BIBLIOGRAPHY

Donaldson, D. C., "Camera for Stereoscopic Photography of Anterior Segment." *Arch. Ophth.*, 43: 1083–1087, 1950.

Donaldson, D. C., "A Stereo-camera for Medical Photography." *Medical & Biological Illustration*, 5: 209–216, 1955.

Linssen, E. F., "Stereo Photography in Practice," London, Fountain Press, 1952.

Morgan, W. D., and Lester, H. M., "Stereo Realist Manual," New York, Morgan & Lester, 1954.

A New Stereoscopic Camera for Extreme Close-ups. *Instrument News*, Perkin-Elmer Corp., Norwalk, Connecticut, p. 6, Vol. 6, No. 3.

*Macrophotogrammetry with the Donaldson Stereo-Camera**

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INTRODUCTION

THE Donaldson Stereo-Camera[1] is being utilized primarily in the fields of ophthalmology and pathology for qualitative analyses. The purpose of this report is to demonstrate and to determine the quantitative capabilities of a camera designed specifically for the interpretation of stereoscopic photographs of the eye and of gross specimens.

The only Donaldson Stereo-Camera conveniently available for metrical analysis was located at the Armed Forces Institute of Pathology, Washington, D. C. which undoubtedly is one of the most modern and well equipped laboratories of its kind in the world. The responsible officials of the Institute encouraged the metrical analysis of the Donaldson Stereo-Camera. A request was made to the Institute for a one day loan of the camera for the purpose of making an elaborate calibration. The loan was not approved for the very legitimate reason that the camera must remain in a continual stand-by condition for emergencies and other unscheduled demands.

Inasmuch as the camera could not be removed from the Institute, it was decided to conduct the analysis in a more simplified manner so that technicians not versed in the science of photogrammetry can duplicate the following procedure.

CAMERA CALIBRATION

Prepare a glass plate grid of transparent lines on a black background. The interval between lines is 5 millimeters. Place the grid, with emulsion side up, on a trans-illuminator (Figure 1).

The scale indicator on the side of the camera is set opposite the index 1 (ratio of image size to object size). The angular orientation of the camera is adjusted and locked when the optical axes are perpendicular (or nearly so)

* This is one of the papers included in the Report of the Reporter for U.S.A. Commission V of the International Society of Photogrammetry.

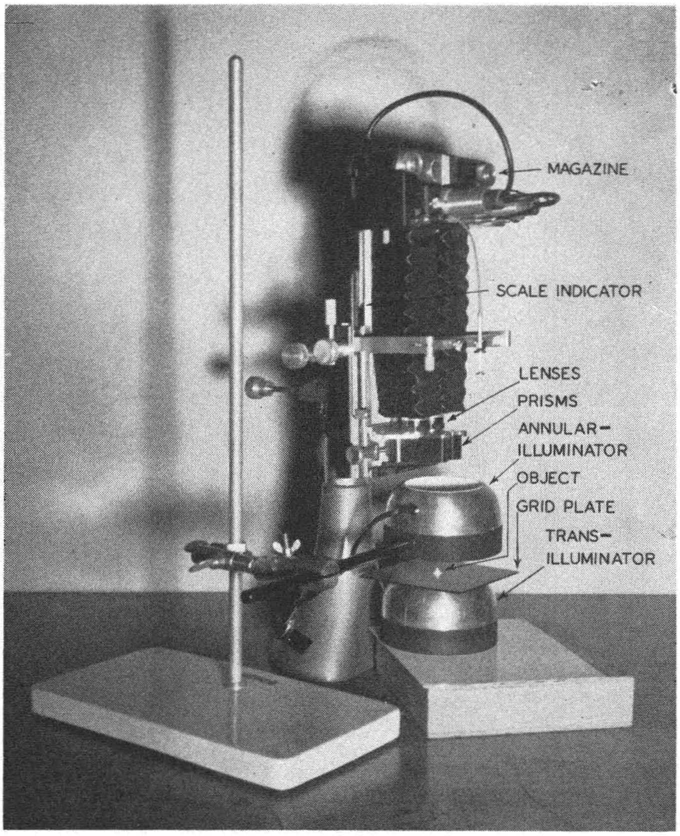

FIG. 1.—Donaldson Stereo-Camera set up for macrophotography.

to the plane of the grid. The entire camera is racked along the vertical column until the grid is in focus.

The Donaldson Stereo-Camera does not include facilities for a time exposure inasmuch as it is designed solely and specifically for electronic flash in all operations. Remove the camera housing and actuate the mechanism to retain the reflex mirror (which also serves as a shutter) in the up position.

A minimum of two elements of camera calibration must be determined:

1) FOCAL LENGTH OF THE OPTICAL SYSTEM

The nominal focal length of the matched stereo-lenses is 80 millimeters. However, two large rhomboidal prisms are located in front of the lenses. The prisms can be rotated and are indexed relative to scale. The camera base is variable but is constant for a given scale. The focal length of the 80 millimeter lens, in combination with the prism, must be determined.

2) PHOTO BASE OF THE STEREO-CAMERA FOR A GIVEN SCALE

The scale selected for the evaluation is 2 (the image size being twice that of the object size). The photo base is equal to the camera base at the scale of the photograph.

The camera calibration is performed without determining lens distortion or the location of the principal point, owing to a lack of facilities, and an intentional oversimplification as an initial approach.

The entire room is darkened. Unexposed film is advanced into position. The trans-illuminator is turned on to make the exposure of the grid. After sufficient exposure, the trans-illuminator is turned off. The film is advanced. The requirement of darkening the room would not be necessary if the shutter included "bulb" or "time" setting rather than being fixed at 1/50 second.

The same procedure is repeated for a scale setting of 2. However, one additional step is required, and that is an intentional double exposure of an object. After the grid is exposed for a scale setting of 2, the film is not advanced but an object 6 millimeters high is placed on the grid and is exposed with the annular-illuminator (Figure 1). This illuminator is turned off after a sufficient exposure. The film is advanced and the room light turned on. The double exposure procedure is similar to the technique used for years by still and motion picture photographers for special effects. The film is removed from the camera and processed.

a) *Determining the focal length:*

1) The measured distance between points a_1 and b_1 (Figure 2) on the right negative of stereo-pair No. 1 is 25.05 millimeters.
2) The measured distance between corresponding points A_1 and B_1 on the grid is 25.00 millimeters.
3) The scale of the negative is

$$S_1 = \frac{a_1b_1}{A_1B_1} = \frac{25.25}{25.00} = 1.010.$$

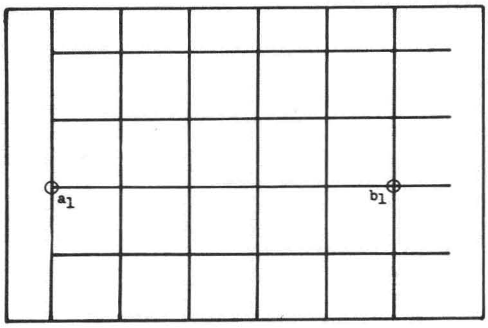

FIG. 2. Point designation for Stereo-Pair No. 1.

4) Repeat steps (1) and (2) above for stereo-pair No. 2 (Figure 2).
5) The scale of the negative is

$$S_2 = \frac{a_2b_2}{A_2B_2} = \frac{19.25}{10.00} = 1.925.$$

6) The measured distance (Δd) between the indices 1 and 2 on the scale plate is 83.4 millimeters.
7) The focal length of the Stereo-Camera optical system is

$$f = \frac{\Delta d}{S_2 - S_1} = \frac{83.4}{1.925 - 1.010} = 91.1 \text{ millimeters.}$$

b) *Determining the photo-base:*

1) The object distance for stereo-pair No. 2 is

$$D = f\left(1 + \frac{1}{S_2}\right) = 91.1\left(1 + \frac{1}{1.925}\right) = 138.4 \text{ millimeters.}$$

2) The differential parallax (Δp) between the grid intersection c and the top of the object n (Figure 3) is measured with a stereometer and found to be 1.60 millimeters.
3) The height of the test object (h) is measured with a micrometer and found to be 6.00 millimeters.

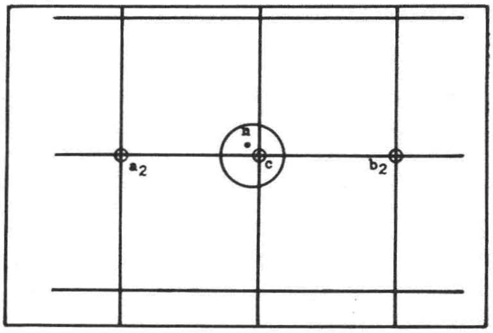

FIG. 3. Point designation for Stereo-Pair No. 2.

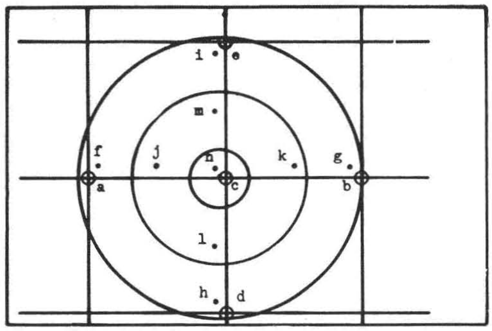

FIG. 4. Point designation for Stereo-Pair No. 3.

4) The photo base is

$$b = \frac{\Delta p(D - h)}{h} = \frac{1.60(138.4 - 6.00)}{6.00} = 35.3 \text{ millimeters.}$$

MEASURING THE OBJECT

An aluminum test object is turned on a lathe and is measured by means of a micrometer. The dimensions are annotated in Figure 6.

The purpose of this phase of the investigation is to determine how closely the same micrometer dimensions can be measured photographically with previously determined calibration data of (1) the focal length (91.1 millimeters) and (2) the photo base (35.3 millimeters).

The procedure is as follows:

1) *The measured distance between points a and b* (Figure 4) on the right negative of stereo-pair No. 3 is 19.35 millimeters.
2) *The measured distance between corresponding points A and B* on the grid in object space is 10.00 millimeters.
3) *The scale of the negative is*

$$S = \frac{ab}{AB} = \frac{19.35}{10.00} = 1.935.$$

4) *The object distance (D) for stereo-pair No. 3* is

$$D = f\left(1 + \frac{1}{S}\right) = 91.1\left(1 + \frac{1}{1.935}\right) = 138.2 \text{ millimeters.}$$

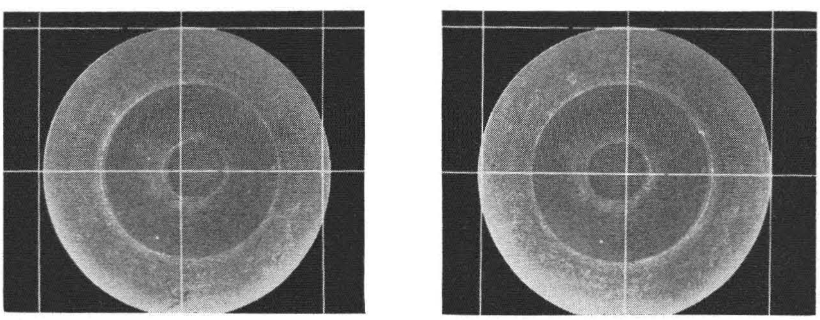

FIG. 5. Stereo-Pair No. 3. (Enlarged 2× for publication.)

TABLE 1. PARALLAX READINGS AND PARALLAX CORRECTIONS FOR STEREO-PAIR NO. 3

Point	Parallax Reading (mm.)	Parallax Correction (mm.)	Corrected Parallax (mm.)
a	4.30	−0.04	4.26
b	4.22	+0.04	4.26
c	4.26	+0.00	4.26
d	4.24	+0.02	4.26
e	4.28	−0.02	4.26
f	4.84	−0.04	4.80
g	4.76	+0.04	4.80
h	4.75	+0.02	4.77
i	4.81	−0.02	4.79
j	5.36	−0.02	5.34
k	5.31	+0.02	5.33
l	5.32	+0.01	5.33
m	5.34	−0.01	5.33
n	5.85	0.00	5.85

5) Refer to the MANUAL OF PHOTOGRAMMETRY[2] for instructions on stereometer-type instruments. The parallax readings and parallax corrections for stereo-pair No. 3 are given in Table 1.

If there were no tilt (negative plane parallel to grid plane), lens distortion, film distortion, calibration error, operator's error in reading the parallax, or other inaccuracies, the parallax correction would be zero for all points. A parallax correction of zero for all points is an idealized condition and is never realized in practice. However, the parallax correction is so easily computed that it can be accomplished mentally. The parallax correction permits the simplification of the procedure outlined in this report, such as the total disregard for lens distortion, location of the principal point, and the magnitude of tilt. There is a resultant error owing to the intentional neglect of these and other factors, but the bulk of the resultant error is compensation in one simple parallax correction operation.

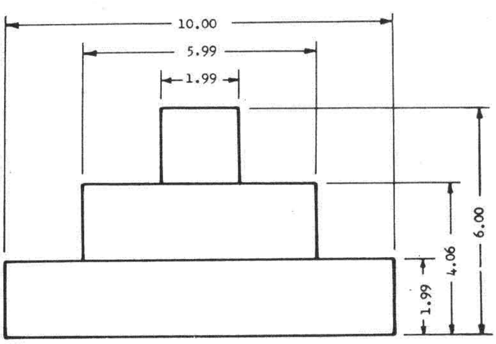

FIG. 6.—Micrometer dimensions of test object in millimeters.

For example, it is known that points *a*, *b*, *c*, *d*, and *e* are of equal elevation since they lie in the plane of the grid. It is also known that parallax readings on points of equal elevation are identical, under the idealized normal case of stereophotogrammetry. Selecting point *c* as the reference (since it is located near the center of the photograph) point *a* must be corrected by −0.04 millimeter to equal the parallax reading at *c*; *b* by +0.04 millimeter, *d* by +0.02 millimeter, and *e* by −0.02 millimeter. All other points are corrected by mentally interpolating between the correction values for the grid points *a*, *b*, *c*, *d*, and *e*. The correction for point *j* is −0.02 millimeter since it is approximately half way between point *a* with a correction of −0.04 millimeter and point *c*, with a correction of 0.00 millimeter.

6) Points *a*, *b*, *c*, *d*, and *e* are designated as plane No. 1; points *f*, *g*, *h*, and *i* as plane No. 2; points *j*, *k*, *l*, and *m* as plane No. 3; and point *n* as

plane No. 4. The parallax readings for the points representing the individual planes are averaged and are as follows:

Plane	*Average Corrected Parallax Reading (mm.)*
1	4.26
2	4.79
3	5.33
4	5.85

The differential parallaxes between the planes, with grid plane No. 1 as the reference, are as follows:

Planes	*Differential Parallax* (Δp), *(mm.)*
1 to 2	0.53
1 to 3	1.07
1 to 4	1.59

7) *The difference in elevation* between the planes is

$$h = \frac{(\Delta p)(D)}{\Delta p + b} .$$

Planes 1 to 2:

$$h_{1-2} = \frac{(0.53)(138.2)}{0.53 + 35.3} = 2.04 \text{ millimeters.}$$

Planes 1 to 3:

$$h_{1-3} = \frac{(1.07)(138.2)}{1.07 + 35.3} = 4.07 \text{ millimeters.}$$

Planes 1 to 4:

$$h_{1-4} = \frac{(1.59)(138.2)}{1.59 + 35.3} = 5.96 \text{ millimeters.}$$

8) *The image diameter* (w) *of planes 2, 3, and 4* are measured on the right negative of stereo-pair No. 3 and are recorded as follows:

Plane	*Image Diameter (mm)*
2	19.65
3	11.90
4	4.05

9) *The object diameter of the planes is*

$$W = \frac{(w)(D - h)}{(S)(D)} .$$

Plane 2:

$$W_2 = \frac{(19.65)(138.2 - 2.04)}{(1.935)(138.2)} = 10.01 \text{ millimeters.}$$

Plane 3:

$$W_3 = \frac{(11.90)(138.2 - 4.07)}{(1.935)(138.2)} = 5.97 \text{ millimeters.}$$

Plane 4:

$$W_4 = \frac{(4.05)(138.2 - 5.96)}{(1.935)(138.2)} = 2.00 \text{ millimeters.}$$

10) *Summary of measured data:*

Dimension	*Micrometer Measurement*	*Photographic Measurement*	*Absolute Error*	*Relative Error*
h_{1-2}	1.99 mm.	2.04 mm.	+0.05 mm.	+2.5%
h_{1-3}	4.06 mm.	4.07 mm.	+0.01 mm.	+0.2%
h_{1-4}	6.00 mm.	5.96 mm.	−0.04 mm.	−0.7%
W_2	10.00 mm.	10.01 mm.	+0.01 mm.	+0.1%
W_3	6.00 mm.	5.97 mm.	−0.03 mm.	−0.5%
W_4	2.00 mm.	2.00 mm.	0.00 mm.	0.0%

Conclusions

The accuracy of the equipment together with the simplified procedure exceeded expectations. The basic principles comprising the system can be utilized, in many instances, for special applications within science and industry.

Increased production and accuracy requirements can soon justify the amortization of more elaborate photogrammetric plotting equipment and the related refinements.

Recommendations

If greater accuracy is required, it is recommended that the camera base be increased inasmuch as the vertical accuracy is directly proportional (approximately) to the camera base (B). For instance, the camera base for the previous example is

$$B = \frac{b}{S} = \frac{35.3}{1.935} = 18.2 \text{ millimeters.}$$

If the camera base were doubled to 36.4 millimeters and all other factors remained constant, the elevation errors would be reduced one-half. If the base were doubled, it would become necessary to use a wide-angle lens. Convergent photography can be utilized in place of a wide-angle lens, but the solution becomes more involved.

The base-height ratio for the numerical example is

$$R = \frac{B}{D} = \frac{18.2}{138.2} = 0.13.$$

The base-height ratio for vertical aerial photography exposed by a 6 inch focal-length lens on a 9×9 inch format with 60 per cent overlap is 0.60 or 4.6 times greater than the 0.13 ratio of the Donaldson Stereo-Camera at a scale of 2. If the height errors of the numerical example were reduced by a factor of 4.6, the maximum error would be 0.01 mm.

The aluminum test object in this report was specifically chosen inasmuch as it could be easily measured by means of a micrometer for comparison with the photographic method. However, if a pencil attachment is secured to the stereometer, then the cornea Figure 4g of Halsman's paper,[1] can be contoured using the tick marks as control.

ACKNOWLEDGMENTS

Grateful acknowledgement is extended to Julius Halsman, Chief, Photography Division and Charles E. Edwards, Chief, Photomicrography Section for producing the photography and to Herman Van Cott, Chief, Medical Illustration Service, for this cooperation in making the facilities of the Armed Forces Institute of Pathology available. Grateful acknowledgement is also extended to the U. S. Geological Survey for furnishing a negative plate of a precise master grid.

REFERENCES

1. Halsman, Julius, "Stereoscopic Medical Photography." PHOTOGRAMMETRIC ENGINEERING, Vol. XXII, No. 2 (1956).
2. McNeil, Gomer T., "Map Compilation with Stereometer-type Instruments." MANUAL OF PHOTOGRAMMETRY, Chapter XIII (1952).

NEWS NOTE

NOLAN HEADS GEOLOGICAL SURVEY

Dr. Thomas B. Nolan has been appointed by President Eisenhower to succeed Dr. William E. Wrather as Director of the United States Geological Survey.

Dr. Nolan has been Assistant Director since December 1944, is a graduate and Ph.D. of Yale University, and has been a career Civil Service employee since his appointment as a junior geologist in 1924.

A member of the National Academy of Sciences and the American Academy of Arts and Sciences, he received the Spendiaroff Award of the XVI International Geological Congress in 1933, and "for meritorious achievement in advancing the science of tungsten," the K. C. Li Gold Medal and $1,000 Prize in 1954.

Between 1925 and the late 1930's Dr. Nolan mapped several mining districts in Utah and Nevada including Gold Hill and Tonopah. Later he was given the assignment of planning and organizing the Survey's studies of all tungsten deposits in this country.

Dr. Nolan is a past president of the Society of Economic Geologists and a member of many scientific and professional organizations, including the Geological Society of America, Mining and Metallurgical Society of American, Geological Society of Washington, American Geophysical Union, American Society of Photogrammetry, American Ornithologists Union, the Explorers Club of New York and the Cosmos Club of Washington.

Dr. Wrather, who is retiring, first joined the Survey for the summer of 1907 and later rejoined when he was appointed Director in 1943. He has guided the activities of the Geological Survey through 12 years of growth in service to the Nation during the difficult years of war and the later period of adjustment to an expanding economy.

Dr. Wrather is well-known to scientists and petroleum men everywhere for his pioneering applications of geology to the underground search for oil, for his discovery of the Desdemona oil field in Comanche County, Texas, and for his war time service with the Metals and Minerals Division of the Board of Economic Warfare. In 1950 Dr. Wrather was awarded the Anthony F. Lucas Petroleum Medal of the American Institute of Mining and Metallurgical Engineers, and in 1954 the 50th John Fritz Medal, highest engineering award in this country.