*Significant Findings of a Stereoscopic Acuity Study**

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ABSTRACT: *A study was performed under contract with the U. S. Army Engineer Research and Development Laboratories, by the University of Rochester Institute of Optics, New York. The comparison of operator stereoscopic acuity was made under a variety of viewing conditions chosen as representative of those found in present-day photogrammetric stereo-plotting instruments. Thirty observers performed 47,000 stereoscopic elevation readings from which comparisons were obtained. The results are given and some significant interpretations are made.*

I. INTRODUCTION

THE development of photogrammetry as a method of mapping physical features has led to considerable interest concerning factors which affect operators of photogrammetric equipment. Much has been written of the theoretical aspects of stereoscopic acuity, but apparently not much data exists on practical tests that measure stereoscopic acuity under controlled conditions.

A contract titled "Study of Visual Stereoscopic Acuity" was awarded in April 1956 by the U. S. Army Engineer Research and Development Laboratories to the University of Rochester Institute of Optics, New York. The contract was completed in July 1958. This paper is a summary of the work with an evaluation of the test results from that contract.

Forty-seven thousand stereoscopic elevation settings, made by 30 observers, were analyzed to obtain the results presented. The observers were University of Rochester students who had been selected from a larger number. They were tested for stereopsis by means of the Keystone M1A1 Stereoscopic Tester. The students had been given approximately eight hours of training in the use of the Multiplex and Stereocomparagraph.

Conventional aerial photographs of an Arizona test area, taken at 10,000 ft. with a six-inch focal-length camera, were supplied by USAERDL. However, the contractor experimented with laboratory stereophotographs made with an 8- by 10-inch view camera containing a $6\frac{1}{4}$-inch Wollensak Anastigmat lens. The standard six-tenths Base-Height ratio was obtained by using a 175 mm. working distance and a camera separation of 124 millimeters. The difference in perception between the aerial and laboratory photographs was found to be negligible, therefore, the contractor decided to use the laboratory-made photographs.

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Figure 1 shows the targets. These were 6 miniature tents photographed against a model of hilly terrain and oriented in a manner such that their ridges were parallel to the X-direction. Ten settings were made on each target in random order by each observer, for

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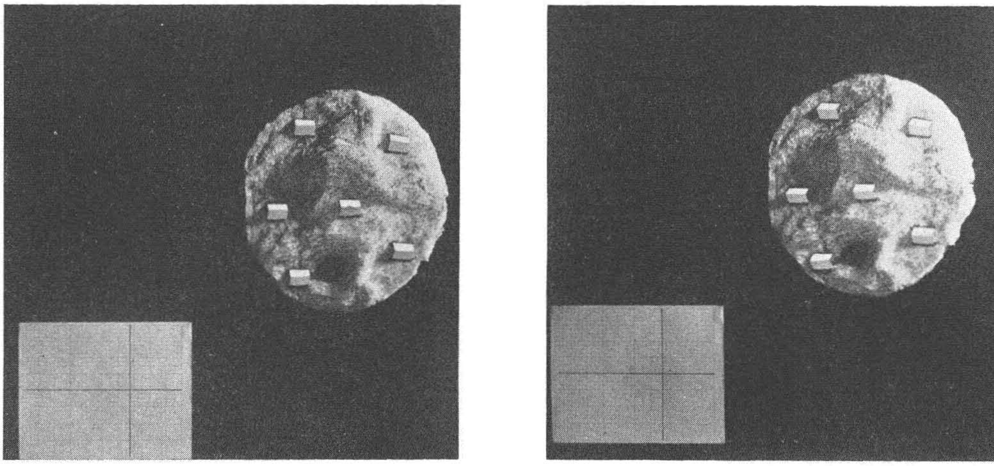

FIG. 1. Stereogram of targets used in study.

every viewing condition. The standard deviations of settings for the individual targets were computed and averaged to yield an index of accuracy. Six experiments were performed to determine the effects of the eight viewing conditions. All of the vertical measurements were converted to their equivalent of horizontal parallax and reduced to a common scale.

II. Comparison of Near and Far Vision

The first problem involved a comparison of Near and Far-Vision. Projector-type stereoplotting instruments, such as the Multiplex and Kelsh Plotters, require that the operator's eyes converge and accommodate for near-vision during operation. Binocular instruments such as the Stereoplanigraph and the Wild Plotters require that the operator's eyes be accommodated for infinity. In Experiment One, the contractor attempted to reproduce this effect by modifying the standard Multiplex; two platens were fastened to the tracing table with the mirror and lens assembly of the Stereocomparagraph placed above them. The Multiplex images were separated and a white light was used to duplicate Far-vision. The lenses were removed and the platens were pushed closer together to simulate Near-vision.

A comparison of the results showed an improvement of 7.9 per cent in the operator's ability to repeat Near-vision stereoscopic measurements over Far-vision viewing.

III. Correlation of Interpupillary Distance to Stereo Acuity

The approximate ratio of the human eye-base (interpupillary distance) to viewing distance varies from 0.22 to 0.30 for near-vision, if the viewing distance is accepted as ten inches. Measurements were taken during the progress of the experiments to determine whether the near-vision stereoscopic acuity of individuals has any correlation to their interpupillary distance. A group of 30 observers whose interpupillary distances varied from 57 to 71 millimeters had an average distance of 63.4. The correlation factor of interpupillary distance to stereo acuity was 0.0143, showing little or no correlation. This experiment confirmed that variations in physical features play only a very small part in near-vision stereo observation.

IV. Comparison of Illumination Intensity

Another problem studied was the effect upon stereo acuity of the intensity of the illumination used in photogrammetric instruments. This effect was tested by using a pair of transparencies (film-positives) placed in the Stereocomparagraph, mounted over a light table. The luminance level was varied to yield 1, 10, and 100 millilamberts. Increasing the illumination from 1 to 10 millilamberts improved the stereo acuity 9.7 per cent; however increasing the illumination ten times again, decreased the acuity 2.2 per cent from the level at 10 millilamberts.

This experiment, in which the luminance was varied from 1 to 100 millilamberts, is considered to indicate that a continual increase in illumination will make the stereo acuity larger to some optimum level higher than 10 but lower than 100, beyond which the acuity will decrease as the luminance is increased. A further investigation should be conducted with considerably more varied illumination intensities to find the range of the average operator's most satisfactory luminance level.

V. Comparison of Unbalanced Illumination

In all stereo viewing systems difficulty is experienced in maintaining equal levels of illumination. Unequal illumination was tested by using transparencies mounted on a light box and viewed with the Stereocomparagraph. A luminance of ten millilamberts was maintained for the left eye. A neutral filter was used under the right transparency to reduce the illumination by 50 per cent. A 2.4 per cent loss of acuity was noted for the unbalanced illumination.

In this particular experiment, the observations were made on stationary targets, and differences that may occur when the floating mark is moving, as in contouring, were not indicated. The small loss of stereo acuity for a 50 per cent disparity of illumination indicated that the eyes can accommodate a considerable imbalance of illumination before the stereo acuity is affected. Further studies of light imbalance using a moving floating mark to observe Von Gruber's "circling effect" might result in other conclusions.

VI. Comparison of the Use of Transparencies with Opaque Prints

A comparison was made of the relative merits of viewing transparencies and opaque prints by using the Stereocomparagraph. One set of readings was made with opaque prints, the other set with transparencies. The illumination level of 10 millilamberts was maintained for both tests. An improvement of 12.8 per cent was noted when the transparencies were used in place of the opaque prints. This observation would tend to suggest that third-order plotters should have means for the viewing of transparencies as well as opaque prints.

VII. Comparison of Color Separation to White Light

Several types of stereoplotting instruments obtain their view by complementary color separation. A series of tests was made to compare anaglyphic (color separation) viewing with that by transmitted white light. Using the same arrangement as in the near and far-vision test, one run of the conventional Multiplex with anaglyphic illumination was recorded and used for control. Another run was made using white light. The resulting standard deviations indicated that the white light system improved stereo acuity 7.0 per cent over the anaglyphic system of using colored filters. It could be argued that modification of the projected image system to use white light would have a slight advantage over the conventional anaglyphic viewing system.

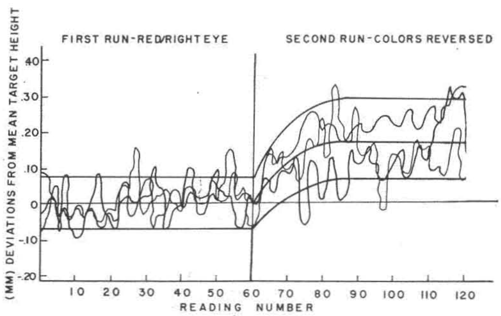

FIG. 2. Diagram showing effects of color.

VIII. Effect of the Reversal of Color Filters

An experiment was conducted with the Multiplex to determine the effect of the abrupt reversal of color filters. One series of readings was made with the red light entering the right eye; the colored glasses of the operator and the filters of the Multiplex were abruptly reversed, and an immediate series of readings was made with the red light entering the left eye. Figure 2 represents the trend of three observers, three solid lines indicating the average and spread of readings, before and after the colors in the Multiplex were reversed. The number of readings are indicated at the bottom; the scale at left shows the magnitude of the deviations. The vertical center line represents the moment of reversal. Observe the effect after the colors have been reversed, not only are the deviations greater, but the datum also was changed.

It was found that considerable loss of accuracy occurred during the first 5 minutes and the drift continued over the next 15 or 20 minutes. The average standard deviations, when comparing the results before and after reversal, showed a loss of 14.3 per cent in accuracy. This loss caused by the reversal of colors could be responsible for some of the accuracy loss which generally accompanies Multiplex bridging operations.

IX. Comparison of the Color of Illumination

The effects of uniform colored illumination for both eyes, upon stereo acuity, were next studied. Filters of red, green, and blue, as well

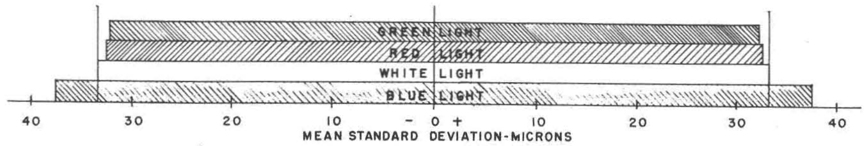

FIG. 3. Comparison of colored illumination in stereo acuity.

as clear white light, were used. Because of the density of the filters, the work was done at a uniform illumination level of 1 millilambert. The transparencies were viewed through the Stereocomparagraph mounted on a light table. Figure 3 shows a comparison of results of measurements using three colors of illumination with clear white light. The scale at the bottom represents the standard deviation above and below the mean. Using white light as a standard, red light improved the stereo acuity by 3.0 per cent; green light by 3.3 per cent, while blue light impaired the stereo acuity by 12.9 per cent. Almost all of the observers complained of the blue light, that the contrast seemed low and that the black floating mark was hard to detect in the shadows. The loss in accuracy might have been less if a bright floating mark had been used in the Stereocomparagraph. The use of colored filters has been widely adopted by European manufacturers of plotting instruments.

X. Relation of Resolving Power to Stereo Acuity

The final experiment was conducted to determine the effects upon stereo acuity of varying the resolution of viewed transparencies. The relationship of resolving power to stereo acuity was tested by printing the original targets in five conditions of resolution. One contact pair of transparencies was made with high resolution. A second stereo pair of transparencies was made with both images printed through one thickness of plastic sheeting and was labeled half-blurred. A third pair was made with the right image printed half-blurred and the left image printed sharp. A fourth pair was made with both images printed through two thicknesses of plastic sheeting and was labeled full-blurred. A fifth pair was made with the right image printed through two thicknesses of plastic sheeting, while the left image remained sharp.

The Stereocomparagraph mounted over a light table which maintained ten millilamberts of illumination was used to view the various combinations of sharp and blurred images. Figure 4 represents the four conditions of diminished stereo acuity compared to that of the high resolution targets. The mean standard deviations are shown in microns at the left side. As the stereo acuity decreases, the spread of the mean standard deviation increases. Both eyes viewing targets printed through one thickness of plastic showed a decrease of 2.7 per cent in stereo acuity compared to that with contact prints. With the right eye viewing a half-blurred image and the left eye viewing a sharp image, a decrease of 24.2 per cent in acuity was noted. With both eyes viewing transparencies printed with two thicknesses of plastic, a decrease of 32.5 per cent was noted. With the right eye viewing a fully-blurred image and the left eye viewing a sharp image, the decrease in acuity was 70.7 per cent.

During the progress of the experiment it became apparent that the eyes could accommodate a considerable loss in resolution before there was an appreciable loss in stereo acuity as long as the images were paired. As soon as one image became poor compared to the other, there was a marked loss in acuity.

The conditions mentioned above may occur in a stereomodel where the center of one vertical photograph is in stereo with the edge of the other photograph, since the resolution is generally poorest at the outer limits of aerial photographs. It could be argued that stereo acuity and the ability to make accurate measurements should be improved for all models which have 100 per cent overlap, such as convergent photography. These results

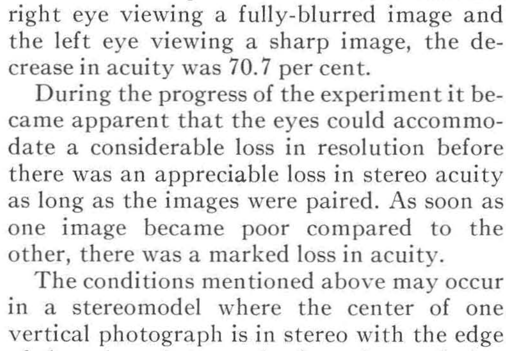

FIG. 4. Diagram showing variations of acuity as a function of resolution.

also indicated a greater need for uniformity rather than an increase in the resolution of aerial photography to be used for mapping.

XI. Evaluation

The merit of this study lies in the great care that was exercised in eliminating differences in the conditions within each experiment-differences which might detract from the reliability of the measurements. The great number of measurements that were made strengthen the validity of small differences in stereo acuity that were found. There are many more variables of stereoscopic viewing which should be studied; however it is hoped that the information in this paper will be useful in the future development of stereo measuring equipment.

*Photogrammetric Measurements in Structural Research**

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ABSTRACT: *The photogrammetric method can be used as a measuring tool for different testing programs in structural research. This paper deals with the advantages, disadvantages, measuring accuracy, and limitations of photogrammetry. Practical applications to test specimens are illustrated.*

Introduction

During recent years, non-topographic photogrammetry has been widely discussed by photogrammetrists and engineers. At the same time, several illustrations of photogrammetric deformation measurements for structural members have been performed in the United States and foreign countries. Photogrammetric methods among other advantages for structural research provide answers rapidly; but, currently, such methods are not widely used as a measuring tool. The reasons for this under-development in applications to structural research are that the required instruments are difficult to obtain and are too expensive. These difficulties might be overcome by the production of standareized instruments which are versatile enought to be used for different purposes but are as simple, rugged, and economical as possible.

Historic Background

In 1937, Dr. Max Zeller had measured the interior roughness of waterpipes by the photogrammetric method,[1] with a special camera designed to photograph objects at close distances.

Professor K. B. Jackson of Toronto University of Canada presented his paper, "An Application of Photogrammetry in Structural Research," at the semi-annual meeting of the American Society of Photogrammetry in 1954.[2] His work dealt with the deformation of curved thin plates under axial loads.[3]

Dr. Bertil Hallert described the test of model airplane wings by a photogrammetric method[4] in PHOTOGRAMMETRIC ENGINEERING, December, 1954.

Around 1955, students at Ohio State University measured the deflections of simple supported beams and slabs photogrammetrically.[5]

At the semi-annual meeting of the American Society of Photogrammetry in March, 1958, Dr. R. D. Turpin presented his research on deflection measurements of highway pavement and soil movements.[6]

Basic Principle

The principle of photogrammetric measurement used in structural research is much

* This paper was awarded Second Prize in the 1958 competition for the Bausch & Lomb Photogrammetric Award. Photo of author is on page 314 of 1959 YEARBOOK.