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3D Display for 3D Telepresence: A Review

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***Abstract*—Over the years, people have tried to advance 3D display technology and researchers as well as developers have created different innovations in recent decades. there are many other different types of 3D display technology that can be classified into stereoscopic, auto stereoscopic, holographic and volumetric 3D displays. This paper, however, discusses the 3D display technology that have been implemented in the telepresence system, which can be divided into two main devices, projectors and head mounted display (HMD). From these two devices, the 3D display technology using projector devices are on-stage hologram, auto stereoscopic display, and holographic projection; while for HMD can be divided into MR headset and VR HMD. This paper provides a review on these 3D display for telepresence. Finally, we make a comparison based on the features of the 3D display technologies such as life-size capability, viewable from different perspectives, headset-free experience number of viewers per device, level of ease of setup and the nausea of discomfort level. To choose the best 3D display technology for a telepresence system, we must first identify the number of users who will be projected and who will be viewed. The goal and activity of using telepresence technology will also define the appropriate type of 3D display.**

***Keywords*—Telepresence, 3D Display, Holographic Projection, Mixed Reality, Virtual Reality**

I. INTRODUCTION

The reconstruction of the three-dimensional (3D) world has constantly been an essential aspect of display technology advancement. The advancement of 3D display technology has been an ongoing venture since the early 1990s, with researchers collecting, developing, and refining various innovations over the last few decades that have benefited technologies that require the viewing of 3D components, such as 3D telepresence. The goal of telepresence is to create the feeling that one is physically present or physically located with a remote individual. [1]. Telepresence might consist of natural size imaging of the people, 3D reproduction of the user or their environment, or mutual interaction of the remote location. It has been demonstrated and as interpreted from previous systems in visual sense that a variety of paradigms can produce this illusion, including a remote user appearing in a local location [2], a remote space emerging to expand beyond the local surroundings [3, 4], and a local user immersed in a remote location [5]. A discussion of the way a telepresence user perceives or views the 3D representation of another remote user or their environment will be presented in this paper. Two main 3D display technologies hardware will be discussed are projectors and head mounted displays (HMD), based on what have been performed and implemented by other researchers or developers to be reviewed.

II. 3D DISPLAY TELEPRESENCE

Although the real world around us is three-dimensional (3D), conventional displays can only display two-dimensional (2D) flat imagery that lacks depth definition. This constraint greatly reduces our ability to perceive and comprehend the complexity of objects in the physical world.

Even with the aid of modern 3D rendering capabilities, anything that is displayed on a 2D-screen, whether it is a complex data pattern or a 3D model, is still unable to accurately and effectively convey depth information. The absence of true 3D displays also hinders the capacity to truly perceive high-dimensional data, which is frequently encountered in advanced science computing, clinical information, 3D telepresence technologies, and a variety of other applications.

When only one remote user needs to see the 3D display for telepresence [6], we may need to project the user in a translucent, human-sized display without a backdrop in order to create a convincing illusion of the remote person's presence in the local environment. For situations where there is just one local user and stereo glass eye contact is required, a transparent head-tracked stereo system may be appropriate.

When numerous local participants are involved, a more significant issue emerges, and it is preferable if the appropriate stereoscopic view from each position be provided to each participant without the need for cumbersome stereo glasses. [7] proposed methods for compressive light field displays, as shown in Fig. 1, to achieve this multi-view stereoscopic display. On-stage holograms, autostereoscopic displays, and holographic projection are all covered in this paper, as well as head-mounted displays (HMDs), which are classified into two categories: mixed reality headsets and virtual reality headsets (VR HMDs).

It is necessary to configure the 3D display presentation of a telepresence system according to the following factors: the number and size of users (local or/and remote users), whether or not they have their own background environment, and the interaction or remote collaboration task that must be performed between the local and remote users.

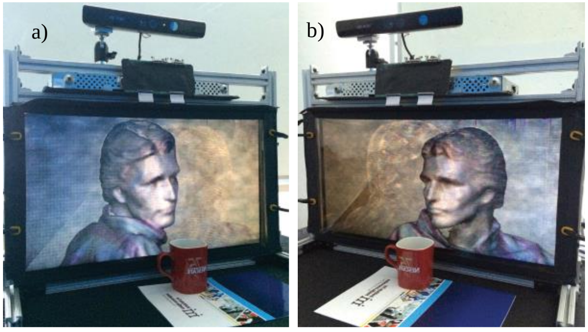

Fig. 1. Two points of view of a multi-view stereoscopic view. a) left-side viewpoint b) right-side viewpoint [7]

III. HARDWARE 1: PROJECTORS

A. On-stage Hologram

Peppers Ghost [8] is an illusion method that was initially used in Victorian theatres in London in the 1860s, as presented in Fig. 2. The brightly illuminated figure from below the stage, away from the audience's vision, is reflected in the glass panel between the performer and the viewer. According to the audience, it appears as though the ghost has arrived on the scene.

By using Pepper's Ghost concept and features of holographic film and a special stage layout a 2D picture that satisfies those psychological depth cues, including occlusion, can give the audiences the 3D feelings. On stage hologram systems three major applications are immersive concerts, holographic telepresence and virtual animation display [8].

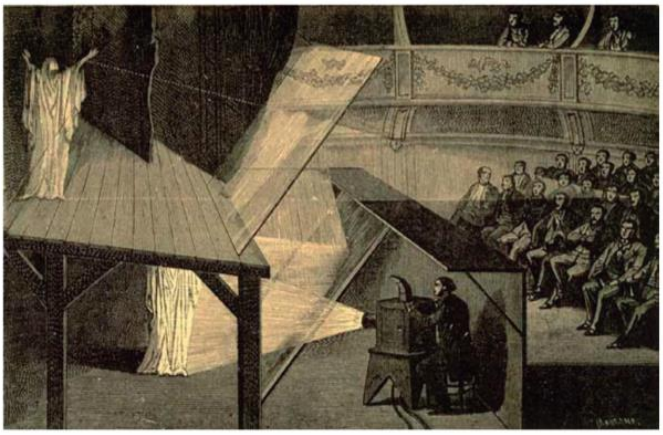

Fig. 2. Stage setup for Pepper's Ghost [8]

Musion is the industry leader in contemporary holographic projection foil technology, which is based on holographic projection foils. A polymer screen known as Eyeliner Foil, is the company's flagship product, and it performs exactly the same function in contemporary holographic displays as a sheet of glass does in the Pepper's Ghost illusion. As shown in Fig. 3, this technology was employed for the Tupac Shakur resurrection performance and is a regularly used medium for holographic projection in general [9].

'Transmission' [10] is the Analema Group's concept for a series of art and scientific projects on telepresence that will include large-scale installations and performances. Pepper's Ghost displays can provide 3D images through the use of optical cues and a defined lighting environment within a space-based environment. With holographic interfaces, you can have a cinematic experience that is almost completely immersive, which helps to achieve the goal of increased social participation.

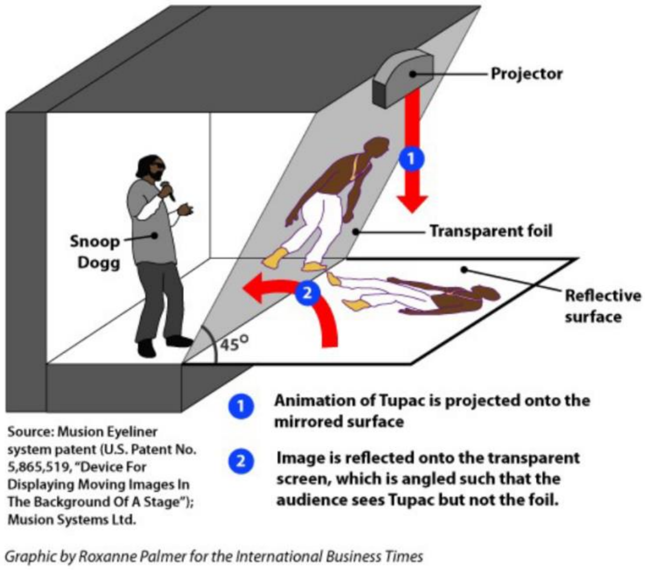

Fig. 3. Schematic setup for large-scale Pepper's Ghost by Musion Eyeliner [9]

B. Autostereoscopic Display

3D vision without wearable instruments are possible with autostereoscopy technology including a lenticular lens, parallax barrier and directional backlight. [11]. Head tracking system can be applied instead as it will either follow the viewer's head orientation or more precisely, track the eye positions. For 3D display that can simply track the middle line of the forehead, a view steering mechanism is enough to allow the left view to follow the left eye and right view to follow the right eye.

With 16 cameras and a lenticular autostereo display, the MERL 3DTV [12] system provided glass and tracker-free capture and display. Framerate was nevertheless low with restricted and repeated vieweing areas. 3Dpresence [13], an enhanced lenticular display system, is developed by the Fraunhofer Institute and the Heinrich Hertz Institute. For a number of people sitting around a table the system allowed multiviews, however, as with the MERL system, the number of views was reduced and horizontal parallax was only possible.

USCICT researchers developed a telepresence system[14] that utilises structured light to acquire 3D data and a volumetric 3D display. The system provided real-time collection, nearly continuous perspectives, and did not require tracking markers or glasses; nevertheless, the system could only capture and show data for a single user size, which is the head-size volume.

Fig. 4. A remote participant, represented in 3D on an autostereoscopic display, is interacted with the audiences. [14]

Holovizio [15] developed a convincing system of projection systems and cameras that enabled real-time 3D dynamic capture and trackerless autostereo vision. However, without true continuous viewing interpolation, the system could only capture at a moderate rate (10–15 Hz), and only a horizontal parallax was provided between a linear sequence of densely packed 2D cameras. It was also a very expensive equipment, with 27 cameras, three personal computers, and a variety of projectors. The FreeCam [16] system demonstrated a high-resolution 3D capture using a pair of depth cameras, although the capture was limited due to the user segmented from the background.

[17] demonstrated a dynamic 3D scene capture and continuous viewing capability, as well as a head-tracked 3D stereo display that does not require the user to wear any tracking or viewing devices, as the system tracked the user's eye position using depth sensors, as illustrated in Fig. 5. There is, however, considerable potential for improvement in terms of temporal noise, which degrades image quality, as well as the system's testing arrangement. TeleHuman [18] is a cylindrical 3D viewing portal for life-size human telepresence that enables 360° parallax motion when the viewer wanders around the cylinder pod and, ideally, the distant user's stereoscopic 3D display.

a) b)

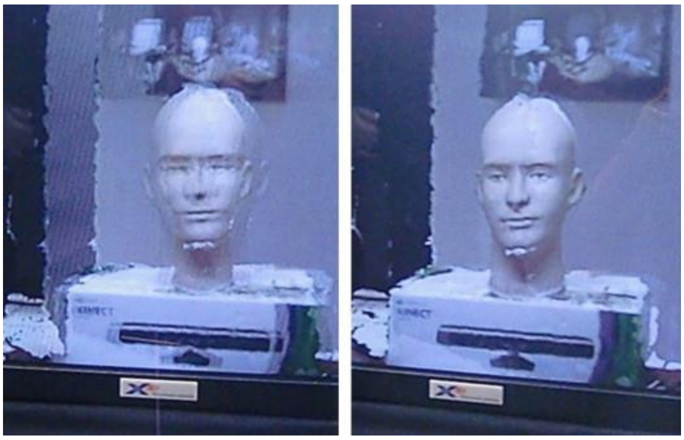

Fig. 5. Head-tracked stereo in motion when the tracking prediction and intra-frame rendering is (a) disabled. (b) enabled [17]

C. Holographic Projection

Holography [19] produces adequate three-dimensional images by reproducing the amplitude and phase information of a scene that may be viewed from a wide range of angles. This technique, according to the concepts stated in holography [20], creates a 3D representation of objects or situations in which the resultant hologram may be seen without the use of eyeglasses and is remarkably close to how we see our actual physical surroundings. A sequence from the original Star Wars film had an impact on the concept of real-time 3D telepresence with dynamic holograms showing a scene in another location, which was later developed further. According to recent trends, telepresence holography has the potential to improve education, modify teaching and learning, and perhaps revolutionise the way we communicate. A study conducted by [8] concluded that holographic projection is the best technique among 3D display technologies since it can accommodate all types of depth indications (full parallax).

Modern holographic telepresence can provide those who live at a distance with a life-sized, realistic, and virtual representation. Telepresence and holographic technologies, when combined, have the potential to create a new paradigm for realistic projection of users from a remote. A new one-way real-time lighting field 3D telepresence system, as seen in Fig. 6, was introduced by [22]. It was also suggested that the seamless horizontal motion parallax and almost real-life scale visualization provided by a one-way system can deliver the highest level of a sense of presence, compared to other solutions.

Fig. 6. The light-field display system of the telepresence [22]

True holographic displays and specialized technology are expensive to produce, and several attempts have been made to develop simulated holographic displays for these reasons [23], which have proven unsuccessful. The remote participant's 3D model afloat on an inverted pyramid is projected to imitate a holographic projection [24], and [25] gives a true life-sized holographic view of the professor, which allows for more efficient connection and impact on the viewers, who are the students.

In an effort to increase the telepresence sensation provided by the lecturer, [26] propose to incorporate holographic projection as an extra supplement to long distance education as an additional complement to long distance education. When the appearance of the professor is projected onto the transparent screen, the foil preserves the projection photons, causing the image to appear as if it is floating, which is telepresence, or the illusion of as if he is there, but he is not there. It is critical to pay attention to the transparency so audience can see the furniture and the white screen behind the transparent screen, which offers a really true feeling of being in an actual space. The holographic screen, the remote robot, and the software to handle long-distance projection were all integrated with the purpose of enhancing the students' perception of telepresence in the classroom.

Fig. 7. Holographic projection of professor from remote location being projected in local campus [26]

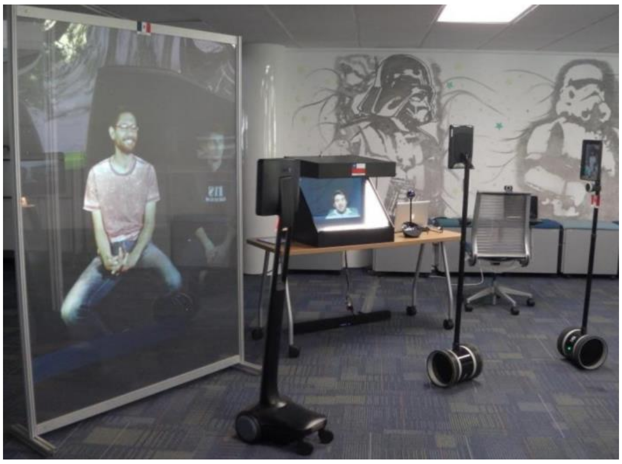

Fig. 8. Holographic projections of three students from various location; holographic glass (Location A), holographic station (Location B) and remote-control robots (Location C) [26]

IV. HARDWARE 2: HEAD MOUNTED DISPLAY (HMD)

Recent breakthroughs in virtual reality and augmented reality have enabled users to virtually project themselves in three dimensions in both simulated and real-world environments. Virtual avatars, similar to traditional teleconferencing, allow remote users to communicate with local MR users when they are embodied in these virtual avatars, which allow local users to believe the remote user is physically there in the same physical room.

An HMD display with a different video source displayed in front of each eye for a stereoscopic effect is visualized in Fig. 9. The user is commonly equipped with a helmet or a glass that has two miniature liquid crystal device (LCD) or organic light-emitting device (OLED) displays, one for each eye [27]. This technology allows for the viewing of stereo videos, pictures, and video games, and virtual displays can be created as well. HMDs can be connected to head-track devices, allowing users to "look around" the virtual environment by turning their heads. To avoid producing nausea to the consumer, performing such improvement needs extensive computer image processing [28].

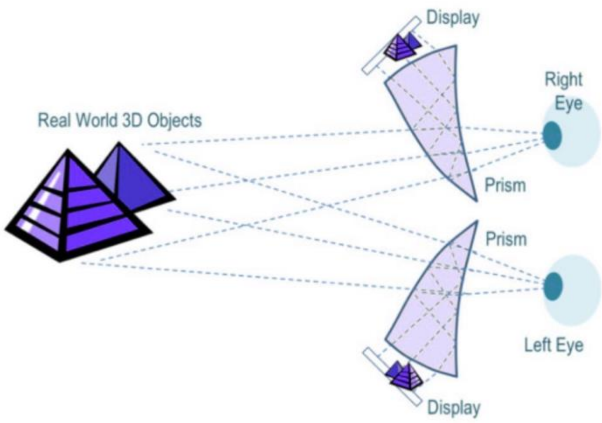

Fig. 9. HMD for stereo 3D display [28]

A. MR Headset

Mixed reality (MR) combines real-world and virtual world information through the use of mediums and displays. A specific application will fall into a different category of the Milgram and Kishino's MR continuum depending on the level of real and virtual data. [29] explores on a robust real-time 3D reconstruction method for MR telepresence. As illustrated in Fig. 10, local user who wore MR headset can view and perform collaborative task with remote user.

It is permissible to include an HMD in this continuum that is not visible in virtual reality (VR) but is visible in augmented reality (AR). It's also worth noting that augmented reality and virtual elements abstracted from the user's video constitute virtuality, while augmented reality occurs when a real-world context is overlaid with a virtual object. AR eye-wear displays may enable participants to engage more freely than multi-autostereoscopic displays, and by incorporating 3D models from both the remote and local location, these HMDs may be possible to accomplish the most-achievable combined presence yet, as claimed by [6].

[30] present a low-cost MR telepresence system where real-time 3D reconstruction of an individual and transmits the reconstructed 3D model wirelessly to the Microsoft HoloLens HMD at frame rates perceptibly smooth.

Fig. 10. MR telepresence user can see the remote user while wearing MR headset [29]

An MR framework that is the outcome of the combination of the telepresence with an application for improved collaborative space exploration were presented by [31] and Fig. 11 shows two users who are geologically distinct can meet each other.

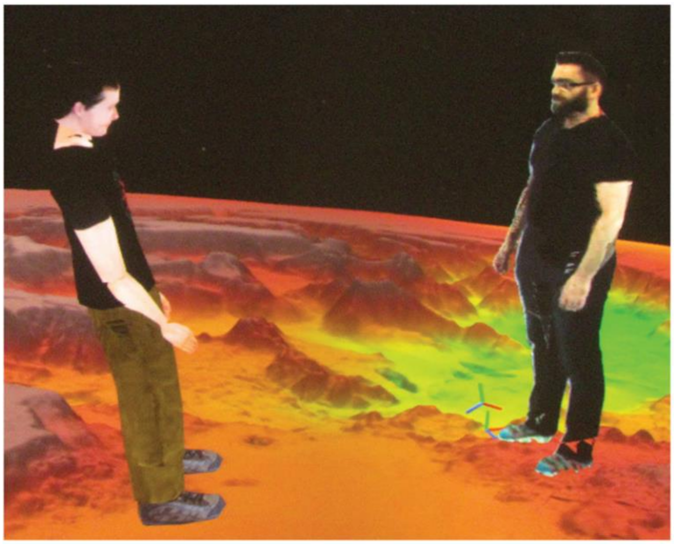

Fig. 11. Two seperate users from two different places met at the Mars [31]

B. VR HMD

We can expect a quick growth in VR solutions as a result of rapid advancements in display technology and the emergence of high-resolution HMD. A head-mounted display (HMD) can be used to enable a user to watch a simulation scenario of a remote place as if they were actually standing in the remote environment, rather than in a computer-generated simulation [32]. With this reasonable element in mind, the majority of telepresence systems that employ a VR approach are primarily utilised for remote exploration of potentially hazardous or out-of-reach locations, such as space. If the user uses this technology to simulate their presence in a remote location or simply to explore the location, the term telepresence is appropriate [32, 33, 34]. If the user performs a task or operation while exploring the remote site, the term teleoperation is feasible [35, 36]. According to [37], teleoperation occurs when the user uses remote device to interact or perform a task within the remote environment. Robot telepresence where a remote device can either attached with sensor and used to capture or scan the remote environment or it could be a humanoid robot with a control device that represent the local user [38,39,40].

V. Summary and Conclusion

A comparison table, such as that shown in Table I, summarises the characteristics of 3D display technologies that have been discussed through most of this paper. According to what we can see, each of the four display technologies can display a life-size model. However, because the on-stage hologram is a pseudo-3D display that is capable of generating a 3D illusion and responding only in specified directions, it can only be viewed from a single point of view, which is the front view of the stage. All other display technologies, with the exception of head-mounted displays, are capable of providing users with a 3D view without the usage of wearing equipment.

When considering the size of these display technologies, holographic projection and on-stage hologram are capable of being watched by multiple users whilst autosteroscopic and head-mounted displays (HMD) are only capable of being viewed by a single user per device. Auto stereoscopy may be capable of supporting multiple viewers, but first and importantly, the head tracking system must be amended and altered. In comparison to the other three devices, setting up the HMD requires fewer components and parts because each of these technologies has an own set of components and elements that can be installed in order for them to function properly. Given the importance of resolution and refresh rate, it is unlikely that an on-stage hologram or holographic projection will induce any pain or nausea, as opposed to auto stereoscopy and head-mounted displays.

TABLE I. COMPARISON TABLE

Features	**Peppers Ghost (On Stage Hologram)**	**Auto-stereoscopy**	**Holographic Projection**	**HMD**
Life-Size Capability	/	/	/	/
Viewable from different perspectives	×	/	/	/
Headset-free experience	/	/	/	×
Viewers per device	Many	1	Many	1
Ease of Setup	Complex	Complex	Complex	Medium
Nausea / Discomfort Level	None (similar to 2D display)	Medium	None	Medium

In conclusion, we have summarize the 3D display technology that have been implemented in the telepresence system which can be divided into two main devices which are projectors and HMD. From these two hardware, the 3D display technology that projector device are on-stage hologram, autostereoscopy, and holographic projection; and for HMD can be divided into MR headset and VR HMD.

As mentioned earlier, to decide the proper kind of 3D display technology for telepresence system, we must first identify the the number of user which will be displayed or projected as well as the one that will be viewing the other user. The purpose and activity involved when using the telepresence technology also be a factor in determine the suitable type of 3D display.

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