

University of Toronto

Holography

Amir Koutahi, Enxi Huang

PHY294
March 19, 2026

Abstract

This experiment investigated the formation of a reflection hologram using a 5 mW He–Ne laser. An interference pattern between incident and object-reflected light was recorded on a photographic plate and later reconstructed under white light illumination. The resulting image exhibited three-dimensional features, including depth and parallax.

Intensity measurements before and after the spatial filter gave a transmission efficiency of approximately 70.9%, consistent with expected values. While the hologram was successfully produced, its quality was limited by suboptimal object selection, alignment constraints, and relatively low intensity. Minor defects such as speckle and small dots were also observed. Overall, the experiment demonstrates the key principles of holography and the importance of precise experimental conditions.

Contents

1	Introduction	1
2	Materials and Methods	1
3	Data and Analysis	3
3.1	Hologram Observation	3
3.2	Intensity Measurements	3
4	Discussion	4
4.1	Method of Visualization of the Hologram	4
4.2	Quality of the Image	5
5	Results	5
6	References	6
7	Appendix: Uncertainty Propagation	6

1 Introduction

Holography is a method used to create three-dimensional (3D) images using light. Unlike regular photography, which produces flat, two-dimensional images, holography records both the intensity and the phase of light waves. This allows the full structure of the light coming from an object to be stored, making it possible to see depth and different perspectives when viewing the image.

In normal photography, a camera captures only a single focused view of an object, which removes most of the depth information. However, humans are able to see in 3D because of a concept called parallax, where the appearance of an object changes when viewed from different angles. Holography works by recording all the light wave information from an object, allowing the image to appear three-dimensional when reconstructed.

The basic principle behind holography is interference. When two light waves combine, they create an interference pattern that depends on their relative phases. In holography, a laser beam is used because it provides coherent, monochromatic light. Part of the beam interacts with the object, while another part acts as a reference. When these beams meet, they form an interference pattern that contains detailed information about the object. This pattern is recorded on a photographic plate.

When the developed hologram is illuminated, the recorded pattern causes the light to diffract and reconstruct the original wavefront. As a result, the observer sees a 3D image that appears similar to the original object.

In this experiment, a single-beam reflection hologram is produced. In this setup, the laser beam passes through the photographic plate, reflects off the object, and interferes with itself to form a standing wave pattern. This pattern is recorded on the plate and later used to reconstruct the image using white light.

The purpose of this experiment is to understand the principles of interference and diffraction, and to observe how holograms can store and reconstruct three-dimensional information. [1]

2 Materials and Methods

Materials

No.	Equipment
1	5 mW He-Ne laser
2	Electro-mechanical shutter
3	Adjustable mirror
4	Spatial filter (10× microscope objective lens and 25 μm pinhole)
5	Photographic plate
6	Plate holder
7	Vibration-free optical table
8	Light sensor
9	Test object

Table 1: Equipment used in the holography experiment.

Experimental Setup

The experiment used a single-beam reflection holography setup. The laser beam passed through a shutter and was reflected by a mirror into a spatial filter. The spatial filter cleaned and expanded the beam to produce uniform light.

The beam then passed through the photographic plate and reflected off the object placed behind it. The reflected light interfered with the incoming beam, forming a standing wave pattern that was recorded on the plate.

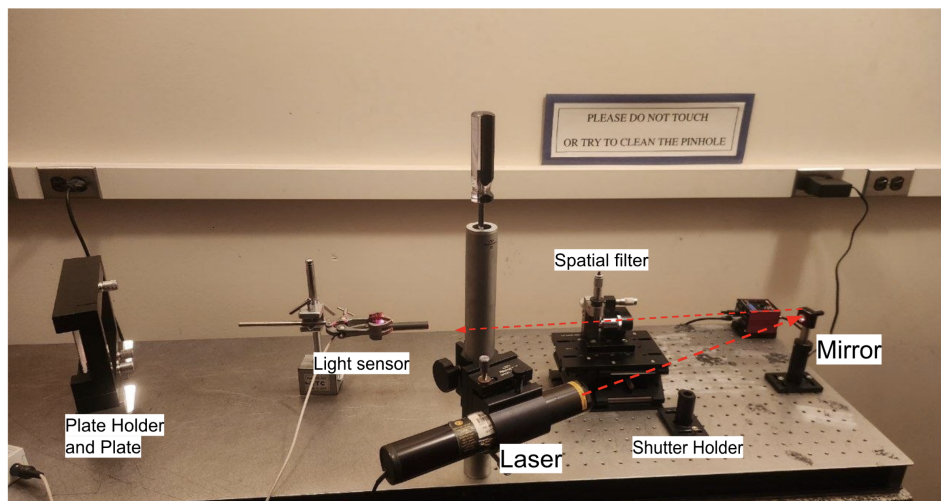


Figure 1: Experimental setup for single-beam reflection holography. This image shows a preliminary setup. In the final configuration, the shutter will be placed at the position indicated by the shutter holder, the object will be positioned directly behind the photographic plate, and the light sensor will be removed.

Procedure

The experiment began by ensuring that all optical components (laser, mirror, spatial filter, and plate holder) were securely mounted on the vibration-free table and positioned as close to the surface as possible to minimize vibrations.

The laser was turned on and the beam path was aligned. The mirror was adjusted so that the reflected beam traveled horizontally and passed through the center of the spatial filter mount. A small piece of paper was used to help visualize the beam during alignment.

The plate holder was positioned approximately 1 m from the spatial filter and oriented at an angle of about 50° – 60° relative to the incoming beam (near Brewster's angle) to minimize unwanted reflections. A dummy plate was placed in the holder to assist with alignment.

The microscope objective lens was installed, and the mirror and plate holder were adjusted until the expanded beam illuminated the central region of the dummy plate evenly. Care was taken to avoid illuminating the edges of the plate to prevent refraction effects.

The initial beam intensity was measured using a light sensor. The pinhole was then inserted into the spatial filter and aligned using micrometer adjustments. A screen was placed in front of the pinhole to observe the output pattern. The pinhole position was adjusted until concentric interference rings were observed and then further refined until a uniform, ring-free illumination was achieved.

The beam intensity after the pinhole was measured again to confirm that it remained within approximately 70–90% of the original intensity, indicating proper filtering.

Once alignment was complete, the shutter was placed into the beam path. The selected

object was positioned directly behind the photographic plate, as close as possible without making contact.

All external light sources were minimized, and the room was prepared for exposure. Under safe lighting conditions, the holographic plate was inserted into the holder with the emulsion side facing the object.

The shutter was activated to expose the plate for approximately 2 seconds, allowing the interference pattern between the incident and reflected beams to be recorded.

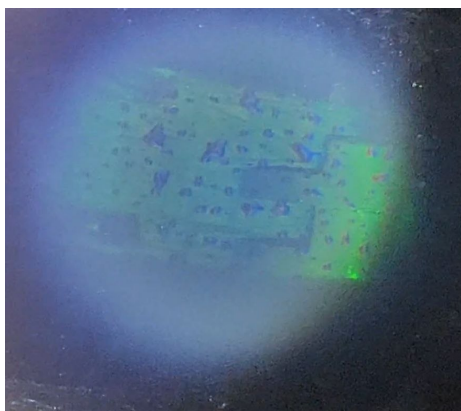
After exposure, the plate was carefully transferred to the darkroom for development. The plate was developed in Kodak D-19 developer for approximately 4 minutes, rinsed briefly with water, fixed for 10 minutes, and then washed under running water for 5 minutes. The plate was then dried for at least 10 minutes.

Finally, the completed hologram was illuminated using a white light source and observed at different angles to reconstruct and view the three-dimensional image. [1]

3 Data and Analysis

3.1 Hologram Observation

The developed hologram was successfully reconstructed under white light illumination. When viewed at different angles, a clear three-dimensional image of the object was observed. The image exhibited depth and parallax, meaning that different perspectives of the object could be seen depending on the viewing angle. This confirms that both amplitude and phase information of the light were successfully recorded during exposure.



(a) Hologram observed immediately after the lab.



(b) Hologram observed after one week using a different laser to obtain a better viewing angle.

Figure 2: Reconstructed hologram under different observation conditions.

3.2 Intensity Measurements

The light intensity was measured before and after the spatial filter to evaluate its transmission efficiency.

The transmission efficiency of the spatial filter is defined as:

$$\eta = \frac{I_{\text{after}}}{I_{\text{before}}}$$

Measurement Location	Intensity (klx)
Before Spatial Filter	2.23 ± 0.01
After Spatial Filter	1.58 ± 0.01

Table 2: Measured light intensities before and after the spatial filter.

Substituting the measured values:

$$\eta = (70.9 \pm 0.6)\%$$

This result lies within the expected range of 70–90% for a properly aligned spatial filter, confirming that the filtering process was effective without excessive loss of intensity.

4 Discussion

4.1 Method of Visualization of the Hologram

The hologram was visualized by illuminating the developed reflection hologram and observing the reconstructed image at appropriate viewing angles. Unlike transmission holograms, which are commonly viewed using a laser passing through the plate, the reflection hologram produced in this experiment is designed to be viewed using reflected light. In this case, the recorded fringe structure inside the emulsion selectively reflects light of the appropriate wavelength and angle, reconstructing the wavefront from the original object. As a result, the observer perceives a three-dimensional image with depth rather than a flat picture.

The visualization process depended strongly on geometry. The hologram was not visible equally well from all directions; instead, the observer had to vary both the angle of illumination and the viewing position until the reconstructed image appeared. This is expected because the interference fringes recorded in the emulsion satisfy a Bragg-type condition during reconstruction. Only when the incident light strikes the hologram at a suitable angle does efficient diffraction occur, allowing the object wave to be reproduced clearly. For this reason, viewing the hologram required careful scanning of angles rather than simply looking directly at the plate under arbitrary illumination.

Immediately after the lab, the hologram could be observed, but the viewing angle was not ideal. Later, after one week, the hologram was examined again under a different laser setup that allowed a better observation angle. Under this improved geometry, the reconstructed image became easier to identify. This comparison shows that the quality of visualization is not determined only by how well the hologram was recorded, but also by how effectively it is illuminated during reconstruction. Even a successfully made hologram can appear faint or unclear if the illumination angle is poor.

Another important point is that the hologram did not present itself as an ordinary bright photograph on the plate. Instead, the image appeared only under specific conditions and often seemed to “emerge” from the plate when the correct angle was found. This is one of the key signatures of holographic reconstruction. The observer could detect depth and a change in perspective with viewing direction, which is consistent with parallax and confirms that three-dimensional information had been stored. This behavior distinguishes the hologram from a simple reflection or surface image.

The clarity of visualization was also influenced by experimental limitations. Since the optical components were rigidly screwed into their holders, fine alignment was more

difficult than desired. This likely affected the recording geometry and may also have made reconstruction more sensitive to angle. In addition, the relatively low intensity available during recording may have reduced fringe contrast, so the final hologram required more careful illumination to be seen well. A stronger exposure and more flexible alignment would likely have produced a hologram that was easier to visualize under a wider range of conditions.

Overall, the method of visualization was successful because the reconstructed image could be observed and its three-dimensional nature could be confirmed. However, the process required careful control of illumination and observation angle, illustrating that hologram visualization is highly dependent on reconstruction geometry. The later observation under improved viewing conditions further demonstrated that proper lighting and angle selection are essential parts of successfully examining a reflection hologram.

4.2 Quality of the Image

The hologram successfully produced a three-dimensional image; however, its overall quality was limited by several experimental factors.

First, the choice of object was suboptimal. The recorded image primarily shows the back of a toy car, including a hook and rear surface, which lacks distinct structural features. A more suitable object, or even positioning the front of the car toward the plate, would likely have resulted in a more detailed and visually informative hologram.

Second, the recorded intensity was relatively low. Although the measured transmission efficiency of the spatial filter was within the acceptable range, the absolute intensity reaching the photographic plate may not have been optimal for achieving high fringe contrast. A higher beam intensity or improved exposure conditions could have increased the fringe visibility and improved the final image quality.

Additionally, mechanical constraints in the setup limited alignment flexibility. Since the spatial filter and optical components were firmly screwed into their mounts, fine adjustments were difficult to perform. This likely introduced small misalignments, reducing coherence quality and degrading the sharpness of the recorded interference pattern.

Finally, small dots were observed in the reconstructed hologram. These are likely due to dust particles, imperfections in the photographic plate, or scattering effects from the spatial filter (e.g., pinhole contamination). Such defects introduce localized noise in the interference pattern, which appears as bright or dark spots in the reconstructed image.

Overall, while the hologram demonstrates the fundamental principles of holography, improvements in object selection, alignment flexibility, and optical cleanliness would significantly enhance image quality.

5 Results

The experiment successfully produced a reflection hologram that was capable of reconstructing a three-dimensional image under appropriate illumination. The reconstructed image exhibited depth and parallax, confirming that both amplitude and phase information of the light field were recorded in the photographic plate. The visibility of the image depended strongly on the viewing angle and illumination conditions, as discussed previously.

In addition to the qualitative observation of the hologram, several conceptual aspects of holography were examined.

A latent image formed on a conventional photographic plate differs fundamentally from a holographic image. A latent image records only the intensity distribution of light, meaning it captures how bright or dark different regions are, without preserving phase information. In contrast, a holographic image is formed from an interference pattern between object and reference waves, encoding both intensity and phase. As a result, while a latent image becomes visible only after chemical development as a two-dimensional representation, a hologram reconstructs a full three-dimensional wavefront when illuminated properly. This distinction explains why holography can reproduce depth and perspective, whereas standard photography cannot. [2] (Question 1)

If the hologram were shattered into smaller pieces, each fragment would still contain information about the entire object. When illuminated, each piece would reconstruct the full image rather than just a portion of it. However, the image would appear dimmer and may have reduced resolution due to the smaller amount of recorded interference pattern available. This behavior is a direct consequence of the distributed nature of the recorded wavefront information. [3] (Question 2)

The image observed from a fragment of the hologram would differ from that of the intact hologram primarily in quality rather than content. While the full hologram provides a brighter and sharper reconstruction, each smaller piece would produce a less intense and potentially less detailed image. Additionally, the field of view may be reduced, meaning that some viewing angles could be lost depending on the size and position of the fragment. Despite these limitations, the entire object would still be visible from each piece. [3] (Question 3)

This property arises because holography records the interference pattern of the entire wavefront across the whole plate. Each region of the hologram contains information about the phase relationships of light coming from all points of the object. Mathematically, the hologram encodes a spatial frequency distribution corresponding to the object wave, so even a small portion of the hologram still contains sufficient information to reconstruct the original wavefront. Therefore, illumination of any portion of the hologram allows the reconstruction of the entire image, albeit with reduced quality. This distributed encoding is a key feature that distinguishes holography from conventional imaging techniques. [2,3] (Question 4)

6 References

1. Holography Lab Manual, University of Toronto, revised by P. Albanelli and S. Fomichev (2014).
2. E. Hecht, *Optics*, 5th Edition, Pearson (2017).
3. J. W. Goodman, *Introduction to Fourier Optics*, 3rd Edition, Roberts and Company (2005).

7 Appendix: Uncertainty Propagation

The uncertainty in both intensity measurements is given as:

$$\Delta I = 0.01 \text{ klx}$$

The transmission efficiency is:

$$\eta = \frac{I_{\text{after}}}{I_{\text{before}}}$$

Using standard uncertainty propagation for a ratio:

$$\frac{\Delta\eta}{\eta} = \sqrt{\left(\frac{\Delta I_{\text{after}}}{I_{\text{after}}}\right)^2 + \left(\frac{\Delta I_{\text{before}}}{I_{\text{before}}}\right)^2}$$

Substituting values:

$$\begin{aligned}\frac{\Delta\eta}{\eta} &= \sqrt{\left(\frac{0.01}{1.58}\right)^2 + \left(\frac{0.01}{2.23}\right)^2} \\ &= \sqrt{(0.00633)^2 + (0.00448)^2} = \sqrt{4.00 \times 10^{-5} + 2.01 \times 10^{-5}} \\ &= \sqrt{6.01 \times 10^{-5}} = 0.00775\end{aligned}$$

Thus:

$$\Delta\eta = 0.709 \times 0.00775 = 0.00549$$

$$\Delta\eta \approx 0.0055$$

$$\eta = 0.709 \pm 0.006$$

or in percentage form:

$$\eta = (70.9 \pm 0.6)\%$$