Simplification of Holographic Procedures

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The present state of the holographic art has set many stringent parameters on the production of holograms, such as extreme mechanical, temperature, and air stability for long periods of time, and slow film emulsions with extremely high resolution. The Physical Sciences Laboratory of the U.S. Naval Training Device Center has investigated, experimented, and produced many clear high resolution holograms in a ground-level Butler Building without, close temperature controls and using other than expensive, massive, and extremely rigid optical mounts and equipment.

I. General

The NTDC's interest in holography stems mainly from the unique, real-world, three-dimensional properties afforded the observer when viewing the reconstructed image of an object or scene formed by the diffraction pattern captured on the emulsion of the photographic plate or film. If the observer changes his viewing position, he can literally look around the object or elements in a scene. In addition, the magnification and demagnification mechanism of holography induced by the ratio of reconstructing to recording wavelengths could also be an important feature in a holographic display system for a training device.

Up to the present time, the practical applications of the science, or rather the art, of holography have been extremely limited. If one reviews this field, he realizes quickly that the present state of the art has placed several stringent parameters on the production of holograms. If the necessity to adhere to these stringent parameters were removed, the avenues of useful application of holography would be increased. With this goal in mind, NTDC began to investigate holographic production design parameters. The literature suggested:

1. Mechanical vibrations: movement of one element of a holographic setup, with respect to another of more than an eighth of the wavelength of the light source, approximately 75 nm would prevent the formation of a hologram. Other investigators claim the need for mechanical stability to 25 nm. To accomplish this, their setup has been performed on large granite block assemblies weighing as much as 4-5 tons.
2. Temperature stability and air turbulence: the safe limits of temperature change and air turbulence during the holographic process have not been firmly established. Some investigators have gone to great lengths to keep these two unknowns at a minimum by using sub-basements that are partially evacuated, or high-level, clean rooms with close temperature and air turbulence controls. Slight movement, talking near the experimental setup, or water running through the pipes in the building would be considered grounds for failure to obtain a hologram.
3. Long exposures and stray light problems: only high resolution spectroscopic plates, Eastman Kodak 649F, with a slow speed, 0.05 ASA, are specified. Naturally, this results in long exposures and increases stray light problems. To overcome the stray light problem, some investigators have made expensive camera bodies and massive optical mounts that allow long exposures with the required stability.
4. Monitoring the fringe pattern during exposure: in addition to the above rigorous measures, some investigators, who have had trouble obtaining a diffraction pattern, are monitoring their experiments by viewing Lloyd fringes during exposures—movement of the fringes during exposure being deemed to contraindicate the formation of a hologram, and those plates or film exposed at that time of movement would be discarded before developing.
5. Laser mode stabilization: a range of laser warmup times from 4 h to 24 h might be required to stabilize the $\text{TEM}_{00}$ mode of making holograms.
6. Optical elements: high-quality precision optical elements and rigid mounts were suggested.

Initially, to relax the above stringent procedure, the following approach was taken. Layout was as shown in Fig. 1. (1) Mechanical vibration: a 84-cm wide by 152-cm long, ordinary 30 kg wooden table with its four legs floating in buckets of commercially clean, dry sand, was used to support the experiment. No provision to level or to true up the surface of the table was made. The experiments were performed on a ground level, 12-cm concrete slab floor of a Butler Building with no

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clean room provisions. (2) Temperature stability and air turbulence: the entire laser beam path from the laser to the photographic plate, and all elements in between, was completely enclosed in styrofoam to reduce heat transfer and air turbulence. The laser itself, with the exception of the output head, was outside this enclosure. (3) Long exposure and stray light problems: the enclosure was in two parts, the second having the additional feature of being light tight for stray light isolation. The control opening between the two parts of the enclosure to pass the laser beam was a mechanical photographic shutter. A powerful 40-mW, cw, helium-neon laser and the direct-beam illumination method (rather than split-beam, with its accompanying beam splitter losses) were used to contain reduction of exposure times of the spectroscopic plates. (4) Monitoring the fringe pattern during exposure: no attempt was made to monitor Lloyd fringes during exposure since a fringe check showed initially only small-amplitude, long-period motion on the table surface.

In addition to the above, the subsequent procedures were employed: (a) a range of intensity ratios of reference to reflected beam as suggested in Ref. 6 was used; (b) to insure a $\text{TEM}_0^0$ mode, the laser was allowed to stabilize for 24 h; (c) exposures were taken only on Saturday, when nobody else was working; the air conditioning, blowers, fans, motors and other operating equipment were not in use; (d) there was a 15-20-min waiting period before exposure in order to stabilize temperature and air turbulence within the styrofoam enclosures; (e) a 3:1 dilution of D-19 developer, controlled to 68°F for 5 min, was used, producing a gamma of 1.5; (f) little regard was given to the control of the angle between the reference and reflected beams, or to the equality of optical path lengths of the beams.

Using the setup as shown in Fig. 1, successful holograms of a toy truck were produced as shown in Fig. 2. Many more intense, high resolution holograms of various objects and scenes were consistently made in the same or similar manner. The following observations resulted from these runs — (1) Exposures times were reduced to several seconds by using a more powerful laser and the direct-beam illumination method. (2) Commercial neutral density filters can be placed in the reference beam without perceptible degradation of the reconstructed image. (3) The angular relationship at the film plane between the reference and reflected beam is important. Small angles with a large fringe pattern produce holograms with higher resolution and more intensity than large angles with a small fringe pattern. (4) Plane waves produce higher resolving holograms than those produced with spherical waves. (5) A greater range of intensities from 1 : 1 to better than 10:1 between the reference and reflected beams produced holograms.

For the setup, as shown in Fig. 1, a ratio of 3:1 proved to be the best. (6) Changes in dilutions on D-19 and also D-76 developer had little or no perceptible effect on the quality of the hologram. (7) An inexpensive single-element, short-focal-length lens can be used in place of the 10X microscope objective. (8) An inexpensive, commercial, front-surfaced plate glass mirror can be used for the reference beam in place of the one twentieth wave etalon.

At this stage, it was decided to reduce further or to remove, one by one, the precautions required previously for the successful formation of holograms. After the removal or reduction of each of the following items, successful holograms were produced (see Fig. 3 for final layout): (1) experiments were performed on a normal work day; (2) air conditioning, blowers, motors and all other normal operating equipment remained in operation; (3) removal of enclosure 1 (see Fig. 1); (4) removal of enclosure 2 (see Fig. 1); (5) a large wooden table, 1.22 X 2.44 m, was used to increase the
scene coverage; (6) laser stabilization time was reduced to 15 min instead of the previous 24 h; (7) immediate exposures were made instead of having the 15-20-min equipment-area-stabilization waiting period.

Change in resolution and intensity of the holograms from (1) through (7) was not detectable. Figure 4 is an example of one of the holograms, and Fig. 5 is its reconstructed image resulting from these modified procedures.

Up to now, all of the holograms produced at NTDC were on Eastman Kodak 649F spectroscopic plates. The ideal photographic material for 3-D holograms should have extremely high resolving power, high sensitivity to the source wavelength, relatively high contrast, and a support completely free of optical defects. Unfortunately, high resolving power and high sensitivity do not go hand in hand, although high resolving power and high contrast generally do. Therefore, a trade-off seems to be in order between resolution and sensitivity.

Holograms were made using (a) Eastman Kodak V-F spectroscopic plates, with resolution better than 225 lines/mm and speed sensitivity approximately 0.5 ASA, and (b) Polaroid film 55 P/N, with resolution better than 160 lines/mm and speed sensitivity approximately 80 ASA.

All of the holograms produced on the above materials have been extremely grainy and low in resolution. Underexposure and developing had little effect on reducing the graininess of these holograms.

A review of the limited results from the three different materials used to date possibly indicates the need for a photographic material midway between the two extremes.

II. Conclusions

The NTDC’s in-house holographic research effort has attained the following significant relaxations in hologram production procedure: (1) a simple, inexpensive, isolated experiment support can be used; (2) close temperature stability and air turbulence control under clean room conditions is not necessary; (3) monitoring the fringe pattern during exposure is not necessary; (4) extremely high quality precision optical elements and mounts are not required; (5) long laser warmup periods for mode stabilization are not necessary.

In view of the above relaxation of the original stringent design parameters, there now seems to be more promise of reaching the NTDC’s training goal. The NTDC’s holographic investigations will continue toward a larger format, image enhanced holograms, single plate multimage holograms, motion holography, instrumental use of holographic images, and, eventually, multicolor holography for use in training devices.

References
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