proceedings

Proceedings

Field of view enhancement of dynamic holographic displays using algorithms, devices, and systems: A review

Monika Rani, Narmada Joshi, Bhargab Das, Raj Kumar*

CSIR-Central Scientific Instruments Organization, Sector 30C, Chandigarh, 160030, India

Correspondence: raj.optics@csio.res.in;

† Presented at Holography Meets Advanced Manufacturing, Estonia, and 20-02-2023.

Abstract: Holography is a prominent 3D display approach as it offers a realistic 3D display without the need for special glasses. Due to advancements in computation power and optoelectronic technology, holographic displays have emerged as widely appreciated technology among other 3D display technologies and have drawn a lot of research interest in recent years. The core of dynamic holographic displays is spatial light modulator (SLM) technology. However, owing to the limited resolution and large pixel size of SLMs, holographic displays suffer from certain bottlenecks such as limited field of view (FOV) and narrow viewing angle. To develop a holographic display at the commercial level, it is crucial to solve these problems. A variety of probable solutions to these challenges may be found in the literature. In this review, we discuss the essence of these approaches. We study the important milestones of the various methodologies from three primary perspectives: algorithms, optical systems, and devices employed for FOV extension, and provide useful insights for future research.

Keywords: holographic displays; field of view; spatial light modulator

Citation: To be added by editorial staff during production.

Academic Editor: Firstname Lastname

Published: date

1. Introduction

In order to make their thoughts come to life, people want to visualize them. The methods through which thoughts and experiences are visualized, have evolved from art to photography, and more recently to 3-D displays with the advancements of science and technology. The four main types of 3-D displays are stereoscopic, auto-stereoscopic, volumetric, and holographic displays [1]. Holography has been recognized as the most suitable method for displaying 3-D images that seem realistic. It has the ability to control crucial aspects of light, such as phase, which cannot be controlled by other methods [2]. Holographic three-dimensional (3-D) displays, which can rebuild 3-D images with complete depth cues, have obtained a broad attention in last few decades for their potential applications in a variety of industries, including the medical and military sectors [3]. Holographic dynamic displays come into picture in order to display information at video rate. Since video-enabled holography needs a lot of pixels and data, implementing it is another difficult task. However, evolution in parallel computing approaches and inventions of optical modulators make the dynamic loading as well as dynamic display of holograms possible. To display the calculated digital holograms, spatial light modulators (SLM) are one of the widely used methods [4]. But field of view (FOV), space bandwidth product (SBP) of the hologram, and the display quality are all constrained by the size and pixel pitch of commercially available SLMs. As a result, the SBP of holographic displays utilizing SLM is often several hundred times lower than that of static holographic media. It implies that for an SLM to display a hologram, either the hologram size or the viewing angle must be inadequate. To achieve a large sized, dynamic, full-color, holographic 3-D display, it is important to overcome these problems. So, in the past few years, there have been various attempts to overcome these barriers for realizing a commercially viable dynamic holographic display technology.

In this review study, we take a look at some of the prominent methods that are proposed by different researchers to overcome the problems associated with limited FOV of holographic displays. This study is divided into three sections. In Section I, the FOV expansion approaches based on algorithms used for CGH generation are discussed. The introduction and principle of various systems and devices employed in optical configurations are explained in Section II and Section III, respectively. The advantages and disadvantages regarding each method are also explored from realization/employment perspective. From this study, we investigate what more is required to have a holographic display with wide FOV in our hands.

2. Algorithmic approaches for CGH generation

One of the most important aspects of holographic displays is computer generated hologram (CGH) generation. The objective of CGH is to model, calculate, and encode holograms from 3D scenes. Algorithms are often separated into three paths from a computational perspective, depending on the various solutions to the wave equation. The approaches mentioned in literature include point source, polygon, spherical, and cylindrical [5]. The main objective of these algorithms is the real-time computation of complex holographic patterns with huge information capacities for multi-color, wide-angle, and large-image systems. However, the spatial frequency and physical size of the CGH affect its information capacity and FOV. As a result, a significant amount of study on overcoming these limitations is reported. Generally, curved holograms such as computer-generated cylindrical holograms (CCGH) are thought to be the best for enlarging FOV as they offer the ability to view an image from any angle, enabling the reconstruction and 360^{o} horizontal viewing of the object [6]. For a large compensation distance, it is impossible to correctly perform the point-to-point phase compensation between wavefront recording plane and CCGH. The approximate phase compensation (APC) technique has also this restriction condition. As a result, a full CCGH cannot be produced, and the FOV extension is constrained, making it impossible to fully use the 360^{o} FOV of the CCGH. This issue has been resolved by gapless splicing of multi-segment cylindrical holograms (mSCH) [7]. In this suggested approach, the limited condition of APC technique was initially examined. Further, the crucial compensation distance requirement was also mentioned. Three SCHs were taken into account as a group in this method and two by two were spliced together at a time. To obtain wide FOV display with above discussed method, curved display screen and flexible display materials are required. It is often convenient to employ LCoS SLMs with inclined illumination since they operate in reflection. The inclination geometry changes the FOV of the holographic display. Modifying an object wavefront obtained from recorded digital holograms for reconstruction at the tilted SLM display is a major challenge with this technology. Kozacki [8] developed a digital hologram processing technique that uses just the required paraxial holographic field by rigorously propagating paraxial fields between inclined planes. Other significant considerations in this method are pixel response and wavefront aberration calibration, SLM calibration based on tilt value, and characterization of tilt-dependent imaging space. Unconventional angular multiplexing techniques [9] are also utilized to multiplex the whole object information in single CGH according to the SLM parameters. This approach results in angle multiplexed CGHs as shown in Fig.1. Although this method only requires one SLM, the FOV it produces is insufficient for binocular vision. Another CGH generation approach [10] is developed based on angular multiplexing but it utilizes three SLMs in a planar configuration to reconstruct the image. So, it is economically inefficient and optical configuration also becomes complex due to use of three SLMs. Two step Fresnel diffraction method [11] for CGH calculation is formulated for expansion of FOV without any physical change in the optical set-up. The virtual image size is increased, resulting in enhanced FOV, by decreasing the sampling interval on the intermediate plane. However, the proposed approach shows promise for the construction of holographic AR near-eye displays with wide FOV. Thus, it is clear from the literature that the algorithms used for CGH generation play a vital role in FOV expansion for a particular holographic display.

3. Configuration of display systems

SLMs are used in holographic displays to replicate wavefronts of an object. Due to employment of SLMs as display systems, FOV of reconstructed images is relatively constrained because small size of available SLMs. It is difficult for the viewer to move around while watching the reconstructions since viewing angle is also small due to large pixel pitch of SLMs. Thus, the depth cue provided by motion parallax is insufficient. Additionally, the size of the reconstructed object is rather modest due to the restricted FOV [12]. To increase the field of view for holographic displays, several techniques are reviewed in this section. As the SLMs can work in reflection mode, so it is easy to illuminated them by tilted plane wave. The FOV of the display increases assymeterically with respect to the tilt angle [8]. The performance of SLM is impacted by incidence angle. In this approach, the limitation is that digital holograms cannot be directly reconstructed due to the geometry and large tilt angles affect the qualtiy of the reconstructed images. Another display system reported by Maeno,K. et. al. [13], in which five transmission type liquid crystal SLMs are placed horizontally side by side. Consequently, there is an expansion of the horizontal FOV. In addition, this technique has limited vertical parallax. To answer this problen, one more method is proposed to enhance the FOV of the reconstructed images. The field of view significantly grows along with the number of SLMs [14] as shown in Fig.2. In the reported geometry six phase-only SLMs are used in a holographic display system that creates holographic reconstructions from a point cloud that is taken from a three-dimensional object [5]. These SLMs are tiled in a three by two pattern. But this method is very expensive because the field of view relies on the number of modulators being employed. Further, J. Hahn et. al. explained another unique strategy [15], in which the display system is made up of a curved array of SLMs. The spatial bandwidth of SLMs is reduced by the curved arrays, which produce more data points. The local angular spectra of the object wave are shown by individually modifying each SLM in the curved array. This configuration has a significant impact on optically reconstructed holographic images.

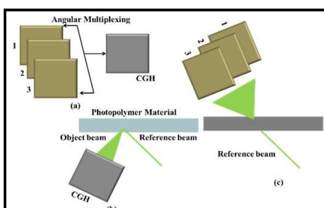

Figure. 1. (a) Angular multiplexing of the different objects in single CGH; (b) Recording, (C) Reconstruction.

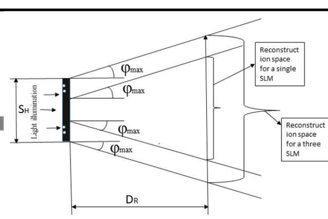

Figure2: Reconstruction space increased when multiple SLMs are used

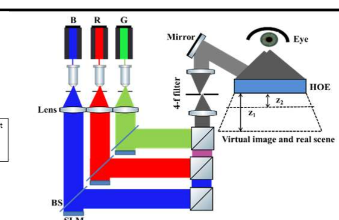

Figure. 3. Schematic view of the wide field see-through holographic display

4. Devlopement of optical devices

In holographic display systems, after CGH generation and display systems, optical configurations are realized for spatial filtering of higher diffraction orders and magnification/demagnification, and propagatation the reconstructed image to the desired distance at the observation plane. The optical devices used in the optical configurations also have a significant contribution in enhancement of FOV. To increase the FOV by time division and space division multiplexing of SLMs, multiple projection systems, and CGH generation at high frame rate are required. Due to the use of number of SLMs, there are gaps observed in the reconstructed image that degrades its quality. A holographic function screen [16] is developed to remove these gaps and further expand the FOV of display systems. This screen has a specific diffusion angle related with the diffraction angle of SLM and it is placed at the image plane. Three SLMs are used and the FOV is increased by 38 times as compare to single SLM with gapless splicing using this functional screen. The system becomes complex and the functional screen reduced the intensity of light reached at the observation plane. Holographic optical elements (HOE) [17] are suggested to achieve the 80^{o} FOV for round view. CGH is uploaded using a phase-only SLM, and noise produced by the dead zone of the SLM is blocked using a 4f optical system and spatial filtering at the Fourier plane. The HOE serves as an eyepiece and, as illustrated in Fig. 3, converges a highly off-axis beam into an on-axis beam in front of the human eye.. The FOV expansion is dependent upon the photopolymer material used for recording as well as the grating structure of HOE. G. Yuchen et. al.[18], obtained a diagnoal FOV about 55^{o} using polarized volume holographic grating (PVG). The angular bandwidth and refractive index modulation of recorded gratings are the responsible factors for the limited FOV. In spite of the fact that PVG has a wider angular bandwidth than volume holographic grating (VHG), a single PVG is unable to accommodate a broad field of view.Thus, the laminated composite PVGs are proposed in this work. The lens array 4f system [19] is adopted to increase the FOV from 1.9^{o} to 7.6^{o} and optimized the SLM phase profile to improve the reconstructed image quality. K. Dongyeon et. al. suggested a FOV expansion technique for the holographic near-eye display without additional mechanical device and micro structured mask. The original intensity is divided into pieces, and each serves as a target profile for each depth plane. The placement of beam splitter array and eyepiece lens with high numerical aperture allows realization of the enlarged FOV. Three times enlarged FOV is achieved by the mentioned approach. Based on the above research studies, it is observed that the devleopement of such devices are helpful in realization of holographic displays with wide FOV.

5. Conclusion

This paper reviews the current state-of-the-art of the FOV expansion for the holographic displays. CGH generation algortihms, configuration of display systems, and the optical devices are identified as the three most promising candidates for the above purpose. The combination of different primitive methods into an optimized algorithm is a good solution to enhance the FOV. In addition, with the development of computer, the combination of fast calculation algorithms and high-performance computing equipment is also an effective means to speed up the calculation and helpful in spatio-temproal multiplexing of SLMs. A path for limited FOV is opened up at the same time by the development of new optical devices. From the perspective of display for practical uses, more system parameters need to be taken into account, such as cost, image quality, uniform intensity distribution, and simplicity of overall system etc. Holographic displays are anticipated to enter the market and become a part of daily life in the near future as a result of advancements in CGH algorithms, devices, and systems.

Author Contributions: Monika Rani: Conceptualization, writing—original draft preparation methodology, Narmada Joshi: writing—original draft preparation, Bhargab Das: supervision, methodology, writing—review and editing, and Raj Kumar: supervision, writing—review and editing, project administration, funding acquisition.

Funding: This research work is financially supported by the CSIR, New Delhi under the project MLP-2014.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Geng, J. Three-dimensional display technologies. Adv Opt Photon 2013, 5, 456–535.
2. Hariharan, P. Optical Holography: Principles, Techniques and Applications, 2nd ed.; Cambridge University Press & Assessment: Shaftesbury Road, Cambridge, UK, 2008; pp. 154–196.
3. Paturzo, M.; Memmolo, P.; Finizio, A.; Näsänen, R.; Naughton, T.J.; Ferraro, P. Holographic display of synthetic 3D dynamic scene. 3D Research 2010, 31-35.
4. Michalkiewicz, A.; Kujawinskaa, M.; Kozackia, T.; Wangb, X.; Bosb, P. J. Holographic three-dimensional displays with liquid crystal on silicon spatial light modulator. Proc. SPIE 2004, 5531, 85-94.
5. Pan, Y.; Liu, J.; Li, X.; Wang, Y. A review of dynamic holographic three-dimensional display: algorithms, devices, and systems. IEEE Trans Industr Inform 2015, 12, 1599-1610.
6. Sando, Y.; Itoh, M.; Yatagai, T. Fast calculation method for cylindrical computer-generated holograms. Opt Express 2005, 13, 1418–1423.
7. Ma, Y.; Wang, J.; Wu, Y.; Jin, F.; Zhang, Z.; Zhou, Z.; Chen, N. Large field-of-view holographic display by gapless splicing of multisegment cylindrical holograms. Appl Opt 2021, 60, 7381-7390.
8. Kozacki, T. Holographic display with tilted spatial light modulator. Appl Opt 2011, 50, 3579-3588.
9. Liangcai, C.; Wang, Z.; Zhang, H.; Jin, G.; Gu,C. Volume holographic printing using unconventional angular multiplexing for three-dimensional display. Appl Opt 2016, 55, 6046-6051.
10. Su-Juan, L.; Xiao, D.; Li, X.W.; Wang, Q.H. Computer-generated hologram generation method to increase the field of view of the reconstructed image. Appl Opt 2018, 57, A86-A90.
11. Wang, Z.; Tu, K.; Pang, Y.; Lv, G. Q.; Feng, Q. B.; Wang, A. T.; Ming, H. Enlarging the FOV of lensless holographic retinal projection display with two-step Fresnel diffraction. Appl Phys Lett 2022, 121, 081103.
12. Yaras, F.; Kovachev, M.; Ilieva, R.; Agour, M.; Onural, L. Holographic reconstructions using phase-only spatial light modulators. In 3DTV Conference: The True Vision - Capture, Transmission and Display of 3D Video, Istanbul, Turkey, 18 July 2008.
13. Maeno,K.; Fukaya,N.; Nishikawa,O.; Sato,K.; and Honda,T.Electro-holographic display using 15mega pixels LCD. In Proc. SPIE.1996, 2652, 15–23.
14. Yaraş, F.; Kang, H.; Onural, L. Multi-SLM holographic display system with planar configuration. In 2010 3DTV-Conference: The True Vision-Capture, Transmission and Display of 3D Video, Tampere, Finland, 07-09 June 2010.
15. Hahn, J.; Kim, H.; Lim, Y.; Park, G.; Lee, B. Wide viewing angle dynamic holographic stereogram with a curved array of spatial light modulators. Opt Exp 2008, 16, 12372-12386.
16. Su-Juan, L.; Wang, D.; Zhai, F.X.; Liu, N.N.; Hao, Q.Y. Holographic display method with a large field of view based on a holographic functional screen. Appl Opt 2020, 59, 5983-5988.
17. Xinhui, D.; Liu, J.; Shi, X.; Zhang, Z.; Xiao, J. Full-color see-through near-eye holographic display with 80 field of view and an expanded eye-box. Opt Exp 2020, 28, 31316-31329.
18. Yuchen, G.; Weng, Y.; Wei, R.; Shen, Z.; Wang, C.; Zhang, L.X.; Zhang, Y. Holographic waveguide display with large field of view and high light efficiency based on polarized volume holographic grating. IEEE Photonics J 2021, 14, 1-7.
19. Minseok, C.; Yoo, D.; Lee, S.; Lee, B. Etendue-Expanded Holographic Display Using Lens Array 4-f System. In Digital Holography and Three-Dimensional Imaging, Cambridge United Kingdom, 1–4 August 2022.
20. Dongyeon, K.; Nam, S.W.; Lee, B.; Lee, B. Wide field of view holographic tiled display through axially overlapped holographic projection. In Ultra-High-Definition Imaging Systems V, California, United States, 3 March 2022.