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Original Article

Evaluation of Stereoscopy in Digital Holography

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Abstract - *With the development of digital holography, the demand for holographic content has increased. Content creators apply their knowledge to the new medium but face the challenges of unknown technology. This study develops a novel test chart for the process of digital hologram creation using the context of stereoscopic image production. The development of a holographic test image is specially designed to illustrate some of the principal characteristics of digital holograms. Analogies are derived from the content creation principles of other types of digital stereograms, such as 3D cinema and multiview images. The objective of this study is to create a reference test chart as a sample for artistic and technological evaluation. This research aims to improve content creation for digital holograms. The increased quality of hologram content can eventually contribute to the wide acceptance and success of the technology.*

Keywords - *Holography, Digital, Stereoscopy, Content, Test chart.*

1. Introduction

Many new visualization methods are referred to as holograms, such as the overlaid 3D objects in an augmented relative head-mounted display (HMD) [1], [2] or the reflection of a pepper's ghost effect in entertainment venues [3]. For disambiguation, this study only focuses on the type of hologram images representing light fields based on wavefronts, as described in the method of its inventor Denis Gabor [4] and practically applied with lasers by Yuri Denisyuk [5]. New methods have been developed to create digital holograms based on images from multiple viewpoints to overcome the limitations in light-field capturing restricted to analogue objects. The pixels of these multiple points of view are decomposed, regrouped into large arrays, and recorded using digital holographic printers [6]. Consequently, almost any type of content can be visualized using the digital content creation process. These results are astonishing, and the latest generation of hologram printers can reach the field of view and resolution of analogue holograms [7]. However, since digital holograms are based on a multitude of viewpoints rather than an entire light field, some particular differences exist that must be addressed in the content creation process. This applies to hologram creation from images acquired by real cameras or rendered by virtual cameras using computer-generated imagery (CGI). The literature describes in detail the technical progress of digital hologram creation based on Hogels [6]. Research rarely addresses the constraints and challenges in digital hologram creation from the content creators' point of view. The novel approach of this paper is to view digital hologram content creation in the context of stereoscopy. Observing a digital hologram can be compared to watching different points of view of similar 3D display devices, such as lenticular or parallax barrier displays HMD, 3DTV, or 3D cinema [8], [9]. The last three display types have been the subject of our recent research on stereoscopy in virtual reality. [10] This paper extends and applies a similar approach to digital holography.

The visualization, as mentioned above, methods are based on the observer watching two distinct images simultaneously—one for the right eye and the other for the left eye. Even with multiple degrees of freedom [11] and without the aid of glasses, stereoscopic vision creates the impression of watching a 3D object. Therefore, stereoscopic vision principles can be applied. During the creation process, they create appealing content and avoid artefacts or even eye strain on the viewer [12].

The technical process for creating multiple-view images involves several parameters. This study addresses and identifies the essential characteristics of binocular vision.

1.1. Image Plane

Stereoscopic, lenticular, and digital holographic images are transplanar [13], which means that their image plane surface is invisible as opposed to planar images, such as paintings and photographs, which have a clearly identifiable surface and the image plane. However, even if the image plane is invisible, the image objects can be positioned at different depth levels inside the holographic image. When image points appear at the level of the image surface, the viewer sees zero parallax between the points on an image pair. Identifying the image planer during image creation is essential for adequately positioning the content inside the hologram.

1.2. Frontmost Plane

While creating and displaying 3D images, the space in front of the image plane is a very important parameter. Constraints resulting from the hologram printing method can enhance or reduce the number of distant objects that can emerge from the image screen. In stereoscopy, this is commonly referred to as a negative parallax. The effect can vary significantly with the viewer's distance and viewing angles. It is a unique and popular feature of 3D movies and holograms [14].

1.3. Background Plane

Symmetrically to the limiting parameters in the front plane of digital holograms, constraints are to be considered for the backplane. This parameter can significantly cause discomfort and eye strain in the 3D cinema if not adequately controlled. Smaller displays also face constraints owing to the eyes' technical features and human physiology [26]. Therefore, identifying the background plane is essential for creating a comfortable viewing experience.

1.4. Identification of Viewpoints

Human factors in stereoscopy have been subject to extensive research [16]. Average adult humans have a constant interpupillary distance of approximately 6.3 cm [17]. However, cameras do not necessarily correspond to the eyes during creation, and different parameters can be used. It is common practice in 3D cinema to shoot with smaller interaxial and anticipate the magnification of a large projection, which can be responsible for divergence and, as a result, eye strain for the audience. [18]

In addition, the interaxial distance can be responsible for the perceived scale of 3D objects. Exaggerated interaxial distances can result in dwarfism, while reduced interaxial distances can make an object seem larger than in reality [19]. When watching a hologram, the content distance and viewing angle can also influence the viewpoint [20]. Figure 1 shows several viewing situations and their sizes. Figures 1a) and 1b) show the viewing of different-sized digital holograms from the same distance. Figures 1b) and 1c) show the different viewing angles when viewing different-sized digital holograms from the same distance.

Therefore, anticipating and defining the viewing environment is crucial in the creation process of content for digital holograms.

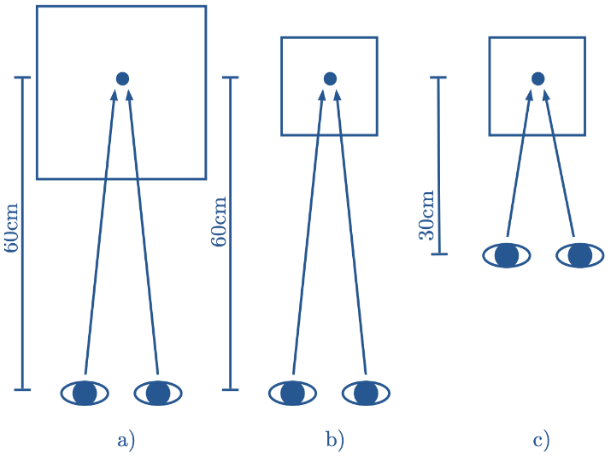


Fig. 1 Viewing situations

Fig. 2 Stereoscopic test image for 3D cinema

These parameters' optimal values and settings must be determined through practical experimentation. This study proposes developing and implementing a test chart for digital holographic content to identify and evaluate the parameters in a specific hologram.

The following section describes the tools and methods used to produce the digital hologram reference test chart.

2. Materials and Methods

Creating a reference test chart is common practice when evaluating new recording or display devices. Figure 2 shows an example of a stereoscopic test chart with two images used for commercial advertising production for a large 3D cinema venue. The purpose of the test content was to explore the optimum values for content creation and to create a safe technical framework for holographic content creation.

Test charts can be created with many tools, from real camera images or calculated images using CGI.

This study's primary tool for creating holographic test images was a 3D animation programme.

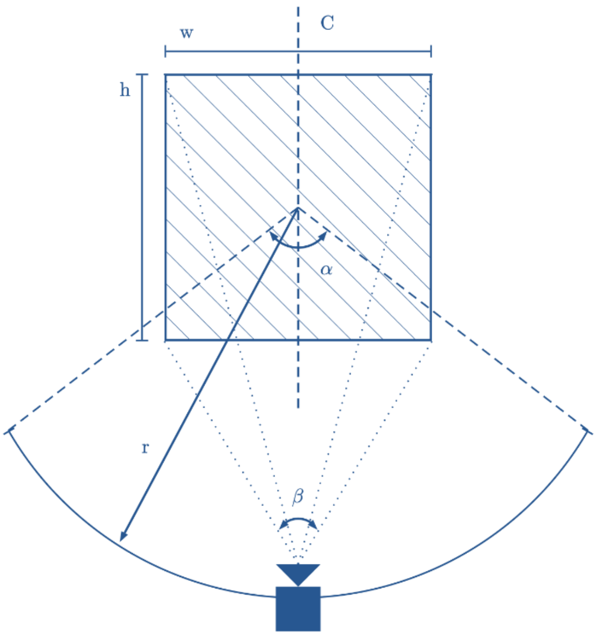


Fig. 3 Scene with hologram frame and camera

Table 1. Scene Parameter Settings

Parameter	Description	Value
w	hologram width	30 cm
h	hologram height	40 cm
r	camera distance	1 m
alpha	hologram viewing angle	120°
phi	horizontal field of view	22.6°
C	Convergence Axis	origin
n	number of viewpoints	768

A computer program provided the greatest precision and greater control of all parameters. This research used the free and open-source 3D modelling and animation software Blender [21]. The methods and tools used to create a holographic sample scene are described in the following subsections.

2.1. Scene Creation

In the first step, software was created to create a unified and normalized space. Figure 2 shows the schema of the principal elements of the 3D test scene. The following subsections describe the functions and values of these elements.

2.1.1. Image Plane

An image plane is an imaginary plane. The plane represents the plane at the centre of the resulting hologram; its width and height are defined by w and h, respectively. This plane is divided vertically by axis C. To simplify positioning in the scene, this axis crosses the origin of the coordinate system at the centre of the scene. A virtual camera is created to create a zero parallax for all pixels on axis C. The camera is set to have a field of view matching the height of the hologram frame. The virtual camera is positioned at a distance r from the centre of C. The camera is constrained to rotate around axis C with radius r on an arc defined by angle alpha. The maximum field of view determines the alpha that the hologram can reproduce and is a technical specification of the printer.

Table 1 lists the parameters used in the setup. The width and height of the hologram are determined by the dimensions of the physical hologram plate used in the printer. Different sizes are available. To create an orthoscopic image, the camera distance should coincide with the hologram viewer distance [22]. The field of view is a constraint that matches the size of the hologram frame in a 3D scene.

2.1.2. Frontmost Plane

In stereoscopy, negative parallax indicates the extent to which a point or object is positioned in front of a screen plane. This difference in perspective creates the effect of objects coming out of the screen. In stereoscopic 3D images, the viewer always views two images. These two images are generally the same regardless of the viewer's position and follow the viewer's angle. The stereograms of hologram images behave differently. Since the perceived image pair for the left and right eyes changes with the viewer's position, the most extreme viewing angle limits the maximum negative parallax and the space available in front of the hologram. Figure 4 shows two points of view from the top. From viewpoint P1, one can see maximum negative parallax M1, while from viewpoint P2, one can see maximum negative parallax M2; the closer the viewpoint is to the hologram plane, the more it will be occluded by the opposite border and end of the image. In an extreme case, parts of the image can be visible to one eye and partially cut off in the other eye. In stereoscopy, this is referred to as window violation and can cause discomfort to the viewer [23].

2.1.3. Background Plane

The background plane requires particular attention for the creation of digital holograms. In 3D cinema, this is often referred to as the background plane or far point. At infinity, far objects are seen by the viewer with eyes in parallel. Large magnifications can exaggerate the disparity on the screen and cause divergence in the eyes of the viewer. This occurrence is less likely on smaller screens, such as 3D televisions or holograms of similar sizes or less. These displays and images are generally observed at much closer distances [24].

Consequently, the viewer is not expecting to see infinity in the image of the size of a postcard. Seeing infinity with eyes in parallel would require a parallax of approximately 6.3 cm, which could exceed the size of the image itself. Stereovision is not equal to natural vision. This is because the Focus plane and convergence on an object are dissociated. The discomfort caused by the dissociation of vergence from accommodation increases the closeness of the image to the viewer [26]. Therefore, the maximum depth is not limited to infinity but the maximum tolerance of discomfort due to the vergence-accommodation conflict. The acceptable disparity must lie within the comfort zone, which increases as the image moves further from the viewer.

Figure 5 sketches three different viewing situations for far-away objects. Figure 5a) shows an oversized magnification of infinity, causing the viewer to diverge. This unnatural viewing experience can be responsible for pain and eye strain. Figure 5b) shows an object very far behind the image plane. The large difference between accommodation on the image plane and vergence far behind the image is beyond the comfort zone. Figure 5c) shows an image point behind the image plane. The point lies within the comfort zone and creates a comfortable viewing experience.

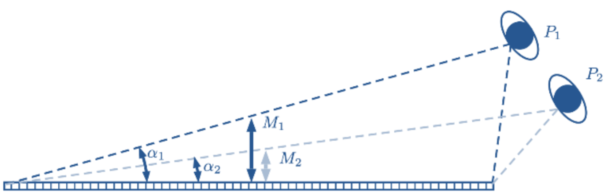


Fig. 4 Negative parallax at two viewpoints

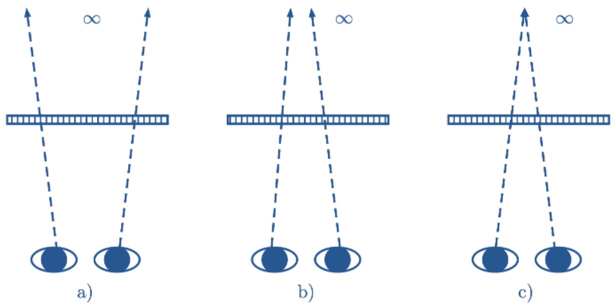


Fig. 5 Viewing situations for far-away objects

To practical experiment with the occurrence and level of discomfort in the background, several objects are placed in the 3D scene: a far-textured tube surrounds the image at one metre. The columns and colour charts represent precise distances regarding the origin. Lines of 0.5 and 0.25 text indicate distances of 50 cm and 25 cm behind the image plane, respectively. The further objects and their distances are listed in Table 2.

2.1.4. Identification of Viewpoints

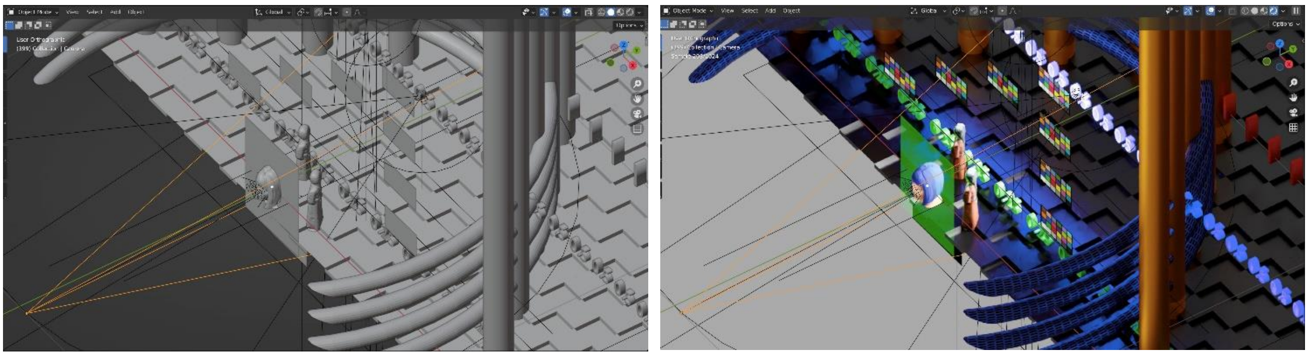
The number of viewpoints for the perspective images shown in Table 1 corresponds to the spatial resolution provided by the hologram printer. Viewpoint identification is achieved by embedding a frame number inside each rendered perspective image. Figure 6 shows the numbers on the image plane with a high-contrast background. In the test image, the viewer should see two distinct images and observe a stereoscopic image. The pair of images the viewer sees depends on the viewing angle and the distance from the hologram image plane. Figure 1 illustrates the different viewing positions that result in different stereoscopic image pairs.

2.2. Rendering and Export

The final scene composition contains additional elements, such as colour charts, to verify the referenced colours and exposure. A head model is often used in reference charts to visualize skint textures and colours. Hair details can indicate the image results in a printed hologram. The floor was created as a chequerboard with 10 cm × 10 cm tiles. Additional objects scanned with photogrammetry were placed 20 and 30 cm behind the image plane. Table 2 summarises the distances in the reference hologram images.

Table 2. Reference objects and distances

Object	Distance
head centre	0 cm origin
numbers	0 cm origin
doll left	30 cm
doll right	20 cm
0.25 text	25 cm
0.5 text	50 cm
1 text	100 cm
centre colour chart	50 cm
centre columns	100 cm



a) b)

Fig. 6 3D scene view: a) objects and b) with shader

Fig. 7 Five sample viewpoints

The complete scene is recorded by one camera following a 1-m constraint with a target on the origin. A total viewing angle of 120° was achieved by an animation which rotated the camera from -60° to +60° on the horizontal plane. Figure 6 shows the complete scene setup.

3. Results and Discussion

The result of the method described in the previous section can be compared to a novel sample data set for digital holography. It is an image sequence of 768 horizontal pictures in a portable network graphics file format (PNG) with 16 bits for the red, green, and blue channels. These represent the perspective views required to calculate the hogels to print a half-parallax hologram [25]. Figure 7 shows an excerpt of five images with viewing angles ranging from left to right. The image sequence number appeared at the bottom of the image.

The sequence of perspective images allows for creating of digital holograms of different sizes and viewing distances. The printed holograms can be evaluated. The test image allows for practical observation and understanding of the available space for holographic hologram creation. The principal features of holographic test charts are based on human physiology and stereographic parameters.

- Identification of the Image Plane
- Identification of the frontmost plane for a given viewing angle
- Identification of background plane for a given size and viewing distance

The test image for digital holograms allows for evaluating the represented space. Difficulties observed in the foreground or background can be easily identified using precise metrics used for the parameters. A test chart can be used to determine the optimum viewing conditions and hologram size. It can also help evaluate the technical quality of the hologram printing process.

The goal of creating a reference environment for the experimental evaluation of the principal stereoscopic parameters inside a digital hologram has been achieved.

Evaluation and measurement of the same content printed on different hologram plates using different technologies and parameters can be part of future research.

4. Conclusion

Significant progress in holographic printing represents a breakthrough in creating digital holograms. The present study introduces a novel test image system for content creation for digital holography based on stereoscopic content creation. This test image can be compared to a sample data set for digital holography. This permits not only to assess a digital hologram printing technology but also to compare one technology with another. Given the technical features of holographic printers and the specific viewer positions of the observer, knowledge of the available image space is crucial for successfully creating holographic content. As in stereoscopic content, creators need to observe human physiognomy to avoid irritation or discomfort when viewing the image.

This study proposes a test chart with clear parameters for developing holographic test images. The results allow content creators and holographic printers to assess the quality of the content and technology. This research aims to enable content creators to gain greater control over the creation process, improve the understanding of digital holograms, and increase the field of applications and propagation of holographic technology.

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References

[1] Robert Harry Black, *Human Factors in the Perception of Stereoscopic Images*-Proquest, 2017. [Online]. Available: https://www.proquest.com/openview/fcedabd0f9184dec93824fc27944828d/1?pq-origsite=gscholar&cbl=51922&diss=y

[2] Blain JM, *The Complete Guide to Blender Graphics: Computer Modeling & Animation,* Fifth Edition (5th Ed.), A K Peters/CRC Press, 2019. *Crossref,* https://doi.org/10.1201/9780429196522

[3] Jeremy Brooker, "The Polytechnic Ghost," *Early Popular Visual Culture,* vol. 5, no. 2, pp. 189–206, 2007. *Crossref,* https://doi.org/10.1080/17460650701433517

[4] Chandrasekera T, Fernando K, and Puig L, "Effect of Degrees of Freedom on the Sense of Presence Generated by Virtual Reality (VR) Head-Mounted Display Systems: A Case Study on the Use of VR in Early Design Studios," *Journal of Educational Technology Systems,* vol. 47, no. 4, pp. 513–522, 2019. *Crossref,* https://doi.org/10.1177/0047239518824862

[5] Thomas Conner, "Pepper's Ghost and the Augmented Reality of Modernity," *Journal of Science & Popular Culture,* vol. 3, no. 1, pp. 57–79, 2020. *Crossref,* https://doi.org/10.1386/jspc_00012_1

[6] Dodgson NA, "Variation and Extrema of Human Interpupillary Distance," *Proceedings Stereoscopic Displays and Virtual Reality Systems XI,* vol. 5291, pp, 36–46, 2004. *Crossref,* https://doi.org/10.1117/12.529999

[7] Flueckiger B, "Aesthetics of Stereoscopic Cinema," *Projections,* vol. 6, no. 1, pp. 101–122, 2012. *Crossref,* https://doi.org/10.3167/proj.2012.060104

[8] Dennis Gabor, "Holography, 1948-1971," *Science,* vol. 177, no. 4046, pp. 299-313. *Crossref,* https://doi.org/10.1126/science.177.4046.299

[9] Ganzherli NM, "Yu. N. Denisyuk's Ideas in the Development of Holographic Methods of Obtaining and Projection of Images," *Technical Physics*, vol. 62, no. 10, pp. 1449–1455, 2017. *Crossref*, https://doi.org/10.1134/S1063784217100127

[10] Jason Geng, "Three-Dimensional Display Technologies," *Advances in Optics and Photonics*, vol. 5, no. 4, pp. 456–535, 2013. *Crossref*, https://doi.org/10.1364/AOP.5.000456

[11] Gentet Y, and Gentet P, "CHIMERA, A New Holoprinter Technology Combining Low-Power Continuous Lasers and Fast Printing," *Applied Optics*, vol. 58, no. 34, pp. G226–G230, 2019. *Crossref*, https://doi.org/10.1364/AO.58.00G226

[12] Hamacher A, "Adding Stereoscopic 3D to 3D Games With the Trioviz SDK, Optimizing the Stereoscopic Viewing Experience," *Journal of the Korean Computer Game Society*, vol. 27, no. 1, pp. 95–101, 2014. *Crossref*, http://doi.org/10.22819/kscg.2014.27.1.012

[13] Hamacher A, "Stereoscopy in Virtual Reality," *International Journal of Engineering Trends and Technology*, vol. 69, no. 6, pp. 126-130, 2021. *Crossref*, https://doi.org/10.14445/22315381/IJETT-V69I6P219

[14] Konrad, Janusz, "Enhancement of Viewer Comfort in Stereoscopic Viewing: Parallax Adjustment," *Stereoscopic Displays and Virtual Reality Systems VI*, vol. 3639, pp. 179–190, 1999. *Crossref*, https://doi.org/10.1117/12.349379

[15] Dr.I.Lakshmi, "Execution of Mobile Video Calls Utilizing Holographic View," *SSRG International Journal of Mobile Computing and Application*, vol. 6, no. 1, pp. 8-15, 2019. *Crossref*, https://doi.org/10.14445/23939141/IJMCA-V6I1P103.

[16] Bernard Mendiburu, "3D Movie Making: Stereoscopic Digital Cinema from Script to Screen," *CRC Press*, 2012.

[17] Yasin Nazzar, Bouchard J, and James Clark, "Detection of Stereo Window Violation in 3D Movies," *ACM SIGGRAPH 2014 Posters*, vol. 1, 2014. *Crossref*, https://doi.org/10.1145/2614217.2630593

[18] Daechul Park, "Lenticular Stereoscopic Imaging and Displaying Techniques with No Special Glasses," *Proceedings International Conference on Image Processing*, vol. 3, pp. 137–140, 1995. *Crossref*, https://doi.org/10.1109/ICIP.1995.537599

[19] Schröter J, "*3D: History, Theory and Aesthetics of the Transplane Image*," Bloomsbury Publishing USA, 2014.

[20] Takashi Shibata et al., "The Zone of Comfort: Predicting Visual Discomfort with Stereo Displays," *Journal of vision*, vol. 11, no. 8, pp. 11–11, 2011. *Crossref*, https://doi.org/10.1167/11.8.11

[21] Michael Unger et al., "Hologram Accuracy Evaluation of Hololens 2 for Thermal Imaging in Medical Applications," *Current Directions in Biomedical Engineering*, vol. 8, no. 2, pp. 193–196, 2022. *Crossref*, https://doi.org/10.1515/Cdbme-2022-1050

[22] Hirokazu Yamanoue et al., “Orthostereoscopic Conditions for 3D HDTV,” *Stereoscopic Displays and Virtual Reality Systems V*, vol. 3295, pp. 111–120, 1998. *Crossref*, https://doi.org/10.1117/12.307153

[23] Xin Yang et al., "High-Resolution Hologram Calculation Method Based on Light Field Image Rendering," *Applied Science*, vol. 10, no. 3, p. 819, 2020. *Crossref*, https://doi.org/10.3390/App10030819

[24] Fabrizio Zeri, and Stefano Livi, "Visual Discomfort While Watching Stereoscopic Three-Dimensional Movies At the Cinema," *Ophthalmic and Physiological Optics*, vol. 35, no. 3, pp. 271–282, 2015. *Crossref*, https://doi.org/10.1111/Opo.12194

[25] Xu Zhang et al., "Accelerated Generation of a Pinhole-Type Holographic Stereogram Based on Human Eye Characteristics in Near-Eye Displays," *Photonics*, vol. 9, no. 2, pp. 95, 2022. *Crossref*, https://doi.org/10.3390/Photonics9020095

[26] Mcintire JP, Havig PR, and Geiselman EE, "What is 3D Good for? A Review of Human Performance on Stereoscopic 3D Displays," *Head- and Helmet-Mounted Displays XVII; and Display Technologies and Applications for Defense, Security, and Avionics VI*, vol. 8383, pp. 280–292, 2012. *Crossref*, https://doi.org/10.1117/12.920017