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Holography at the U.S. Army Research Laboratory: Creating a Digital Hologram

by Karl K. Klett, Jr., Neal Bambha, and Justin Bickford

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14. ABSTRACT
This report describes how to create a digital hologram. Creating a hologram is the first step in supporting the U.S. Army Research Laboratory's efforts to remotely sense high spatial resolution three-dimensional (3-D) images. The digital hologram itself is an interference pattern of two sources of light, one source being from a laser that illuminates a target object and the other source being the light from the target itself. A holographic image has several components, and these components come from the mathematics that describe holography. These different components are discussed. Finally, a comparison is made between a holographic image and regular images that might be made with a digital or film camera.

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1. Introduction

The U.S. Army Research Laboratory (ARL) is embarking on a program of holographic interferometry to understand its limitations for the purpose of remote sensing. A pre-requisite for this work is to record a digital hologram. When two holograms are recorded and processed, using two different wavelengths, three-dimensional (3-D) images are formed. Such images, depending on the wavelengths selected, show depth information that can approach microscopic dimensions. Other advantages of using holographic techniques are the large depth of field, the lack of a need for mechanical focusing mechanisms, and perfect image reconstruction that possess both phase and amplitude information of the object being examined, instead of just intensity information that is in a regular photograph.

Although this work can and has been performed with chemical films, digital imaging and processing of images can be accomplished much more quickly. This report describes the laboratory procedures used to make a hologram.

2. Methods, Assumptions, and Procedure

2.1 A Comparison of Digital Holography and Conventional Imaging

Digital holography, sometimes called lensless imaging, is different from imaging using a lens. The latter is referred to as direct imaging. Digital holography mixes light to create interference patterns. These interference patterns, which are called holograms, are then transformed to create an image. The Fresnel method of transformation, which uses Fourier transforms, is used here to make an image from the hologram. The contrasts between holography and direct imaging are shown in figure 1. When a lens is used as a primary objective in an optical system, it performs the Fourier transform. In a holography system that does not use a lens, the Fourier transform must be performed mathematically on the fringe patterns that form from the interference of light of the object and reference beams (Takeda, 1996). Such a fringe pattern is shown later on in figure 4.

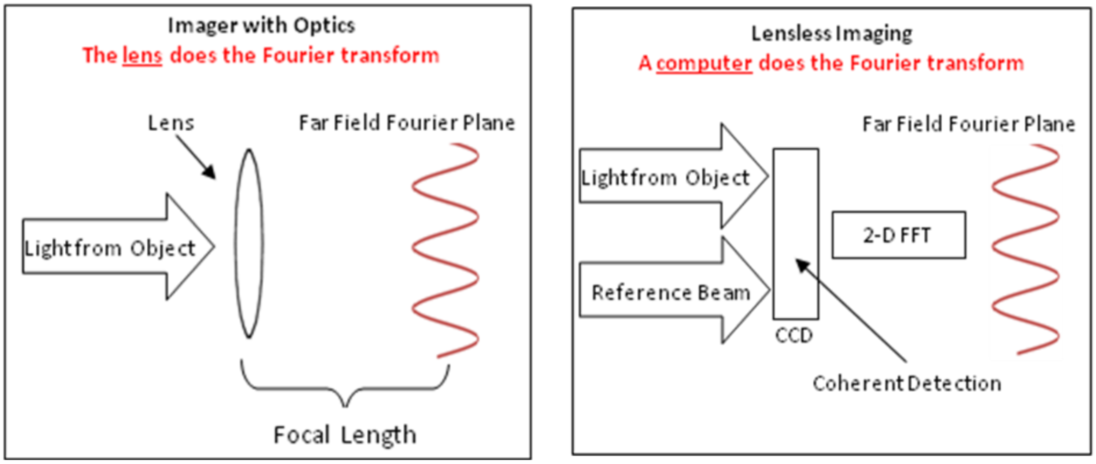

Figure 1. A comparison of traditional and holographic imaging.

2.2. Laboratory Equipment and Implementation

Figure 2 shows a notional description of components required for holography (Wagner, 1999). Light is mixed at the charge-coupled device (CCD) using a beamsplitter from the laser source and the target. This equipment is mounted on a floating optics table to reduce vibration, because any movement, on the order of one wavelength of light, will cause destructive interference of the light that is required to make the hologram. The coherence length of the laser sets the minimum distance requirement between components. If the laser coherence length is 1 m, then the round-trip distance of the laser to the target and back to the CCD must be 1 m. Our actual setup is shown in figure 3. The laser is model LM-685-PLR-45-1, which is a solid-state laser made by Ondax. It has a center wavelength of 685.1 nm and is tunable over a range of about 0.3 mn with variable power up to 100 mW. The CCD is an Opticstar DS-142 ICE with dimensions of 1360x1024. The pixels are square and have dimensions of 4.65 microns. The other components were purchased from Thor Labs. The spatial filter is required so that there is no spatial structure in the reference beam. We found that we could view images with the CCD to ensure that we obtained fringes. Vibration, lack of laser coherence, and cleanliness of the reference beam were various reasons that we did not record good fringe patterns. In the beginning of our work, we found it useful to set beam ratios of approximately 1:1 between the reference beam and the target beam. The use of neutral density filters (or variable circular beam splitters) may be required, placed between the laser and the CCD, so that the beams ratios are correct. These are required to attenuate the laser beam going to the CCD, since it is brighter than the radiance from the target. We used an array averaging capability of the CCD to check the beam ratios.

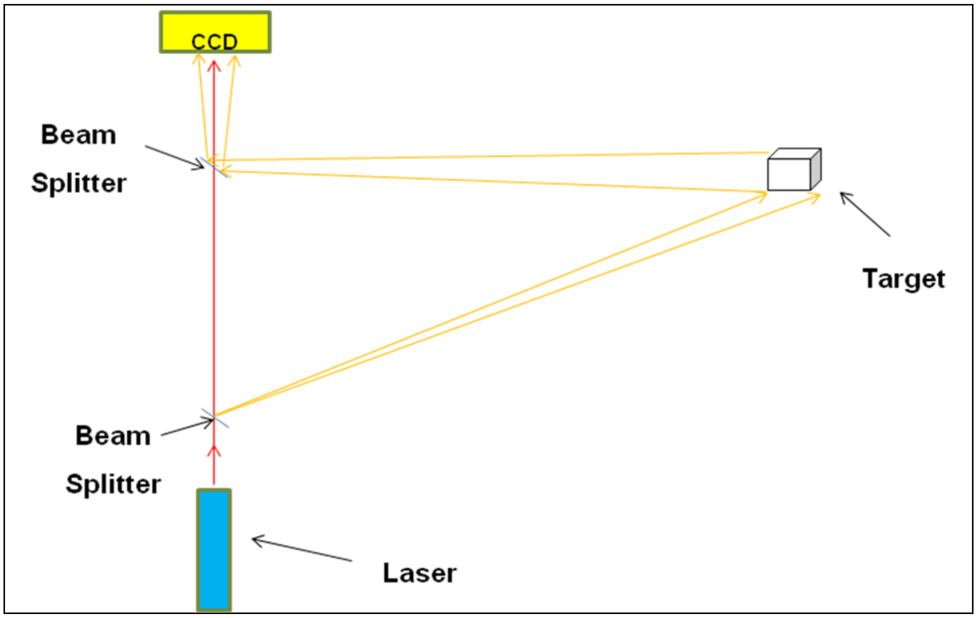

Figure 2. Notional components required for holography.

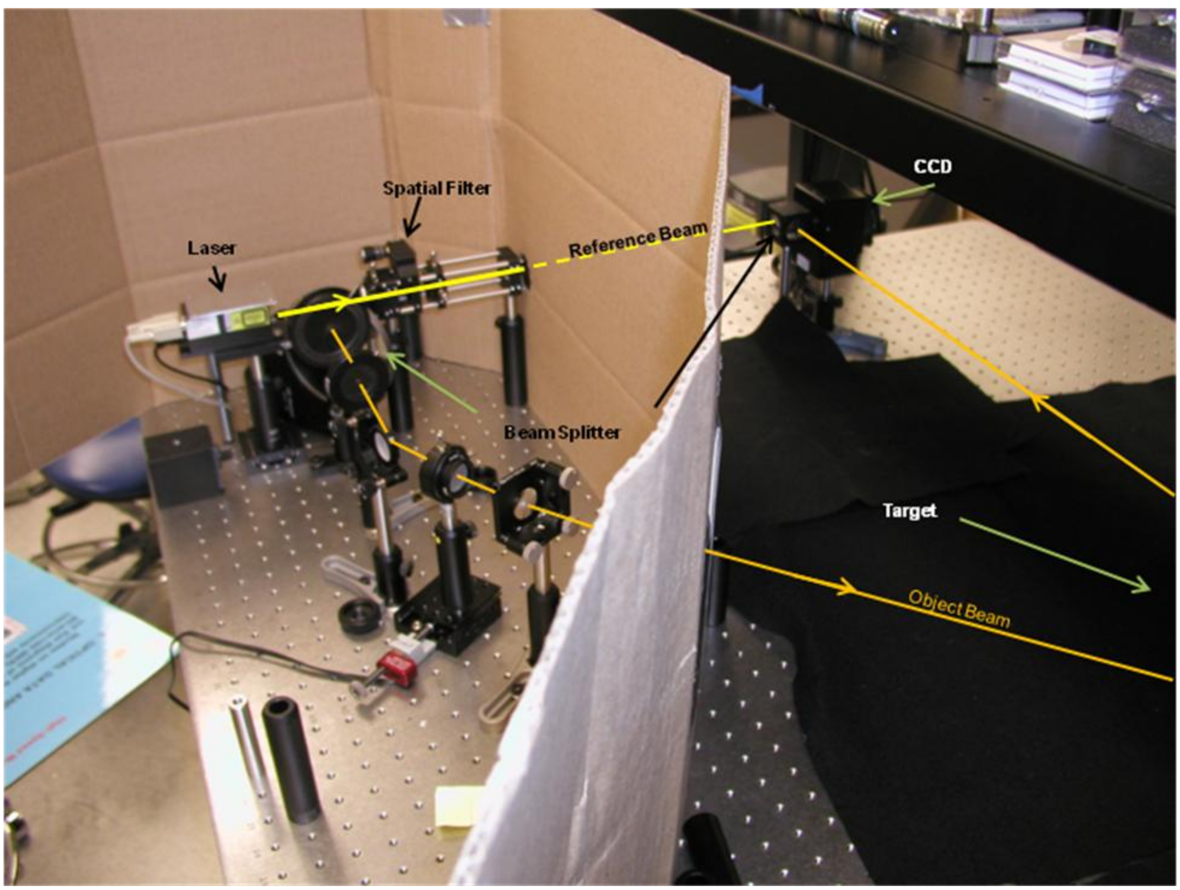

Figure 3. ARL holographic laboratory test setup.

3. Results and Discussion: The Hologram, Use of a Transform Equation to Form an Image, and Components of the Holographic Image

We first imaged a die, since it reflects visible light well and has spatial detail, as our first image at a distance of about 1 m. Its hologram is shown in figure 4. The hologram consists of, what appears to be, a braided interference pattern. If this pattern does not exist, the hologram is probably not correct. One must make sure that the optics table is stable, the reference beam has no structure, and the reference and target beams are balanced.

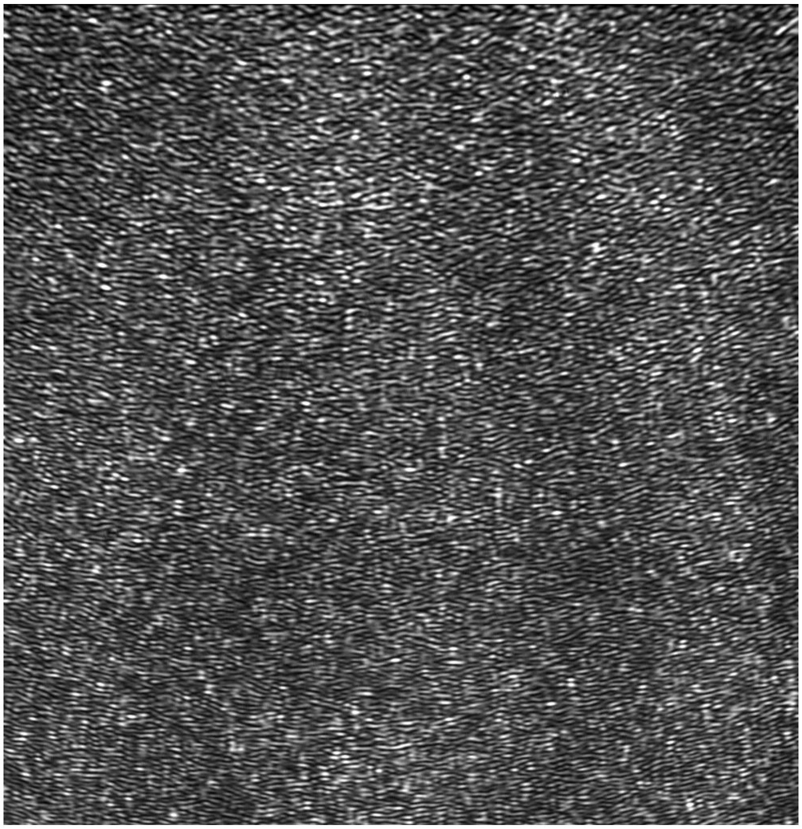

Figure 4. Hologram of a die.

To view the target image, the hologram must be transformed. At ARL, a Fresnel transformation, which used a Fourier transform, was used, which is listed as equation 1 (Schnars, 2010).

$$U=\sum_{k=0}^{N-1}\sum_{l=0}^{N-1}\underbrace{E_R(k,l)h(k,l)}_{\text{CCD Signal}}\underbrace{\exp\left[-i\frac{\pi}{\lambda d}(k^2\Delta x^2+l^2\Delta y^2)\right]}_{\text{Spherical Wave}}\underbrace{\exp\left[i2\pi(\frac{km}{N}+\frac{\ln}{N})\right]}_{\text{2-D Fourier Transform}}dxdy \qquad (1)$$

The pixel intensity that makes up the hologram of figure 4 is the first term in equation 1, which is labeled the "CCD Signal". The Fourier transform is the third term of equation 1 and the second term is a spherical wave term that removes distortion from the image. The "k" and "l" indices in equation 1 are matrix locations of the CCD in terms of rows (k) and columns (l). When figure 4 is processed, using equation 1, the following image is formed (figure 5). There are four components in the holographic image of figure 5, which come from the interference of light from the local oscillator (the reference beam) and the target as shown in equation 2 (Schnars, 2010):

$$(E_T + E_{LO})^2 = |E_T|^2 + |E_{LO}|^2 + E_T E_{LO}^* + E_T^* E_{LO} \qquad (2)$$

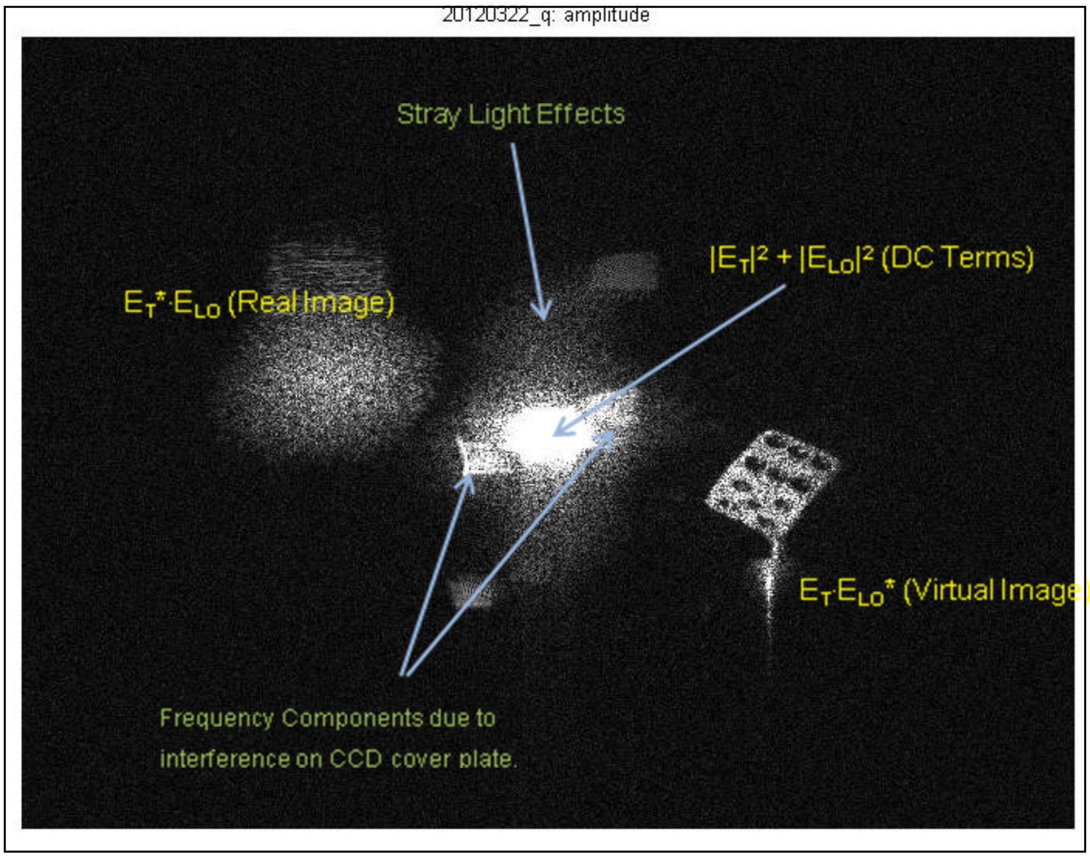

Figure 5. Fourier transform of figure 4, showing components of a hologram image, which are focused virtual image, unfocused real image, DC terms, and stray light artifacts.

The subscripts "T" and "LO" refer to the target and local oscillator, respectively. The real image is actually focused, not by reimaging, but by changing the value of "d" in equation 1 to "–d"

4. Conclusion

Digital holography is the foundation for many scientific and engineering measuring methods. The general setup, shown in figure 2, may be modified, as long as reference and target beams interfere. Recording an interference pattern, like figure 4, is the first step in making a digital hologram image. Equation 1 describes the matrix equations that must be used to transform an image from the fringe patterns that make up a hologram into a holographic image. Failure to form an image may result from an unstable optics table, instabilities in the air that change its refractive index, spatial variability of the reference beam, or unbalanced beam ratios.

5. References

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