Practical Teaching Note on Systematic Approach to Record and Reconstruct Hologram at Undergraduate level

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Abstract

Ever since the invention of holography in 1948 (theoretically) and in 1962 (experimentally), it has continuously fascinated optics enthusiasts. There is so much learning in building into setting up a successful holography recording and reconstruction system. However, the failure to carry out successful recordings of a hologram is demotivational and acts as a big deterrent. We report here practical teaching notes on systematic approach to successfully record and reconstruct a hologram with locally available low-cost components. It is truly understood that holography is a well-established technique. However, in this paper we have attempted to present to the minutest details the intricacies involved in hologram recording and made an effort to address the possible failure points. The success of the approach has been ratified with scores of undergraduate students successfully carrying out recording and reconstruction of the hologram with 100% success rate. They have adopted 'Train the Trainer approach' and have trained their peers, leading to creation of a pool of successful hologram recording enthusiasts at UG level. It is envisaged that the present work will encourage optics enthusiasts and facilitate successful hologram recording and reconstruction.

1. Introduction

Holography is a captivating technique that elucidates through the principles of interference. The term "holographic" derives from the Greek words "holos," meaning "whole," and "graphe," signifying "drawing," encapsulating a technique that initially captured the complete light field information, encompassing both amplitude and phase [1]. Dennis Gabor, acknowledged as the progenitor of holography, was awarded the Nobel Prize in Physics in 1971 for his groundbreaking invention and development of the holographic method [2].

Holography serves as a fascinating experiment that ignites students' interest in the field of optics. Previous endeavors, such as those by E. A.Franke, and J. M. Franke, have focused on demonstrating and applying holography for undergraduate students [3]. Pombo et al. have underscored the utility of holography as a teaching tool, illustrating its efficacy in experimental optics teaching and its potential to inspire a profound interest in the study of physics at the school level [4].

Furthermore, advancements in technology have leveraged holography as an alternative to learning technology. Comparative studies have been conducted to evaluate the effectiveness of holographic teaching in Information and Communication Technology (ICT) [5-6]. This paper provides a comprehensive, step-by-step guide to ensure the successful recording and reconstruction of holograms. Notably, this approach is advantageous due to its simplicity, making it easily comprehensible for undergraduate students, and its implementation can be achieved using cost-effective components and equipment that are mostly available in any optics/photonics laboratory. The learnings from this experiment can be extended to set-up various type of interferometers for their multiple potential applications.

1.1 Basic Principle of Hologram

Holography, a groundbreaking imaging technique, captures and reconstructs three-dimensional images using the principles of light interference and diffraction. The process of studying holography involves two main steps: recording the hologram and reconstructing it using lasers or white light. Unlike traditional photography, in which we capture only intensity information, in holography, we record both the intensity and phase of scattered/reflected/diffracted light waves, resulting in lifelike, three-dimensional representations [7].

The fundamental holographic process involves splitting coherent laser light into two beams—an object beam and a reference beam. The object beam interacts with the subject to be imaged, and the resulting interference pattern is recorded on a photosensitive medium (here, we have used silver halide photographic emulsions). During playback, when illuminated by the reference beam, the recorded interference pattern reconstructs the original three-dimensional scene. This versatile technique finds applications in art, entertainment, scientific visualization, microscopy, interferometry, and security.

The elegant interplay of light's wave nature and interference in holography showcases the transformative ability of science to sculpt three-dimensional illusions before our eyes. Advancement in lasers, photosensitive film/plate, and methods of demonstration have all combined to allow holography to be studied in graduate, undergraduate, and school levels. The demonstration generate interest among all - science, engineering and art students. The positive attitude is not only from undergraduate students but also from school teachers and students. It is now well established that holography can be used as a teaching tool with great success and highly motivating for the experimental teaching. It has truly encouraged the students towards optics education at the undergraduate level.

For a deeper understanding of holography principles and applications, interested readers can refer to the roadmap on holography published by John T. Sheridan et al. in 2020 (J. Opt. 22, 123002) [8]. This comprehensive review explores holographic theory, advancements, and emerging trends, providing valuable insights for researchers, students, and enthusiasts. To further delve into the scientific intricacies of holography, resources such as "Basic Principles and Applications of Holography" and "Basic Principle of Holography - Engineering Physics" ([9,10]) can be consulted. In addition, one can refer the book [11] by Saxby for deep knowledge of Practical Holography. Further, in another work by Salancon etal. [12] they have upgraded some of the previous developments to make colour holograms. However, the use of a high power 20mW He-Ne laser makes the development cost ineffective. Though there is abundant literature available including some of the above listed important references, there are no crisp recipes described for a sure shot successful hologram recording.

The significance of this work lies in its potential to democratize access to holography, making it an accessible and feasible learning tool for educational institutions with limited resources. The step-by-step instructions offered in this paper serve as a valuable practical teaching note for individuals seeking a failure-free experience in both recording and reconstructing of holograms. By breaking down the process into detailed instructions highlighting the important steps that lead to the failure of the hologram recording, the paper empowers users with the knowledge to implement holography techniques successfully, fostering a sense of self-reliance and accomplishment at very low cost.

Thus, the present work suits the best for Indian University/colleges/school system if they want to demonstrate this wonderful optics learning through holography. The unique feature in this paper is that the complete experiment was set-up and conducted independently by undergraduate students with 100% success rate. This is the result of our belief as we highly emphasize on 'train the trainer' philosophy under the SPIE Student Chapter University of Delhi at Acharya Narendra Dev College. In the present paper, cost-effective methodology has been explained and authors emphasize to popularize holography in university, colleges and schools.

2. Experimental Setup

This section provides a comprehensive overview of the equipment employed in the holographic recording and reconstruction experiment. It is emphasized here that we have not discussed the detailed technical specifications of each of the components but described them in general. These components are available in routine from various scientific suppliers in India at affordable costs. Following a detailed component/equipment description, a clear and concise diagram of the experimental setup is presented. Towards the end, a step-by-step procedure guiding the readers through the recording and reconstruction processes is presented for easy and successful replication.

2.1 Components/Equipment Details

2.1.1Beam Splitter

It is used to split the incident light beam into two separate beams by a designated intensity ratio as shown in Fig.1. Additionally, beamsplitters can also be used in reverse to combine two different beams into a single one. Beamsplitters are classified according to their construction. We have used a single beam splitter 30/70 in the present experiment.

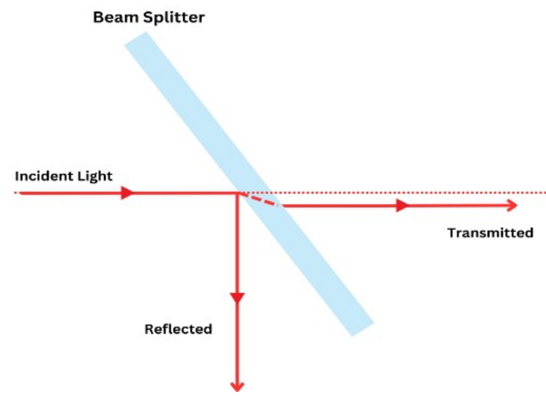


FIG. 1: Ray diagram of the Beam Splitter.

2.1.2 Optical Mirror

It is an optical component used to reflect the laser light in any direction. Since they are having 100% (approximately) reflectivity, the incident beam is mostly reflected in the desired direction. A mounted 2” diameter optical mirror is as shown in Fig.2. We have used two such optical mirrors in the present set-up.

FIG. 2: A mounted Optical Mirror of 2” diameter.

2.1.3 Microscope Objective (MO)

It consists of a multi lens system and is used to magnify the spot size of the input laser beam. The basic parameters that are usually specified for a MO are its magnification, numerical aperture; lens image distance and cover slip thickness specified in mm [13]. Fig. 3 shows the MO used in the present experiment having the following specification: magnification 10X, numerical aperture 0.25; lens image distance 160mm and cover slip thickness 0.17mm. We have used two such MOs in the present set-up. The magnification should be chosen such that the beams can cover the whole object and the reflected rays are projected on the photographic film.

FIG. 3: Mounted Microscope Objective.

2.1.4 Mechanical Mounts/ Supports

These are different types of mechanical hardware that holds optical components such as an object holder, microscope objectives holder, sandwiched photographic film holder etc. (Fig. 4 (a) - 4(c)). We can easily mount the bases of these optical mounts on an optical breadboard using M6 LN screws. They provide stability to the overall equipment set-up to ensure the minimum vibrational disturbance.

(a) *(b)* *(c)*

FIG. 4: (a) An object holder on which the object is mounted using a hot glue gun. (b) A Microscope Objective holder. (c) A photographic film holder.

2.1.5 Photographic Film

The recording medium employed is PFG-01[14], a red sensitive (for 632.8 nm), high resolution photographic film comprising of silver halide. These are specially designed for recording holograms using a continuous wave laser, a red He-Ne laser in the present case. They are to be processed in green light. We have used the standard Kodak D-76 developer and Sodium Thiosulphate as fixer. Fig. 5 shows a developed photographic film.

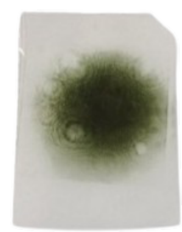


FIG. 5: Hologram (Developed Photographic Film).

2.1.6 Laser

We have used a 2mW He: Ne laser (Fig. 6) that emits a bright red laser beam whose wavelength is 632.8 nanometers.

FIG.6: A 2mW He: Ne Laser [15]

2.1.7 Object

In this case, we are taking an object (Fig. 7) made of marble whose 3D image will be recorded on a high-resolution photographic plate. One can choose any similar object for this purpose.

FIG. 7: Object in the form of marble Shivling.

2.1.8 Optical Breadboard

It is an optical tabletop (a part of vibration isolation system) that is used to mount systems used for laser and optics-related experiments in science, engineering, and manufacturing through an array of M6 threaded holes or magnetic bases. The surfaces of these tables are designed to be very rigid with minimum deflection so that the alignment of optical elements remains stable over time. Many optical systems require that the vibration of optical elements be kept to minimum. As a result, optical tables are typically very heavy and incorporate vibration isolation and damping features in their structure, reducing the ability of vibrations in the floor to cause vibrations in the tabletop. The surface of an optical table is typically ferromagnetic steel with a honeycomb structure inside and has a rectangular grid of tapped M6 holes in either metric or imperial units [16]. They can be placed on an ordinary table or workbench or on specially designed vibration isolation systems. A typical optical breadboard is as shown in Fig. 8. In the present experiment, we have used an already available optical breadboard in the lab of size 6' x 4'. A size of 2' x 3' is sufficient to carry out such type of hologram recording.

FIG. 8: An Optical Breadboard [17].

2.1.9 Tyre's Inner Air Tube

Since vibration isolation systems cost around USD 2500, we have used two-wheeler vehicle tyre's inner air tubes (Fig. 9) beneath the optic table top instead of vibration isolators. This makes our experimental setup more cost-effective and simpler for users by providing required vibration isolation to carry out holography recording successfully. We have used four such tubes placed at the four corners of the optical bread board. The pressure in the tube is adjusted to 20 psi for best results.

FIG. 9: Image of a Tyre's Inner Air Tube [18].

2.1.10 Glass Plates

In this experiment, we have used two glass plates (Fig. 10) of size 2" x 2" to sandwich the photographic film. This arrangement keeps the films straight as well as reduces the cost of expensive holographic plates.

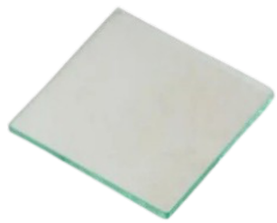


FIG. 10: A Glass Plate.

The component numbers and their tentative cost is as mentioned in the Table 1(a) with comparative cost break up as Table 1(b) below:

Table 1(a): Cost break-up

S. No.	Item Name	Quantity	Unit cost (Ex-Works) INR
1.	He: Ne Laser (2 mW)	01	45000
2.	Laser Holder Mount	01	3500
3.	Beam Splitter 2”	01	1850
4.	Beam Splitter Holder 2”	01	1600
5.	Mirror 2”	02	2000
6.	Mirror Holder 2”	02	1600
7.	Microscope Objective (MO)	02	2000
8.	MO Holder	02	1200
9.	Plate holder	02	2000
10.	Processing Trays	03	400
11.	Film	1 Set	9500
12.	Chemicals	01 Set	4000
13.	Safe (Green) light	01	900
14a.	Table Top (4 feet x 4 feet x 2.4” approx.)	01	1,25,000
14b.	Vibration Isolators	04	-
14c	Tyre’s Inner Tubes	04	400
15.	Air Pump (Foot Pump)	01	500
16.	Polarizing Sheet 2”x2”	01 (2”x2”)	300
17.	M6 Screws with Key	01 Set	800
18.	Miscellaneous Items	01 Set	4000

Table 1(b): Comparative Cost break-up

S.No. (corresponding to Table 1(a))	Unit cost (Ex-Works) INR (corresponding to Table 1(a))	Unit Cost (CIF) (USD)	Total Cost (CIF) of equipment / components of Our Set-Up (USD)*	Total Cost (CIF) of equipment / components in the optical research laboratory (USD)**
1.	45000	550	550	2300
2.	3500	40	40	130
3.	1850	22	22	50
4.	1600	20	20	55
5.	2000	25	50	280
6.	1600	20	40	110
7.	2000	25	50	2400
8.	1200	15	30	50
9.	2000	25	50	90
10.	400	05	15	15
11.	9500	128	128	128
12.	4000	50	50	50
13.	900	12	12	12
14a.	1,25,000	1600	1600	3200
14b.	-	-	-	2500
14c	400	5	20	-
15.	500	8	8	8
16.	300	5	5	105
17.	800	10	10	10
18.	4000	50	50	50
	Total cost (CIF)		**2750**	**11543**

* The latest price of all the equipments/components as taken from the Indian supplier(s).

** The price of most of the optical and mechanical equipments/components may be verified any time from the supplier. Some (Ex-works) prices from ThorLab (ThorLab.com). are given for the ready reference:

Microscope Objective : 9.458,50 €
Laser : 1.770,87 €
Laser mount : 113,79 €
Beam splitter 30/70 : 37,27 €
Mirror Holder : 42,75 €
Mirror 2” : 111,58 €
Microscope Objective holder : 18,57 €
Glass plate holder : 71,93 €
Polarizer Plane 2” diameter : 88,38 €
4 leg vibration isolators set : 1.973,85 €
Bread Board Table Top : 2.140,65 €

Any research optics lab will have most of these equipment/components. We have used here very cost effective equipments/components and successfully completed the process of recording and reconstruction of holograms in our undergraduate laboratory.

2.2 Setup Diagram and Methodology

2.2.1 Setup Diagram for Recording of Hologram

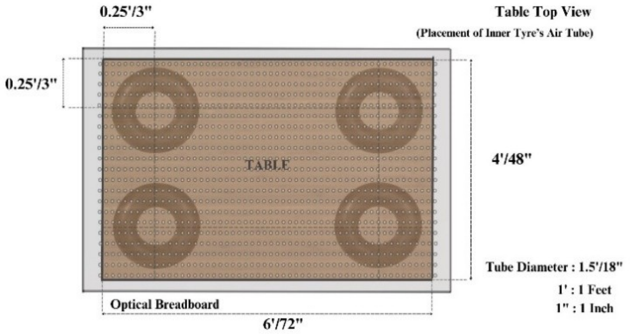


FIG. 11(a): Placement of air tubes below the optical breadboard.

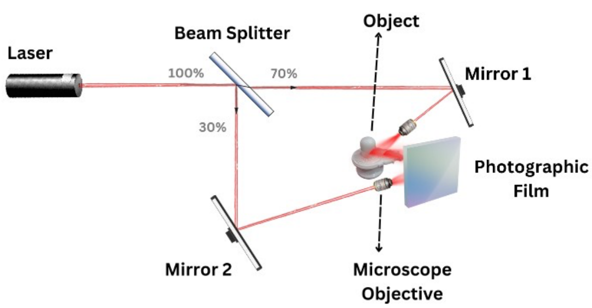


FIG. 11(b): Schematic view of the setup of the construction of the hologram.

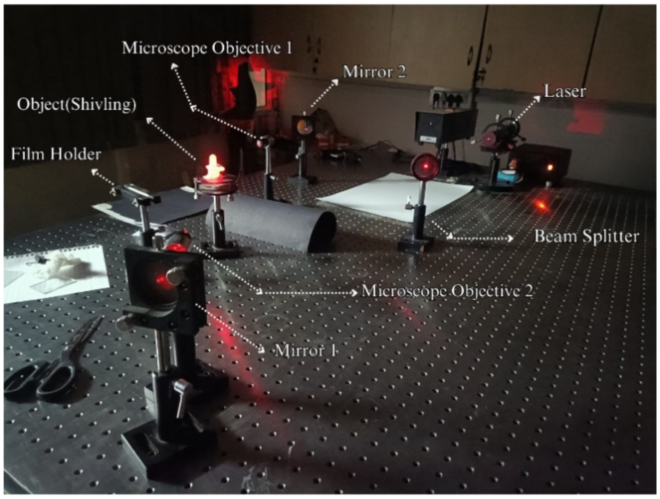


FIG. 12: Actual setup on the optical breadboard.

2.2.2 Methodology of Construction of Hologram

A. ***Setup for Recording***

1. Arrange the four air tubes with air pressure 20 psi at the four corners of the optical breadboard (Fig. 11(a)) to ensure the required vibration isolation.
2. Carefully arrange all components /instruments as shown in Figure 11(b). All the components shall be firmly fixed on the optical breadboard using M6 screws. We should use the glue gun to ensure that the object is fixed on the object table. Glue gun can be used at different places to reduce the probability of vibrations.
3. It is very important to make path length of the object beam approximately equal to the path length of the reference beam.
4. Switch on the laser at least half an hour before recording hologram, so that its output power is stabilized.
5. It is to be made sure that the object beam is maximally illuminating the object. The scattered beam from the object and the magnified reference beam are both overlapping on the dummy screen mounted at the place where photographic film will be mounted.
6. Once the above requirements are fulfilled, block the laser beam by placing a black cardboard sheet in front of it.

B. ***Prerequisites before starting recording***

1. Turn off all unnecessary lights in the lab to minimize background light interference.
2. Unwrap the photographic film and use a scissor to cut it into square pieces, also make a small cut on the top right side of the film so that in the future you will know which side was placed in front and which one in back.
3. Sandwich the film between a cleaned set of glass plates. Clamp the glass plates sandwiching the photographic film with paper clip.
4. Replace the dummy screen by the sandwiched photographic film.
5. Continue to block the laser beam using a black cardboard sheet directly in front of its opening. Leave the optical breadboard undisturbed for at least one minute to let vibrations (if any) settle.
6. After the settling period is over, carefully lift the black sheet without moving it away from the laser. Hold it with your hands in front of the beam such that it still blocks the laser beam without touching the table.
7. Wait for another forty-five seconds for any vibrations to fully settle down.

C. ***Recording***

1. The intensity of the reference beam should be four to five times more than the object beam, measured at the recording plane. A cardboard piece in L-shape may be used as shutter by first gently lifting it slightly above the table for few seconds and then removing for an exposure of (say) 60 seconds.
2. During this crucial exposure time, one must be extremely careful not to disturb the optical breadboard in any way including:
    a. Avoid vibrations from phones or any other electronic gadget.
    b. Don't blow air including your breath towards the table.
    c. Do not touch the optical breadboard/table on which it is kept or its components
3. It is to be noted that even miniscule variation in the path length caused by vibrations can affect the quality of the interference pattern which is recorded on the photographic film.
4. The exposed film can be kept in black envelope before development.
5. The actual set-up in the dark room is as shown in Fig. 13

It is to be noted that for making high efficiency holograms we need to use spatial filters in place of microscope objectives and shutter for proper time of laser beam exposure.

Figure 13. Photo of the Hologram recording Setup in the dark.

D. ***Photographic Film Development***

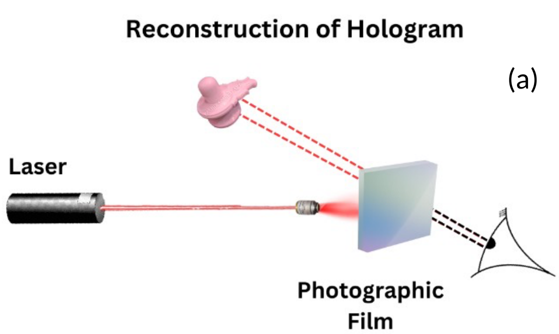
1. All the film processing has to be done in green safe light.
2. We have used Kodak D-76 developer (packet supplied by Kodak company). The method of preparation of Kodak D-76 developer solution is printed on the packet. 10% Sodium thiosulphate (commonly called hypo) solution is prepared for fixing the image on photographic film. Generally, we use distilled water for making our developer. We can also use deionised water for making the developer.
3. Take three different plastic trays. Put the developer solution in the first tray, Fixer solution in the second tray, and Normal tap water in the third.

4. Take out the exposed photographic film from the black envelope, dip the film in the first tray containing the developer solution and gently move the tray back and forth slowly and evenly to cause the solution to move continuously over the film. Develop the film for six minutes. The development time can be different depending upon which developer solution is being used.
5. After development, wash the film in the third tray for two minutes.
6. Now put the film into the second tray containing the fixer solution and fix the film for five minutes.
7. Wash the film for another three minutes in the third tray and then wash the film for one minute in running water.
8. Dry the film manually by moving it back and forth in air by holding it in your hand. One should avoid the use of a hot air blower or any kind of hot air source to dry it, as it can damage the recorded interference pattern.

E. ***About Developer Solution and Fixer***

We have used Kodak D-76 Developer for preparing the Developer solution and Sodium Thiosulphate Solution as Fixer for high-resolution photography. The details about development time etc., one can refer to Kodak Developer D-76 [19].

2.2.3 Setup Diagram for Reconstruction of Hologram.



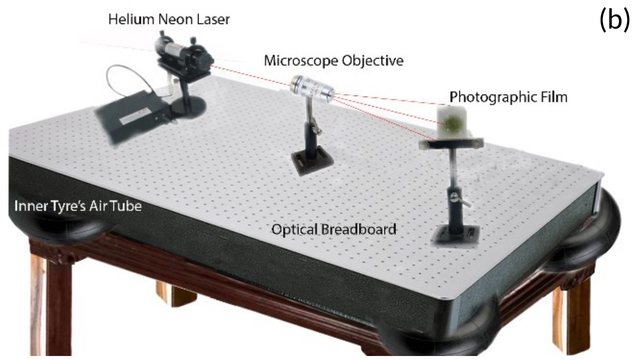


Figure 14. (a) Schematic view of the setup of the reconstruction of the hologram. **(b)** Setup on the optic table.

The schematic of the set-up for reconstruction of the recorded hologram is as shown in Figure 14.

2.2.4 Methodology of Reconstruction of Hologram.

1. ***Setup for Reconstruction:***

Arrange the developed holographic film/plate, laser light source, and microscope objective in the identical configuration used for the initial recording process (as shown in Figure 14).

2. ***Reconstruction of Wavefront:***

When the reference beam is incident on the hologram then the diffracted light from the holographic plate reconstructs the original wavefront that was present when the hologram was recorded.

3. ***Formation of 3D Image:***

1. A 3D image of the object is formed in the space where the original object or scene was located during the holographic recording. This is called virtual image of the object.
2. We can easily see that two images will be formed, the first one is a REAL image which is seen towards the observer (-1 Order), and the second one is a VIRTUAL

image which is behind the photographic film (1 Order) (Figure 15).

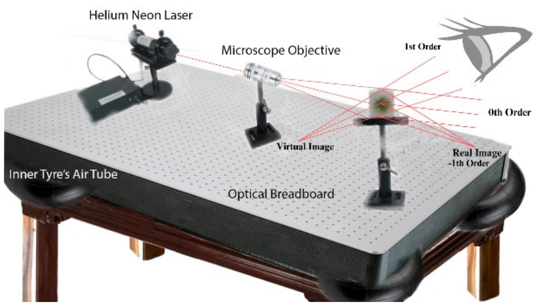


Figure 15. Reconstruction of Holograms with image formation with their positions.

3. Results.

In the present paper, we have explained about the systematic approach for successful recording and reconstruction of holograms in a cost-effective manner at undergraduate level. Notably, due to the intricate equipment and sensitive setup involved, meticulous execution is crucial for achieving clear and accurate holographic recordings. Fig. 16 shows the successfully recorded and developed holographic films.

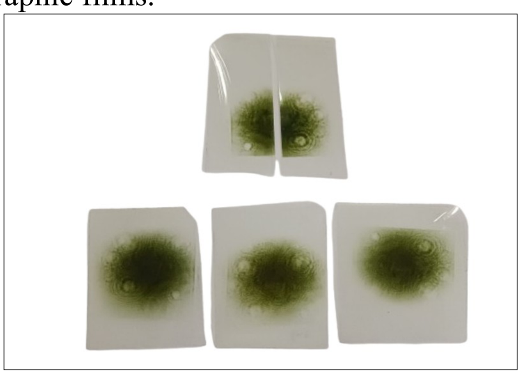
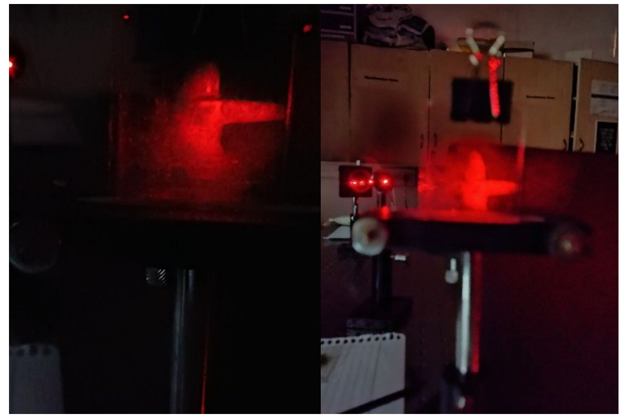


FIG. 16: Successfully recorded Holograms (Photographic films).

The reconstructed images of the holograms with object as Shivling are as shown in Fig. 17(a) and 17(b).



(a) **(b)**

FIG. 17: **(a)** A close-up view of the image formed on the Photographic film. **(b)** A sandwiched hologram film between glass plates using a paper clipper.

While the experiment presented certain challenges due to the potential for error and subsequent failure in generating high-quality holograms, careful procedures and close attention to detailed procedure allowed for five successful consecutive recordings.

4. Discussion.

Ensuring a vibration-free environment poses a critical challenge in this experiment, as even minute vibrations can disrupt the laser beam's path length, irreversibly distort the interference pattern and thus render an unsuccessful recording of the hologram. Traditional vibration isolation methods often rely on specialized equipment, leading to considerable cost constraints in research and development projects [20,21]. This study presents a unique solution: leveraging readily available air tubes as a cost-effective substitute for conventional vibration isolators. Surprisingly, our results demonstrate that air tubes offer comparable isolation performance, effectively negating vibrations that could compromise experimental accuracy and data integrity. The key lies in the intrinsic properties of air. By strategically employing air tubes within the experimental setup, we were able to exploit its natural damping characteristics to dissipate unwanted vibrations. This innovative approach not only delivers performance at par with expensive isolators but also unlocks significant cost savings. With readily available materials and simple implementation, air tubes can present a compelling alternative for a wide range of research applications.

Unlike conventional photographs, holograms exhibit remarkable resilience to fragmentation. Cutting a hologram creates miniature complete object replicas, each retaining the full image, albeit with reduced resolution and intensity (Figure 18). This unique property, rooted in the redundant encoding of information, defies the limitations of two-dimensional representations, offering a fascinating glimpse into the world of holographic data storage and retrieval.

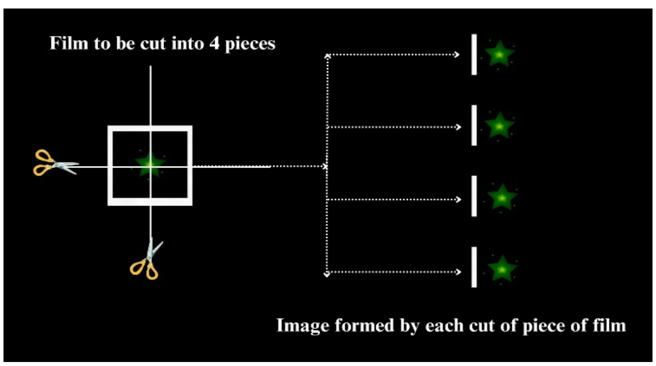


FIG. 18: Represents the retrieval of the original image of the object from each cut slides.

4.1 Cautions

1. Before commencing recording (minimum 30 minutes), deactivate all potential vibration sources within the lab, including air conditioners, exhaust fans, and other equipment generating air movement.
2. Avoid film exposure to any light source until the development stage is complete. Light exposure before development can negatively impact the final holographic image quality in the present case. However, optimized some pre-exposure to white light may be used when the intensity output of the laser light is very low.
3. Refrain from using hot air blowers for drying the photographic film after development. Employ alternate drying methods that are gentle and controlled, preventing damage to the delicate film layer.
4. Maintain cleanliness and meticulous upkeep of all equipment, particularly the glass plates used to sandwich the photographic film. Dust, impurities, or imperfections on these surfaces can affect the recording process and image quality.
5. Always handle the photographic film by the corners. Avoid touching the film surface from anywhere else, as fingerprints or other contaminants can affect the final image quality.

4.2 Importance of the present work

In this paper, a cost-effective and straightforward hologram recording process designed to be accessible even to undergraduate students. By simplifying the complexities traditionally associated with holography, this method opens up new possibilities for experimentation and learning in optics and imaging. This technique utilizes basic optics principles and accessible materials, demonstrating the fascinating world of holography while fostering hands-on learning and experimentation. It combines affordability with educational value, offering a clear pathway for enthusiasts and academics alike to explore the fascinating world of holographic technology. Holographic technology can also be probably used as a motivating and interdisciplinary education strategy. At AND College (University of Delhi) we frequently organize workshop on holography for interacting with undergraduate/graduate/school teachers and students. These efforts have shown that co-operation between university/college and school is very important in order to promote understanding of holography and its applications in education.

5. Conclusion

By successfully mastering the intricacies of holographic recording and reconstruction at an undergraduate level, the present work signifies valuable learning outcomes for undergraduate students including practical exposure to real-world optics experiments. This work showcases a systematic and cost-effective approach to holography, catering specifically to the needs of researchers and students at the undergraduate level. The demonstrated error-free method outlined in this paper not only provides a comprehensive guide that has not been reported so far in this manner but also emphasizes simplicity, affordability, and success in hologram recording and reconstruction.

One of the key strengths of this method is its adaptability. The instructions provided enable users to customize the process according to their specific requirements, promoting creativity and exploration in holography. This adaptability not only supports individual learning but also encourages teamwork, as users can collaborate to refine and enhance the methodology based on their collective experiences.

The emphasis on optics education at the undergraduate level is noteworthy, as it aligns with the growing demand for practical, hands-on learning experiences in science and engineering disciplines. By offering an affordable and easily implementable holography method, this work contributes to a more engaging and enriching educational experience for students. Furthermore, the paper serves as a bridge between theoretical concepts and real-world applications, enhancing the understanding of holography within the academic community.

Acknowledgements

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