A UNITED STATES
DEPARTMENT OF
COMMERCE
PUBLICATION

NOAA Technical Memorandum NOS 10

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Survey

Evaluation of the Space Optic Monocomparator

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ROCKVILLE, MD.

June 1971

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EVALUATION OF THE SPACE OPTIC MONOCOMPARATOR

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UDC 528.722.81.001.42

528.7	Photogrammetry
.722	Instruments for restitution of photograms in photographic central projection
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EVALUATION OF THE SPACE OPTIC MONOCOMPARATOR

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ABSTRACT. This report describes a series of metric tests performed to evaluate the overall performance of a new monocomparator design. The test results demonstrate that the comparator is mechanically stable for precise measurements, is virtually free of screw backlash, and can produce measurements accurate to a standard error of better than 2 micrometers. The comparator design is metrically sound for use with glass plates.

INTRODUCTION

The Space Optic Monocomparator has recently been made available to the general photogrammetric market. Readers not familiar with its measuring principles and its design characteristics should acquaint themselves with Smialowski (1963), Krishnamurty and Smialowski (1966), and Space Optic Limited (1970).

Because of unique design of the monocomparator, a test of the screw harmonics was not performed in this evaluation. Also, since the comparator contains 144 dot-shaped measuring marks beside 144 cross-shaped measuring marks, a complete calibration of all measuring marks would be too lengthy and expensive. Instead, a well-distributed sample of 25 cross measuring marks was chosen as statistically representative of the total array.

EVALUATION

Four measurement tests were performed to evaluate the precision, accuracy, and overall performance of the comparator: 1) pointing precision, 2) measuring screw backlash, 3) mechanical stability, and 4) measuring accuracy. A 10- by 10-inch calibrated glass grid plate was used for all of the test measurements performed. This calibrated grid plate is engraved with lines 10 micrometers in width arranged to form a 20-cm. square array containing 25 grid line intersections (reseau points) spaced at intervals of 5 cm. The standard error of the calibrated coordinate values (σ_g) is 0.25 micrometers for this grid test plate. Descriptions and results of these tests are as follows:

Pointing Precision

The pointing precision (σ_{p_s}) for each of four calibration sets of measurements was computed by:

$$\sigma_x = \sqrt{\frac{\sum_{j=1}^{p}\left\{\sum_{i=1}^{t}(x_i - \bar{x}_j)\right\}}{N - p}} \qquad \sigma_y = \sqrt{\frac{\sum_{j=1}^{p}\left\{\sum_{i=1}^{t}(y_i - \bar{y}_j)\right\}}{N - p}}$$

$$\sigma_{p_s} = \sqrt{\frac{\sigma_y^2 + \sigma_y^2}{2}}$$

where: N = total number of pointings in set

t_j = total number of pointings of intersection "j" in set

p = total number of grid reseau points measured

x_i, y_i = coordinates of the ith pointing or reseau point j

$\bar{x}_j$, $\bar{y}_j$ = mean measured value of reseau point j

The total pointing precision for all sets (σ_p) was computed under the valid assumptions that all cross measuring marks used are of equal quality, and that all grid reseau points are of equal quality and were pointed upon with equal precision regardless of the approximately orthogonal rotations of the grid between sets. The computation involved summing t_j for all four sets.

The computed overall standard error of pointing precision (σ_p) is ±1.18 μm, with σ_x = ±1.19 μm, σ_y = ±1.17 μm, for 471 pointings.

Since 10-power magnification was used the pointing precision was lower than would have been expected with the 20-power oculars normally available. However, the pointing precision probably will not be better than ±0.85 μm with either the cross or the dot measuring marks. The cross measuring marks were used for the precision values stated; however, pointing tests with the dot measuring marks produced similar results.

Measuring Screw Backlash

Replicative target measurements were read with approach from each of the four quadrant directions. In the analysis of the variations of the four mean coordinate set values computed for the target position, no systematic backlash was perceivable. However, since backlash could develop with time and wear, a consistent direction-of-pointing approach is recommended. The apparent lack of backlash improves pointing speed by reducing the backoff distance required between pointings.

Mechanical Stability

A test with the plate suspended in its normal measurement position in the comparator for 18 hours revealed no evidence of plate movement. This test was conducted by comparing the mean measurement position of five well-spaced targets at the beginning, during, and at the end of the stability test period. Closeout measurements were also made on the initial points read on the four comparator calibration measurement sets. These measurement sets were from 45 minutes to 3 hours in duration. Evaluation of the closures demonstrated that plate shifts did not occur. However, since the pressure clamps holding the plate are metallic, large variations in room temperature could create shifts of the plate.

Comparator Calibration and Accuracy

Linear Corrections

The calibrated grid plate was measured in the four possible rotation positions (four sets) in the comparator. Each set of measurements was processed through a least-squares general affine linear transformation:

$$\begin{bmatrix} X \\ Y \end{bmatrix} = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} e \\ f \end{bmatrix}$$

where: X, Y represent the calibrated coordinates of the 25 equally-spaced reseau points measured.

x, y represent the measured coordinates of the 25 reseau points.

a, b, c, d represent transformation parameters of which scaler x, scaler y, nonorthogonality angle between x, y axes, and rotation angle between coordinate systems are exactly derived functions.

e, f represent translations between the coordinate systems.

The mean results of the least-squares general affine linear transformations of the four sets produced the following linear corrections with their pooled standard errors:

X scaler = 13.22 μm/m ±3.57 μm

Y scaler = -9.24 μm/m ±3.57 μm

Nonorthogonality angle = ±0".859 ±1".042

The pooled standard error of a single observation of unit weight after linear correction (σ_o) is ±1.85 μm.

The significance of the spread between the X and Y scalers may be reasoned as follows. Since the 25 calibrated grid reseau points were symmetrically spaced across the full format of the comparator, one can infer from these linear corrections that the MMM (multiple measuring mark) plate was fabricated with an average difference of 5 μm between the outermost X measuring marks dimension and the outermost Y measuring marks dimension.

Nonlinear Corrections

A 4th-degree polynomial least-squares fit was chosen to determine nonlinear calibration corrections for use with the nominal measuring mark coordinate values. The polynomial model used is:

$$vx = Ax + By + Cx^2 + DY^2 + Ex^3 + Fy^3 + Gx^4 + Hy^4 + J$$

$$vy = A'x + B'x + C'x^2 + D'y^2 + E'x^3 + F'y^3 + G'x^4 + H'y^4 + J'$$

Where: vx, vy represent the x and y coordinate residuals after the least-squares general affine linear transformation,

A - J, A' - J' represent parameter coefficients of the polynomial, and

x, y represent the linearly corrected coordinates of the reseau point measurements.

The pooled standard error of a single observation of unit weight after linear and nonlinear corrections is ±1.35 μm.

Average Correction

The residuals produced from the least-squares general affine linear transformations of the four sets were used to determine a set of corrections to the nominal comparator measuring mark coordinates. Analysis revealed a need for an average correction of 1.1 μm in X and 1.4 μm in Y, determined with a pooled standard error (σ_m) of ±0.83 μm. The maximum measuring mark coordinate error found was 4.3 μm ±0.3 μm. A summary of the single coordinate errors determined for the 25 selected measuring marks calibrated is shown in table 1 and on figure 1.

Table 1 - Distribution of single coordinate errors.

Error(μm)	No. of coordinates
> 4.0	1
3.5 to 4.0	1
3.0 to 3.5	1
2.5 to 3.0	1
2.0 to 2.5	4
1.5 to 2.0	7
1.0 to 1.5	13
0.5 to 1.0	13
0.0 to 0.5	9

Sources of Error

To evaluate the pooled standard error of a single observation of unit weight after linear correction (σ_o), the variances of the contributing known or measurable sources of error (both random and systematic) must be taken into account. These include errors of pointing precision (σ_p), errors of the calibrated grid measured (σ_g), errors of the nominal measuring mark coordinated values used (σ_m), and other undetermined errors (σ_r) which include random errors (noise) and systematic screw harmonic errors (which were not determined in this calibration).

The variance of the errors of the nominal measuring mark coordinate values (σ_m^2) was computed by pooling the individual measuring mark variances. These individual measuring mark variances are based on calibration set differences from each mean measuring mark correction determined.

The pooled standard error of the nominal measuring mark coordinate value (σ_m) used is ±0.83 μm.

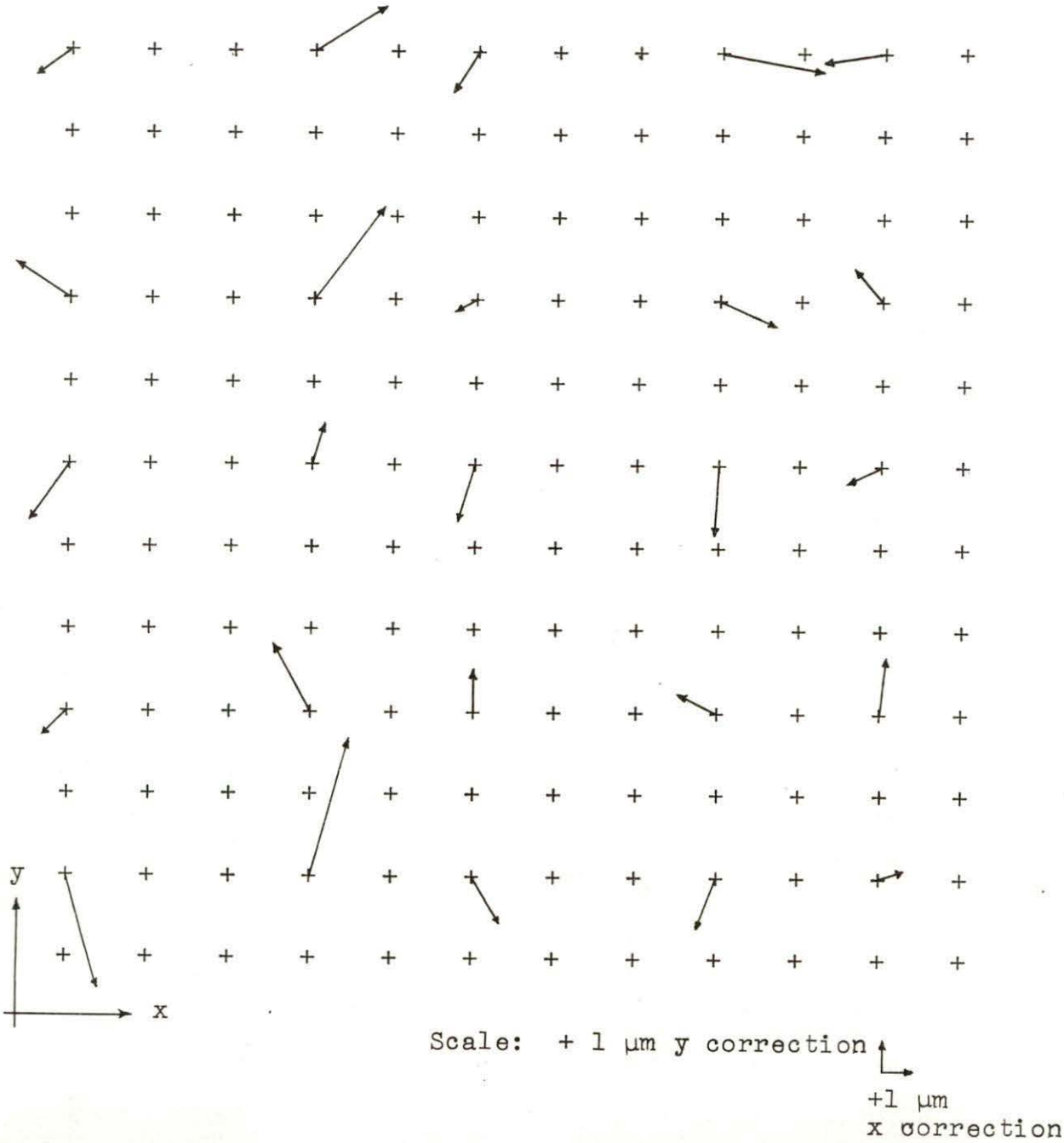

Figure 1 - A display of the corrections to the nominal measuring mark coordinates.

Since a check could not be readily made for systematic screw harmonic errors, they were combined with other noise errors in the analysis. The standard error of all these undetermined errors (σ_r) was found to be ±1.13 μm as computed from a rearrangement of the following error propagation equation:

$$\sigma_o^2 = \sigma_p^2 + \sigma_g^2 + \sigma_m^2 + \sigma_r^2$$

where: σ_o (= ±1.85 μm) is the standard error of a single observation of unit weight after linear adjustment,

σ_p (= ±1.18 μm) is the standard error of pointing precision,

σ_g (= ±0.25 μm) is the standard error of master calibration grid used,

σ_m (= ±0.83 μm) is the standard error of nominal measuring mark coordinate values used, and

σ_r (= ±1.13 μm) is the standard error of random errors including contribution of screw harmonic errors.

COMPARATOR CHARACTERISTICS

1) The comparator fulfills Abbés comparator principle rigorously.
2) Slewing speed is very rapid.
3) All solid state electronics provide high reliability and easy interfacing.
4) There is a choice of dot or cross measuring marks.
5) The comparator is stable; frequent calibrations are not needed.
6) Electronic zeroing of the instrument is easily performed and easy to check.
7) The comparator is comfortable to operate, and does not require much space.
8) Speed of fine setting is greatly increased by the apparent lack of backlash.
9) The feel of the handwheels is excellent and a positive pressure to the hand is always provided.
10) The optics and illumination characteristics of the comparator are good.

11) An output buffer is needed to achieve maximum speed of measurement and to reduce blunders. (A buffer can be installed inexpensively and easily).

12) The dimensions of plates that can be measured range from approximately 9 to 10 inches; glass should be a minimum of 1/4-inch thick.

13) There is no provision for measurement of film.

14) A basic calibration of the true measuring mark positions is desirable for high-quality metric measurements.

15) There is no provision for rotation of plates.

16) A scale for ocular focus setting is needed.

17) A set of safety spacers should be developed to protect the MMM plate from abrasion during measurement, either by means of warning signals or by installing a mechanical obstruction.

18) It is very difficult to check the screw harmonics with existing calibrated standards.

The comparator is a fine instrument for aerotriangulation. With a complete calibration of all of its measuring marks it will provide highly precise measurements. The life of the photo engraved MMM plate may be limited, since there is a chance of damaging it during the plate removal process or by using poor cleaning procedures.

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