Production and Reconstruction of a Single-Beam White-Light Reflection Hologram

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1 Abstract

In this experiment, the process and theory of developing a white-light reflection hologram were investigated using monochromatic light sources to project 3D images onto a thin photographic film. The transmission efficiency of this lab was determined to be $(71.4 \pm 2.2)\%$, verifying an accurate spatial filter alignment in the apparatus setup. While holograms start with a latent interference pattern, a hologram's ability to capture the full information of a light wavefront, including the wave amplitude, intensity and phase, makes it different from latent images that can only capture intensity. This unique property enables the full image of the hologram object to be preserved even if the plate is shattered.

2 Introduction

The goal of this experiment is to produce a single-beam white-light reflection hologram. Holography uses monochromatic light to record the full information of a light wavefront, allowing for the reconstruction of a truly three-dimensional image using interference patterns created by the disturbance of a reference beam by an object (Fomichev. and Albanelli 2014). When reconstructed, the hologram provides depth through the parallax effect, which is the apparent difference in an object's appearance when observed from different viewpoints (Nebraska-Lincoln n.d.).

In a single-beam reflection setup, the laser beam is both the reference and the object beam. The beam first passes through the photographic plate (the reference beam) and then reflects off the object behind it. These two beams interfere at the plate, forming a standing wave pattern, occurring because the light is coherent (same-phase). The resulting fringes are captured in the emulsion, and once processed, they force light to follow the original diffraction and interference patterns to reconstruct the object's wavefront.

To ensure a high-quality holographic image, it is necessary to minimize internal reflections within the glass plate that could create unwanted noise. This is achieved by setting the incident laser beam to Brewster's angle, $\theta_B = 50° - 60°$ (Paschotta n.d.). When light is p-polarized (horizontally polarized in this setup) and incident at this specific angle, the reflection of the beam from the glass surface is minimized.

Laser beams often contain "spatial noise"—interference patterns caused by dust particles or optical imperfections in the lenses. A spatial filter is used to "clean" the beam. It consists of a microscope objective lens that focuses the beam through a tiny pinhole. Because diffracted noise separates from the undiffracted beam at the focal point, the pinhole allows only the clean, central part of the beam to pass through. The required diameter D of the pinhole is influenced by the laser wavelength λ, the magnification of the objective M, and the beam diameter d:

$$D \approx \frac{0.6\lambda}{Md}$$

3 Materials and Methods

The experiment followed the procedure for a single-beam reflection hologram, where the reference beam passes through the plate before reflecting off the object to form a standing wave. The setup for the lab is shown in Figure 1.

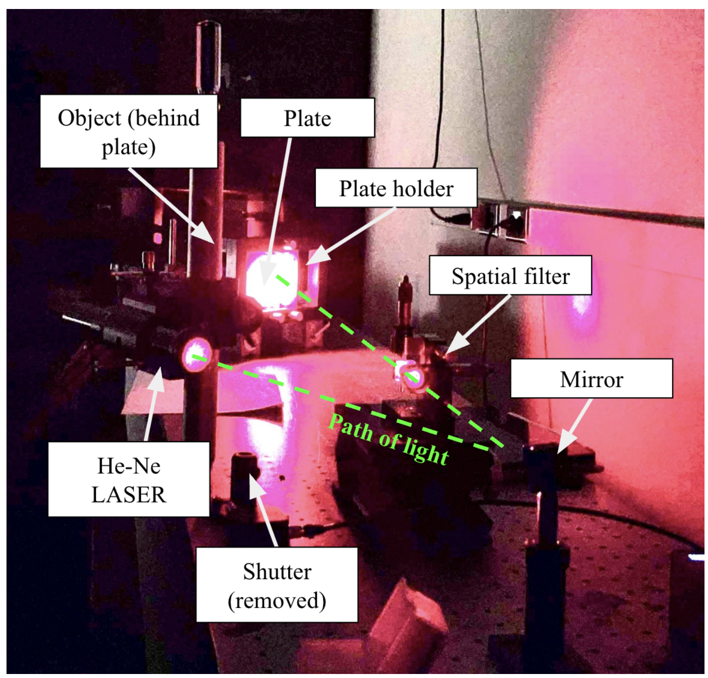

Figure 1: The experimental arrangement for producing a single-beam white-light reflection hologram. A 5 mW He-Ne laser beam is directed by a tilt mirror through a spatial filter (10× objective and 25 µm pinhole) to create a clean, diverging beam. The light is incident on the holographic plate at Brewster's angle ($\theta_B \approx 56°$) to minimize glass reflections. The object is placed immediately behind the plate, where the reference beam and reflected object beam interfere to form a standing wave pattern captured in the emulsion.

The schematic and setup of the components in Figure 1 are also shown in Figure 2.

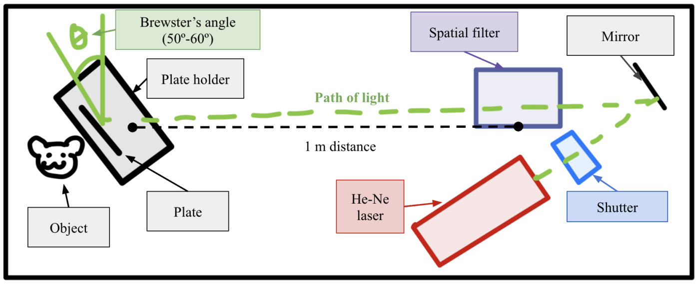

Figure 2: The birds-eye-view schematic for the arrangement of the apparatus. The object is placed behind the plate (in the plate holder) at Brewster's angle, 1 m away from the spatial filter. The light is released by the He-Ne laser, passing through the shutter, and reflecting off the mirror.

All components were anchored to the vibration-free table as close to the surface as possible to ensure stability. The laser beam was levelled horizontally by comparing vertical distances from the table at the laser aperture and the mirror. Using the tilt mirror, the beam was centred on the spatial filter mount. The plate holder was positioned 1 meter from the filter at an angle of 50°–60° to approximate Brewster's angle and minimize glass reflections.

A 10x microscope objective was installed to diverge the beam. The 25 μm pinhole was then magnetically attached to the x, y, z controls of the spatial filter. The micrometres were adjusted until an interference pattern of concentric rings appeared on a white screen, indicating the beam was passing through the pinhole. The pinhole was moved toward the lens focal point until a uniform field of illumination, free of spatial noise, was achieved. Alignment was verified by ensuring the light intensity was 70-90 % of the unfiltered beam.

The electromechanical shutter was placed in the beam path, and the target object was fixed immediately behind the dummy plate. In total darkness with only the safelight active, a holographic emulsion plate was loaded into the holder with the emulsions side facing the object. The shutter was triggered for an exposure of 2 seconds.

The plate was brought to a darkroom, where it was:

1. Developed in Kodak D-19 (1:1) for 5 minutes with slow agitation.

2. Rinsed briefly in cold water.

3. Submerged and slowly moved back and forth for 10 minutes in a fixer solution.

4. Washed under running water for 5 minutes.

5. Dried for 15 minutes in a dryer.

To visualize the hologram, the completed plate was illuminated with a point-source white light (such as a phone camera) at a tilted 50-60° for optimal viewing of the image. This was similar to the position used for Brewster's angle to align the reference beam during exposure, which allowed the recorded interference fringes to diffract the light and reconstruct the original wavefront.

4 Data and Analysis

The light intensities taken at the centre of the light from the laser were recorded before and after placing the spatial filter, and recorded in Table 1. The measured transmission efficiency satisfies the procedural requirement that the filtered beam retain 70 % to 90 % of its original intensity.

Measurement Condition	**Light Intensity** (klx)
Before Spatial Filter	0.56
After Spatial Filter	0.40
Transmission Efficiency	$(71.4 \pm 2.2)\%$

Table 1: Light intensity measurements taken to verify spatial filter alignment.

Our experimental results, as seen in Figure 3, demonstrate a successful reconstruction of the object wavefront. A notable observation is the colour of the reconstructed image. Although a red He-Ne laser was used for exposure, the reconstructed lion appears green-yellow. This is a direct result of the emulsion shrinking by approximately 50 to 100 nm during the chemical fixing and drying process. This reduction in the spacing of the captured interference fringes causes the hologram to reflect shorter wavelengths (roughly 500–550 nm) when viewed under white light.

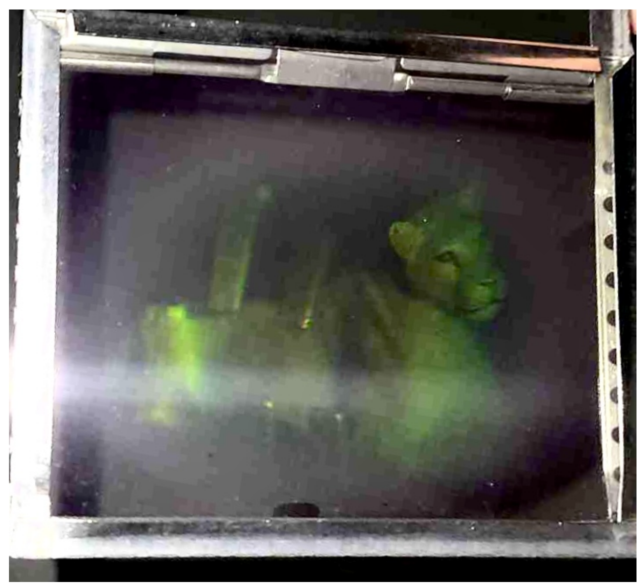

Figure 3: Experimental results showing the reconstructed wavefront of the lion object. Note the characteristic green colour, indicating the film shrank by approximately 50 to 100 nm after processing.

5 Discussion and Conclusion

In the following experiment, the holograph setup exhibited a transmission efficiency of $(71.4 \pm 2.2)\%$, causing the wavelength in the image to appear yellowish-green, shifted from the original red laser colour.

5.1 Difference between a hologram and a latent image

While a hologram is similar to latent images, as they both store light information to create images, they differ in the type and amount of information stored and how the image is developed. A latent image, which uses a lens to be developed, is a chemical change in silver halide grains that requires development to become visible (Sprawls n.d.). Each silver halide crystal has silver ions that become exposed to the light and absorb the incident photons; thus, if one part of the photo were exposed to different amounts of light, the photo would develop different in each side (Pant 2026). While a hologram also starts as a latent interference pattern, it differs because it records the phase and amplitude of the light wavefront for the whole film, giving it depth and a 3D perception and allowing for the image to 'operate as a whole.' Therefore, latent images have far less redundancy, and cutting an image in half would result in a loss of information compared to a hologram.

5.2 Shattered holograms

A hologram is known to extract all the information that is carried by a wavelength, similar to the human eye. Before hitting the plate, the light is scattered by the object, creating 3D depth perception in the hologram. Therefore, shattered holographic pieces can reconstruct the entire 3D scene from a single piece because the image is not stored as a direct, localized map like a photograph, but rather as an interference pattern distributed across the entire medium. Each portion of the hologram captures light waves scattered from every point of the object, meaning the whole scene is recorded in every part of the film.

If a hologram was shattered, each piece of the hologram holds the same amount of information, as it stores interference patterns, allowing for a single piece of the hologram to 'reconstruct' the entire image (Fomichev. and Albanelli 2014). However, a shattered hologram has reduced detail, lower resolution, and a narrower viewing angle. Because each part of the hologram records information about the entire subject, the image is not lost but becomes noisier and less sharp.

5.3 Sources of error

Some notable factors could have influenced the quality of the hologram, such as the atmospheric conditions, the quality of the plates used and the alignment of the lasers.

For one, while vibration and light interference were minimized, slight movements can change the interference patterns. Within the setup, the shutter operating screen emitted light, the shutter clicked before opening, and cracks in the walls of the dark room had light seeping in, all which could cause abnormalities. Furthermore,Many LED lights, when closed immediately, release 'residual light' waves that can take a while to die down and can tamper with the waves in the meantime. Since the plate remains sensitive until fixed, this "residual light" can fog the emulsion, reducing the contrast of the interference fringes. According to Pollack n.d., the best holograms are made at night because there is little ventilation or light that can possibly interfere with the hologram.

Second, the plate was assumed to be 100% reflective, when in reality, this is not the case. The absorbance of light from the plate causes less light to be scattered, which can reduce the intensity of the image in the hologram. Rainbow streaks observed near the edges of the lion figurine likely indicate refraction from the sides of the glass plate. In the future, painting the edges of the plate black can mitigate these unwanted internal reflections (Avantier 2025).

Third, the rainbow streaks near the edge of the object can be due to light entering the sides of the plate if the laser was slightly misaligned. The lighter sides can interfere with the laser light and the reference beams. According to the literature, a common way to avoid this is to paint the sides of the plate black so that light cannot enter through the sides, which can create this reflection ("INTEGRAF — FAQ — Making Holograms" n.d.).

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6 Appendix

6.1 Error Propagation of Ratio

The transmission efficiency is defined as $\eta = \frac{I_f}{I_0}$, where I_f is the filtered intensity and I_0 is the initial intensity. The propagated uncertainty $\Delta\eta$ is calculated using the relative uncertainty formula for a quotient:

$$\Delta\eta = \eta\sqrt{\left(\frac{\Delta I_f}{I_f}\right)^2 + \left(\frac{\Delta I_0}{I_0}\right)^2} \quad (1)$$

Assuming a standard instrumental uncertainty of $\pm 0.01\,\mathrm{klx}$ for the light sensor, $I_0 = 0.56 \pm 0.01\,\mathrm{klx}$ and $I_f = 0.40 \pm 0.01\,\mathrm{klx}$.

Substituting these values yields a final efficiency of $71.4 \pm 2.2\%$.