Final Project: RGB Hologram

6.2370 Modern Optics Project Laboratory

Maggie Slowikowski
Department of Electrical Engineering and Computer Science
maggislo@mit.edu

Daniel Sanango
Department of Electrical Engineering and Computer Science
danango@mit.edu

Brenna Kennedy-Moore
Department of Electrical Engineering and Computer Science
brennakm@mit.edu

***Abstract*—Holography is an advanced imaging technique where the phase information of an object is captured in the recording medium, resulting in a 3-dimensional reconstruction of the object when the hologram is read out with light. Typically, holograms are written with only one color of laser, resulting in a reconstruction that does not capture the true colors of the object, but instead is the color of the exposure laser. This project explores two approaches to writing RGB holograms that capture the true colors of an object: 1) simultaneous exposure and 2) sequential exposure to red, green, and blue light. Our experiment demonstrates a successfully written hologram with only red and green light as we encountered challenges while incorporating blue light due to vibrations from the multimodal Argon laser. Our findings suggest that writing an RGB hologram with sequential light exposure results in a more defined hologram due to reduced interference between separate laser sources.**

I. Introduction

RGB holography is an advanced imaging technique that utilizes color channel mixing and wavefront reconstruction to produce vivid three-dimensional reproductions of the object being captured. It has great potential for fields such as medical imaging and display technology, and provides an integrated practical application for many of the theoretical optics principles we have studied this semester. After the success of the monochromatic holography laboratory exercise we completed in class, in which we were able to capture crisp holographic images of a 3D printed lobster, we were excited to dive more deeply into the subject area and expand our knowledge and ambitions throughout the course of our final project.

Imaging systems are a crucial part of both daily life and modern scientific work. The goal of any imaging system is to create a visual representation of an object or event that can be revisited in order to analyze data, gain information, or communicate large amounts of information efficiently. There are many kinds of imaging techniques: microscopy, CT imaging, MRI, X-Ray, photography (digital and analog), holography, radar-based satellite imaging, etc. Each is concerned with its own subset of the spectrum of electromagnetic (or even sound) waves and their interactions with the subject of the image. Magnetic Resonance Imaging (MRI), for example, is a technique that uses the radio frequency band of the electromagnetic spectrum and has revolutionized our ability to visualize soft tissue in a non-invasive manner. Holography is a technique that operates within the visible light spectrum, much like photography, but for many reasons has not found a niche of commercial or scientific application in quite the same way as many other imaging systems have.

In contrast with photography, arguably the most widely used imaging technique of all (especially with the advent of inexpensive and mass-producible semiconductor-based sensors), holography requires a rigorous and meticulous process and is often considered a bit of a novelty or something only seen in gift shops and credit card security features. The key distinction between the two lies in the inclusion of the phase information from the incident light waves, taking the 2D imaging system of a photograph into 3D. This ability to capture phase information is what allows for wavefront reconstruction when the hologram is read out, regardless of what type of light source is used to reilluminate the finalized hologram. Specialized recording media is exposed under carefully controlled circumstances, producing permanent changes to the atomic structure of the emulsion that correspond directly to the contrast between an object and reference wavefront, most often coming from a laser illumination of the subject. The object wave and reference wave produce interference patterns that construct the illusion of a multidimensional image when the emulsion is reilluminated with any kind of concentrated light. Fig 1 and Fig 2 demonstrate schematics of the basic setup of a holographic imaging system.

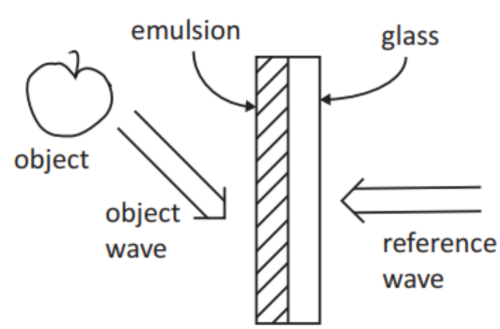

Fig. 1: Schematic of Reflection Hologram Write Process [MIT 6.2370 Lecture Notes]

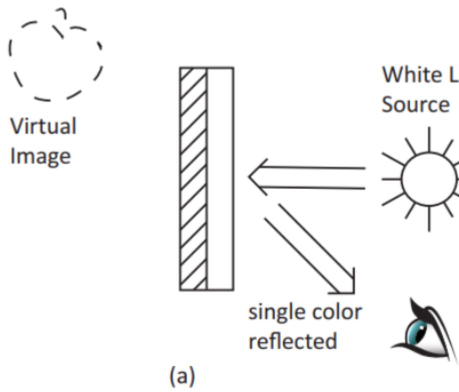

Fig. 2: Schematic of Reflection Hologram Read Process [MIT 6.2370 Lecture Notes]

II. Approach

To write our RGB holograms we begin with the following optical setup (Fig 3) utilizing a HeNe laser (red) and a multimodal Argon laser (blue and green). We first expand the beams and direct them to a beam splitter, where they are each split into an object beam and a reference beam. The reference beam reflects off of a mirror and onto the recording medium while the object beam reflects off of the object and onto the recording medium. These beams then interfere to form our hologram fringes.

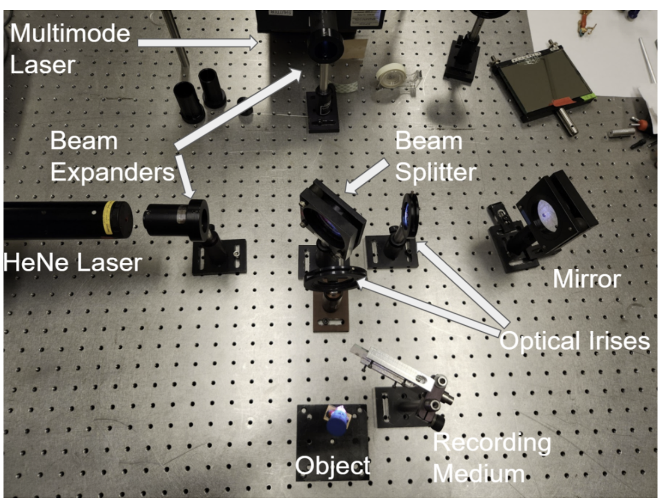

Fig. 3: RGB hologram writing setup

The holograms were written with two different approaches:

1) write with both the HeNe and Ar laser simultaneously (Fig 4)
2) write with each laser separately (Fig 5)

By experimenting with two different exposure approaches, we are able to compare the two results and conclude whether one approach is better than the other for writing RGB holograms which may be helpful in future projects.

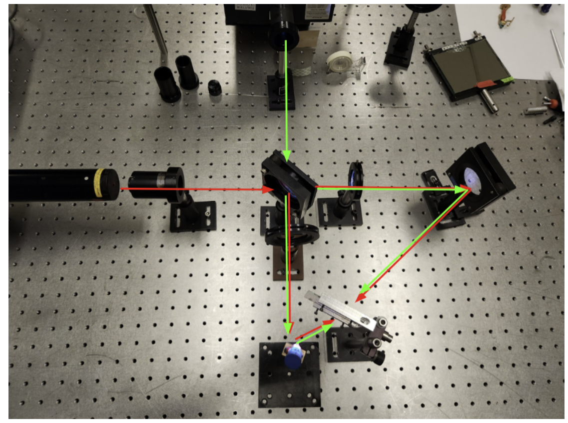

Fig. 4: RGB hologram writing setup

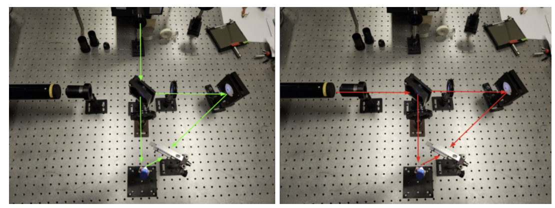

Fig. 5: RGB hologram writing setup

III. Results and Analysis

First, we wrote a hologram using red light from the Helium-Neon laser. After some test exposure times, we found that an exposure time of two minutes produced an optimal red hologram. Fig 6 and Fig 7 display successful holograms with this setup.

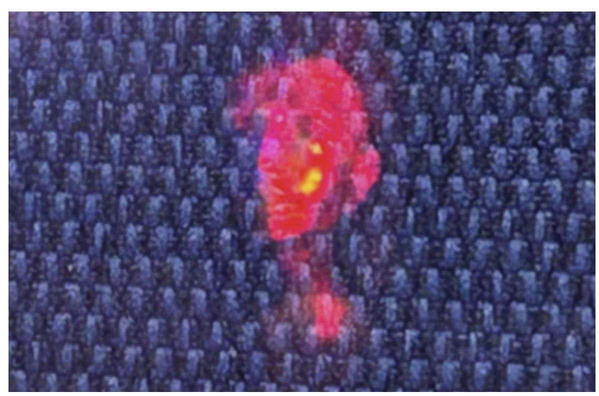

Fig. 6: Red hologram of Egyptian figure.

Next, we wrote a hologram using a multimode Argon laser from the Modern Optics Lab. Fig 8 demonstrates our result. While the green blob demonstrates that the holographic material interacted with the green light, it is apparent that a clear image was not formed. It was determined that the Argon laser likely introduced too much table vibration due to its noisy cooling system, interrupting clean fringe creation and, thus, the writing process.

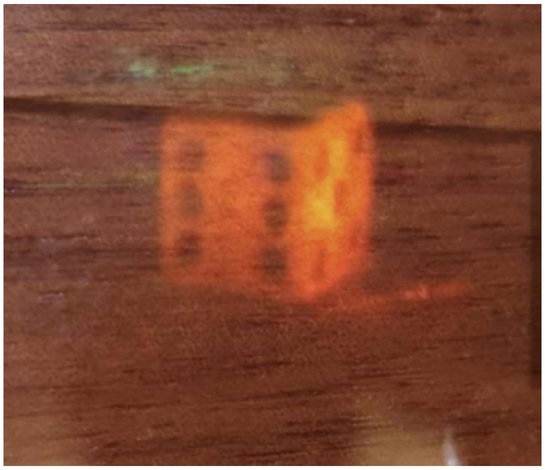

Fig. 7: Red hologram of dice.

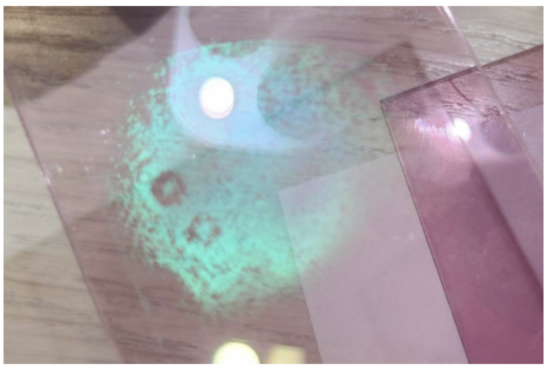

Fig. 8: Multimode laser failed hologram of dice.

After this discovery, we found a replacement green light source and tested exposure times. The replacement laser had no cooling system and, thus, was more likely to produce a clear hologram. Fig 9 demonstrates a hologram formed by the replacement laser with a three minute write time.

Fig. 9: Replacement green laser hologram of dice.

After testing these individual processes, we decided to write a hologram with both lasers. Although the replacement for the Argon laser was successful, one major drawback was that we no longer had a blue light source. Thus, our final result only has red and green write light as opposed to red, green, and blue.

We tested two writing procedures. In procedure 1, we wrote with both lasers on at the same time. We kept both lasers on for two minutes, then turned the red light off and let the green light continue exposure for one minute. Fig 10 demonstrates the resulting hologram.

Fig. 10: Procedure 1: simultaneous write process.

In procedure 2, we wrote with one laser on at a time. We first wrote with red light for two minutes. We then wrote with green light for three minutes. Fig 11 demonstrates the resulting hologram.

Fig. 11: Procedure 2: individual write process.

IV. Discussion

Overall, an individual write process seems to have produced a better red-green hologram. One reason this may have been the case is because of interfering electric and magnetic fields between both laser sources. The superposition of the sources may have produced unintended beam features and, thus, a less defined hologram. By writing individually, the beams may have maintained their field properties better, leading to a higher-definition writing outcome.

After performing the experiment, we looked at manufacturer notes for the materials used. For the emulsion material, we found that the minimum lifespan for the holograms was 12 months [1]. The age of our emulsion material may have had negative effects on our holograms, as at some point, we ran out of emulsion material manufactured in 2024 and had to resort to materials from April 2023. The material manufacturers also provide recommended exposure energy for laser color sources. For blue, green, and red light, the exposure densities are given as $80mJ/cm^2$, $30mJ/cm^2$, and $20mJ/cm^2$, respectively. With this information, one could determine the beam size of our write beam using a ruler and find the exact exposure energy required. From there, a photodetector could be used to find the power of the red and green laser beams. From there, Using $P = \frac{dE}{dt}$, assuming energy has a linear relationship with time, we could say that $t = \frac{E}{P}$, where t is the write time. Ultimately, some guessing as to the perfect write time may have to be done. It could be helpful to contact the emulsion material manufacturers for their experimentally-determined ideal laser power and write times.

Another interesting detail about the holographic material used is its advertised "instant" hologram feature. The feature allows a hologram to instantly form after laser exposure. Normally, a hologram would undergo a chemical bath to fully develop its write features. While the "instant" feature was helpful in getting quick results, in future developments, it may be worth exploring holographic materials that undergo different write processes and developments to compare image quality.

Finally, it appears that none of the lasers we used in the laboratory have online spec sheets. This is likely due to the lasers being old and, thus, likely a discontinued product. To get specific details about our lasers, we could contact the manufacturers or use more-modern devices with online spec sheets.

V. Conclusion

Overall, we were not able to produce a hologram using red, blue, and green light. However, we successfully produced a hologram written with red and green light, demonstrating the feasibility of creating RGB holograms. Although it did not perfectly capture the actual color of the object, our red-green hologram produced an image whose color was much closer to the object's true color than our red-only or green-only holograms. From this, we can conclude that adding the blue laser would further improve the recorded color of the object.

While incorporating blue light to our system, we encountered challenges regarding the added vibrations induced by the Argon laser. To add blue light, we would likely have to construct an entirely new setup placing the Argon laser on a separate table to minimize the vibrations introduced to the system. However, it is worth noting that the vibrations from the laser may still impact hologram quality due to noise and potentially shaking of the laser beam itself and thus, it may be best to create a new setup with a vibration-free laser.

Future work should focus on the limitations identified in this project including optimizing laser exposure times, material quality, and incorporating blue light using a vibration-free source. Doing so, we can enable more accurate color reproduction to advance holographic imaging technology with potential real-world applications in fields such as medical imaging and display systems.

References

[1] "Hologram Film." Litiholo.com, 2024, www.litiholo.com/hologram-film.html. Accessed 16 Dec. 2024.