Lab 5: Holography

6.2370 Modern Optics Project Laboratory
Daniel Sanango

I. Introduction

This lab experience aims to explore hologram production and readout processes. Holograms construct three-dimensional images on a two-dimensional plane, with modern uses aimed towards information storage and artwork. Two variants of holography are explored in this lab: transmission and reflection.

II. Approach

The approaches for each experiment will be separated into sections. This procedure and layout will also be followed in Section III (Results and Discussion).

Section A will discuss our attempt to recover the readout geometries of the images produced by a transmission hologram with unknown properties. This section seeks to explore methods for hologram analysis. Section B will discuss our attempt to produce a reflection hologram. This section seeks to explore methods for hologram creation.

A. Transmission Hologram

The objective of this exercise was to locate high-power real and virtual images produced by a transmission hologram. In this experiment, we were given a transmission hologram with unknown properties.

Fig 1 demonstrates the typical production process for transmission holograms. A beam splitter is used to separate a wave into two components. One wave goes to the object being holographed. Light reflects off the object and travels to a recording medium. The other wave travels directly to the medium. These two waves interact with each other at the medium and ultimately produce a hologram.

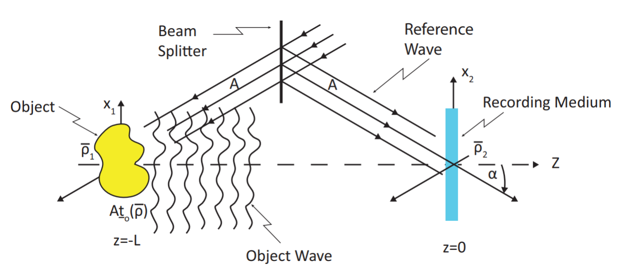

Fig. 1: Schematic of Transmission Hologram Write Process [MIT 6.2370 Lecture Notes]

In the figure, the "Reference Wave" (also known as the write wave) is shone at a particular angle towards the hologram. This angle is critical to reconstructing the holographed image.

The only information we were given about our mystery transmission hologram is the face of the hologram the write wave interacted with. Fig 2 demonstrates a typical readout setup and results for a transmission hologram with the write face facing the read light. First, a "read" light (labeled $\underline{U_p}(\bar{\rho})$) is shone at a particular angle α at the hologram. This angle is the same as the one made with the write wave and the medium. When this angle is achieved, a real and virtual image are produced. With this setup, the virtual image receives the most power from the read wave while the real image receives the least power.

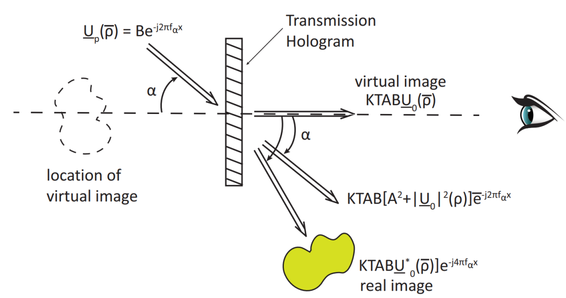

Fig. 2: Schematic of Transmission Hologram Readout [MIT 6.2370 Lecture Notes]

A central idea in holography dictates that, if the conjugate of $\underline{U_p}(\bar{\rho})$ is used to read the hologram, most of the output power is put into the real image. Fig 3 demonstrates the difference in observed images with the conjugate wave.

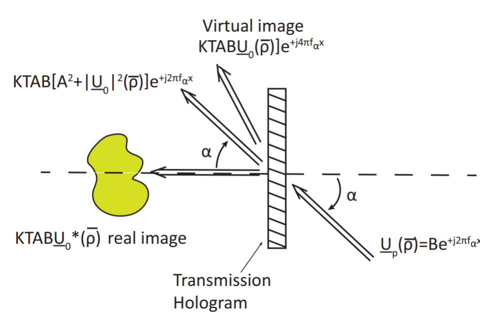

Fig. 3: Schematic of Transmission Hologram Readout With Conjugate Wave [MIT 6.2370 Lecture Notes]

Our approach to figuring out the hologram's write geometry was to first arbitrarily angle the hologram. A diverging light source was used to account for numerous incident angles, giving a wide range of read angles that could match that of the write light. Since we were working with a high-power laser, a diverging beam was also useful in spreading out the laser's power density and, thus, limiting the severity of retinal damage. Next, we arbitrarily angled the recording medium and looked around the hologram for a virtual image. A virtual image was decided on because it has high definition at various distances away from the hologram. With a real image, however, we would have had to place a piece of paper at a precise distance from the hologram, making the process of guessing the image angles much harder. Based on the readout geometries in Fig 2 and Fig 3, we were able to deduce the plane of the medium that the write light interacted with, as well as recover high-definition real and virtual images of the transmission hologram. Geometrically, taking the conjugate of a complex wave rotates the wave by 180 degrees. To avoid the annoyance of rotating the entire laser around the setup, we instead rotated the hologram 180 degrees to get the conjugate readout.

B. *Reflection Holograms*

The objective of this exercise was to understand the optical workings of reflection holograms. The reading and writing geometries of a reflection hologram are distinct from the transmission hologram. Fig 4 demonstrates a simple reflection hologram production process. First, a reference wave hits the recording medium. Some of the reference wave transmits through the medium and hits the object. Light from the object is then reflected back towards the hologram. The original reference wave and the object wave then interact with each other, forming a fringe pattern and hologram.

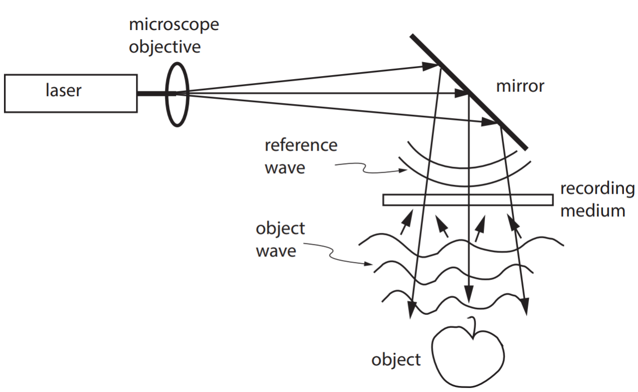

Fig. 4: Schematic of Reflection Hologram Write Process [MIT 6.2370 Lecture Notes]

The same write angle logic from the transmission portion of the lab is then used to find a virtual image. Fig 5 demonstrates a sample schematic result of this. While reflection holograms produce a real image when read out with the conjugate wave, we are not interested in this result for the scope of this lab.

Using these principles, we were able to make our own reflection hologram. The recording medium we used required complete isolation from light until use to produce a hologram, requiring us to work in the dark for most of the experiment. First, we reconstructed the setup in Fig 4. After this, we chose to holograph a white object. White objects reflect more light and would thus produce a clear hologram. To make the quality even better, we put the object on a black background. Black objects reflect very little light, allowing for the white light from the object to be more dominant in the virtual image. To ensure the virtual image would look sharp, we floated our table with helium gas and taped our object to the table. We also generally refrained from moving. Vibrations are unideal due to even slight displacements messing up the interference and diffraction fringes in the medium. Once this was achieved, we turned off the lights and carefully placed a recording medium on our setup. Before turning the laser on, we isolated our recording medium storage from light. After this, we turned the laser on for two minutes. Ultimately, a hologram with an object of our choosing was produced.

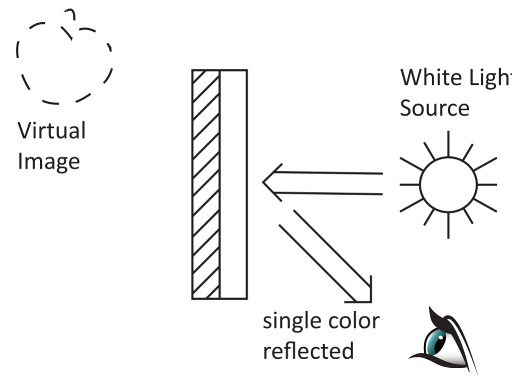

Fig. 5: Schematic of Reflection Hologram Readout To Produce a Virtual Image [MIT 6.2370 Lecture Notes]

III. Results and Discussion

The results and discussion for each exercise will be separated into sections.

A. *Transmission Hologram*

Fig 6 demonstrates our transmission hologram producing a real image of clock hands at maximum power. The paper background required precise positioning to generate a clear image. Besides the clock, there is a large red arc, a strong bright spot to the left, and a zigzag near the right-center. This is overall an excellent real image, but has a couple discrepancies that prevent it from obtaining optimal power. Firstly, the transmission hologram was known to have a slight crack, which would cause some unoptimal light bending and, thus, not place full power on the hologram. The squiggly area at the middle-right is likely produced by this crack. The circular arc demonstrates the read light going slightly out of the hologram medium area. This could be fixed by decreasing the beam size. Notably, however, thus would also increase safety risks, as a smaller beam would have more power density and, thus, pose greater potential retinal damage.

Fig 7 demonstrates our transmission holograph producing a virtual image of the clock hands at maximum power. The

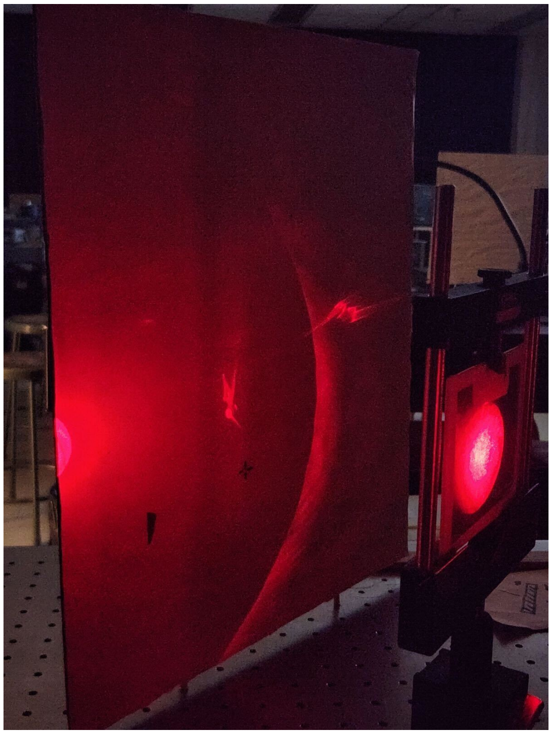

Fig. 6: Transmission Hologram Real Image

red light is mostly circular, with a slit discrepancy appearing towards the right of the image. This is overall an excellent virtual image. The only major discrepancy in the virtual image is produced by the known crack on the hologram medium. This produces the hair-like section on the virtual image noted in the results. This crack could ultimately be limiting an optimal virtual image.

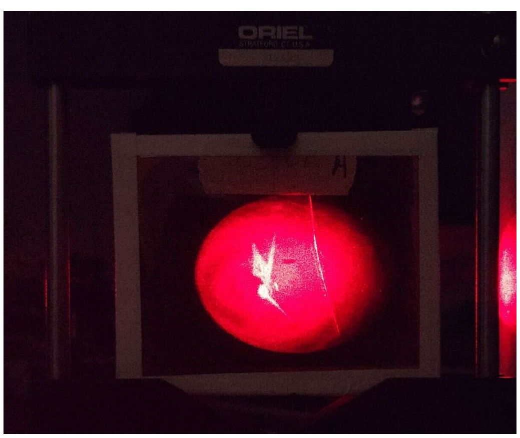

Fig. 7: Transmission Hologram Virtual Image

B. *Reflection Holograms*

Fig 8 demonstrates a faint set of keys and coins read out using room lights. The faintness could imply a a bad viewing angle or low-power readout light. This is overall a poor virtual image. This could be remedied by potentially angling the viewing position better. It is likely that this hologram requires a specific wavelength to produce a high-definition virtual image. It could also be that there was a manufacturing error with the hologram, such as too much vibration during the writing process. More light intensity could also be placed on the hologram medium to see if a stronger virtual image is produced, such as by placing the hologram close to a white-light lamp.

Fig. 8: Reflection Holograph Demonstrating Keys

Fig 9 demonstrates a mostly-yellow owl with high definition and some colorful spots. The sharpness demonstrates a satisfactory viewing angle. This is overall an excellent virtual image. The owl has a great definition, implying a good viewing angle. The colorful patches suggest that the reflection hologram supports numerous wavelengths. If the picture was angled differently, these different colors may have been more prominent. Ultimately, however, yellow appears to be the most dominant color and, likely the write wavelength used.

Fig. 9: Reflection Hologram Demonstrating an Owl

Fig 10 demonstrates our object for our personal hologram. The produced hologram generated a very clear virtual image. The reflection hologram was ultimately very high quality. This demonstrates that we were able to minimize vibrations well. The edges of our object were slightly fuzzy, likely due to to strong reflections from the surface our object was placed on during the writing process. We attempted to remedy this by placing black cardboard under our object, but the result was of slightly poorer quality due to a fingerprint smudge.

Fig. 10: Reflection Hologram Production Setup

IV. CONCLUSION

We have demonstrated a method of recovering the geometic properties of transmission holograms. The ability to do this is useful for discovering write geometries in holograms with undocumented readout instructions.

We have also demonstrated a successful technique to producing high-quality reflection holograms. In our case, we used reflection holography to produce artwork. This lays an essential foundation for more advanced reflection hologram productions, such as full-color holograms and holographic encryption.

Overall, holography is a powerful and efficient tool for three-dimensional data storage. By using fundamental properties of holography, one is able to produce high-definition works.