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EVALUATION OF AUTOMATED COORDINATOGRAPH AND ATTENDANT PHOTOGRAMMETRIC PROCEDURES FOR HIGHWAY DESIGN MAPPING

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16. Abstract

Several large scale mapping projects are used to test the accuracy and efficiency of an automated coordinatograph (automatic plotting table) interfaced to a precision stereoplotter. Test results for evaluating the accuracy capability of the interfaced coordinatograph are established using aerial photography flown at flight altitudes that required photo scale to final map scale enlargement factors of 8.33X and 10X. Withheld horizontal and vertical analytical aerotriangulation test point results are tabulated and used in evaluation of the equipment under study. Test results are compared to large scale mapping accuracies required for compliance with national map standards for highway mapping.

17. Key Words

AUTOMATED COORDINATOGRAPH
ANALYTICAL AEROTRIANGULATION
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INTRODUCTION

Technological advances in the optical design and functional characteristics of precision aerial cameras and precision stereoplotter mapping instruments have resulted in greater image resolution and measurement accuracy. These advancements in photogrammetric instrumentation are critical to the efficient production of large scale topographic mapping and the map accuracy required by various highway engineering disciplines.

Until recently much of the available optical train stereoplotter instrumentation that had benefitted from these advancements did not allow full utilization of the intrinsic precision designed into the instrumentation. The inability to fully utilize the enhanced instrument measurement capability was the direct result of hardware limitations that greatly restricted any further betterment of mapping procedures.

Preliminary investigations and contact with various mapping firms indicated that advancements had been made in mapping technology that would overcome past hardware limitations. Much of the new mapping technology was aimed at the electronic interface of automated plotting tables (automatic coordinatographs) with optical train stereoplotters.

The automated coordinatograph is a computer-assisted, high speed, electronically driven, flatbed plotter system. When attached to a precision stereomapping instrument, the automated coordinatograph provides a graphic enlargement of ground features measured and traced from aerial photography oriented within the stereoinstrument. Through electronic linkage with the analogue measuring components of the stereoinstrument, it is the function of the coordinatograph system (via microprocessors) to convert the tracing and measurement of map-worthy ground features to digital form. The transformation of plotting information to digital form is used to activate servo units that drive and direct the travel of the coordinatograph's drafting head during its replication of an enlarged graphical tracing of topographic and planimetric ground detail into a completed map.

The automatic coordinatograph system does away with the use of previous hardware linkage that imposed undesirable, built-in, mechanical enlargement constraints associated with mechanical stress and wear. The computer-aided design of the automated plotting table appears to have the capability of transforming measurement data into graphic form without adversely degrading the measurement accuracy. This retention of plotting accuracy could permit use of increased enlargement factors. These factors would allow the choice of a greater range of engineering map scales producible from aerial photography taken at a given flight altitude.

PURPOSE AND OBJECTIVES

The purpose of this investigation is to establish and report tested procedures and accuracy findings that are the result of utilizing an automated coordinatograph that has been interfaced with a precision optical train stereoplotter. Using the equipment under investigation, the objective of the study is to design and develop photogrammetric mapping procedures that will maintain accuracy standards, reduce costs, and improve production.

SCOPE

This report is concerned with the result of using aerial photography that was flown at flight altitudes higher than customarily used for the direct compilation of various large scale topographic maps. The aerial photography acquired for the topographic mapping projects in this study resulted in photo scale and final map scale relationships as follows:

Table 1. Photo - Map Scale Relationships

Photo Scale	Photo Scale/Map Scale Enlargement	Resulting Compilation Scale and Contour Interval
1"=200'	10X	1"=20' with a 1 foot C.I.
1"=250'	8.33x	1"=30' with a 2 foot C.I.
1"=500'	10X	1"=50' with a 2 foot C.I.

The horizontal positions and elevations of test points that were used to evaluate the accuracy of the automated coordinatograph were developed by full analytical aerotriangulation procedures using the bundle method of adjustment. This report contains the accuracy results that were obtained and a comparison of these results with national map accuracy requirements for five, large scale, highway mapping projects produced in the course of this study.

TEST CRITERIA AND PRINCIPLES

The criteria used to test and evaluate the procedures and equipment are aimed at the development and use of methods and instrumentation that will result in bettering the production of large scale topographic maps that comply with national map accuracy standards for highway mapping.

The list below contains a summary of the National Map Standards for Highway Mapping:

Contours: Ninety (90) percent of the elevations determined from the contours on the map shall be accurate within one-half (1/2) the contour interval, or better. The remaining ten (10) percent of the elevations shall not be in error by more than one contour interval.

Spot Elevations: Ninety (90) percent of all the spot elevations on the map shall be accurate within at least one-fourth (1/4) of the contour interval, and the remaining ten (10) percent shall not be in error by more than one-half (1/2) the contour interval.

Coordinate Grid Lines: The grid lines will be plotted within one one-hundredth (1/100) of an inch of their true grid value on the manuscript.

Horizontal Control: Horizontal control points shall be plotted on the map manuscript within one one-hundredth (1/100) of an inch of their true position as determined by the plane coordinates computed for the horizontal control points.

Planimetric Features: Ninety (90) percent of the well defined features imaged on the photographs will be plotted on the finished map to an accuracy within at least one-fortieth (1/40) of an inch of their true coordinate position, and none shall be in error by more than one-twentieth (1/20) of an inch of their true coordinate position.

"C" Factor:

When the major variables affecting a given photogrammetric system are controlled and the limitations of the system have been established by test results, a reasonably predictable measure of the accuracy capability of the system can be determined by calculation of the system's "C" Factor. The "C" Factor = H/C.I.; where (H) is the average flight height above ground used to obtain the mapping photography, and (C.I.) is the contour interval that can be reliably plotted from the mapping photography.

Statistical Methods for Analysis

The root mean square error (sometimes called the 68 percent error) used in the statistical analysis of the test results in this report is determined as follows:

$$RMSE = \sqrt{\frac{\Sigma e^2}{n}}$$

e = the error determined for a tested elevation or the coordinate error of a tested horizontal position

n = the number of elevations or horizontal positions being tested

Other important terms used in the report are as follows:

RMSE (X), RMSE(Y), RMSE(Z)---Root mean square error for the X, Y, Z coordinate error of tested points

RMSE(XY) ---Root mean square error of the radial vectors that result from computing the combined effect of the RMSE(X) and RMSE(Y) values for the coordinate errors of tested points. Computed as follows:

$$RMSE(XY) = \left[(RMSE(X))^2 + (RMSE(Y))^2\right]^{1/2}$$

MAX(XY) ---Radial vector of a point having the largest X, Y Coordinate error within a given set of tested points

MAX(Z) ---Largest vertical error within a given set of tested points

$\overline{X}, \overline{Y}, \overline{Z}$, ---The arithmetic mean of the X, Y, Z coordinate errors

Equipment and Materials

- Aerial Camera: Wild Heerbrugg RC-8, 6 inch focal length wide angle lens
- Aerial Film: Eastman Kodak, double X aerographic film 2405 (Estar Base)
- Ground Control: All grounds control points were paneled using white plastic cross with a black background

- Diapositives: Eastman Kodak, .130 inch thick glass dipositives printed through the film base for emulsion-down plotting. Drill holes for identification of analytical points were drilled using Wild Heerbrugg Pug III with 40 micrometer diamond drill.

- Aerotriangulation Instrumentation: Zeiss Stereocomparator with Altek Digital Reader

- Manuscript Layout: Grid and control plotting using a 60 inch x 80 inch precision Aristo Coordinatograph

- Manuscript material: Dupont Cronaflex, .007 inches thick

- Stereoplotter: Wild Heerbrugg B85 Aviograph, with Dellfoster Digital Readout

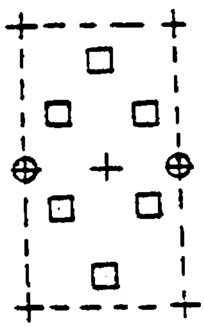
- Automatic Coordinatograph: Wild Heerbrugg "TA" digital plotting table

EVALUATION

The newly formulated planning measures and mapping procedures used for the selected mapping test projects were geared not to exceed the previously established "C" Factor of 1500 for the photogrammetric instrumentation involved in the study.

The following diagram shows the density and distribution of the wthheld horizontal and vertical analytical aerotriangulation points used to test the planimetric and vertical accuracy of the compiled stereomodels within the selected mapping projects.

Figure 1. Horizontal/Vertical Analytical Aerotriangulation Points



+ given analytical horizontal and vertical control for stereomodel.

□ Withheld analytical horizontal and vertical test point,

⊕ Photo center and adjacent analytical control point for stereomodel.

Distribution of control and withheld test points for each tested stereomodel.

Outline of Project Data and the Root Mean Square Error Tabulation of Withheld Test Point Results

Table 2. Project I Data

Photo Scale:	1"=250'	Photo Scale/Map Scale Enlargement
Final Map Scale:	1"=30'	Factor: 8.33X
Contour Interval:	2 feet	"C" Factor = 750

RMSE TABULATION (IN FEET) FOR TEST POINTS IN EACH MODEL

Model No.	1	2	3	4
RMSE(X)	.22	.21	.36	.09
RMSE(Y)	.12	.17	.15	.15
RMSE(Z)	.21	.21	.14	.21
RMSE(XY)	.25	.27	.39	.18
MAX(XY)	.40	.36	.51	.32
MAX(Z)	.40	.30	-.30	-.40

ARITHMETIC MEAN TABULATION (IN FEET) FOR TEST POINTS IN EACH MODEL

Model No.	1	2	3	4
X	-.05	.12	.33	.02
Y	-.05	-.02	.07	.10
Z	.12	-.05	.03	-.15

RMSE TABULATION (IN FEET) USING ALL 24 TEST POINTS IN PROJECT I

RMSE(X)=.24 RMSE(Z)=.20
RMSE(Y)=.15 RMSE(XY)=.29

ARITHMETIC MEAN TABULATION (IN FEET) FOR ALL 24 TEST POINTS IN PROJECT I

$\bar{X}$=.10
$\bar{Y}$=-.03
$\bar{Z}$=-.03

SUMMARY OF TEST RESULTS FOR PROJECT I

ALLOWED LIMITS FOR COMPLIANCE WITH NATIONAL MAP ACCURACY		TEST RESULTS	
90% of positions within	.75 ft.	90% of positions within	.48 ft.
10% of positions not to exceed	1.50 ft.	100% of positions within	.51 ft.
90% of spot elev's within	.50 ft.	90% of spot elev's within	.33 ft.
10% of spot elev's not to exceed	1.00 ft	100% of spot elev's within	.40 ft.

Table 3. Project II Data

Photo Scale:	1"=200'	Photo Scale/Map Scale Enlargement
Final Map Scale:	1"=20'	Factor: 10X
Contour Interval:	1 foot	"C" Factor = 1200

RMSE TABULATION (IN FEET) FOR TEST POINTS IN EACH MODEL

Model No.	1	2	3	4	5
RMSE(X)	.04	.16	.11	.08	.14
RMSE(Y)	.06	.12	.13	.08	.18
RMSE(Z)	.07	.14	.16	.08	.13
RMSE(XY)	.07	.20	.17	.12	.23
MAX(XY)	.14	.36	.28	.14	.42
MAX(Z)	.10	.15	.27	-.10	.20

ARITHMETIC MEAN TABULATION (IN FEET) FOR TEST POINTS IN EACH MODEL

Model No.	1	2	3	4	5
X	.02	.12	.00	.03	.10
Y	.00	-.08	.00	.00	-.17
Z	.02	.13	.08	-.07	.10

RMSE TABULATION (IN FEET) USING ALL 30 TEST POINTS IN PROJECT II

RMSE(X)=.11 RMSE(Z)=.12
RMSE(Y)=.12 RMSE(XY)=.16

ARITHMETIC MEAN TABULATION (IN FEET) FOR ALL 30 TEST POINTS IN PROJECT II

$\bar{X}$=.04
$\bar{Y}$=.05
$\bar{Z}$=.05

SUMMARY OF TEST RESULTS FOR PROJECT II

ALLOWED LIMITS FOR COMPLIANCE WITH NATIONAL MAP ACCURACY		TEST RESULTS	
90% of positions within	.50 ft.	90% of positions within	.30 ft.
10% of positions not to exceed	1.00 ft.	100% of positions within	.42 ft.
90% of spot elev's within	.25 ft.	90% of spot elev's within	.20 ft.
10% of spot elev's not to exceed	.50 ft	100% of spot elev's within	.30 ft.

Table 4. Project III Data

Photo Scale:	1"=500'	Photo Scale/Map Scale Enlargement
Final Map Scale:	1"=50'	Factor: 10X
Contour Interval:	2 feet	"C" Factor = 1500

RMSE TABULATION (IN FEET) FOR TEST POINTS IN EACH MODEL

Model No.	1	2	3	4
RMSE(X)	.17	.19	.32	.41
RMSE(Y)	.07	.18	.24	.32
RMSE(Z)	.26	.19	.21	.24
RMSE(XY)	.18	.26	.40	.52
MAX(XY)	.32	.42	.57	.78
MAX(Z)	-.40	.30	.40	.40

ARITHMETIC MEAN TABULATION (IN FEET) FOR TEST POINTS IN EACH MODEL

Model No.	1	2	3	4
X	-.08	.10	.32	.38
Y	.05	.15	.05	.25
Z	.00	.17	.17	.00

RMSE TABULATION (IN FEET) USING ALL 20 TEST POINTS IN PROJECT III

RMSE(X)=.29 RMSE(Z)=.22
RMSE(Y)=.22 RMSE(XY)=.36

ARITHMETIC MEAN TABULATION (IN FEET) FOR ALL 20 TEST POINTS IN PROJECT III

$\bar{X}$=.21
$\bar{Y}$=.00
$\bar{Z}$=.10

SUMMARY OF TEST RESULTS FOR PROJECT III

ALLOWED LIMITS FOR COMPLIANCE WITH NATIONAL MAP ACCURACY		TEST RESULTS	
90% of positions within	1.25 ft.	90% of positions within	.59 ft.
10% of positions not to exceed	2.50 ft.	100% of positions within	.78 ft.
90% of spot elev's within	.50 ft.	90% of spot elev's within	.36 ft.
10% of spot elev's not to exceed	1.00 ft	100% of spot elev's within	.40 ft.

Table 5. Project IV Data

Photo Scale:	1"=250'	Photo Scale/Map Scale Enlargement
Final Map Scale:	1"=30'	Factor: 8.33X
Contour Interval:	2 foot	"C" Factor = 750

RMSE TABULATION (IN FEET) FOR TEST POINTS IN EACH MODEL

Model No.	1	2	3	4	5	6
RMSE(X)	.08	.10	.14	.11	.17	.07
RMSE(Y)	.11	.20	.09	.10	.09	.15
RMSE(Z)	.13	.11	.06	.17	.14	.14
RMSE(XY)	.14	.22	.16	.15	.19	.17
MAX(XY)	.22	.30	.20	.22	.36	.22
MAX(Z)	.20	.20	.10	.20	-.20	.20

ARITHMETIC MEAN TABULATION (IN FEET) FOR TEST POINTS IN EACH MODEL

Model No.	1	2	3	4	5	6
X	-.03	-.07	.12	.08	.15	.02
Y	-.08	-.18	.05	.07	-.05	.08
Z	.10	.05	.03	.15	-.13	-.13

RMSE TABULATION (IN FEET) USING ALL 36 TEST POINTS IN PROJECT IV

RMSE(X)=.12 RMSE(Z)=.13
RMSE(Y)=.13 RMSE(XY)=.18

ARITHMETIC MEAN TABULATION (IN FEET) FOR ALL 36 TEST POINTS IN PROJECT IV

$\bar{X}$=.02
$\bar{Y}$=-.07
$\bar{Z}$=.02

SUMMARY OF TEST RESULTS FOR PROJECT IV

ALLOWED LIMITS FOR COMPLIANCE WITH NATIONAL MAP ACCURACY		TEST RESULTS	
90% of positions within	.75 ft.	90% of positions within	.30 ft.
10% of positions not to exceed	1.50 ft.	100% of positions within	.36 ft.
90% of spot elev's within	.50 ft.	90% of elevations within	.20 ft.
10% of spot elev's not to exceed	1.00 ft	100% of elevations within	.20 ft.

Table 6. Project V Data

Photo Scale: 1"=500' Photo Scale/Map Scale Enlargement
Final Map Scale: 1"=50'
Contour Interval: 2 foot "C" Factor = 1500

RMSE TABULATION (IN FEET) FOR TEST POINTS IN EACH MODEL

Model No.	1	2	3	4	5	6
RMSE(X)	.34	.31	.54	.23	.15	.38
RMSE(Y)	.29	.29	.15	.16	.34	.24
RMSE(Z)	.08	.24	.15	.25	.06	.09
RMSE(XY)	.45	.42	.56	.28	.37	.45
MAX(XY)	.61	.63	.73	.41	.61	.54
MAX(Z)	.10	-.40	.20	.40	.10	-.10

ARITHMETIC MEAN TABULATION (IN FEET) FOR TEST POINTS IN EACH MODEL

Model No.	1	2	3	4	5	6
X	.18	-.25	.53	-.20	.02	.38
Y	.27	.23	.12	.07	.30	.23
Z	.03	-.05	.02	.03	.00	-.08

RMSE TABULATION (IN FEET) USING ALL 34 TEST POINTS IN PROJECT V

RMSE(X)=.35 RMSE(Z)=.17
RMSE(Y)=.26 RMSE(XY)=.44

ARITHMETIC MEAN TABULATION (IN FEET) FOR ALL 34 TEST POINTS IN PROJECT V

$\bar{X}$=.09
$\bar{Y}$=.20
$\bar{Z}$=-.003

SUMMARY OF TEST RESULTS FOR PROJECT V

ALLOWED LIMITS FOR COMPLIANCE WITH NATIONAL MAP ACCURACY		TEST RESULTS	
90% of positions within	1.25 ft.	90% of positions within	.72 ft.
10% of positions not to exceed	2.50 ft.	100% of positions within	.75 ft.
90% of spot elev's within	.50 ft.	90% of spot elev's within	.30 ft.
10% of spot elev's not to exceed	1.00 ft	100% of spot elev's within	.40 ft.

CONCLUSION AND IMPLEMENTATION

The accuracy results indicate that the previously established "C" Factors of our photogrammetric system appear valid. When staying within the established "C" Factors, it appears that the automated coordinatograph will enable us to meet national map standards for vertical and horizontal accuracy while more fully exploiting the precision and output potential of our existing plotting instrumentation.

The bulk of our large scale highway mapping projects are in the scale/contour interval range of 1"-20'/C.I.=1 foot to 1"=50'/C.I.=2 foot. The study reveals that use of the automatic plotting table justifies flying most of these mapping projects at twice the flight altitude previously used for our mapping projects. In addition, the opportunity to fly higher and stay within our "C" Factors now enables us to accept work loads for 1"-20'/C.I.=1 foot mapping at a flight altitude that is within FAA regulations in large segments of metropolitan areas. Flying at the increased altitude, for twenty foot to the inch mapping, precludes the necessity and expense of having to otherwise use special aircraft and aerial camera systems in order to comply with the FAA regulations.

Aerial photography acquired at the justified increases in flight altitude will be used to significantly reduce the number of photographs to be controlled by labor intensive field survey methods. It is anticipated that there will be at least a 30 percent increase in the production output of large scale topographic mapping assigned to the plotting equipment that is linked to the automatic coordinatograph.

REFERENCES

1. American Society of Photogrammetry, "Manual of Photogrammetry," 4th Ed., 1980, Chapter VII

2. Wolf, P. R., "Elements of Photogrammetry," McGraw-Hill, Inc., New York, 1974.

3. Kissam, P., "Surveying for Civil Engineers," McGraw-Hill, Inc., New York, 1956.