3D glasses

Different from binocular stereoscopic glasses, holo-glasses based on monocular stereoscopic technology are also called deep holo-glasses. Binocular parallax can be considered basic 3D or shallow 3D. Monocular depth information is related to the focal length of each lens, and the difference of depth information can be seen through the degree of blur. Monocular stereo can be interpreted as motion parallax stereo display with especially high viewpoint density. In order to adjust the lens of the human eye, the number of viewpoints entering the human eye at the same time is more than two, that is, the distance between adjacent viewpoints is less than the diameter of the pupil of the human eye can achieve monocular stereo. The advantage of deep holo-glasses is that they can solve the real vision more effectively, but the disadvantage is that the viewpoint density is too high to realize

(3) Industry maturity

Stereoscopic glasses were first proposed in the 1960s and then entered the mobile experience stage around 2000. Stereoscopic glasses are divided into light 3D glasses and deep 3D glasses, among which light 3D glasses have not been well developed due to the lack of bandwidth and content and image display. Compared with deep 3D glasses, the experience is better, but the technology is more difficult to achieve breakthroughs. Under the premise of lack of content and insufficient network conditions, it is necessary to adjust the recognition of human monocular lens. Therefore, in the future, deep 3D glasses will become the focus of the industry, but there is still a long way to achieve great breakthroughs.

Summary

With the large-scale commercialization of 5G technology and the deepening of 6G communication technology research, holographic products will receive more reliable technical support. In the future 6G era, holography will develop in the direction of "digital twin + AI + holography."

The holographic scene highly integrates the virtual image with the actual image of the user, bringing a very impactful experience. At the same time, relying on the close combination of holographic technology and communication technology, users can communicate and interact in real-time across time and space, breaking the limitations of physical space and time. The transmission and display of information is no longer a single vision or hearing but multi-dimensional information that can integrate three-dimensional images and five senses of audio-visual touch, smell, taste, and taste. While reproducing original photos brings users an immersive experience of physical interaction.

In the 6G era, holography combines artificial intelligence, big data, and other technologies to build multi-agents to achieve organic integration and multi-directional interaction between the physical world and the digital world. The scenes established by holographic products use sophisticated display equipment and exquisite picture content to give users a specific visual impact and, at the same time, provide a real-life experience that blends virtual and real. Holography is not just a simple display tool. And it will integrate more artificial intelligence and multiple interaction methods and give users a two-way and multiple-cycle coupling experience in more dimensional information such as visual, auditory, and tactile information. And beyond the physical limitations of time and space, to achieve leap-forward interaction between people, things, and environments, create a system that integrates content tools and artificial intelligence, and create a beautiful vision of "integration of virtual and real, extending time and space, embodied interaction, and face-to-face communication."

With the emergence and popularization of the metaverse concept, holography, as the essential underlying technology, will affect the development of the Metaverse and achieve a more profound application experience. The ultimate form of the Metaverse is to build a virtual world parallel to the natural human society, with open space, decentralized operation, human-computer interaction close to the human level, unified identity, and a complete digital economic system. The technological integration of "digital twin + AI + holography" will provide a deep, immersive interactive experience for the Metaverse at the experience layer and human-computer interaction layer, which is a crucial realization path to the Metaverse. It is also the core technology that helps the realization of the Metaverse to achieve human vision and imagination of digital life. People's expectations for holographic communication are gradually increasing, and the white paper hopes to lay the foundation for the development of holographic communication under the network in the future. Contribute to the change of holographic technology, industrial upgrading, and enrichment of business scenarios so that holographic communication can better serve life, improve the quality of life, and help development. China Mobile is committed to expanding the application boundaries

of holographic technology and building a panoramic technology application platform. It also hopes to work with the industry to jointly promote the development of holographic technology and applications and create new applications under the future network.

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Digital Twin, Ubiquitous Intelligence