APPLICATION OF HOLOGRAPHY IN TRAINING DEVICES

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Since its renaissance period of 1962-1964, holography has expanded quite rapidly and revealed many of its potentialities. Hundreds of papers have been written which describe its applications and theory of operation. However, one of our specific interests is in applying holograms to training devices which require visual simulation.

A hologram is a photographic recording of a wavefront of radiation from an object. One forms a hologram by recording on a photographic plate the interference pattern produced by coherent beams of light—one a reflected object beam, and the other a reference beam (figure 1).

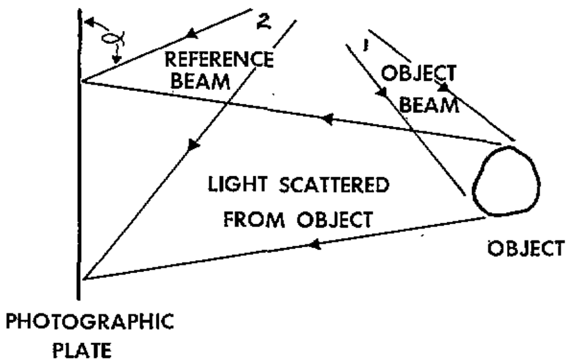

Figure 1. Recording a Hologram

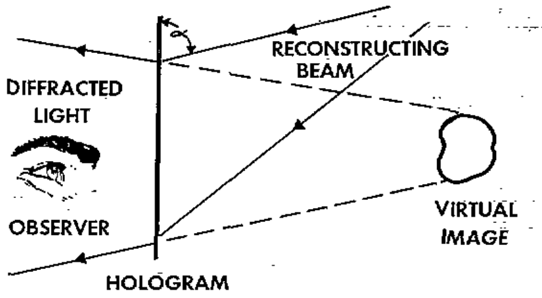

Figure 2. Viewing the Hologram

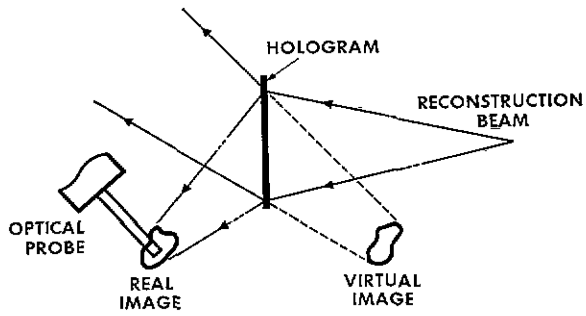

Figure 3. Viewing the Real Image

The photographic plate is then developed in a standard fashion. To view the hologram, the photographic plate is illuminated with a monochromatic source of light which has the same angle of incidence that the original reference beam had (figure 2).

An observer, when viewing through the hologram as if it were a window, sees a three-dimensional image with all the same visual features as the original object. The image which is viewed can be either real or virtual. The virtual image appears behind the hologram and the real image appears in front of the hologram.

At the present time, it is foreseen that holograms may be employed as visual aids in the areas of simulators and classroom instruction. Their usefulness in both these areas is made possible by their unique properties. The following discussion will include some of these properties and a few applications.

The hologram is capable of accurately storing a three-dimensional image on an essentially two-dimensional medium. This stored image can be retrieved with three-dimensional fidelity at some later time. This property allows one to replace an actual object or model with a hologram that has identical visual characteristics. This is a most effective tool if the actual object is not available at all times for training, e.g., a ship engine. While the ship is at sea, the trainees could continue their program of instruction in navigation, repair, or other duties, using pulsed holograms.

Holograms may be duplicated quickly and inexpensively in a photographic or holographic manner. This would be advantageous if several hundred trainers were required which used a model of intricate design. Under present conditions, many hours would be required in the model shop for each duplicate, thus delaying the delivery date of the trainer and skyrocketing the price. However, if holographic methods were employed, one could have the required number of copies (each being an exact duplicate) in a shorter time and at a reduction in cost.

Using the three-dimensional real image produced by the hologram, one may apply techniques that were not before possible with an actual model (figure 3).

For example, if the simulation were of an aircraft carrier landing, the trainee could approach the 3-D image and actually go into it with an optical probe (simulating destruction) without injuring the object or probe. This type image might also be useful in a docking maneuver or in-flight refueling.

Map training may prove the usefulness of pulsed holograms. The necessity of topographical maps in the training situation is well known. But, if one could properly facilitate a pulsed hologram, the trainee would not only have a three-dimensional map, but it could be of the actual terrain and could have contour lines displayed on it. Another advantage in using a holographic map is that large portions of the map could be changed quickly or magnified without the awkwardness of a three-dimensional model.

Full freedom in viewing (nearly 4 π steradians) can be had by using one of several techniques. At the present time, 360° holograms seem to be coming to the forefront (figure 4). To form a 360° hologram, one makes a ring of film around the object at the desired distance (compatible with the coherence length of the laser). Then the entire scene is illuminated with laser light. That portion of the light which impinges directly on the film is the reference wavefront. That portion which is reflected from the object is the subject wavefront. To read out the hologram, one illuminates the film in the same position as it was made and the observer views from any side.

Strip holograms are another method for making 360° views. A strip hologram can be made as shown in figure 5.

The first strip is exposed to the object in position one. Then the object is turned or the plate is moved to position two and the second strip is exposed to the object. This procedure is continued until the object or plate is rotated through 360°. Reconstruction is accomplished by illuminating one or more strips at a time with the reference beam.

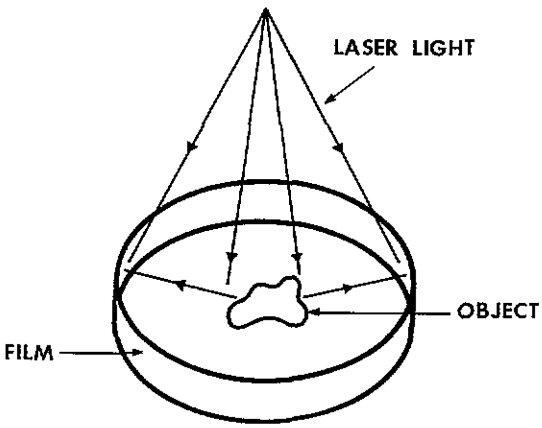

Figure 4. Recording a 360^{o} Hologram

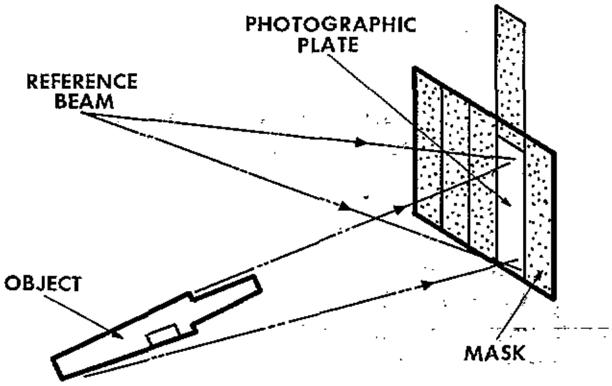

Figure 5. Making a Strip Hologram

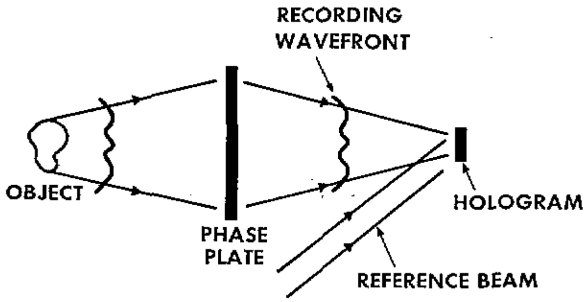

Figure 6. Recording of the Hologram

Spot holograms are an extension of the above idea. One merely divides the plate into strips in both the vertical and horizontal directions and exposes one spot at a time. This allows holograms of the object to be made while it is being rotated in the horizontal plane and a vertical plane. Readout is accomplished by illuminating one spot at a time. All these images could be accessed by a computer-controlled deflection device. Any one of these methods could be used to present the trainee with a complete view of the equipment that he will be using or repairing.

Ultrasonic holography should become useful in oceanographic trainers. Ultrasonic holograms are made by recording (perhaps temporarily) the interference pattern produced underwater by two coherent ultrasonic wavefronts—one a reference wave and the other a wave reflected from the object. These holograms could give a three-dimensional display to the trainee to simulate a return from underwater objects.

Multicolor holography is another recent development which is fast reaching the stage of production. Three-dimensional color images will yield realism and rapport to any of the training situations already mentioned.

The recent development of holographic movies is a tremendous step forward for visual simulation in training. The principles involved in storing several images on a single photographic plate have long been known; but the recent development of storing holograms in volume recorders may provide the possibility of recording thousands of three-dimensional images on a small cube. If a volume hologram will extinguish in two minutes of arc, there is plenty of storage medium in a one centimeter cube to record a usable movie of several minutes. This minimum of recording media allows for cost reduction and versatility. If we can now incorporate three dimensions and multicolor into this idea, we can realize training situations which were previously impossible to simulate at such a low cost.

In classroom training, one finds even more uses for holography. The three-dimensional image can be applied to many specific training tasks. The student can be taught to recognize tools, ships, or airplanes. These could be pulsed holograms of the actual objects. This instruction could be extended to full coverage with 360° or strip holograms.

By an extension to movies, the instructor could show 3-D assembly of component parts in full color. In order to have holographic movies, one must overcome the problem of having a small recording medium (e.g. 70mm) and yet having a large viewing area suitable for an audience of about ten students.

One method for solving this problem is data reduction by use of a phase plate between the object and the hologram. The small holograms are recorded as shown in figure 6.

The phase plate causes each ray which proceeds from the object toward the photographic plate to be scattered into a wavefront of secondary rays. This allows the hologram to record a sampling of all the rays that propagated from the object in a larger solid angle than in the standard method. The phase plate puts an added phase (e.g. $e^{i\theta}$) into the recorded wavefront. The hologram is viewed as shown in figure 7.

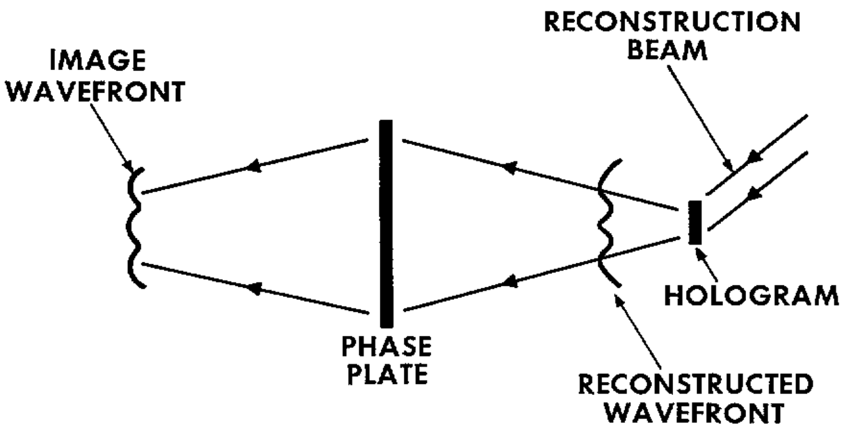

Figure 7. Reconstruction of the Hologram

Upon sending the reconstructed wavefront through the phase plate in the opposite direction, each ray covers its original route and a phase (e.g. $e^{-i\theta}$) is added to the wavefront. This phase exactly cancels the "extra" phase added in recording (i.e., $e^{i\theta} \cdot e^{-i\theta} \doteq 1$); thus the phase plate disappears. The image which is viewed covers a larger solid angle than was available from the small hologram.

The mass storage available in the hologram is also valuable in the training situation. The student can have instantaneous access to flag symbols, parts, or pages of a book. A language translation device could be employed by using the English word as the object beam and say its French counterpart as the reference beam (figure 8). Then by illuminating one language or the other, one has instantaneous visual translation. This device could be facilitated with computer controlled spot holograms.

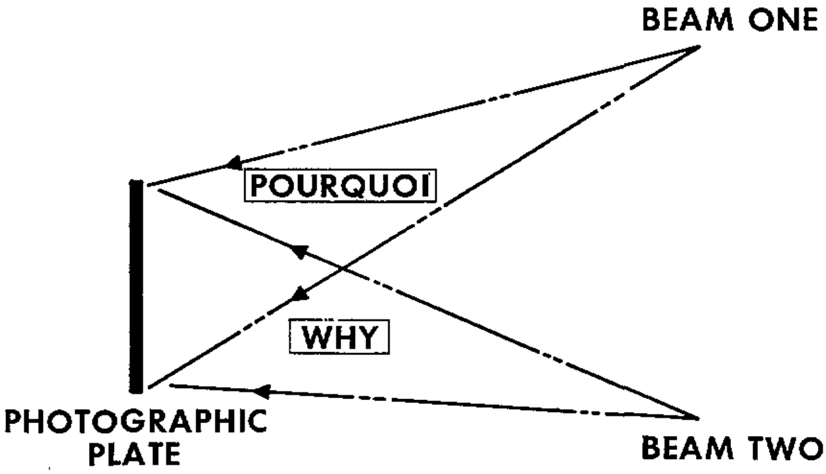

Figure 8. Language Display

One could also employ holograms for instructing the medical corps. For example, X-ray holograms could yield three-dimensional motion views of a patient, or regular holograms could display a patient's entire medical history from a very small spot.

Interferometric holography can be an aid in teaching stress and strain of metals. An interferometric hologram can be made by first exposing the object to the photographic plate, then making a second exposure with a force applied to the object. The slight movements of the object due to the applied force will be revealed as dark interference lines across the object. Another method of making an interferometric hologram is by exposing the object to the film, then developing the film and replacing it in position such that the virtual image and the object are coincident. Again, dark interference lines will appear where the object moved due to applied force. The interference pattern visible on the holographed object might reveal to a ship repairman the weak spots in a solder joint, drill hole, or ship's bow. This method can be employed to teach the force on a hull due to collision with a dock, or a mine. Heat dissipation and air flow can be made visible through interferometric holography; thus, the trainee quickly understands the importance of correct circulation or insulation.

Some of the interference patterns produced by this type holography, would be useful in teaching equipotentials, electric field lines, and other principles of electromagnetic theory to students who are new to the subject. Interferometry could also be used to teach the student how to check the surfaces of optical components, or vibrating surfaces.

Holographically prepared spatial frequency filters, could be useful in coding and decoding devices, teaching Fourier transforms, or the principles of a carrier frequency. These filters could also be used in key word or object recognition. The trainee might be presented a line of vehicles and told to count the number of tanks among the trucks. Then, the filter would select out the particular vehicles and give the trainee instant feedback.

The future of holography at the Naval Training Device Center seems bright. There is at this time great expectation for the application of holography in training devices. Some of the possibilities in the near future include landing and docking simulators, mass data storage, 360° holograms, multicolor holograms, pulsed holograms, strip holograms, and motion picture holography. The use of these and other holographic techniques are hoped to increase cost effectiveness in training devices.