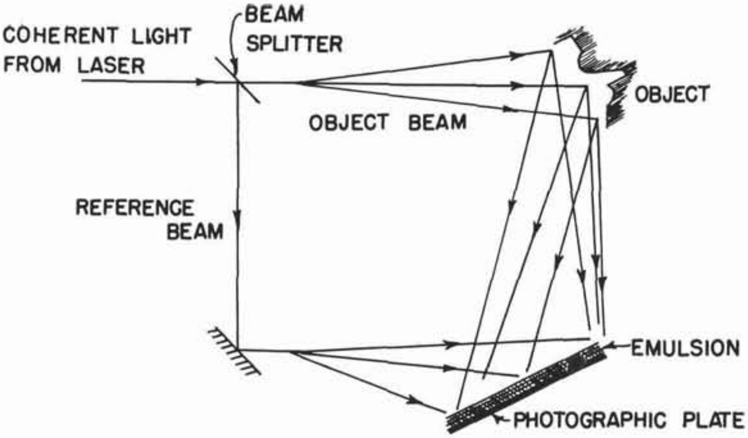

FIG. 1. A hologram is produced by exposing a photographic plate to two mutually coherent light beams. The light from the laser is split by a beam splitter to form the reference beam and the object beam.

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Mensuration Aspects of Holograms

The feasibility is established for close-up applications where the object is stationary.

(*Abstract on next page*)

INTRODUCTION

EVER SINCE IT was first demonstrated that images of three-dimensional objects could be reproduced through holography, photogrammetrists have been considering how a hologram might be applied to problems in topographic mapping as is indicated by the Bibliography.

Holography was originally called *wavefront reconstruction* because the hologram reproduces the wavefront that originally came from the object to the plate. A hologram records both the amplitude and phase from the incoming light (Figure 1) and reconstructs these components upon being viewed. (Figure 2.) As the hologram records both the amplitude and the phase, there is no need for focusing. In addition, it is possible to treat the image produced by a hologram by optical filtering techniques. This is of great value to those working with optical correlation equipment.

If the reference beam is passed through a diffuser, or is reflected off a diffused object before striking the plate, the hologram acquires another interesting property. It is now possible to break the hologram and to see the whole object in any one of the pieces. However, this has one serious drawback in that the resolution of the hologram decreases as the pieces decrease in size.

In viewing a hologram the viewer can move about within certain limits. If at one point

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one object obscures another, the latter can often be seen by simply moving the viewing point. The ability of changing the viewing point is however constrained by the physical size of the hologram. This ability to see obscured objects is totally missing in conventional photogrammetric stereomodels. Shadowed areas which are lost in conventional photogrammetry can often be seen in a hologram of the same object.

In contrast to conventional photography, holography requires extreme stability and freedom from random motion. In fact, if any component in the hologram production set-up moves relative to another more than 1/4 of the wavelength of the light, no hologram will be produced. To eliminate the relative motion, the equipment is set up on large vibration-free tables. Coupled with this requirement, relatively long exposures are used in holography depending on the size of the laser and the type of emulsion used. As an example, if the Spectra-Physics Model 120 Laser (5 milliwatt at 6,328 nanometers) is used, typical exposures vary from 1/10 sec. for Agfa Gavaert 10E70 Scientia plates, to 10 sec. for Kodak 649F plates.

Another factor to be considered in making holograms is that coherent light *must* be used. To image a three-dimensional object, coherent light must be reflected off that object. This is easy to do in the laboratory with small objects but nearly impossible to do with objects the size of those used in conventional mapping, namely the ground. At least at the present time, in order to make true holograms of the ground, some intermediate process must be developed. Some attempts have been made to produce holographic views of the terrain from overlapping photographs.

Current efforts in holography pertaining to photogrammetry have been limited to three areas: optical correlation techniques,[6] contouring in perspective, and holographic stereograms. The area of holographic stereograms is more directly related to photogrammetry in that it presents a first step toward attaining holograms of an object, indirectly through photography. Although efforts until now have been concerned with situations which are very special cases of the conventional concept of the stereomodel, the works of George[5] and Redman[10] are valuable contributions to this novel area of investigation.

Although many authors have discussed the imaging conditions, and have computed the location of the image, very few have actually made physical measurements to verify their theories. One such quantitative study of the imaging properties of holograms was performed by Champagne.[1] In his study, he observed the image of a point object under different conditions of holographic recording and viewing. Quantitative data were obtained by viewing the real image with a device called a *snooper-scope* which yielded the distance from the holographic plate to image points.

A second method of measuring the real image is to observe the image on a screen. The screen is placed in the real image and translated until the sharpest image of the obectj is seen on the screen. The position of the screen is then taken to be the position of the image. Other authors made use of microscopes for measurement but were hampered by their extremely small depth of field and high magnification.

ABSTRACT: *The mensuration of holograms is feasible for close-up applications where the object is stationary. A Wild A7 plotter is adapted for measuring holograms through the application of a fiber optic to produce a measuring mark. Pointing precisions of 0.003 inches in X and Y (parallel to the hologram) and 0.012 in Z were obtained from direct unaided viewing of the holographic virtual image. Simulation studies, verified by laboratory measurements, show that distortions due to deviations in the reconstructed beam of up to 4° are sufficiently linear to be treated by a 7-parameter conformal transformation. The general potential and application of holograms for mapping are related to the quality of the hologram and to the application of photogrammetric operations to it.*

HOLOGRAPHY FOR CLOSE-RANGE OBJECTS: THEORY AND EXPERIMENTS

Inasmuch as metric holograms of the terrain have not been produced yet, we decided to concentrate on holography for near-range objects. In many instances holography may be used instead of near-range photogrammetry because of some features that make it preferable over photogrammetry. The remainder of this paper will deal with the general characteristics, geometric parameters, and metric quality of holograms of near-range objects.

One problem in photogrammetry of near-range objects is depth of field. The nearer an object to the camera the smaller the depth of field. In holography however, depth of field is not the relevant criterion. Instead, the important question is the maximum object size that can be holographically recorded. This depends on the coherence length of the laser beam used in recording. For example, our laser (the Spectra-Physics Model 120) has a coherence length of approximately 1/2 meter. Consequently, an object of up to 1/4 meter in depth may be recorded holographically with this laser. It is possible with some lasers to obtain coherence lengths of up to 10 meters.

The second advantage of holography over photogrammetry is that objects of complex shapes can be imaged with a minimum of shadow problems. Holography records information about any point of the object that radiates light to the holographic plate. If the object is very complicated, more than one object beam can be used to illuminate it and remove most of the shadows.

Another quite important advantage is that image parallax in a hologram is not restricted to one direction. The holographic plate has to bear a certain fixed relationship to the reconstruction beam, but there are no restrictions on the observer's position. He can move about and rotate his eye-base to any orientation with respect to the holographic plate and still see the hologram. This is sharply contrasted in photogrammetry by the existence of only x-parallax and the condition that the observer's eye-base must be approximately parallel to the direction of conjugate image separation (flight line in aerial photography).

Finally, resolution of a hologram is controlled by the size of the holographic plate and the resolution limit of the emulsion. In general, the larger the plate size the higher is the resolution obtained. As far as the resolution limit of the emulsion, this is normally quite high, as for example the Kodak 649F plates have more than 4,000 lines per millimeter resolution.

Aspects of Laboratory Experimentation

In order that we may study metric characteristics and mensuration possibilities of holograms, we obviously had to become familiar with laboratory techniques of making holograms. As was mentioned earlier we used a Spectra-Physics laser with 5 milliwatts output energy at a wavelength of 6328 nanometers. For stability and freedom from vibration, arrangements for holographic recording were made on top of a 600-pound gray cast-iron surface plate which is mounted on pneumatic shock absorbers. The holograms were recorded on both Kodak and Agfa Gavaert photographic plates, both kinds measuring 4 by 5 inches. In keeping with this size plate, our objects were specially designed test blocks which on the average did not exceed the space of a 4-inch cube.

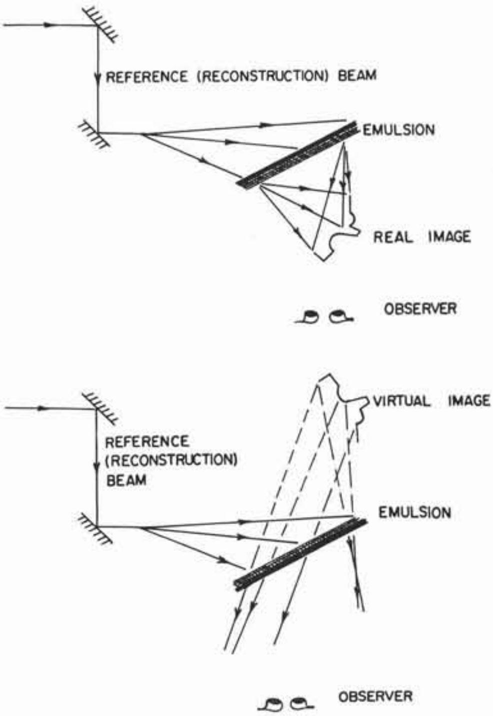

FIG. 2. The real image (upper view) can be seen by reversing the hologram in the reconstruction beam. Note that the image, which is in front of the hologram, is pseudoscopic. The virtual image (lower view) can be seen if the hologram is illuminated by the reference beam. The observer sees an image of the object in the same location that the object originally occupied.

Each hologram can produce two images, one real and the other virtual. (Figure 2.) For the purpose of actual measurements on the hologram we considered the fundamental question of pointing to discrete images and recording the three spatial rectangular coordinates. Here, at least in principle, one can use either of the two images. But in order to make pointings, one must have some type of a reference mark to move about in the space of the image to be measured. We first conconsidered the real image in conjunction with a *mark* such as a dot or a cross on a glass plate. This possibility was discarded, however, because the glass plate would interfere with the reconstruction light as well as the difficulties encountered in recording the movements of the plate. Next, we thought of making a hologram of the reference dot at the same time the hologram of the object is being made. This idea was also abandoned for two reasons. First the hologram of a dot is a Fresnel zone plate which would distort the reconstruction beam and, second, we would be again faced with the difficulty of recording the movements of a glass plate (in this instance, the hologram of the dot).

We then turned to the virtual image for consideration, which frankly we always found to be easier to view to begin with. In viewing a hologram in a room of low ambient light, there will be no light behind the holographic plate in the apparent position of the virtual image. (Figure 2.) Consequently, any measurements on that image by a physical reference point can be made only if that point is self-illuminated. This obviously precludes dots, crosses, and the like, etched on glass plates because one would simply be unable to see them. Conveniently for us photogrammetrists, we have an ideal self-illuminated reference point in the form of the measuring marks used for double-projection instruments such as the Multiplex or Kelsh plotter. In addition to being readily available, its movements can be easily recorded in three dimensions.

The first mensuration system we used consisted of a Kelsh tracing table attached to a rack-and-pinion coordinatograph. The two readings from the coordinatograph were automatically recorded on a card punch, whereas the third coordinate was read off the platen's counter and manually punched. For convenience, the holographic plate is normally mounted vertically and the observer views it looking horizontally through it. This makes it impossible to see the dot on the horizontal platen, unless it is made to appear in a vertical plane. This was done by placing a 90° prism on top of the tracing table. We also found it effective to paint the platen black so that no stray light may be reflected off its surface and interfere with the viewing process.

It must be emphasized that no light is present behind the holographic plate and therefore the tracing table movements in no way affects the image. Consequently the mark can be moved from one point to another and the corresponding coordinates can be recorded.

After some experimentation with this first system we found that the floating mark did not remain stationary if the observer moved his head to be sure of his pointing. This led us to constraining the light from the prism to a horizontal narrow slit-like area. With this modification some more readings were taken and reduced, but we were still interested in more system improvements. This is because we found out that the precision in the x-direction (Figure 3) was noticeably higher because of the constraint just mentioned.

To avoid such directional bias we decided to eliminate the prism altogether. Instead we used a piece of fiber optic which is 0.001 inch (.025 mm.) in diameter with one end set into the hole in the tracing table. The other end was firmly attached horizontally on the table thus forming the luminous dot used in the measurement. This arrangement proved to be much more satisfactory than the prism.

The combination of a tracing table and a coordinatograph, although succeeding in producing hologram mensuration results, had one drawback. The x-coordinate was read off the table's counter and recorded manually, whereas the other two, y and z, were automatically recorded. To alleviate this rather undesirable feature we sought a system of three mutually orthogonal axes whose readings can be recorded automatically. As photogrammetrists, and having a Wild A7 with an EK5 digitizer, we had at our disposal the main components of what we were looking for. It

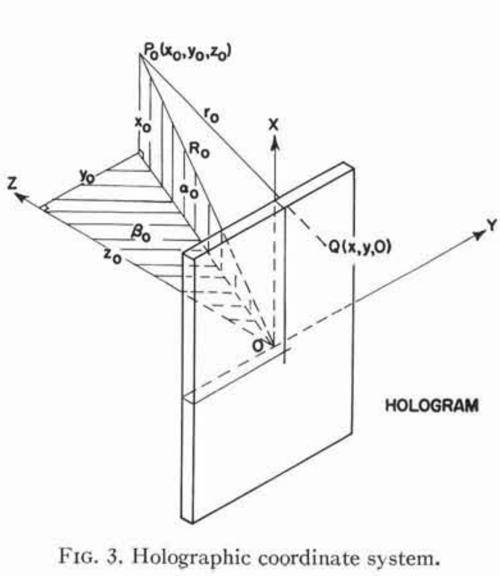

FIG. 3. Holographic coordinate system.

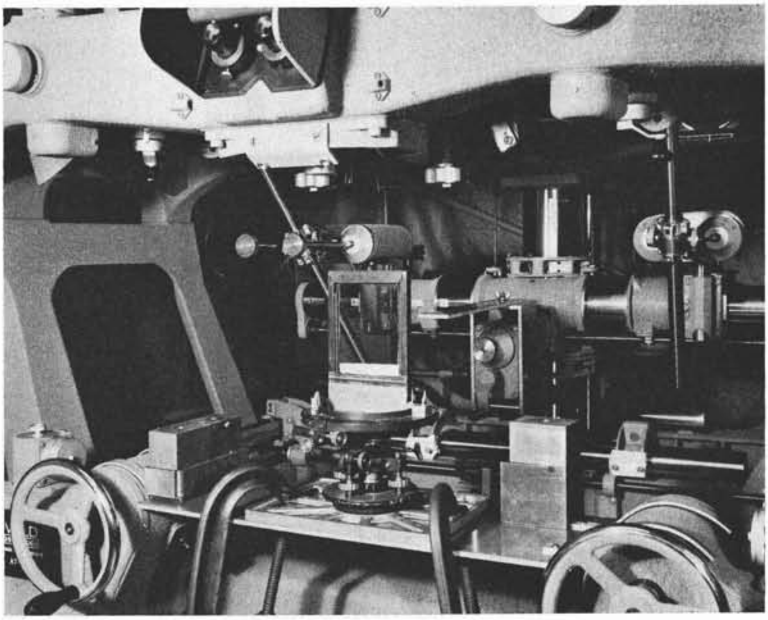

FIG. 4. A Wild A7 plotter is adapted for measuring a hologram.

was then possible to build a bracket between the gear boxes to hold the hologram, the laser was placed on the plotting table, and a long segment of fiber optic brought the light from one projector's lamp to a position behind the hologram. (Figure 4.) A few sets of measurements with this most recent configuration proved that the system is quite good. One of its advantages is that the least reading on all three axes is 0.007 mm. (The least unit in the model is designated as 0.01 mm., but physically it is actually 0.007 mm.)

THEORETICAL ANALYSIS AND INVESTIGATION

Even though the developed holographic plate bears no resemblance whatever to the recorded object, one can still analyze it mathematically. The final location of either a real or virtual point-image can be determined in terms of the locations of the original object and reference beams as well as that of the reconstruction beam. For mathematical analysis the origin of the coordinate system is set at the center of the hologram with the z-axis normal to the plane of the hologram. The x-axis is taken upward as shown in Figure 3.

The beam locations, besides affecting the geometry of the final image, also must fit certain constraints. The angle between the reference beam and the z-axis determines the maximum resolution limit needed of the film. If the angle is too great the resolution limit of the film will be exceeded and the hologram will be lost. Conversely, if the beam is too close to the axis, twin images will appear simultaneously.

Expressions for the position of holographically produced images have been derived by Meier[9] and others. They assumed that lateral dimensions of the object are small compared to the distance between the hologram and the object. This assumption is referred to as a paraxial approximation as it is applicable only if the object is near a line normal to the plane of the hologram and passing through its center. This is similar to the paraxial or Gaussian approximation used in classical optics. With reference to Figure 3, and using this approximation, the location of an image is given by

$$\frac{1}{Z_i} = \frac{1}{Z_c} \pm \mu\left(\frac{1}{Z_o} - \frac{1}{Z_r}\right)$$

$$\frac{X_i}{Z_i} = \frac{X_c}{Z_c} \pm \mu\left(\frac{X_o}{Z_o} - \frac{X_r}{Z_r}\right)$$

$$\frac{Y_i}{Z_i} = \frac{Y_c}{Z_c} \pm \mu\left(\frac{Y_o}{Z_o} - \frac{Y_r}{Z_r}\right)$$

where the subscripts designate i for image, o for object, c for reconstruction beam, and r for the reference beam. The ratio of reconstruction beam wavelength to reference beam wavelength is μ.

The upper or plus sign in these expressions is used for the virtual image whereas the lower sign is for the real image. A virtual image will be formed if the upper sign is used and Z_i is greater than zero. Similarly a real image will appear only if the equations using the lower sign produce a negative value for Z_i.

Champagne[1] was probably the first one to work an alternative set of relationships relaxing the constraint of near-axis optics. They take the form

$$\frac{1}{R_i}=\frac{1}{R_c}\pm\mu\left(\frac{1}{R_o}-\frac{1}{R_r}\right) \tag{1}$$

$$\frac{X_i}{R_i}=\frac{X_c}{R_c}\pm\mu\left(\frac{X_o}{R_o}-\frac{X_r}{R_r}\right) \tag{2a}$$

$$\sin\alpha_i=\sin\alpha_c\pm\mu(\sin\alpha_o-\sin\alpha_r) \tag{2b}$$

$$\frac{Y_i}{R_i}=\frac{Y_c}{R_c}\pm\mu\left(\frac{Y_o}{R_o}-\frac{Y_r}{R_r}\right) \tag{3a}$$

$$\cos\alpha_i\sin\beta_i=\cos\alpha_c\sin\beta_c \pm\mu(\cos\alpha_o\sin\beta_o-\cos\alpha_r\sin\beta_r) \tag{3b}$$

where the symbol R represents the total length of the vector from the origin to the different points (R_i for image, R_o for object, etc.), and the angles α and β as defined in Figure 3.

Differentiating Equations 1, 2b, and 3b with respect to R_c, α_c, and β_c, respectively, gives

$$dR_i=\left(\frac{R_i}{R_c}\right)^2 dR_c \tag{4}$$

$$d\alpha_i=\frac{\cos\alpha_c}{\cos\alpha_i}d\alpha_c \tag{5}$$

$$d\beta_i=\frac{\cos\alpha_c\cos\beta_c d\beta_c-\sin\alpha_c\sin\beta_c d\alpha_c}{\cos\alpha_i\cos\beta_i}. \tag{6}$$

The cartesian coordinates of a point can be expressed as functions of α_i, β_i, and R_i. That is,

$$X_i=R_i\sin\alpha_i \tag{7}$$

$$Y_i=R_i\cos\alpha_i\sin\beta_i \tag{8}$$

$$Z_i=R_i\cos\alpha_i\cos\beta_i. \tag{9}$$

Differentiating Equations 7, 8 and 9, and substituting for dR_i, $d\alpha_i$, and $d\beta_i$ gives

$$dX_i=\sin\alpha_i\left(\frac{R_i}{R_c}\right)^2 dR_c+R_i\cos\alpha_c d\alpha_c \tag{10}$$

$$\begin{aligned} dY_i={}&\frac{Y_iR_i}{R_c^2}dR_c\\ &-\left(X_i\cos\alpha_c\frac{\sin\beta_i}{\cos\alpha_i}+R_i\sin\alpha_c\sin\beta_c\right)d\alpha_c\\ &+R_i\cos\alpha_c\cos\beta_c d\beta_c \end{aligned} \tag{11}$$

$$\begin{aligned} dZ_i={}&\frac{Z_iR_i}{R_c^2}dR_c-\left(X_i\frac{\cos\beta_i}{\cos\alpha_i}\cos\alpha_c-\frac{R_i\sin\beta_i\sin\alpha_c\sin\beta_c}{\cos\beta_o}\right)d\alpha_c\\ &-R_i\frac{\sin\beta_i}{\cos\beta_i}\cos\alpha_c\cos\beta_c d\beta_c \end{aligned} \tag{12}$$

In our study, we were particularly interested in the errors produced by a small rotation in the reconstruction beam. If the reconstruction beam is exactly equal to the reference beam, a perfect image would be formed and X_i, Y_i, Z_i, would be equal to X_o, Y_o, Z_o. Usually, to produce the brightest image, the hologram has to be moved slightly from the perfect image condition.

We assumed that α_i, β_i, R_i were equal to α_o, β_o, R_o and the α_c, β_c, R_c were equal to α_r, β_r, R_r. This assumption is not unrealistic because the differences between them are in fact the differential errors which are small. Also it was found that using collimated reference and reconstruction beams ($R_r=R_c=\infty$) eliminated any scaling errors. Under the above conditions the error equations reduced to

$$dX_i=R_o\cos\alpha_r d\alpha_c \tag{13}$$

$$\begin{aligned} dY_i={}&-\left(X_o\cos\alpha_r\frac{\sin\beta_o}{\cos\alpha_o}+R_o\sin\alpha_r\sin\beta_r\right)d\alpha_c\\ &+R_o\cos\alpha_r\cos\beta_r d\beta_c \end{aligned} \tag{14}$$

$$\begin{aligned} dZ_i={}&-\left(X_o\frac{\cos\beta_o}{\cos\alpha_o}\cos\alpha_r-\frac{R_o\sin\beta_o\sin\alpha_r\sin\beta_r}{\cos\beta_o}\right)d\alpha_c\\ &-R_o\frac{\sin\beta_o}{\cos\beta_o}\cos\alpha_r\cos\beta_r d\beta_c. \end{aligned} \tag{15}$$

EXPERIMENTAL RESULTS

Inasmuch as we are predominantly concerned with mensuration aspects of holography, we performed to date a number of tests designed to answer a few fundamental questions. The first of these questions concerned precision of pointing to targets in the virtual holographic image using the previously discussed measuring systems. Next, we were concerned with geometric fidelity of the holographic image. A third aspect which we studied was evaluating the effect of rotating the reconstruction beam from its theoretical position on the geometry of the holographic image. Such a rotation was found to be necessary in order to obtain the brightest image.

TABLE 1. PRECISION IN POINTING ON THE HOLOGRAPHIC MODEL

Observer	*No. of Pointings*	*Standard Deviation in Inches*		
		X	*Y*	*Z*
I. 3/28/70 Tracing table with prism on drafting table				
MKK	20	0.002	0.056	0.021
MKK	20	0.004	0.056	0.018
GHG	20	0.002	0.030	0.015
GHG	20	0.003	0.031	0.025
II. 5/01/70 Tracing table with fiber optic on drafting table				
MKK	10	0.002	0.007	0.012
GHG	10	0.003	0.007	0.035
III. 5/18/70 Tracing table with fiber optic on Kelsh Slate				
GHG	20	0.002	0.003	0.014
GHG	20	0.002	0.007	0.022
IV. 6/26/70 Autograph A7 system				
GHG	10	0.0026	0.0018	0.0142
GHG	10	0.0013	0.0027	0.0129
V. 8/4, 5/70 Autograph A7 system				
GHG	20	0.0022	0.0027	0.0107
GHG	20	0.0034	0.0033	0.0128
GHG	20	0.0029	0.0029	0.0141

Furthermore, we developed a computer program for simulating different situations affecting the geometry of the holographic image. In the following sections we present the results obtained.

POINTING PRECISION

In order to attain a feeling for the task of pointing onto a holographic image as compared to a photogrammetric stereomodel, we performed some 1,000 pointings under varying combinations. Table 1 shows the results for five different situations which were conducted specifically for evaluating pointing precision. These situations follow the chronological order of the development of mensuration systems as discussed above.

GEOMETRIC FIDELITY

Two laboratory test objects were made to serve as targets, and several holograms of each of them were exposed. One target contained 9 regularly spaced machined screws of three different lengths, 1/2, $1\frac{1}{2}$, or $2\frac{1}{2}$ inches. The second target was formed of 20 regularly spaced rods whose lengths varied from 1/2 to $2\frac{1}{2}$ inches, with 1/2-inch spacing. The first target board was measured twice by three observers under similar conditions using the first measuring system of a tracing table with the prism. The raw data were recorded on punch cards and was transformed using a 7-parameter transformation so that we could compare the measured coordinates of the points to their true values.

The second test board with 20 targets was used to make several holograms with $\alpha_r = 0$ but at different recording angles β_r (see Figure 3). Each hologram was viewed under two or three different reconstruction angles β_c and 5 pointings were made on each of the 20 targets. The pooled estimate of the standard deviation was computed from

$$\sigma_p = \frac{\text{Total sum of squares from respective means}}{\text{Total number of degrees of freedom}}.$$

As 5 pointings are made on each of 20 targets, the number of degrees of freedom is 80. The mean of the 5 readings for each target was then used in a 7-parameter transformation to fit them to the test values, and the standard deviations of the residuals were computed. The results from both of these computations are given in Table 2.

EFFECTS OF RECONSTRUCTION BEAM SHIFT

As mentioned earlier, in order to get the brightest image the angle of the reconstruction beam was found to be different from that of the reference beam. This has been mentioned in the literature and is attributed to

TABLE 2. GEOMETRIC FIDELITY OF THE HOLOGRAPHIC MODEL

β_r	β_c		*Standard Deviation in Inches*		
			X	*Y*	*Z*
Tracing table with fiber optic 4/14/4/70, 5/18/70					
50°	50° (Perfect)	Pooled estimate	0.009	0.017	0.017
		Estimate from residuals	0.010	0.008	0.016
		Scale = 1.00899			
	52°	Pooled estimate	0.003	0.005	0.013
		Estimate from residuals	0.011	0.005	0.016
		Scale = 1.00729			
	54° (Brightest)	Pooled estimate	0.003	0.006	0.018
		Estimate from residuals	0.014	0.005	0.017
		Scale = 1.00453			
Tracing table with fiber optic 1/22/4/70/5/19/70					
45°	45° (Perfect)	Pooled estimate	0.004	0.017	0.027
		Estimate from residuals	0.009	0.009	0.018
		Scale = 1.0096			
	49°	Pooled estimate	0.003	0.009	0.019
		Estimate from residuals	0.011	0.013	0.017
		Scale = 1.0130			
Autograph A7 system 4/14/4/70/7/15/0					
50°	50°	Pooled estimate	0.0056	0.0051	0.0261
		Estimate from residuals	0.0063	0.0048	0.0192
		Scale = 1.01147			

shrinkage in the emulsion thickness. Such a shift is a function of the emulsion used, its thickness, the developing process and the geometric location of the object and reference beams relative to the hologram. We were concerned about this shift because it affects the geometric fidelity of the image. If it is sufficiently small, then the error produced can be assumed linear and the geometric fidelity of the image would be preserved. By mounting a plate holder on a modified 1-minute transit (Figure 4), we were able to measure this shift. With Kodak 649F plates, the object normal to the plate, and the reference beam 50° from the normal, we observed a shift of 4°. This was the largest amount of shift we obtained in a number of different tests.

In order to appreciate the effect of this shift on the image geometry, we ran the simulation program for the holographic image of a 4-inch cube. A representative example is given in Figure 5 which shows an exaggerated schematic drawing of the image relative to the object as produced by a Calcomp plot. It depicts a differential error of $+3°$ in α in which α_r was 0° and β_r was 50°.

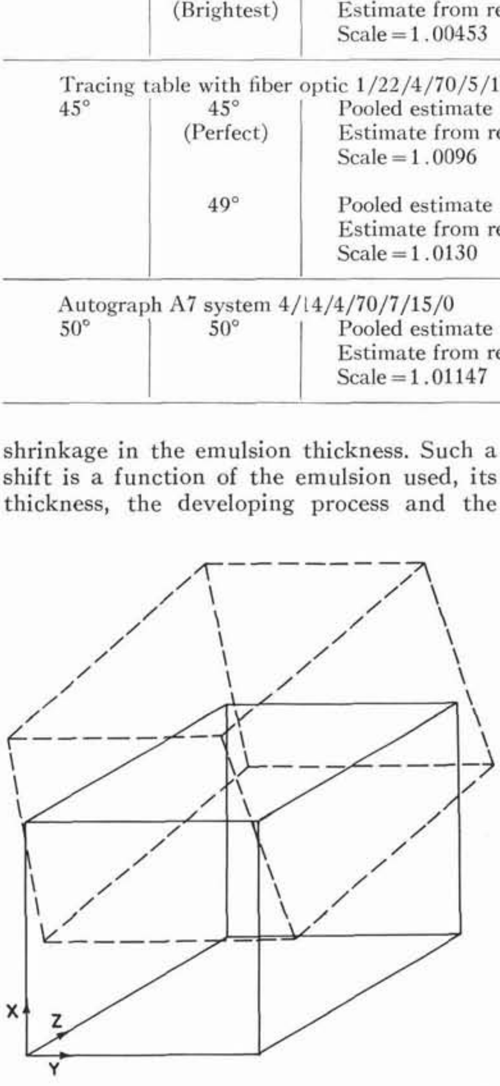

FIG. 5. Simulated shift of a holographic image if $d\alpha_c = 3°$. The original position is shown with a solid line and the shifted position with a broken line.

CONCLUDING REMARKS

A hologram of a three-dimensional object is a true three-dimensional replica of that object, and compared to a conventional stereomodel, it stores more complete information. Therefore, for close-range applications, the hologram would be an attractive alternative to a photogrammetric stereomodel if its mensuration and geometric characteristics were satisfactorily determined. This has been the objective of this research.

With slight modifications of existing photogrammetric tools, it was possible to make direct measurements on holographic images of laboratory test targets. Although the results given are not extensive, it is considered that mensuration of holograms is certainly feasible; only the techniques may need to be modified and improved upon. Furthermore, it should be recognized that we made our own holograms, and therefore an improvement in their quality due to increased experience would be expected.

Having found a practical and efficient means of measuring holographic images, our next concern was with possible geometric distortion. Our efforts so far concentrated on the lack of correspondence between the angles of the reference and reconstruction beams. Through simulation as well as limited laboratory experiments we were able to study this problem and obtain some quantitative results. There are a number of other factors which need to be considered, and we are continuing the research on them at the present time.

This paper is in effect a progress report about a continuing research effort into the general potential and application of holograms for mapping. Such an effort will include a number of fundamental questions both as related to the quality of the hologram and to the application of photogrammetric operations to it. Regarding the quality of the hologram, we shall consider several factors such as: type of emulsion, image contrast, developing process, and the wavelength of the laser used and its effect on the observer's eye. With respect to photogrammetric operations on a hologram we shall consider plotting, contouring and cross-sectioning. Another important problem will be to study the question of magnifying the holographic image through the use of lasers of different wavelengths.

Another very important problem will be to determine the practicality of making holograms of properly restituted photogrammetric stereomodels. All of the efforts expended so far on this phase, all by non-photogrammetrists, were concerned with situations other than a regular stereomodel. We have made preliminary studies on this specific problem and believe that it is possible to make a hologram of a photogrammetric model. However, there are expected to be some difficulties in viewing the images from such holograms.

If we hypothesize at the moment that the above-mentioned difficulties will be overcome, the door will be open for the photogrammetrists to consider many possibilities. Recognizing the simplicity of reconstructing a hologram as compared to a stereomodel, we visualize considerable simplification in future instrumentation required for information extraction. In addition, with the capability of one holographic plate to record several holograms, efficient and economical means of storing photogrammetric data can be expected. Finally, perhaps in the not-too-distant future the hologram itself may be used as a medium for data display in the same way the map has been for so many years.

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