HOLOGRAMS IN DICHROMATED GELATIN

Denis R. Breglia
Alfred Rodemann
Physical Sciences Laboratory
Naval Training Equipment Center

INTRODUCTION

I am sure everyone is familiar with holography and a hologram's property of displaying a three-dimensional image. This property is a consequence of a hologram's more general property of recording and reconstructing wavefronts. It is this more general property which will be discussed today. The holograms which will be described are meant to be used as image relaying or imaging devices rather than as image storage and displaying devices.

A hologram which is the recorded interference pattern produced by two mutually coherent wavefronts has the ability to reconstruct or recreate either of the two recorded wavefronts upon illumination by the other. This is illustrated in the first figure. In the recording process, wavefronts or beams A and B illuminate the recording material. After processing, the recording material has the ability to reconstruct A upon illumination by B or vice-versa with some losses due to less than 100% diffraction efficiency and aberrations due to a variety of reasons. In the most familiar holograms the two recorded wavefronts are the wavefront formed by light scattered from a three-dimensional object and the unperturbed reference wavefront. Figure 2 illustrates the recording and reconstruction of such a hologram. In the reconstruction of the object wavefront by illumination with the reference wavefront, an observer sees a virtual image of the object when he looks through the window formed by the hologram. In our case, however, the recorded wavefronts are much less complex. One wavefront is plane, essentially originating from a point at infinity, and the other is spherical originating from a point at some finite distance. Figure 3 shows the recording geometry. The recorded hologram in this case is essentially an optical element having several interesting optical properties. It acts as a collimator in that it will change an incoming spherical wavefront with the proper curvature and orientation into an outgoing plane wavefront. Of course, the converse is also true, but of no interest to our application. This hologram also has a mirror-like property of changing the direction of the outgoing wave with respect to the incoming wave. Figure 4 illustrates these properties using the hologram recorded in the previous illustration. A point source of light at A will be collimated and redirected such that to the observer the point appears to be A' located at infinity. The same reasoning applies to an array of points or an area close to A. This area will essentially appear as a virtual image near A'. The fidelity of Region A' in appearance to Region A will be an inverse function of the size of Region A. The larger Region A, the poorer the image quality of Region A'. For small areas, the image aberrations may be small enough to be acceptable.

APPLICATION

The application of the holographic element just described to heads-up displays is immediately obvious. A small, monochromatic display located close to an observer (for example, a pilot in a cockpit) is made to appear at infinity without obstructing the observer's view of any scene beyond the hologram. If the hologram is a phase hologram, the hologram itself will be almost invisible to the observer. Of course, the function of the holographic optical element can also be accomplished by conventional optics (a collimating lens and a dichroic beam splitter), but the hologram does the job in a small, lightweight, inexpensive, and easily replicable single element. Admittedly there remains a significant amount of investigation to improve the holographically relayed image quality.

Figure 5 lists the desired characteristics of a hologram for the heads-up display application. The hologram should be a phase recording rather than an absorption recording. This will give the hologram the appearance of a clear window, and not distract the observer from the relayed image information. High diffraction efficiency will allow the relayed image to be as bright as possible so that it will have sufficient contrast to be viewed against a bright background scene. Aberrations should be minimized to give the desired imaging properties. The hologram recording material should be readily available, and the hologram should not deteriorate in time.

PHASE RECORDING MATERIALS

There are many types of phase hologram recording materials. These include bleached silver halides, electro-optic crystals, photopolymers, thermo plastics, and dichromated gelatins. Our efforts have been directed almost entirely to dichromated gelatins. The reasons for this being that dichromated gelatins had been found to give the best results by other workers in the field and that high quality gelatin layers could easily be obtained by fixing out the silver and sensitizers from standard silver halide emulsion coated glass plates.

Dichromated gelatins are relatively slow and sensitive only to short wavelength light. Our exposures were made with the 488 nanometer light from an argon ion laser with total exposure of the order of 10 millijoules per cm^2.

PREPARATION OF DICROMATE PLATES

In order to have a fairly consistent source of gelatin coated glass plates, commercially coated photographic plates were used. Kodak 649F emulsion coated plates were used because of their availability in our lab. These plates are fixed and hardened to remove the silver and washed to remove the sensitizing dye before sensitizing with the dichromate solution. The entire procedure is outlined on Figure 6.

1.	Fix and harden	- 5 Minutes	- Kodak Rapid Fix with Hardener 20°C
2.	Wash	- 25 Minutes	- Continuous Agitation Distilled Water
3.	Wash	- 5 Minutes	- Methanol 20°C Continuous Agitation
4.	Wash	- 3 Minutes	- Fresh Methanol 20°C Continuous Agitation

5. Sensitize - 10 Minutes - 4.5% By Weight Ammonium Dichromate In Water 20°C Continuous Agitation

6. Dry - 6 Hours Minimum Room Temp with R.H. 50%-65%.

EXPOSURE AND PROCESSING

The sensitized plates are usually exposed within 12 to 48 hours after sensitizing. We have found optimum exposure to be 5 to 10 millijoules/cm^2 using the processing procedure outlined in Figure 7.

1. After exposure, let plates stand 2 to 3 hours in dark room temperature environment.
2. Wash - 15 minutes in 68°F running water constant agitation.
3. Wash - 2 minutes in 40°-45°F 50/50 isopropanol/water constant agitation.
4. Wash - 2 minutes in 40°-45°F 90/10 isopropanol/water constant agitation.
5. Wash - 15 minutes in 40°-50°F isopropanol constant agitation.
6. Dry - Blow dry air at 5-10% R.H.
7. Seal - Cover glass and Eastman 910 adhesive.

RECORDING PROCESS

The mechanism of recording high efficiency gratings in a dichromated gelatin is not well understood. The most reasonable theory proposes the following explanation. Sensitizing a pre-hardened gelatin layer by soaking it in a dichromate solution leads to incorporation of chromium ions in a high ionization state (Cr^{6+}) in the gelatin. During exposure, the absorption of light changes this to some lower ionization state, possible Cr^{3+}. The presence of this ion causes cross linking and hardening of the gelatin in areas of exposure. A water wash then removes the excess dichromate. The crucial step which greatly amplifies the efficiency is rapid dehydration after the water wash caused by immersion in isopropyl alcohol. It is assumed that this immersion in alcohol and consequent rapid dehydration cause the gelatin to shrink and tear apart creating voids in the gelatin layer. These voids are responsible for the large phase changes necessary for high efficiency diffraction. If there were no voids created, the change of index of refraction caused by hardening alone would not be sufficient to yield the observed efficiencies in thin layers or multiple exposures.

RESULTS

The hologram recording set-up utilized for all of our experiments consisted of two beams of blue laser light intersecting at right angles. The spatial frequency in the interference pattern was approximately 3000 fringes per millimeter. Our measurements of diffraction efficiency are direct measurements of light out over light in with no adjustments made for reflection losses. Diffraction efficiency was measured at the blue wavelength only.

Using the previously described processing procedure, we are able to routinely produce clear holograms with diffraction efficiencies of 60% to 80%. However, our experimentation has led to the conclusion that many things can go wrong. Problems encountered included low diffraction efficiency, striated patterns, and cloudiness of the holograms. The high diffraction efficiency was obtained primarily by much trial and error experimentation which led to the processing procedure described above. The chief villain in this case appears to be water, either in the atmosphere or in the final alcohol bath. The striations appear to be caused by non-uniformities in the gelatin which may be present in the plates before they are used, or may be caused by uneven drying. We have found the striations to be objectionable on one plate and absent on the next with the same sensitizing, exposure and processing as far as we know. More rigid controls on washing and drying together with an annealing step in the plate preparation should eliminate the striations. The cloudiness seems to go hand-in-hand with high diffraction efficiency, but the low temperature alcohol baths do minimize it to an unobjectionable level.

FUTURE EFFORTS

Providing that our sensitizing and processing procedures are utilized, we know that we can produce clear, high efficiency holograms; but the application of these holograms to the heads-up display problem requires further investigation into the areas defined in Figure 8.

Before application, the practical limitations on imaging fidelity will have to be investigated. Problems of optical aberrations will determine the type of display inputs which may be used. Non-monochromatic displays, such as CRT phospor screens, might require filtering or other means to reduce chromatic aberrations. Reflection type holograms which incorporate their own filter will also be investigated. Thick holograms tend to have greater angular sensitivity, therefore having a self-limited acceptance angle. By combining several exposures with point sources separated by an angle such that each exposure only accepts inputs from a small area of the display, image quality of the display can be improved. The same reasoning applies to the completely different situation of having multiple input channels. By separating two exposures over a large angle, two displays can be superimposed at the same time. Continued efforts in the investigations of holographic recording materials should lead to higher sensitivities and greater resistance to deterioration.

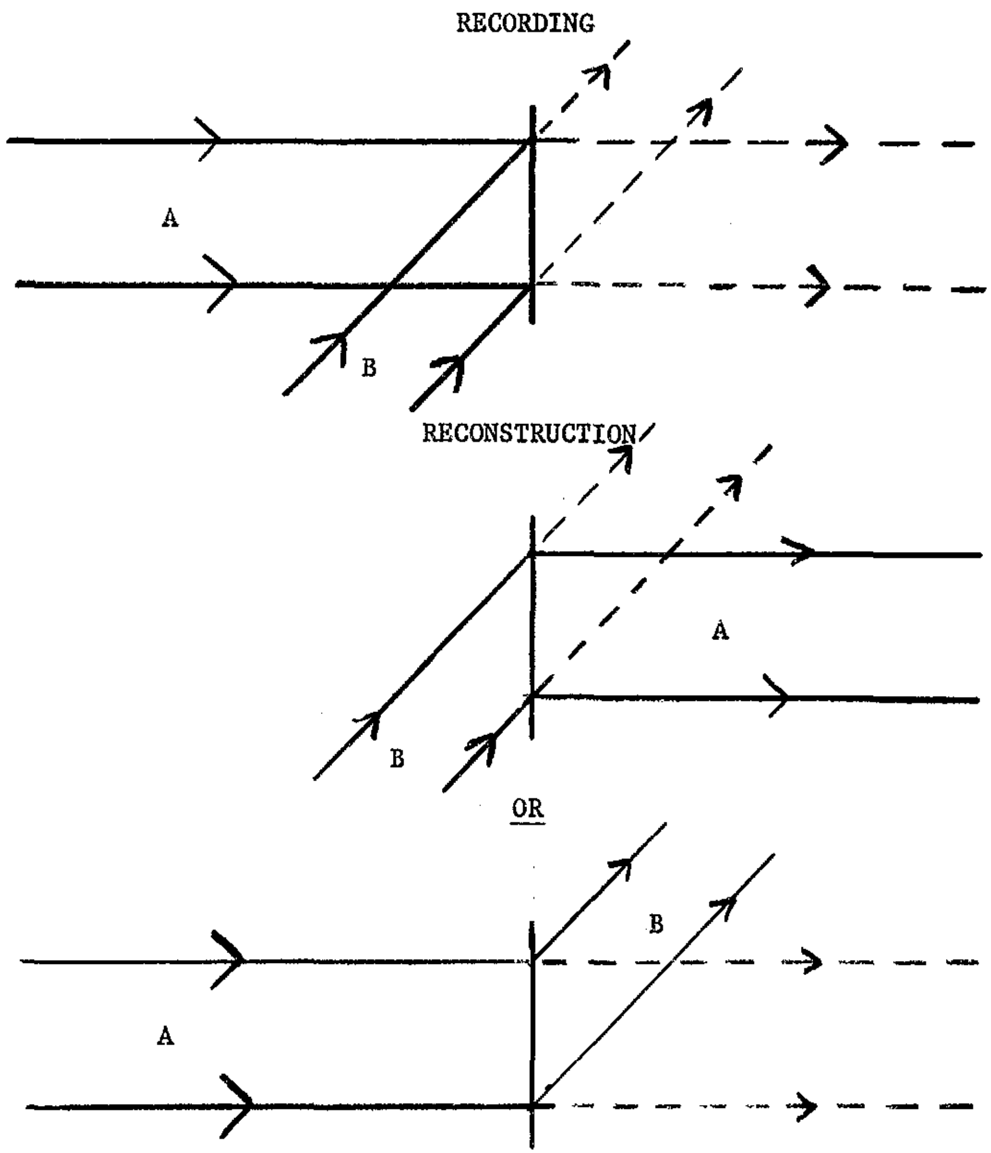


Figure 1. RECORDING AND RECONSTRUCTION

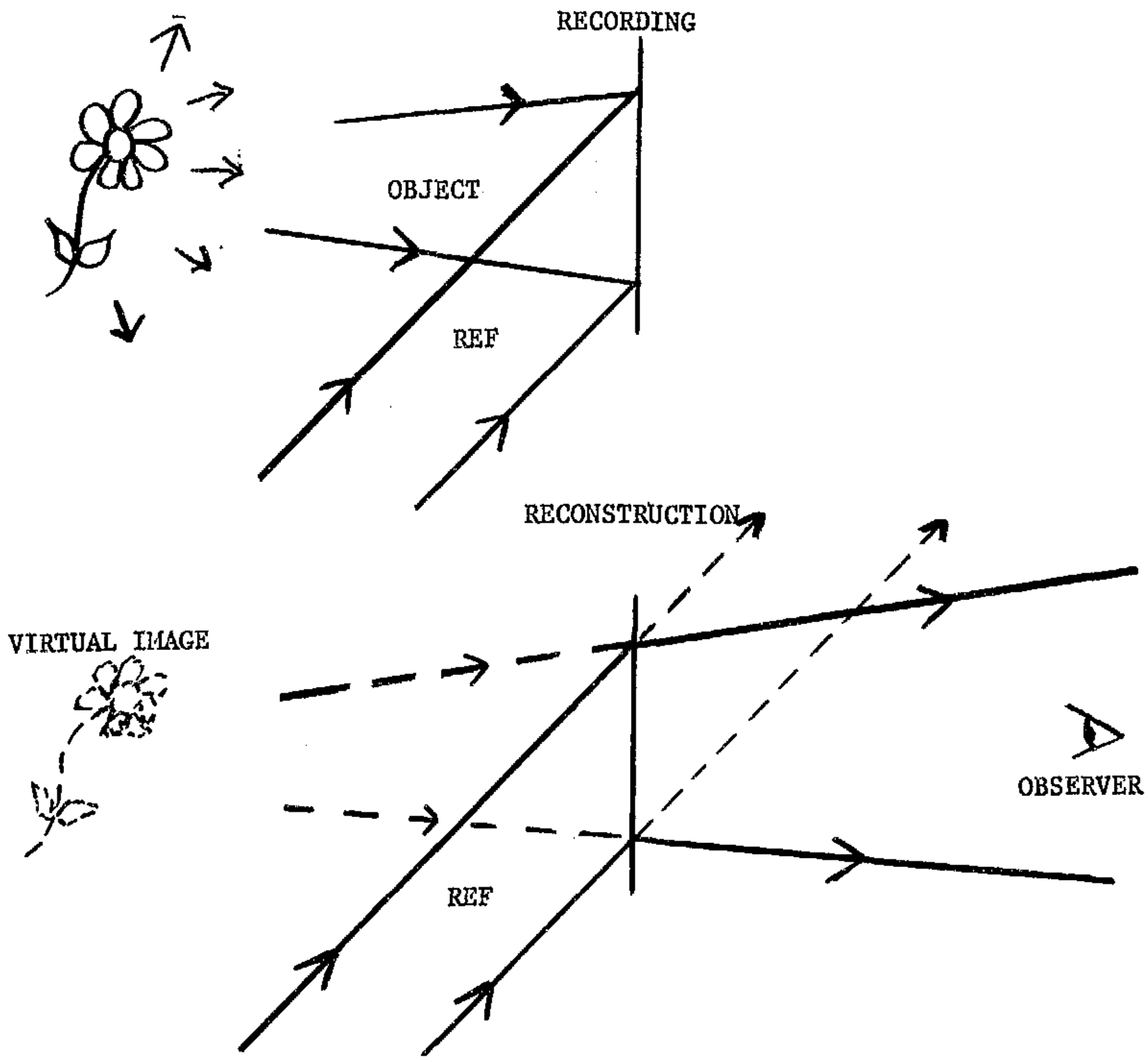
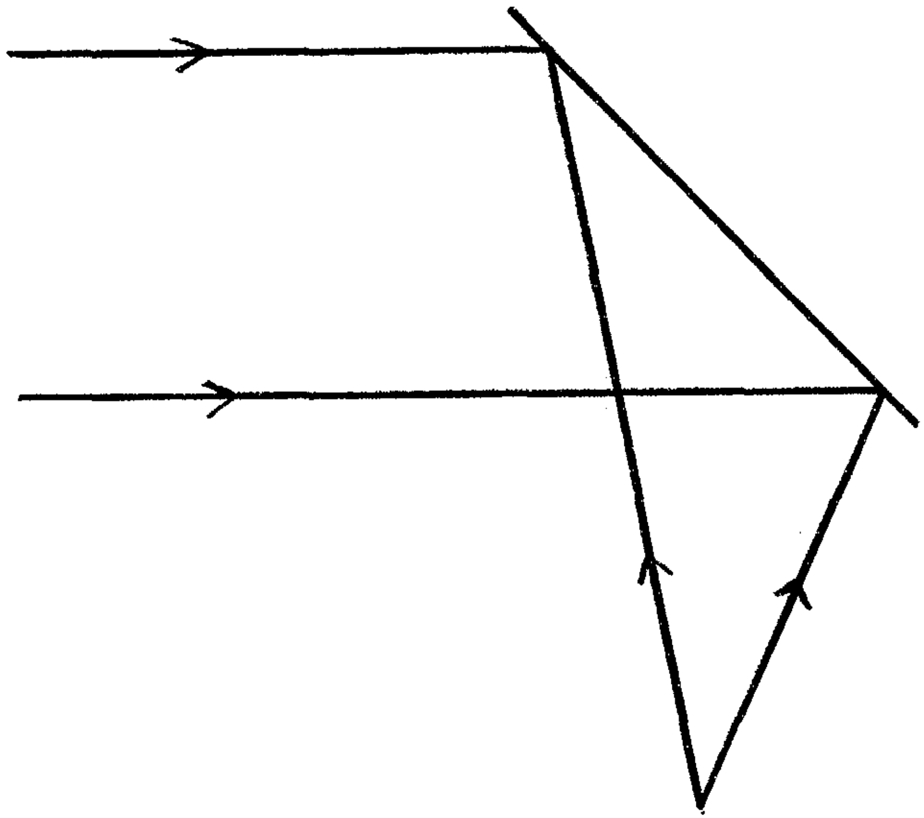


Figure 2.THREE-DIMENSIONAL HOLOGRAPHY

RECORDING



Figuré3. HOLOGRAM OF POINT SOURCE AND PLANE WAVE

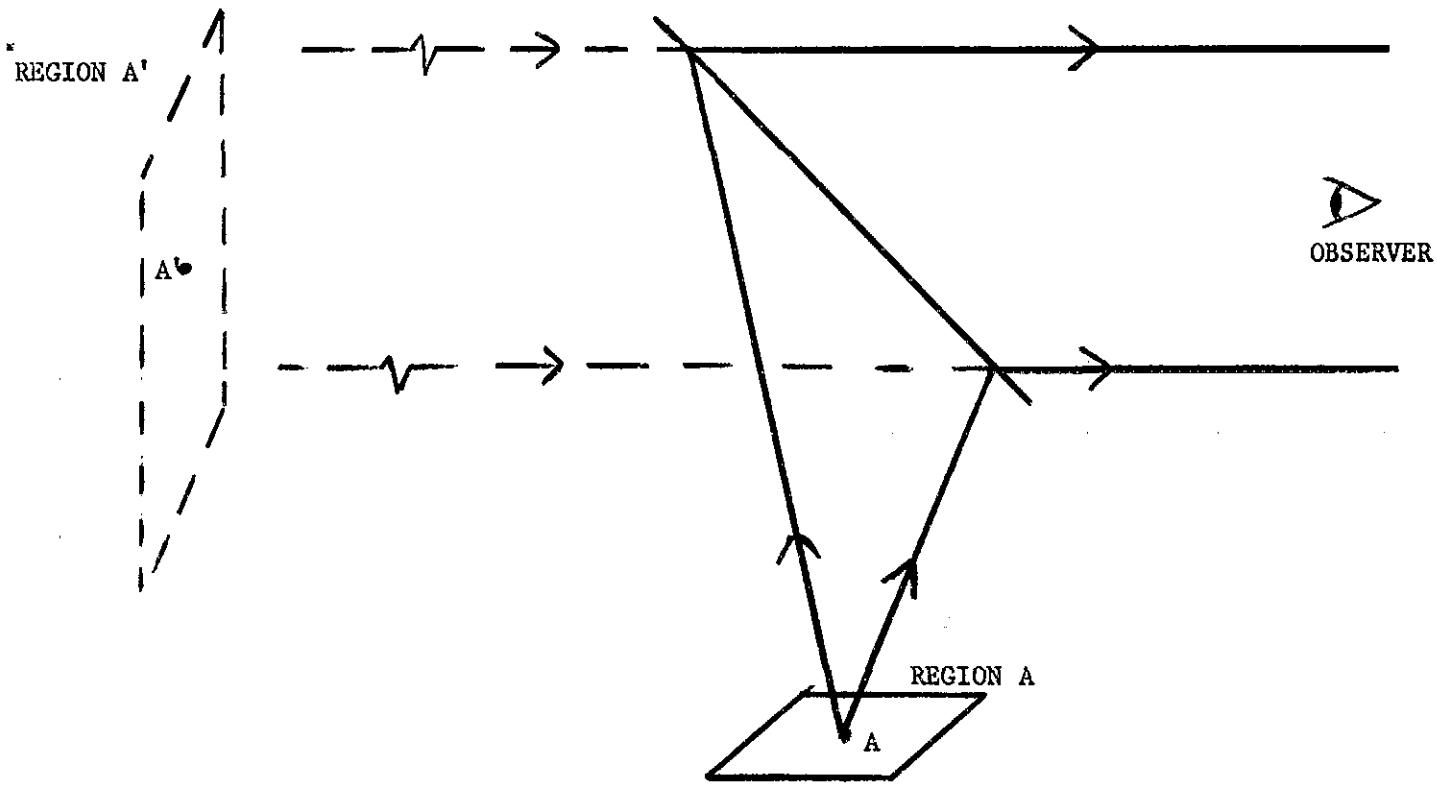


Figure 4. FUNCTION OF HOLOGRAM AS OPTICAL ELEMENT

1. TRANSPARENT
2. HIGH DIFFRACTION EFFICIENCY
3. GOOD IMAGING PROPERTIES
4. EASILY PRODUCED

Figure 5. DESIRED PROPERTIES

1. FIX AND HARDEN	5 MINUTES FIX WITH HARDENER
2. WASH	25 MINUTES WATER
3. WASH	5 MINUTES METHANOL
4. WASH	3 MINUTES FRESH METHANOL
5. SENSITIZE	10 MINUTES 4.5% AMMONIUM DICHROMATE
6. DRY	12 HOURS

Figure 6. PREPARATION AND SENSITIZING

1. WAIT	3 HOURS
2. WASH	15 MINUTES RUNNING WATER
3. WASH	2 MINUTES 50/50 ISOPROPANOL/WATER
4. WASH	2 MINUTES 90/10 ISOPROPANOL/WATER
5. WASH	15 MINUTES ISOPROPANOL
6. DRY	15 MINUTES DRY AIR
7. SEAL	METHYL CYANO-ACRYLATE ADHESIVE, COVER GLASS

Figure 7. PROCESSING PROCEDURE

1. IMATE ABERRATIONS
2. NONMONOCHROMATIC PERFORMANCE
3. MULTI-EXPOSURE
    * IMAGE QUALITY IMPROVEMENT
    * MULTICHANNEL INPUT
4. MATERIALS

Figure 8. FUTURE WORK

ABOUT THE AUTHORS

MR. DENIS R. BREGLIA is a Research Physicist at the Naval Training Equipment Center. He is involved in Holography and other Laser applications such as weapon fire simulation. He holds a B.S. and M.S. in Physics, and has been with the Center since May 1966.

MR. ALFRED H. RODEMANN is a Research Physicist in the Physical Sciences Laboratory at the Naval Training Equipment Center. He is working on applications of Lasers and Holography to visual simulation in training devices. Before coming to the Center in 1964 Mr. Rodemann worked for 5 years at Kollsman Instrument Corporation in the space program. He received his degree in 1958 from the Polytechnic Institute of Brooklyn.