AEROTRIANGULATION USING DATA FROM ANALOGUE PLOTTERS

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ABSTRACT

In spite of recent developments, analogue plotters continue to play a major role, especially in third world countries. Their usefulness for aerotriangulation is evaluated in this paper, by dealing with the following approaches:

-- analogue relative orientation and independent model block adjustment, with and without self-calibration.

-- analytical relative orientation using x, y, z (for p_x) and ω (for p_y), followed by independent model adjustment.

-- plotter used as mono comparator plus bundle adjustment.

-- decomposition of model coordinates into photo coordinates plus bundle adjustment.

The results are compared against bundle adjustments using comparator data.

RESUME

Malgré les développements récents, les restituteurs analogiques continuent à jouer un rôle important, spécialement dans les pays du tiers monde. Leurs utilisations pour l'aérotriangulation est evaluées dans cet article selon les approches suivantes:

-- Orientation relative analogique, et compensation par modèles de blocs indépendants, avec et sans auto-étalonnage.

-- Restituteur utilisé comme mono-comparateur plus la compensation de faisceaux.

-- Décomposition des coordonées-modèle en coordonnées-photo plus la compensation de faisceaux.

Les résultats sont comparés avec la compensation de faisceaux utilisant les données du comparateur.

ZUSAMMENFASSUNG

Trotz moderner Entwicklungstendenzen spielen die Analogauswertegeräte, insbesondere in den Entwicklungsländern noch immer die Hauptrolle in der Photogrammetrie. Die vorliegende Abhandlung befasst sich mit ihrer Eignung für die Bildtriangulation, wobei folgende Verfahren behandelt werden:

-- gegenseitige Orientierung am Gerät und unabhängige Modellausgleichung mit und ohne Selbstkalibrierung.

-- numerische gegenseitige Orientierung mit x, y, z (für p_x) und ω (für p_y) und unabhängige Modellausgleichung.

-- Einsatz des Auswertegeräts als Monokomparator und Bündelausgleichung.

-- aus Modellkoordinaten abgeleitete Bildkoordinaten und Bündelausgleichung.

INTRODUCTION

Research in aerotriangulation has been concentrating on improving accuracy and computations, reducing control,

utilizing different observations, searching for small blunders and the like. The relevant photogrammetric measurements are nearly always performed with a comparator (mono or stereo), providing a least count reading of 1 μm.
Yet, in photogrammetric practice there are relatively few comparators in use. Even with the ever increasing emphasis on digital systems, the analogue stereoplotter is still the most popular photogrammetric instrument. This fact is even more pronounced in third world countries, where the analogue stereo plotter is likely to remain the photogrammetric workhorse because of its versatility and relative insensitivity to variations in electrical power and related changes in the operational environment (e.g., breakdown in air conditioning systems, etc.).
The majority of photocontrol for medium and small scale mapping is being determined with independent model triangulation using analogue plotters.
In this study, the use of the analogue plotter for aerotriangulation was investigated in a more general fashion.

ANALOGUE PLOTTER MEASUREMENTS AND THEIR EVALUATION

Commonly, model coordinates provide the data for independent model block adjustments. There are, however, other possible approaches as well, namely the utilization of the plotter as stereo- or mono-comparator [Levy, 1964; Boniface, 1969].

-- model coordinate measurements

After performing an optical-mechanical relative orientation, x,y,z-model coordinates are measured in a local model coordinate system. These are normally input directly into an independent model block adjustment which may have additional parameters. However, it is also possible to decompose them into photocoordinates for processing in a bundle adjustment using reseau or fiducial coordinates [Jeyapalon, 1972]. A more general method is to record the orientation elements of both projectors which slightly increases the observation time. Then the rotational matrices can be formed for both projectors, and with the collinearity equations photo-coordinates are derived. Since each bundle is part of two models, the two respective halves have to be joined by a similarity transformation via common points.

-- model measurements in stereo-comparator mode

In addition to x,y photo-coordinates, x- and y-parallaxes are measured in a stereo-comparator. Since an analogue plotter does not have direct parallax-measuring facilities, one specific motion each is used to eliminate the respective parallax. The reading thus obtained is easily transformed into the parallax if needed. The x-parallax is replaced by the z-model coordinate, while the y-parallax is best measured with b_y, and if a b_y-motion is not available, with ω [Harley, 1971]. Thus, instead of performing a relative orientation on the plotter, the y-parallax is eliminated - and measured - at each point thus reducing the observation time by at least one third. Then an analytical relative orientation is performed and model coordinates become available for subsequent independent model adjustment.

-- analogue plotter as mono-comparator

Provided that all rotations are properly initialized, photo-coordinates - perhaps multiplied with a scale factor - can be directly measured, utilizing one of the projectors of an analogue plotter. Known fiducial coordinates, grid plates, or reseau points, if available, are used in a projective transformation to account for residual errors in the initialization [Exintavelonis, 1981; Gagnon, 1969]. Unless the plotter has base-out capabilities, only part of the plate can be observed at once. Thus the plate has to be rotated and remeasured. Points in the common area are then used to transform both sections into one photo-coordinate system.
Once photo-coordinates are obtained, they are input into a bundle adjustment program. There is about a 10% time saving over conventional independent model measurements.

PRACTICAL INVESTIGATIONS

All the approaches mentioned have been investigated with the aid of two practical blocks in Eastern Canada. In addition, the ISP textbook data [Anderson et al., 1973] were used to study the effect of different sets of additional parameters for independent model block adjustments.

-- characteristics of test blocks:

1) Edmundston Block: photo scale 1:7 200 with 60%/30% overlap. 3 strips of 5 photos each, 25 horizontal and 26 vertical control points.

2) Milton-Brooklyn Block: photo scale 1:10 000 with 60%/20% overlap. 4 strips with 16, 16, 13 and 7 photos respectively, 11 horizontal and 25 vertical control points.

3) ISP Ficticious Testblock: photo scale 1/66 000 with 60%/60% overlap and 60%/30% overlap with alternate strips. A subblock of 4 strips with 5 photos each was utilized.

-- software packages used:

1) PAT-M-43 [Ackermann et al., 1973], a rigorous independent model block adjustment program, iterating between planimetry and height.

2) NRC-Models [Schut, 1980], a rigorous 7 parameter independent model program with additional parameters. The following modifications were used:

a) no additional parameters
b) 6 additional parameters as suggested by Schut [1980].
c) 11 additional parameters as suggested by Ebner [1976].
d) 15 additional parameters, derived by the authors [Atilola, 1984] from parallax equations.

e) 16 additional parameters, derived by the authors [Atilola, 1984] by extending El Hakim's spherical harmonics approach [El Hakim and Faig, 1977] to models.

3) UNBASC2 [Moniwa, 1977] a bundle adjustment with photo-variant self-calibration.
4) GEBAT-D [El Hakim, 1979] a bundle adjustment with additional parameters and direct implementation of observed distances.

-- test series:

A Wild Autograph A-10 was used for all analogue plotter observations.

1) Variation of additional parameters. This was performed with all three blocks.

2) Edmundston Block:
   a) independent models (relative orientation on plotter)
   b) independent models (analytical relative orientation, using x,y,z,ω readings)
   c) bundle adjustment (mono-comparator)
   d) bundle adjustment (using stereo comparator measurements taken at a Zeiss, Oberkochen PSK-1)

3) Milton-Brooklyn Block:
   a) independent models (as in 2a)
   b) independent models (as in 2b)
   c) bundle adjustment (using decomposed model coordinates)
   d) bundle adjustment (as in 3c)

Unfortunately, the PSK-1 has been out of commission for nearly one year. A number of dalays of several months each in scheduling the repair have forced the authors to cancel the planned comparison with comparator observed bundle adjustment results of the Milton-Brooklyn block.

RESULTS

In Table 1 the results of the first test series are summarized, dealing with the different sets of additional parameters.
The test series using the Edmundston Block is summarized in Table 2, while the Milton-Brooklyn Block test results are listed in Table 3. Since comparator measurements were not available for the Milton-Brooklyn Block, and since the control was located such that effectively none could be used as check points, mean coordinates were computed for all points using all adjustments. RMS values against these were used for comparison purposes in addition to the internal RMS values in the model - photo systems respectively.

Case of Additional Parameters	RMS Values at Check Points in (µm) Photo Scale																								RMS Value Against Mean (µm) at Photo Scale					
	ISP Test Block (3 strips, 12 models 60/30 % overlaps)									ISP Test Block (5 strips, 20 models 60/60 % overlaps)									Edmundston Block						Milton-Brooklyn Block					
	Error Free			Random Error			Random and Systematic			Error Free			Random Error			Random and Systematic			Rel. Orient. on Plotter			Analytical Rel. Orient.			Rel. Orient. on Plotter			Analytical Rel. Orient.		
	x	y	z	x	y	z	x	y	z	x	y	z	x	y	z	x	y	z	x	y	z	x	y	z	x	y	z	x	y	z
a(0 A.P.)	2	2	4	8	8	15	10	14	18	2	2	3	6	5	10	7	12	20	35	47	57	26	17	43	17	24	30	18	26	33
b(6 A.P.)	1	2	4	9	8	14	11	13	20	0	1	3	7	6	10	9	11	19	43	56	53	15	17	33	17	23	28	18	25	32
c(11 A.P.)	1	2	4	9	8	15	13	13	18	1	1	3	7	6	10	9	11	20	46	57	57	24	17	54	16	23	29	19	26	40
d(15 A.P.)	1	2	5	10	8	15	13	13	24	1	1	3	7	6	10	9	10	20	39	72	56	25	12	54	16	22	34	17	25	32
e(16 A.P.)	2	2	4	8	8	15	11	13	18	2	2	3	6	6	10	8	10	20	47	68	51	20	30	30	14	22	30	16	25	33

TABLE 1: Different Sets of Additional Parameters for Independent Model Block Adjustments.

Adjustment Procedure	No. of Control Points		No. of Check Points		RMS Values (µm) at Photo Scale									Software Package
					Control Points			Check Points			All Model/ Image Points			
	H	V	H	V	x	y	z	x	y	z	x	y	z	
a) Relative Orientation on Plotter	23	25	-	-	21	25	38	-	-	-	36	39	21	NRC Models
	6	10	17	18	12	28	14	35	49	57	32	39	21	
	23	25	-	-	14	14	21	-	-	-	29	33	22	PATM-43
	6	10	17	18	11	12	17	35	30	62	28	33	21	
b) Analytical Relative Orientation	23	25	-	-	12	11	24	-	-	-	18	19	25	NRC Models
	6	10	13	16	12	12	22	26	17	43	15	18	24	
	23	25	-	-	10	8	21	-	-	-	14	16	23	PATM-43
	6	10	17	16	12	10	28	22	22	64	14	16	21	
c) Bundle: Plotter as Monocomparator	23	25	-	-	21	38	39	-	-	-	11	12	-	UNBASC2
	6	10	18	16	15	43	46	32	39	51	12	13	-	
	6	10	14	14	-	-	-	46	47	56	17	17	-	GEBAT-D
d) Bundle: Comparator - ZEIS PSK	23	25	-	-	14	25	44	-	-	-	9	8	-	UNBASC2
	6	10	17	15	19	38	58	17	25	53	9	8	-	

TABLE 2: Edmundston Block - RMS Values at Control and Check Points.

Adjustment Procedure	No. of Control Points		RMS Against Mean µm			RMS of All Model/Photo Points (µm)			Software Package
	H	V	x	y	z	x	y	z	
a) Independent Models: R.O. on Plotter	11	25	17	24	30	9	11	13	NRC Model
	11	25	16	21	28	8	11	14	PATM 43
b) Independent Models: Plotter as Stereo-Comparator Analytical R.O.	11	25	18	26	33	8	12	14	NRC Model
	11	25	19	25	36	7	10	12	PATM 43
c) Bundle: Decomposed Model Coordinates	11	25	73	85	58	10	11	-	UNBASC2
	11	25	33	44	64	13	15	-	GEBAT-D
d) Bundle: Plotter as Mono-Comparator	11	25	45	66	86	14	18	-	UNBASC2
	11	25	46	66	80	17	21	-	GEBAT-D

TABLE 3: Milton Brooklyn Block Test Results.

CONCLUDING REMARKS

As expected, additional parameters do not significantly improve an independent model block adjustment. By performing a relative orientation with overdetermination (analogue or analytical) the sytematic effects are randomized.
Somewhat surprisingly, the bundle adjustment results from mono-measurements on the plotter as well as from decomposed model coordinates give no improvement over independent model adjustments. In fact, the results are often worse. Thus it is not recommended to use the plotter to obtain photo-coordinates. The best approach is the use of the plotter as stereo comparator, where in addition to a significant reduction in measuring time, the best accuracies are obtained.

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