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"Speckle" in Hologams

. . . is a random interference effect caused by phase distortions induced in lasers; it degrades the accuracy of measurement.

Introduction

This work was performed as part of a general program in the metrology of holograms. The objective of this experiment was to test the *stereoscopic* pointing ability of observers in the presence and absence of laser *speckle* in a hologram reconstruction. Settings were made repeatedly, in depth only, on a featureless plane area of a virtual hologram image under conditions of normal reconstruction in which speckle is strong, and also using a diffused reconstruction beam which smears out speckle but degrades image quality. Analysis was then performed to find any significant difference between settings made under these two conditions.

Abstract: *Papers are beginning to appear in the photogrammetric literature on the metric fidelity of holograms, but the precision of pointing and measuring in relation to image quality has not been examined. Power-density speckle patterns induced by random phase refraction of laser light in hologram reconstructions pose a unique image-quality problem where holograms are measured. Measurements made in the presence of steady speckle are compared with those in which the speckle is averaged out by rapid phase changes induced in the reconstruction beam.*

Holograms, which are becoming interesting to photogrammetrists because of their ability to encode depth information in a single frame or picture, can reproduce dimensions of the recorded object very accurately, but the accuracy with which an observer can measure these dimensions may be limited by the effect of *speckle*. Speckle is a random interference effect caused by the phase distortions induced in the laser light with which the hologram is reconstructed by the variations in thickness and refraction of the gelatine on the hologram plate. These variations cause the reproduced hologram to be covered with random light and dark spots, all about 0.1 millimeter in size. This speckle may interact with the reconstructed object on the observer's retina and thus degrade performance.

It is possible to reduce the contrast of speckle to a very low value by placing a moving diffuser (ground glass) in the reconstructing beam[1]. Measurement made with and without this diffuser should show the effect, if any, of this speckle on the observer's performance.

Background

Measurement, particularly measurement involving vernier acuity such as placing similar figures in coincidence or finding the center of a symmetrical figure, is a complex process which depends on a multitude of interrelated, mutually influencing variables. There is, for example, the hand-eye servomechanism central to all manipulation tasks. Within a seemingly simple sensor such as the observer's eye there are also competing and reinforcing mechanisms that influence the subjective response characteristics of observer to scene.

The human eye responds strongly to sharp discontinuities in a scene such as high contrast borders. The sharper the edge, the more it influences the area of the retina on which it is imaged. The array of cones in the retina is much more than a simple collection of light sensors; it is a dynamic single entity with dense cross-connections between cones. These

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interconnections serve to enhance the contrast of a scene by altering the threshold of each sensor in accordance with the stimuli being received by neighboring cells. This mechanism is noticeable, in simple instances as the *Mach-band* phenomenon. It helps us to see detail in our environment more acutely and is generally very helpful in discrimination tasks because it emphasises the differences between subject and background.

Contrast enhancement by lateral inhibition and facilitation, as it is called, can be a disadvantage in some situations, however. Motokawa[2] found that strong figures (high contrast, sharp gradient edges) produce *fields* of retinal response which can distort the perception of other details falling within a small retinal distance from the exciting figure.

This investigation was begun because of these theoretical considerations, and because speckle is annoying to an observer trying to see fine detail in a hologram image. The speckle may also interact with a small measuring mark in a comparator and prejudice results of photogrammetric measurement. If this is true, comparators for measuring holograms should use a reconstruction technique which destroys or minimizes speckle in the reconstructed image for best results.

Experimental Procedure

The granular nature of a coherent image is a direct consequence of the optical roughness of the surface of the object and the recording emulsion interacting with the high coherence of the laser source used for illumination. The size of the individual speckles can be shown to be roughly the size of a single *resolution cell* on the object. This *resolution cell* is the point-spread function of the hologram. If the object of interest is near the resolution limit of the system, the speckle effect can be quite bothersome.

It seems that the only technique in the literature for removing speckle is to use a moving scatterer to change rapidly and randomly the phase of the reconstruction beam wavefront. This technique only works if the scattering plate is placed where the reconstruction beam is wide enough. The illuminating source then becomes a diffused or wide-angle source. The essentials of this technique are outlined by Buinov:[3] "Diffuse illumination widens the hologram spread function and leads to a worsening of the image (Figure 1). . . . the image becomes mottled due to noise caused by the granularity of the scatterer. Disturbance of the illumination coherence by setting the diffuse scatterer into motion leads to an improvement in image quality."

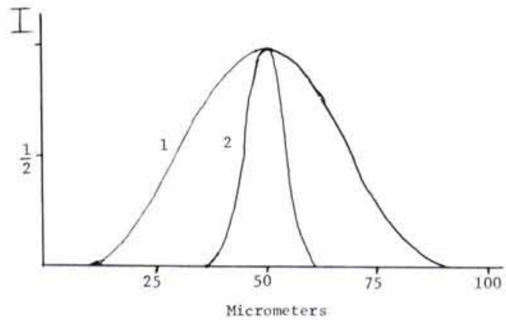

FIG. 1. The spread function of hologram images with a diffuser (*1*) and with a pure collimated beam (*2*). After Buinov[3].

It was found that ground-glass diffused the beam too much so that insufficient energy was delivered to the hologram plate to get a clear reconstruction. A good compromise scatterer was found in the glass of the non-reflecting type used to cover framed photographs. This is a slightly roughened glass that allows most of the laser beam to propagate as in the usual reconstruction but induces enough random phase variation to wash-out speckle if the glass is properly placed in the beam and moved fast enough.

The basic apparatus for the pointings is shown in Figure 2. A three-axis comparator was assembled from a Mann two-axis comparator carrying a Kelsh tracing table with light-point floating mark. The horizontal plane could be measured to within one micrometer with the Mann comparator, but the vertical screw of the Kelsh tracing table had a lower precision, reading out to 0.001 of an inch, or 25 micrometers. To make this axis compatible with the other two, its displacement was read out with a laser interferometer which gave it a least count of 0.2 micrometer.

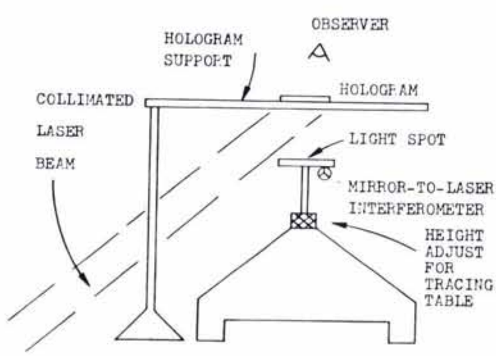

FIG. 2. Diagram of the pointing apparatus.

The hologram was positioned above the comparator in a rigid frame and illuminated by the same beam geometry used for the reference beam when the hologram was made, thereby preserving the geometry of the original object.

The reconstruction beam was collimated and the hologram placed so that the virtual image plane measured was perpendicular to the setting motion along the line of sight of the observer. Only the vertical axis was used to perform the settings, giving a test of stereoscopic acuity only. To avoid any prejudice, the results of settings were read out by a separate observer and not revealed to the person making the settings. The diffuser was cut to a plate 12.7 cm in diameter which was cemented to a motor shaft and mounted in the beam. The plate was rotated at 20 rpm (a speed found to be sufficient to eliminate any flicker from the reconstruction) and placed so that the center of the beam was at a radius of 5 cm. This gave a linear motion of the diffuser of approximately 10 cm/sec. The diffuser was removed from the beam for those pointings with sharp speckle.

The hologram used was made and viewed with a collimated reference beam from a helium-neon laser emitting in the red at 632.8 nanometers wavelength. The object was a white-painted plane base 2 inches square, with dowels of various heights set in the base for different height pointings. For this experiment, settings were made only on an unmarked area of the base between two dowels. This was done to avoid the effect of parallax clues on a marked surface. Three observers performed ten series of ten pointings each in the presence of sharp speckle and ten similar series with a diffuser in the beam to smooth out the speckle. Series were intermixed in an order determined by lottery. Two observers, the author and O'Connor are experienced in this type of setting task. The third observer, Toki, was inexperienced. The author and Toki performed settings from underneath the image up to the surface. O'Connor set the mark from above down onto the image of the surface. Results of pointings were punched onto digital tape and analyzed on a time-shared computer with Fortran programs implementing the mathematics shown below.

Analysis

Each observer performed 100 settings in the presence of sharp speckle and 100 settings with diffused speckle. These settings were grouped in series of 10 ordered as previously described. The standard deviation was found for each series of 10. After this, the standard deviations were grouped according to observer and whether they were with or without speckle. This gave two groups of ten standard deviations for each observer. These groups of standard deviations were tested for homogeneity by Bartlett's criterions.[4] Toki' results without speckle were found to be inhomogeneous. Examination of her data revealed a learning curve due to her inexperience. If her initial two standard deviations without speckle were replaced by those from two new sets of observations, the resulting group of 10 standard deviations was found to be homogeneous.

Where homogeneity of groups of standard deviations had been proven, each group of ten standard deviations was considered to be a normally distributed variable, and the mean standard deviation and its standard deviation were found for these groups. The hypothesis to be tested was whether or not there was a significant difference in the setting accuracy in the presence of sharp speckle as compared with the accuracy of setting with diffused speckle. Standard deviation of settings was considered to be a proper index of ease of setting. If a significant difference occurred between the average standard deviation for the two instances for a given observer, one could say whether or not removal of the speckle by a rotating diffuser is beneficial to stereoscopic measurement. Significance is tested by applying the t-test to the comparison of the difference between the two group standard deviations and its standard deviation. A summary of the results follows in Table I.

TABLE 1. THE STANDARD DEVIATIONS OF "STEREOSCOPIC" SETTING, AND THEIR DIFFERENCES FOR THREE INDEPENDENT OBSERVERS IN RED LIGHT

Observer	*McDonnell*	*Toki*	*O'Connor*
Setting Direction	From below	From below	From above
$S_{diffuse}$	0.282	0.402	0.305
$S_{speckle}$	0.214	0.436	0.270
S of $S_{diffuse}$	0.093	0.098	0.077
S of $S_{speckle}$	0.099	0.083	0.065
ΔS*	0.067	−.034	0.035
S of ΔS	0.135	0.129	0.103

* $\Delta S = S_{diffuse} - S_{speckle}$

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