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PROBLEMS AND POSSIBILITIES OF HIGH ALTITUDE WORLDWIDE MAPPING

16 JANUARY 1967

SIMULATED ERROR ANALYSIS
UTILIZING MATHEMATICAL
SYSTEM GEOMETRY MODELS

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PROBLEMS AND POSSIBILITIES OF HIGH ALTITUDE WORLDWIDE MAPPING

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SIMULATED ERROR ANALYSIS
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SYSTEM GEOMETRY MODELS

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1. INTRODUCTION

On 10 December 1965, Subtask Report for Task 1, Subtask C, Development of Mathematical System Geometry Model [redacted] was completed and submitted. The document explained the philosophy of the mathematical exercises required in the generation of error analysis programs for determining the mapping potential of calibrated panoramic (PG) and metric imagery.

The error analysis programs, based on the theoretical panoramic calibration, were completed by June 1966, and simulated tests were run at that time. Prior to June, however, the error analysis programs were expanded to provide a mathematical tool for performing control intensification in the operational mapping task.

Subsequently, due to technical calibration complications, the philosophy of panoramic calibration was revised, thus requiring reprogramming of the system geometry models to make them operationally applicable. However, the error analysis, based on the theoretical calibration concept, still provides a useful tool for pan-metric systems analysis.

The purpose of this report is to present an example of the use of the system geometry model computer program, as an error analysis tool. In the particular example shown here, the capability of calibrated panoramic materials to produce accurate relative point locations is estimated and compared with a given set of map accuracy specifications.

The system selected is a J-1 PG unit with internal geometry calibrated to ±4 arc-seconds (1-sigma level) flown at an operational altitude of 85 nautical miles. All other mission and system parameters are in accordance with real operational data.

[redacted]

2. SYSTEMS GEOMETRY MODEL

The pan-metric adjustment of the systems geometry model is a classic weighted block adjustment modified to functionally constrain the camera stations to a simple Keplerian orbit and to allow inclusion of convergent panoramic photography. Interior orientation elements for both the frame and panoramic cameras are included as adjustment parameters (as are the exterior orientation angles of both cameras) with those for the panoramic cameras expressed as cubic functions of time. Time is included as an independent measured variable for the panoramic model; i.e., each image of interest on a panoramic photograph will not only have a measured x and y coordinate, but also a measured time coordinate.

From the standpoint of describing the physical conditions existing during a panoramic camera exposure, i.e., the position and orientation of the camera and ground coordinates changing as functions of time, the adjustment is unique. The application of this adjustment technique is at present limited to the number of panoramic photographs which lie within one metric model due to computer storage limitations and the fact that Keplerian elements will adequately approximate the true position of the camera as a function of time only for short periods.

The required inputs to this adjustment are photocoordinates and the variances of points of interest (photocoordinates of images on panoramic photographs are defined as including a time coordinate as well as x and y coordinates). Estimates of all parameter values are also required. As desired, variances and covariances of all parameters can be included as input.

In general, the output from this adjustment is the covariance matrix of the adjusted parameters; however, due to the data processing technique utilized, the contribution to ground positioning error from the photographic measurements and the parameter can be—and is—separated. All internal computations take place in a siderial geocentric system, but for interpretative reasons ground coordinates with their attendant variance-covariance matrices are transformed into three other systems: (1) geocentric x, y, and z; (2) geographic latitude, longitude, and elevation; and (3) cross-track, in-track, and elevation.

This program has been more fully described in Task 1-C, Development of Mathematical Systems Geometry Models, [redacted] December 1965.

The following tables list the various input and output conditions for the pan-metric adjustment program.

Table 1 presents the assumed standard error to be expected in each of the variables entering the model. The program utilizes these errors to provide constant weighting factors in the least squares fit.

Two covariance matrices [Tables 2(a) and 2(b)] are presented in terms of Keplerian elements as well as cross-track, in-track, and elevation standard deviations. The first of these matrices

[redacted]

is the input covariance matrix obtained from the tracking data or orbit determination program. The matrices listed in Table 2(a) were obtained from the Aerospace Trace Program.

Since the pan-metric program is an adjustment program, the possibility of improvement of orbital elements exists, based upon the photogrammetric condition equations. The second covariance matrix [Table 2(b)] is the covariance matrix of the adjusted orbital elements. The improvement can be noted by comparison of the diagonal elements.

Table 3 presents the standard deviation for the ground point locations to be expected from the reduction. Table 4 presents the errors in distance and elevation from the centroid of the ground point distribution to the point as functions of the distance from the centroid.

[redacted]

Table 1 — Input Covariance Data

J-1 PG

Orbit 85 nm

Photo points frame

$\sigma_{xi}^2 = \sigma_{yi}^2 = 25 \times 10^{-6}\ mm^2$	($\sigma = 5 \times 10^{-3}$ mm)

Photo points pan

$\sigma_{xi}^2 = \sigma_{yi}^2 = 169 \times 10^{-6}\ mm^2$	($\sigma = 13 \times 10^{-3}$ mm)

Frame camera orientation (local system)

$\sigma_\kappa = \sigma_\varphi = 10$ arc-sec.	$\sigma_\omega = 35$ arc-sec

Pan camera orientation (local system)

Unconstrained

Parameters held to constant σ for all cases

Times	$\sigma_A^2 = 9 \times 10^{-6}\ sec^2$	($\sigma = 3$ ms)
	$\sigma_R^2 = 25 \times 10^{-10}\ sec^2$	($\sigma = 50\ \mu$sec)
	$\sigma_{T_1T_2} = 0.899873 \times 10^{-6}$	(Covariance to express relative time)
Ground points	$\sigma_\varphi^2 = 2.7976 \times 10^{-10}\ rad^2$	($\sigma = 106.5$ m)
	$\sigma_\lambda^2 = 5.5573 \times 10^{-10}\ rad^2$	($\sigma = 106.5$ m)
	$\sigma_h^2 = 92903.04\ m^2$	($\sigma = 1000$ ft)

(A σ of 106.5 meters corresponds to a 90 percent C.E.P. of 750 feet)

Frame	$X_p\ \sigma = 5 \times 10^{-3}$ mm.	$\sigma^2 = 25 \times 10^{-6}$
	$Y_p\ \sigma = 5 \times 10^{-3}$ mm.	$\sigma^2 = 25 \times 10^{-6}$
	$F\ \sigma = 15 \times 10^{-3}$ mm.	$\sigma^2 = 225 \times 10^{-6}$
Pan	$PX_p\ \sigma^2 = 1 \times 10^{-28}$ mm	
	$PY_p\ \sigma = 5 \times 10^{-3}$ mm.	$\sigma^2 = 25 \times 10^{-6}$
	$PF\ \sigma = 1.5 \times 10^{-2}$ mm.	$\sigma^2 = 225 \times 10^{-6}$
	$Cam\ \sigma = 2 \times 10^{-3}$ mm.	$\sigma^2 = 4 \times 10^{-6}$

[redacted]

	Ω	ω	i	e	η	τ
	8.0997771[illegible]0E-13	4.[illegible]E-12	-3.938703240E-13	3.922096530E-15	1.478438430E-17	3.929728780E-09
		3.[illegible]E-09	-[illegible].681901080E-12	-1.155163620E-11	1.390383760E-15	2.756398490E-06
			[illegible].048915750E-12	-1.797391690E-13	2.196218740E-17	-7.866548010E-09
				2.765900000E-13	-8.738319570E-17	-9.772200000E-09
					1.471575190E-19	1.597836440E-12
						2.294600000E-03

σ_{meters} Cross-Track	σ_{meters} In-Track	σ_{meters} Elevation
8.2	12.5	3.5

Table 2(a) — Original Covariance Matrices

	Ω	ω	i	e	η	τ
	8.023244530E-13	4.[illegible]E-12	-4.359179280E-13	4.566390950E-15	1.031958920E-17	3.813449140E-0[redacted]
		3.[illegible]E-09	-7.731583310E-12	-1.142390600E-11	1.064559960E-15	2.746941290E-06
			[illegible].695304730E-12	-1.654486780E-13	3.644392990E-17	-6.912511510E-09
				2.710490100E-13	-7.960492910E-17	-9.627468190E-09
					1.309841220E-19	1.236287950E-12
						2.284561170E-03

σ_{meters} Cross-Track	σ_{meters} In-Track	σ_{meters} Elevation
7.6	11.1	3.4

Table 2(b) — Adjusted Covariance Matrices

[redacted]

Table 3 — Output Standard Deviations

Ground Point No.	σmeters Cross-Track	σmeters In-Track	σmeters Elevation
13	31.2	20.4	43.7
14	31.1	20.2	43.5
18	30.7	19.2	42.3
22	31.3	19.7	41.6
26	31.2	20.3	41.[illegible]
30	30.3	21.3	40.7
33	30.4	22.3	40.5
37	31.1	24.4	40.9
39	31.1	24.8	40.6
66	15.2	20.1	43.5
67	14.2	19.4	43.1
70	15.1	19.4	42.5
74	17.7	19.1	42.1
75	17.2	19.1	41.5
79	17.3	20.[illegible]	41.[illegible]
82	17.4	21.7	40.5
86	18.1	22.3	40.5
90	14.8	21.1	41.4
91	15.[illegible]	24.6	40.5
118	10.[illegible]	20.1	43.6
120	10.4	19.7	43.0
124	10.7	19.2	42.0
126	15.[illegible]	19.1	41.7
130	10.1	19.5	41.1
132	10.1	19.8	40.9
134	[illegible]	20.7	40.5
139	10.1	22.[illegible]	40.5
143	[illegible]	24.[illegible]	40.5
144	11.0	21.[illegible]	40.6
171	12.4	20.2	40.5
174	18.6	19.6	42.8
177	14.1	19.4	42.1
179	14.[illegible]	19.2	41.8
183	14.[illegible]	19.8	41.2
186	14.1	20.1	40.9
189	14.1	21.[illegible]	40.7
191	1[illegible].3	21.[illegible]	40.7
195	14.5	23.5	40.6
198	14.4	2[illegible].[illegible]	4[illegible].3
223	32.[illegible]	20.[illegible]	43.7
227	31.4	19.7	42.7
231	31.[illegible]	19.[illegible]	42.1
236	[illegible]	19.[illegible]	41.4
240	31.1	20.5	41.1
243	[illegible]	21.8	40.9
244	31.[illegible]	21.[illegible]	40.9
248	31.5	23.6	40.8
252	31.[illegible]	25.[illegible]	41.1

[redacted]

Table 4 — Distance and Elevation Standard Deviations as a Function of Distance from Centroid

Ground Point No.	σmeters Distance	Miles Distance	σmeters Elevation
13	32.[illegible]	73.7	52.1
38	32.5	75.	50.2
86	[illegible]	4[illegible].5	5[illegible].1
118	23.[illegible]	26.[illegible]	51.7
124	2[illegible].[illegible]	13.[illegible]	5[illegible].8
144	23.[illegible]	30.[illegible]	49.8
179	17.1	35.7	5[illegible].8
223	33.[illegible]	74.7	52.1
252	33.[illegible]	7[illegible].9	50.3