Building an Operational Holography System

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Theory and Implementation

Holography

Holography is a reconstruction of optical waves at a holographic film or digital detector. Image information is encoded in the transparency of an optical wave and is built from the interference of two waves of similar wavelengths. The two waves are an *object wave*, that which reflects off of the object to be imaged, and a *reference wave*, that which goes unimpeded in its path and strikes the detector in the same location as the object wave reflection. A hologram is the product of the reference wave and the transparency.

Let there be an optical wave $U_o(x, y)$ that strikes the object, and an optical wave $U_r(x, y)$ that is the reference beam. Pertinent information to the expression of transparency is the amplitude and phase of $U_o(x, y)$. The amplitude is $|U_o(x, y)|^2$, and the phase is Exp[i*k*sin(θ)*x], where k is the wavenumber and θ is the angle of interference between the two optical waves. These qualities are true for $U_r(x, y)$ also. The transparency is proportional to:

$$t \,\alpha\, |U_o + U_r|^2 = |U_r|^2 + |U_o|^2 + U_o U_r^* + U_r U_o^*$$

$$= I_r + I_o + 2(I_r I_o)^{1/2} * cos[\, arg\{U_r\} - arg\{U_o\}\,]$$

with *I* denoting intensity.

To reconstruct the hologram, the reference beam must strike the recorded image at the angle at which it was recorded, and to see it, one must look from the other side of the film. Mathematically, this reconstruction wave (U(x,y)) is expressed as:

$$U\,(x,y) = I_r + I_o + I_r^{1/2} U_o(x,y) + I_r^{1/2} U_o(x,y)^*$$

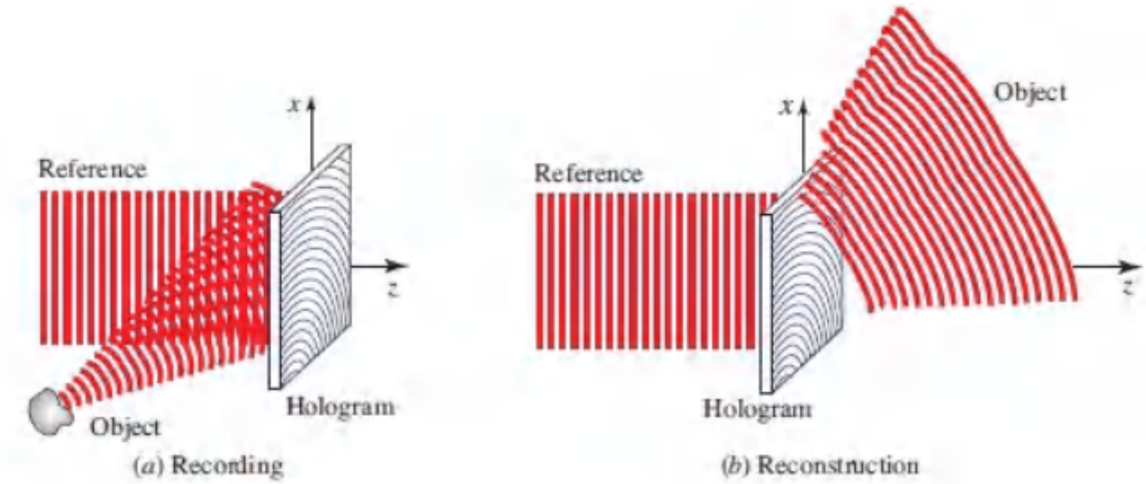

Figure 1: a simple depiction of waves striking a holographic recorder (a) and a holographic reconstruction of a hologram (b); in (a) the hologram is recorded and in (b) the hologram is viewed (courtesy Saleh and Teich Chapter 4.5)

Photonics Components

A natural procedure for holography systems is to have $U_o(x, y) = U_r(x, y)$ until the object wave strikes the object. This demands at least one beam splitter be used somewhere in the system. A beam splitter is, as the name suggests, a photonics device that ideally splits a beam in two at some ratio (this ratio is unknown for several of the splitters in the LMO lab, but one of them, purchased in Fall 2023, has a 50:50 reflection to transmission ratio). If aligned properly, beam splitters have a plane inside that reflects one beam 90 degrees from the path and allows the other to transmit without refracting. You should do your best to have the incident beam strike the beam splitter normal to the incident surface.

Other photonics devices you may encounter include mirrors, lenses, apertures, and pinholes. You can expect to lose anywhere from an insignificant to significant amount of beam intensity when striking any photonics component. Whenever you are in doubt about the vitality of your beam, you can use any of the detectors found in the lab to measure its wattage.

Mirrors are generally assumed to be perfectly reflective and have minimal power loss. You should first try to align the mirrors so that the laser strikes the center, and then continue to the fine alignment where this will not be necessary.

Lenses converge, diverge, and widen the beam depending on how they are used. To make practical sense of convergence and divergence, you must consider beam expansion. Beam diameter can be increased using a series of two lenses (aka, a *beam expander*) and separating them by a distance equal to the sum of their focal lengths. The beam is magnified (magnification *M*) by the ratio of their focal lengths ($f_1 < f_2$):

$$M = f_2/f_1$$

The diameters (D) are related by:

$$D_2 = M * D_1.$$

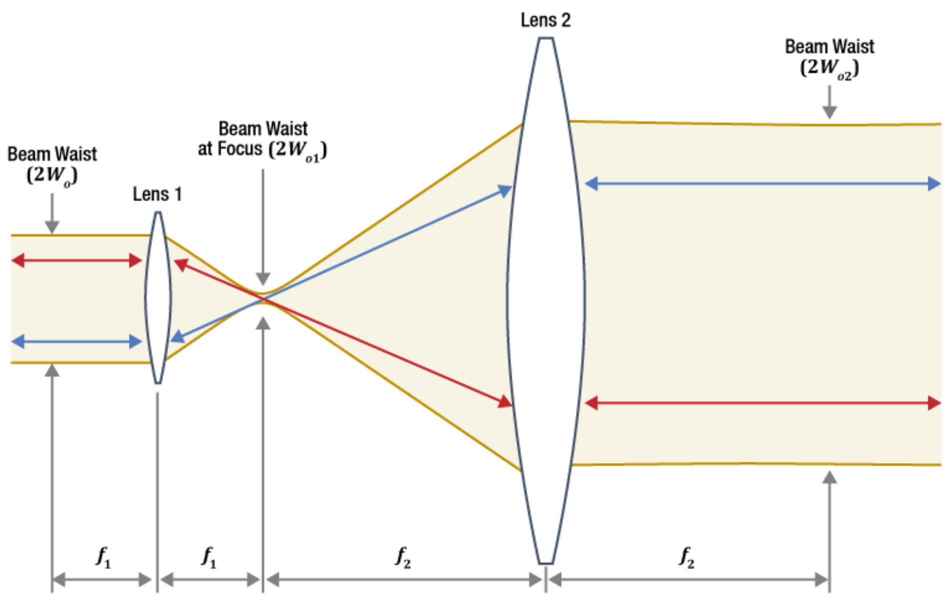

Figure 2: Diagram of Beam Expander [4]

It is unlikely that you will align the lenses perfectly. If they are too close, the beam will converge to a focus; too far, and the beam diverges infinitely. You can, however, optimize this with trial and error. If you want to consider a relatively constant diameter, do your best to place the focus at a point near infinity relative to the system. Near infinity is any distance far enough from the beam expander where you wouldn't expect the beam to focus or diverge at any point in your system. Say, for example, you needed your wide beam to travel a net 10 centimeters after hitting several mirrors. If the beam expander is flawed and shrinks the beam, you want to make sure this happens at a point far greater than 10 cm from the second lens. You can do this by moving the lenses closer together or further apart – it will take patience, but that is the art of optics. You can do more with lenses; do not forget that you can use one lens to focus and diverge the beam, as beams diverge after they focus.

Beam widening can be achieved with apertures and pinholes. The beam will experience single slit diffraction if the aperture opening is small enough, and pinholes are designed explicitly for this purpose. Pinholes are extraordinarily difficult to align, and none of our tested systems made use of one. We considered that the difficulty was not worth the novelty of seeing single slit diffraction in practice, and the beam would lose much of its intensity along each fringe. It is by all accounts easier to build beam splitters. Apertures theoretically could be used for this same purpose in a crude way, but the lone aperture in our system was used to expose the holographic film as though it were a camera.

Exposing the Film

Holographic film does not need to be prepared or finished in any solution. You should expose the film for 3 - 7 minutes (our successes were recorded in 3 minutes, although a larger exposure time may help for weaker beams) and wait for 1 minute before viewing your hologram. You must keep the space in complete darkness for the duration of recording. You must be silent and avoid hitting the table to avoid vibrations, which disturb the record. A low intensity green light flashlight is available for setting up the hologram, and you should avoid shining this light directly at the film if possible because the provided film (Litiholo C-RT20) is sensitive to green light.

It is important to note that the best results were achieved when the laser was warmed up prior to exposure. This means turning the laser on; for exactly how long is uncertain, but one could suppose a time greater than a few minutes. To keep the laser warm without exposing the film, simply use an aperture to block the beam at an early point in the system; a successful system had the aperture at a point between the laser and first mirror. Some apertures in the lab are connected to a control box used to open and close the aperture indefinitely, instantaneously, or for a time delay.

Experimental Design

- Holography requires, at a bare minimum, a reference beam and an object beam.
  - These two beams must originate from the same wavelength source (laser) and are split via a beam splitter.
  - The reference beam reconstructs the information from the object beam, which scatters off the object itself, on the holographic plate.
- To increase the diameter of the source, object, or reference beams, a series of beam expanders and diffraction lenses may be used.
  - This is necessary to ensure that the entire object is bathed in light to be transmitted and recorded.

- Beam expanders are constructed by placing two lenses a distance equal to the sum of their focal lengths apart.

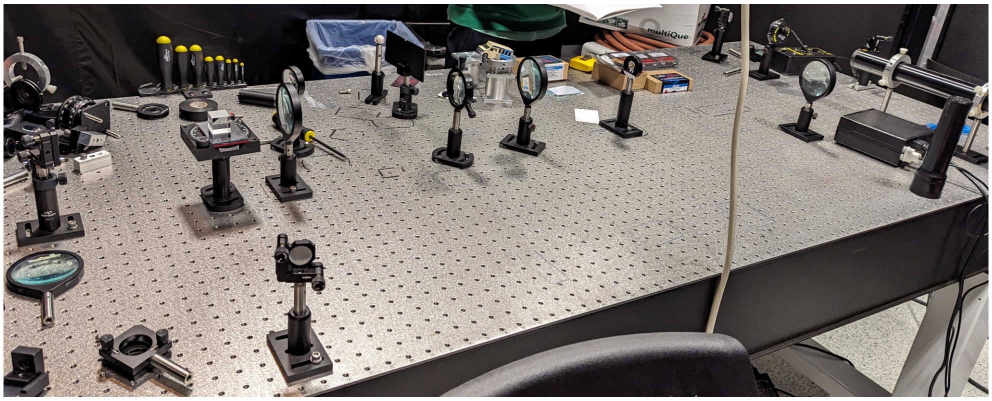

Figure 3: Picture of the setup which produced a hologram.

- The reflected object beam and the reference beam must hit the incidence plane of the holographic plate at the same point.
  - The reference beam should be expanded to a diameter that fully envelopes the reflected object beam.

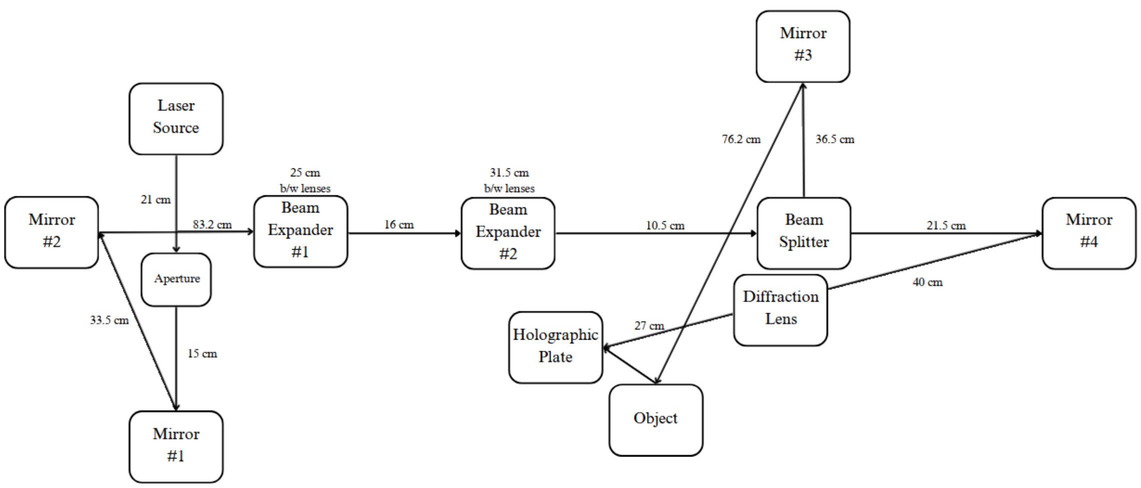

Figure 4: Block diagram of a functional holography setup. Distances are not to scale.

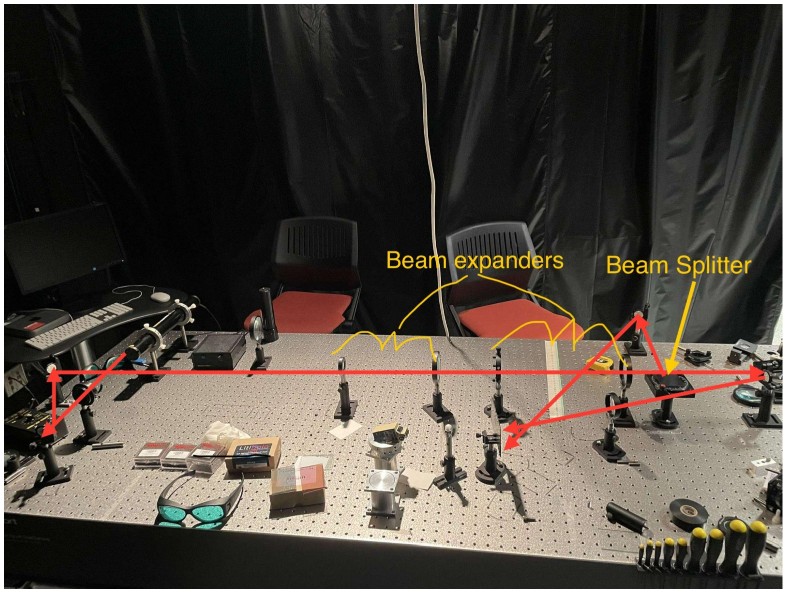

Figure 5: Actual Setup. Placements can very for other experiments

Tips, Tricks, and Safety

- Ensure that you are wearing laser glasses at any point in time when the laser is on.
- When attempting to record a hologram, ensure that the curtains are closed, the lights in the lab are off, and there is as little light as possible entering the dark room. Keep silent as well.
- Holography setups are fairly flexible, which allows for a variety of setup configurations. One does not need to copy our setup exactly, and perhaps will have to try something different if something does not work.
    - The most fun aspect of this experiment is thus crafting your own setup; tinkering with the optics table to make a system that is wholly your own.
- Measuring focal lengths
    - Several focal lengths are not listed on the lenses. To measure the focal length, hold the lens beneath a ceiling light with gratings. Hold the lens between your

hand and light. The image of the light will be very clear at some distance from your hand, and this distance is approximately the focal length.

- Before attempting to record a hologram, it might be necessary to allow the laser to warm up for a couple minutes in order to increase resolution.
    - We used an aperture for this, which allowed us to let the laser warm without exposing the holographic plate prematurely.
- The LMO lab has several lenses available. We recorded approximate focal lengths, and they roughly correspond to size:
    - 1x 4.5 cm
    - 1x 9 cm
    - 1 x 10 cm
    - 1 x 21 cm
    - 3 x 23 cm
- There are six cube beam splitters and one plate beam splitter. One of the large ones was purchased in Fall semester 2023 and suffers the least random scattering and intensity loss. It is a 2.5 x 2.5 x 2.5 cm^3, 50:50 split ratio beam splitter.
    - The plate beam splitter is terrible and doesn't work, but you can look at it to see what it looks like
    - Two of the small beam splitters have a black casing. These do not reflect well, and we did not use them
    - Two of the small beam splitters have no casing. One of them was purchased in Spring semester 2023, and one is old.

- In fact, we used the two large beam splitters for an initial unsuccessful system. We chose not to use the smaller beam splitters, although we attempted it several times when troubleshooting.

References

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