Single-Beam Reflection Holograms

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“Help me Obi-Wan Kenobi, you’re my only hope.” - Princess Leia [1]

1. Introduction

Photography is “the art or practice of taking and processing photographs” [2]. Photographic methods capture and store two-dimensional images which can seem unnatural to us as humans living in three dimensions. Holography, which is an alternative to photography, is a technique that uses monochromatic light sources to capture 3D images [3]. The technique is based on the interference pattern that is a result of a light beam being split or going through diffraction, travelling on different paths, then being recombined on a surface. An object can be placed in the path of the beam which is then recombined and captured by a photographic plate or film. The captured interference pattern includes all the information about the object resulting in a 3D image to our eyes. In this experiment, Holography is explored by creating a white-light reflection hologram of a small object on an emulsion plate using a single light beam. Although the plate won’t reproduce a 3D projection hologram as seen in movies, the goal is to have a hologram that appears to be a 3D image to our eyes.

2. Procedure

2.1 Equipment

- 5mW Laser
- Shutter
- Mirror
- Microscope Lens
- Spatial Filter w/ 25 μm Pinhole
- Glass Plates (one for setup and one with Photographic Emulsion)
- Object (and Object Holder)
- Safelight
- Developer
- Fixer
- Dryer

2.2 Method

There are two parts to this experiment, both requiring rooms that can ensure total darkness. One is for capturing the hologram which uses an emulsion plate that cannot be exposed to light or else the hologram will be ruined, while the other one is a darkroom to develop the hologram from the emulsion plate.

Before starting, ensure that both rooms are prepared and that the darkroom has the developer, fixer and a source of water for cleaning.

2.2.1 Capturing the Hologram

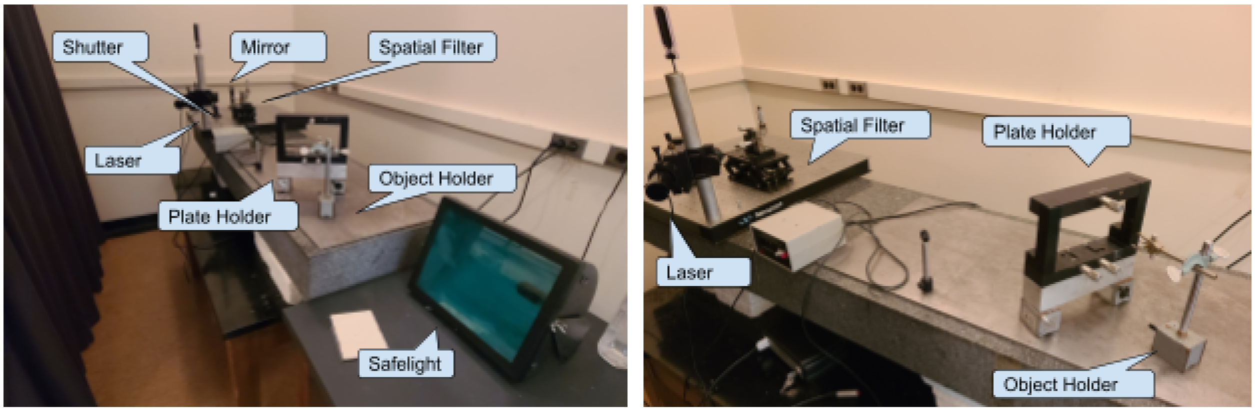

Figure 01. Picture of the Experimental Setup

The setup for this procedure is entirely based on the positioning of the equipment. The laser will fire a monochromatic beam at the emulsion plate which will go through the plate and hit the object. When the light beam hits the object it will capture the information of the object in its beam and reflect back into the plate, creating interference on the emulsion plate.

Place a mirror to angle the laser beam without having to move the laser directly. Position the laser beam at the plate holder so that the laser will go through it. For the best holograms, the plate holder should be placed at the Brewster's angle, but an angle of about 45 degrees should be fine. Once the laser is in position, turn it on by flipping the switch on the lab table and place either the test plate or a white piece of paper on the plate holder. Once you have positioned the plate holder, use the magnetic clamps to lock it into place.

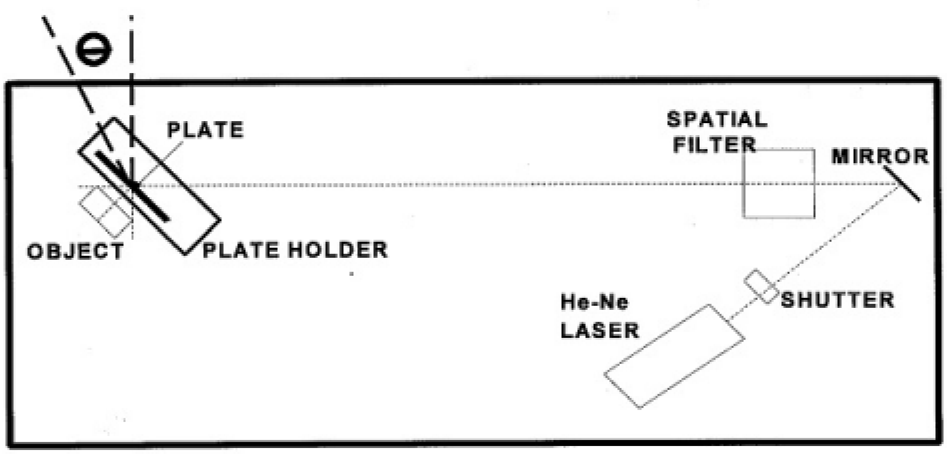

Figure 02. Diagram of experimental setup [3]

If the beam is not hitting where the plate holder is, adjust the mirror so that you can see the beam on the surface. Then attach the microscope lens and pinhole to the end of the mirror beam. The beam might not be seen on the surface now, which is okay. Just adjust the x- and y-directional knobs on the laser until the beam goes through the lens, filter and then the surface.

There should be interference patterns in the shape of concentric circles on the surface now. This means that your laser and lens are not positioned so that the plate holder is at the focal length of the lens. Adjust the z-directional knob to move the focal length slowly. As you do so the beam might move around in the x- and y- directions. Adjust the knobs accordingly to keep the beam on the surface. The concentric circles should expand in this process.

Once the lens is at the focal length, the interference would have expanded away and you're only left with the centre circle. It should also be at its brightest at this point. Once this happens, add the shutter in front of the laser beam which will block the laser’s path.

Adjust the shutter speed to 2-5 seconds and ensure that opening the shutter lets the light from the laser come through. Then, place the object to be captured in the object holder and position it behind the plate holder, using the magnetic clamps to lock it into place. For a hologram with more depth, position the object at an angle.

The emulsion plate cannot be exposed to outside light before being used in the experiment. Use the test plate to practice putting on and taking off the plate as you will be handling the emulsion plate in the dark with only the safelight to guide you.

Once you’re ready, turn off all the lights except for the safelight and lock the door. The emulsion plate has two sides, a regular glass side, and the side with the emulsion. To see which side is which, breathe onto both sides of the plate. The side with glass will be the one to fog up and will be the side you turn towards the laser. Bring out the emulsion plate and place it onto the plate holder making sure the glass side is the one towards the laser. Once locked in place, trigger the shutter. Once the shutter closes again, carefully place the emulsion plate back into its container and transport the emulsion plate to the dark room to be developed.

2.2.2 Developing the Hologram

Similar to film photography, the hologram must be developed before it can be seen. Once the emulsion plate’s container (with the plate inside) in the darkroom, ensure that all lights are off except for the safelight before taking the emulsion plate out.

Take out the emulsion plate and place it in the developer for five minutes, making sure to keep it moving within the liquid. Use an analog method to keep track of the time.

Next, quickly rinse off the emulsion plate before putting it into the fixer for ten minutes. Again, keep the emulsion plate moving throughout this process. Next, we place the emulsion plate into a bin with water letting the water spill out for another five minutes. At this point, the emulsion plate is safe to expose to light. You’ll notice a dark black spot on the emulsion plate, that is where the hologram will be.

Once the emulsion plate has been washed, dry it in the plate dryer for ten to fifteen minutes. When finished, take out the plate and point a flashlight at it to see the hologram.

3. Data

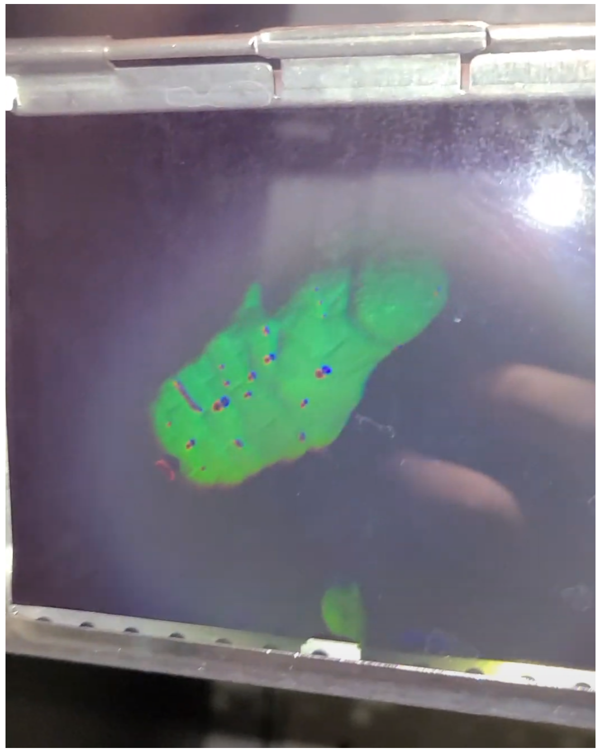

Figure 03. Picture of the final Hologram created from the Experiment. Object is a small statue of Santa Claus on a chimney.

4. Analysis

4.1 Method of Visualization

Emulsion plates are formed by suspending a chemical that is sensitive to light in a gelatin placed on a plate of glass. The most common chemicals are Silver Halides (Halides referring to the chemical group) which is extremely sensitive to light with a wavelength less than 500 nm. [4]

After creating the latent image from the laser setup, the visual information of the object is imprinted on the emulsion plate, but it's not visible to the human eye yet. Any change to the emulsion crystals is invisible, even if we know it's there. In order to visualize the hologram, we have to develop the latent image similar to film photography.

Using the supplied developer, the emulsion underwent a reduction reaction, which reduces the emulsion crystals to a visible metal. Then the plate is put into a Fixer that removes the unchanged emulsion (doesn't have the object information) by forming a salt which is then washed away in the final cleaning step [4] The object's visual information, and therefore the hologram can now be seen on the plate.

4.2 Quality of Image

Under certain light, the hologram is clearly visible on the plate. Regular building (white) light works most of the time but the best result is found when applying a flashlight to the plate directly. The object is clear and coloured green, because the hologram reflects lower wavelength light, going from the original monochromatic red light to green.

Despite the fact that the entire object is visible from multiple angles of the plate, at certain extreme angles, the hologram becomes blurry. This is due to the refraction of the light on the actual plate. This is analogous to viewing a reflection on a window. If you view the reflection on an extreme angle, the light has to pass through more of the glass before hitting your eyes. That extra distance scatters the light, blurring the image.

On top of the santa claus image, the hologram seems to have accidently captured a stud from the plate holder. Without viewing the hologram, there is a blank spot in the middle of the dark spot that shows the hologram. When you use a light to view the hologram, one can see a bit of green which is the information captured from the stud.

4.3 Comparison to Photographs

The hologram has a similar look to film photography. Different emulsion/film, developer and fixer types will create a different range of colours. Many film photos can have a warmer or even green tone to them. Similarly, the hologram produced in this experiment, although produced using a Red Laser, is mainly green. This is due to the emulsions layer shrinking through the developing process; the original interference from a larger red wavelength gets shrunk to the smaller wavelength of green, leaving a green visible image.

The key difference is that Photography, which produces 2D images, is based on the reflection of light onto a camera sensor or film/medium. Light from the side of an object facing the camera is directly reflected into the lens. This only represents a snapshot of the 2D plane that is in focus and does not truly capture depth [3]. In contrast, Holography, which produces 3D images, is based on the diffraction of a light beam which recombines on the film or plate to leave its interference pattern. The interference pattern contains information about the object and is left on the emulsion plate from the wavefront first going through the plate then bouncing back and interfering with the reference (original) beam on the plate in a standing wave [3]. When light passes through the plate and hits the eye, the brain can register the full depth of the image.

4.4 Reconstruction of image from a partial piece

If you were to take a photograph and cut it in half, you would only be able to see half of the original object in that piece of the photograph. This is the other limitation of photographs, the whole photograph has to be intact in order to view the full image.

Holograms however do not have the same issue. If you were to break the holographic plate in half, the whole image can still be seen in one piece. Since the hologram allows you to see depth through the parallax effect, by turning the plate, you can view the different parts of the object. The change is in how much you can see at a time.

An analogy for this property is if you think of the plate as a window with the object on the other side. When you turn your head (or in this case the plate), you can see the object at different angles. This doesn't change even if the window becomes smaller and you can only see through a part of it [4].

The reason the hologram has this effect is that the single light beam is reflected off the object into every part of the emulsion plate. This is what allows the hologram to show depth. You can look at the object from different angles because the whole object's interference is captured onto the plate [3].

This property unfortunately is constrained by the diffraction of the light at specific angles, blurring the images at extreme angles. A piece of the plate near the edge of the overall developed hologram area, there required viewing angle would be too extreme, as well as too much distortion, to be able to view the desired hologram.

5. Conclusion

In this lab we were able to successfully create a White Light Reflection Hologram. This showed how the interference of light waves can be used to capture visual information of a 3D object similar to a photograph, but with an image that still displays parallax and depth.

The time-consuming nature and cost of this process limit the commercial use of these holograms to laboratory experiments. Other methods of creating parallax, such as the stereoscopy used in AR and VR headsets or 3D hologram fans, are cheaper and easier ways of making 3D images but do not create true holograms. In the end, none of these technologies comes close to the holograms shown in movies. Perhaps one day, holographic technologies and techniques will evolve to be more accessible and possibly extend into true holographic videos that can be watched without being bound by a headset.

6. References

[1] George Lucas, Star Wars 1977
[2] Oxford Advanced American Dictionary, Photography
[3] P. Albanelli and S. Fomichev, Holography 2014
[4] Graham Saxby, Practical Holography