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Holography: Principals and Mechanism for Constructing and Operating Holograms

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***Abstract*—Holography is a sophisticated technique that facilitates the recording and subsequent reconstruction of wavefronts. While holography is most commonly associated with the creation of captivating three-dimensional images, its practical applications extend far beyond this realm. In essence, holograms can be produced for various types of waves, showcasing their versatility. Additionally, it is possible to generate computer-generated holograms by digitally modeling and combining two wavefronts. The resulting digital image is then transferred onto an appropriate medium, such as a mask or film, and illuminated by a suitable light source to reconstruct the desired wavefront. Throughout this discourse, we shall delve into the intricacies of hologram construction, operation, and fundamental principles.**

Keywords*—*Holography, Wavefronts, Versatility, Digital modeling, light source, Three-dimensional images, Photographic plates, Interference, Diffraction.

I. Introduction

The concept of Holography was pioneered by Dennis Gabor in 1947, who coined the term by combining two Greek words: “Holos,” meaning whole, and “Graphe,” meaning writing. Essentially, holography refers to the recording of an optical image that encompasses the complete optical information of light scattered from an object. Ideally, a hologram is a three-dimensional image reproduced from an interference pattern captured using coherent light beams. Holography is a meticulous process involving the reconstruction and inscription of a hologram.

Holography, a photographic technique, captures the dispersed light from an object and presents it in a manner that creates a perception of three-dimensionality. It encompasses the scientific principles and methodologies involved in producing holograms, which are advanced photographic representations capable of recording images in a three-dimensional format.

Holography possesses significant historical connections to the field of electrical engineering and demonstrates the substantial potential for addressing various electrical engineering challenges. The fundamental issue tackled by holography is elucidated through a comprehensive exploration of its physical and mathematical aspects. Emphasis is placed on drawing an analogy between the hologram of a point-source object and the linear frequency modulation (FM) signals utilized in chirp radar systems [1]. An adaptive optical wireless system that utilizes a limited set of restored holograms. Specifically, it introduces a novel approach termed Fast Delay, Angle, and Power Adaptive Holograms (FDPA-Holograms), which is based on a Divide & Conquer methodology [2]. The current spatial light modulators (SLMs) available in the market exhibit limited resolution when it comes to displaying large holograms. Consequently, it becomes necessary to explore techniques that enable the enlargement of reconstructed images [3]. The most effective compromise for optimizing the SLM’s bandwidth involves employing binary data. Holograms obtained from real objects need to be converted from grayscale to a binary format.

The present study explores the interactive aerial projections of three-dimensional (3D) hologram objects through the utilization of a pyramid hologram and parabolic mirror system, in conjunction with the Leap Motion sensor [5]. Computer-generated holograms (CGHs) have garnered significant interest and engagement among researchers due to their potential applications [4]. However, it is worth noting that computer-generated (CG) objects are typically represented using multiple mono-color points, thereby limiting the availability of high-resolution color holograms depicting real scenes. Consequently, there exists a scarcity of comprehensive color holograms for realistic scenes in the realm of computer-generated holography [4].

Holograms encompass [1] comprehensive three-dimensional information, including binocular parallax, convergence, and accommodation. As a result, the reconstructed holographic image offers a natural spatial effect [6] that provides viewers with a compelling sense of depth, especially when the image appears to protrude from the hologram plane. Image-type computer-generated holograms [4] possess complete parallax and have the capability to be reconstructed using white light. These holograms are generated from three-dimensional computer graphics polygon data, resulting in objects with shaded surfaces and the effective removal of hidden surfaces. This process ensures the creation of visually detailed holographic representations.

Ordinary white light, originating from natural or artificial sources such as the sun or light bulbs, comprises a broad spectrum of colors. However, for holographic purposes, such light proves unsuitable. Instead, lasers are employed due to their ability to emit a concentrated, monochromatic beam that possesses uniformity and phase coherence. The interaction of two laser beams generates a unique wave pattern known as a hologram. Initially, holography predominantly served static display purposes. However, ongoing advancements in this field have significantly broadened its range of applications. Holography can also be employed as a technique for the optical storage, retrieval, and processing of information. A three-dimensional hologram is characterized as a projection that exists independently in space and is perceptible to observers without the requirement of three-dimensional glasses. This capability of holography allows for the storage and presentation of information in a spatially immersive and accessible manner.

II. Principal of hologram Recording

Holography is a sophisticated technique that allows for the recording and subsequent reconstruction of a light field. Typically, the field originates from a light source interacting with objects, and holography enables the preservation of this field even when the original objects are no longer present.

A. Laser

Holograms are produced by illuminating a scene with a brief burst of light, similar to the process of capturing a photograph. However, an additional step is involved where a portion of the light beam, known as the reference beam, is directed onto the recording medium itself. This reference beam is essential for creating the hologram. Laser light serves as the primary light source for holography, offering precise control and emitting light with a consistent wavelength. This is in contrast to sunlight or conventional form external light sources, holograms are typically captured under conditions of darkness or with low-intensity light of a different color than the laser light employed during the hologram recording. Similar to photography, holography necessitates a specific exposure time, which can be regulated using a shutter or by electronically timing the laser.

B. Apparatus

A hologram is created by dividing the light beam into two parts and directing each part toward different elements. One part, known as the illumination or object beam, is expanded using lenses and directed onto the scene through mirrors. The scattered light from the scene then falls onto the recording medium. The other part called the reference beam, is also expanded using lenses but is directed away from the scene and onto the recording medium.

Various materials can be utilized as the recording medium, with one commonly used option being a film similar to a photographic film, but with a higher concentration of light-reactive grains to achieve the required resolution for holograms. This recording medium, such as silver halide, is attached to a transparent substrate, typically glass or plastic. The hologram formation involves dividing the light beam, directing it through different optical elements, and utilizing a recording medium, such as a high-resolution film, to capture the holographic information.

C. Process

When the two laser beams reach the recording medium, their light waves intersect and create interference. This interference pattern is then imprinted on the recording medium. The resulting pattern appears random as it represents the interaction between the scene's light and the original light source, rather than the original light source itself. This interference pattern can be seen as an encoded representation of the scene, which requires the specific key -the original light source-to decode and view its contents.

The missing key, provided later on, involves illuminating the developed hologram with a laser beam that is identical to the one used during the recording process. As this beam illuminates the hologram, it undergoes diffraction by the hologram's surface pattern. Consequently, it generates a light field that is identical to the one produced by the original scene and scattered onto the hologram. The resulting effect forms an image on a person's retina, known as a virtual image.

D. Condition for Recording a Hologram

To create a hologram, it is necessary to have a suitable object or a set of objects along with a suitable laser beam. A portion of the laser beam is directed towards the object, known as the object beam, while another portion is directed towards the recording medium directly, known as the reference beam. This setup allows the reference beam and the light scattered from the object to form an interference pattern. The recording medium, which can be a photographic plate or a similar material, converts this interference pattern into an optical element that modifies the incident light beam's amplitude or phase based on the intensity of the interference pattern.

It is crucial to maintain an environment that provides adequate mechanical and thermal stability to ensure the stability of the interference pattern during the recording process. The object should be fully exposed to the radiation, allowing proper interaction with the laser beam. The chosen recording medium, such as a photographic plate, should possess high resolution, high sensitivity, and a wide spectral range to accurately capture the holographic information.

III. Construction and working

The process of creating and recording a hologram consists of two main stages: the "Hologram Recording" phase and the "Hologram Reconstruction" phase.

A. Hologram Recording

The process of hologram recording is based on the principle of interference and involves several components: a laser source, a plane mirror, a beam splitter, an object, and a photographic plate. A laser beam emitted from the laser source is directed towards a plane mirror or beam splitter, which serves to divide the beam. One portion of the split beam, known as the reference beam, is reflected by the beam splitter and directed toward the photographic plate. Simultaneously, the other portion of the split beam, referred to as the object beam, passes through the beam splitter and interacts with the object before reaching the photographic plate.

The object beam, upon reflection from the object, combines with the reference beam at the photographic plate, resulting in the interference of these two beams. This interference gives rise to a distinctive pattern of alternating dark and bright fringes, which is captured and recorded on the photographic plate. The recorded photographic plate, containing the interference pattern, is commonly referred to as a hologram. It is worth noting that the photographic plate is also known as Gabor zone plate, named after Denis Gabor, the pioneer of holography.

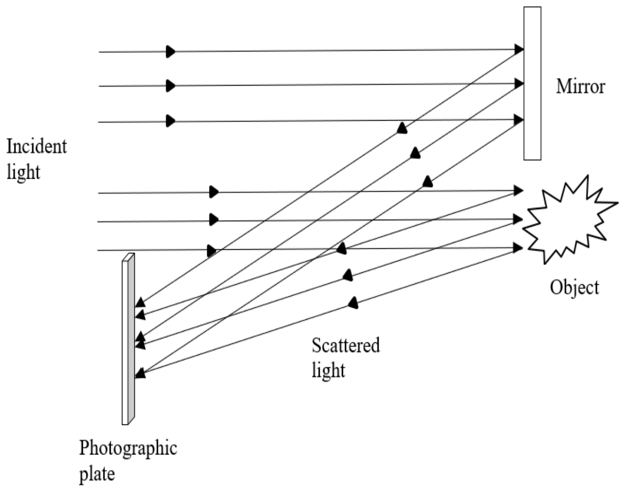

Fig-1

Remarkably, every section of the hologram receives light from multiple points of the object. Consequently, even if the hologram is fragmented, each individual segment retains the ability to reconstruct the complete object.

B. Hologram Reconstruction

During the reconstruction phase, the hologram is illuminated by a laser beam known as the reconstructed beam, which shares identical characteristics with the reference beam employed in the initial hologram construction.

The hologram function as a diffraction grating, causing the reconstructed beam to undergo the process of diffraction as it passes through the hologram. Consequently, the reconstructed beam, upon traversing the hologram, generates both a real and a virtual image of the original object.

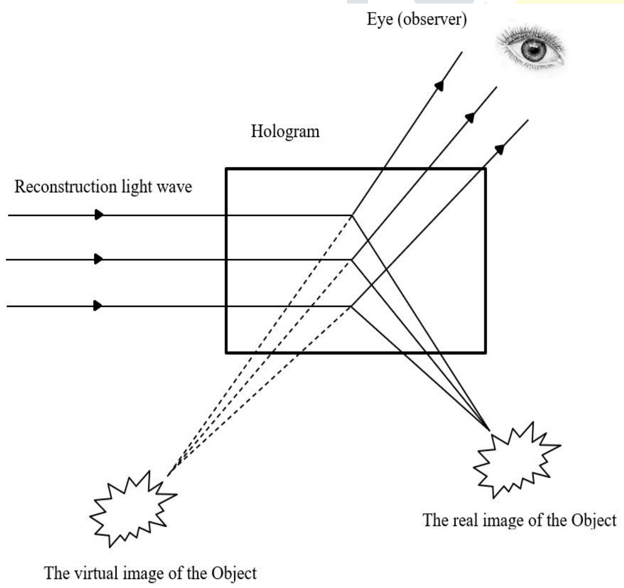

Fig-2

One of the diffracted beams emanating from the hologram displays a divergent pattern that gives the impression of originating from a virtual object when projected backward. As a result, a virtual image is formed behind the hologram at the original position of the object, while a real image materializes in front of the hologram. Consequently, an observer perceives light waves dispersing from the virtual image, which closely resembles the actual object in its entirety. By moving around the virtual image, the observer gains visibility of previously unnoticed aspects of the object from different perspectives. Thus, the virtual image exhibits comprehensive three-dimensional characteristics. The real image has the capability to be recorded on a photographic plate.

IV. Conclusion

Holography has emerged as a genuine three-dimensional photographic technique, possessing the ability to capture the depth of space. Its distinctiveness lies in the capacity to record the phase information of light, setting it apart from conventional photography. Interference phenomena serve as the sole means for preserving the phase of light. Consequently, a coherent light source becomes indispensable for achieving light interference, and the advent of laser technology has played a pivotal role in propelling the advancement of holography at a rapid pace.

Ultimately, we have explored the diverse applications of holography and recognized its significant untapped potential. Particularly in the realm of data storage, where existing technologies are approaching their limits, holography emerges as a promising next-generation solution. Moreover, the increasing demand for immersive 3D entertainment presents a valuable opportunity for the advancement and utilization of holographic technology.

V. Scope Of Future Work

Emerging technologies in the realm of Graphic Processing Units (GPUs), such as Direct 3D 11 with Compute-Shaders and OpenGL ¾ integrated with OpenCL, offer enhanced efficiency and flexibility for GPU-based solutions. These advancements facilitate the realistic simulation of natural viewing experiences. Additionally, the optimization of VHDL designs (VHSIC hardware description language) is being pursued to develop specialized holographic Application-Specific Integrated Circuits (ASICs). Another focal point involves the development or adaptation of suitable streaming formats for integration into existing game or application engines. Looking ahead, future applications of holography encompass diverse areas, including military and deceptive warfare strategies, virtual sales presentations, remote corporate meetings, personal recording for future generations, holographic tourism experiences, virtual reality training, mind conditioning techniques, augmented pilot training, and holographic assistance. Ongoing efforts are also aimed at reducing the cost of key components and further advancing holographic display technologies.

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