The Leica system for orientation of linear array sensor imagery

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ABSTRACT

The use of linear array satellite imagery, expecially SPOT, is extensive and growing in popularity because of its stable orbit, image-quality, continuous global coverage, and suitability for a lot of mapping tasks. This model is based on the approach of Westin where a precise orbit is derived from the ephemeris and then used to derive a simplified orbit based on fewer parameters, so chosen that there is simpler derivation of the dynamic parameters of orientation. Control points are used to make the required small adjustments to these parameters via bundle adjustment, with the option of utilising tie points.

The modelling approach benefits the achievement of a precise real-time program for the Leica Mapping Terminal (LMT). This RTP has taken the approach articulated by Kratky, and making extensive use of polynomials linking orientation and desired plate position, with modifications. The concept of the Leica Photogrammetric Workstation, which is realised on SD2000 and SD3000 instruments as well as on upgraded DSR and Wild AC/BC instruments, is completely unchanged by the implementation of the SPOT model.

Using seven well spaced control points, this model consistently showed RMS. errors in the 1 pixel region at check points. With more control points the combined RMS. errors at GCPs and check points stabilised just below the pixel region. The Westin model as originally articulated is not adequate for modelling the SPOT dynamic system. A linear parameter in phi showed the highest sensitivity, removing the misfits to the points field.

KEYWORDS: SPOT, Linear Arrays, Real-time realisation, Analytical, Block Adjustment

1.0 INTRODUCTION

The utilisation of satellite imagery, especially SPOT, has been increasing rapidly in recent years. SPOT imagery meets all specifications for 1:100,000 mapping and has been shown to have 80% of the information requirements for 1:50,000 mapping (Gugan and Dowman 1988). Space-borne data sources for mapping is expected to increase with the imminent launching of the first orbiting platform of the earth observation system (NASA 1993) and of a new SPOT satellite with sensors offering better performance. This paper discusses the the SPOT module of Leica's linear array geometric processing system.

Leica has been involved in the development of an orientation system for SPOT imagery for more than 10 years. Leica's SPOT_MS software offers state-of-the-art SPOT modelling in a user-friendly, graphics driven Windows environment. It is designed with a similar interface as other LEICA orientation software and is supported by a rigorously computed real-time realisation for the Leica Mapping Terminal (LMT).

1.1 The SPOT Imaging System

SPOT1 is a sun-synchronous, near circular orbiting satellite launched by France in 1986,. This polar orbiting satellite carries two CCD-imaging devices (HRV1 and HRV2, High Resolution Visible) which operate in Panchromatic (P) and multispectral (XS) modes. The two imaging devices can operate at the same time, and each device can operate in either of the two modes but not both modes simultaneously. Each HRV instrument has 3 panchromatic CCD-sensors with 6000 imaging detectors spaced at 13 μm. These CCD-imaging devices are linear arrays operated in pushbroom mode. In panchromatic (PAN) mode, readings from these sensors are integrated into one set of 6000 pixels per line; In multispectral (XS) mode, readings of succesive pairs of detectors are added to produce 3 sets of 3000 pixels per line.

Measuring radiation reflected from imaged surfaces at intervals of 1.5004 micro-seconds (μs) in PAN imaging results in a average of 10 metres in ground sample distance (GSD) per pixel along track. The XS mode, samples are at at 3.008 micro-seconds with an equivalent GSD of 20 metres. A mirror attached to the imaging devices allow for viewing angles of up to ±27 degrees, at which the GSD in panchromatic mode could reach 13.5 metres. A stereo made of two views separated by 45 degrees view-angle would typically give a base-height ratio of 1. The panchromatic band covers 0.51 to 0.73 (μm) in wavelength, the multispectral bands are 0.5 to 0.59 μm (green), 0.61 to 0.68 μm (red), and 0.79 to 0.89 μm (infra-red).

Spot scenes are segmented and delivered in an average GSD of 10m for the panchromatic image or 20m for the multispectral image in 60 km x 60 km scenes. For photogrammetric processing, the required SPOT product is processed to level 1A; only radiometric correction has been done. Level 1AP refers to hard copy negatives with specially marked image corners for faster and more accurate inner orientation measurements.

2.0 THE SPOT GEOMETRIC MODEL

Many SPOT models have been developed in recent years. Many have been based on determinated orbital parameters from ephemeris data (Gugan and Dowman 1988, Westin 1990, Radhadevi 1994). Usually, six independent parameters can be used to describe a Keplerian orbit; one possible set of parameters are:
Semi-major axis (a), Eccentricity (e), Inclination (I), Right Ascension of ascending node (Ω), Argument of the perigee (ω) and, Mean Anomaly (M).

The Leica model is based on Westin's approach, chosen because it is known to be very accurate and its reduced parameter set allows for

more efficient real-time realisation, but extended with one more parameter for improved precision. This model assumes a simplified orbital, which could be approximated to a plane circle with adequate accuracy during the imaging period of a scene. The orbit radii determined from the ephemeris are fitted to a third-degree polynomial to represent the deviations of the orbit from this circular shape. The constant term of the polynomial is allowed to change in the adjustment, but the linear, quadratic and third degree terms are kept fixed. The orbital parameters used are thus reduced to four:
Inclination (I), Right Ascension (Ω), Time at Ascending node (t = t o), Orbital radius at Ascending node (ro).
But the central travel angle is derived by v = (t - t°) 2π/P, where P is the orbit period which for SPOT is 101.46 hours. A 'leader' (*.lea) file is delivered with SPOT imagery. This leader file contains a predicted ephemeris and measured angular velocities. Initial orbital parameters could be derived from a block adjustment of ephemeris data. The angular velocities measured about every 82 lines (125 µs) are assumed to be of high, but not sufficient, accuracy to model attitude variations of the imaging platform. Relative attitude angles in kappa, phi and omega are computed by integration, but are interpolated into an 80-lines spacing (76 values) to ensure a fast look-up access. This is crucial to the real-time implementation for the Leica mapping terminal (LMT).

With these relative attitude angles, only the constant offsets in kappa, phi, and omega are left to be determined. A linear rate of change for phi is added for a total of 8 parameters. Linear rates for kappa and omega were found to be insignificant, and the same was found for quadratic rates of change for the three attitude parameters. Simulations showed that the Westin model does not sufficiently model SPOT without at least a linear phi parameter. The orientation model is usually set-up for a SPOT-panchromatic image. A SPOT-XS image set-up would only require minor refinements for its doubled size of imaging elements and reduction by half in number of pixels across- and along-track. If unchanged, results will still be similar.

3.0 SPOT FUNCTIONAL MODEL

The adjustment is done in the earth centred inertial geocentric co-ordinate system (ECI), but transformations are required between these other systems:

- The earth centred, earth fixed geocentric system (ECEF).
- A local geodetic system with a known relationship to geographical co-ordinates.
- A sensor co-ordinate system as described in section 3.21.
- A local orbital system which coincides with the attitude reference system when all three attitude values are zero.

Control information would normally be available in a local geodetic coordinate system. These must be tranformed to geographical coordinates, then the ECEF, and finally to the ECI system before they could be used in this model.

The link between a ground control point and its image co-ordinate is:

Xg = **Xs** + Δ Ri Rb Rs **xP**

where

- **xP** = image co-ordinates vector.
- Xg = ground co-ordinates vector in ECI
- Xs = satellite position vector in ECI
- Δ = scale factor
- Ri = Rotation from the orbital reference system to the ECI

- Rb = Rotation between the attitude reference system and the orbital system. The interpolated attitude changes from the measurement system are used here. Only the values of kappa, phi, and omega offsets at the beginning of the scene are calculated in the adjustment.
- Rs = Rotation between the sensor and the attitude reference system; the primary rotation in omega is the mirror inclination; it would also take care of the CCD-sensor off-sets, if any. SPOT is no longer publishing angular CCD off-sets, usually derived from calibration.

Rs is optional because the system can accomodate for the absence of this rotation in the model. Accordingly, the mirror inclination angle can be used as an initial value for omega in Rb instead of a zero value.

The reverse equation is:

xP = 1/Δ . R . **(Xg - X0)**

where R =(Rs . Rb . Ri)

In matrix form, this becomes:

$$\begin{bmatrix} 0 \\ y_p \\ -c \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} \bullet \begin{bmatrix} X_g - X_0 \\ Y_g - Y_0 \\ Z_g - Z_0 \end{bmatrix}$$

yp is the y-image co-ordinate, and c is the focal length of the SPOT camera. The SPOT header file provides a scene-center-time from which imaging times for any lines could be calculated using the CCD integration time which is 1.5004 µs for SPOT. Radial data from the ephemeris data is fitted to a third degree polynomial with respect to time. Ephemeris data is also used to calculate the time at the acending node, enabling the dynamic calculation of the travel angle at any image point. The radius at any image point could be used to generate the camera position co-ordinates by the inverse transformation with the orthogonal matrix of keplerian rotation angles (Ri); see below. Of the keplerian rotations parameters, Right ascension (Ω) and Inclintion (I) remain fairly constant; only the travel angle (v) is changing rapidly with time.

$$F_1 = 0 = -c \bullet \frac{r_{11}(X_g - X_0) + r_{12}(X_g - X_0) + r_{13}(X_g - X_0)}{r_{31}(X_g - X_0) + r_{32}(X_g - X_0) + r_{33}(X_g - X_0)}$$

$$F_2 = y_p = -c \bullet \frac{r_{21}(X_g - X_0) + r_{22}(X_g - X_0) + r_{33}(X_g - X_0)}{r_{31}(X_g - X_0) + r_{32}(X_g - X_0) + r_{33}(X_g - X_0)}$$

The adjustment could correct five observations y-image co-ordinate, time of imaging GCP (t, equivalent to x-pixel coordinate), Longitude (φ), Latitude(λ) and height (**h**).:
[yp, t, φ, λ, h].

The 8 parameters of orientation to be corrected are:
[Io, Ωo, to, ro, ωo, ρo, κo, ρto].

ρto is the linear component of the phi rotational parameter. A Taylor's series expansion of the collinearity equations are done but only the first order terms are taken.

$$A_k = \begin{bmatrix} \frac{\delta F_1}{\delta y_p} & \frac{\delta F_1}{\delta t} & \frac{\delta F_1}{\delta \varphi} & \frac{\delta F_1}{\delta \lambda} & \frac{\delta F_1}{\delta h} \\ \frac{\delta F_2}{\delta y_p} & \frac{\delta F_2}{\delta t} & \frac{\delta F_2}{\delta \varphi} & \frac{\delta F_2}{\delta \lambda} & \frac{\delta F_2}{\delta h} \end{bmatrix}$$

$$B_k = \begin{bmatrix} \frac{\delta F_1}{\delta I} & \frac{\delta F_1}{\delta \Omega} & \frac{\delta F_1}{\delta t_o} & \frac{\delta F_1}{\delta r_0} & \frac{\delta F_1}{\delta \omega_o} & \frac{\delta F_1}{\delta \rho_0} & \frac{\delta F_1}{\delta \kappa_0} & \frac{\delta F_1}{\delta \rho_{to}} \\ \frac{\delta F_2}{\delta I} & \frac{\delta F_2}{\delta \Omega} & \frac{\delta F_2}{\delta t_o} & \frac{\delta F_2}{\delta r_0} & \frac{\delta F_2}{\delta \omega_o} & \frac{\delta F_2}{\delta \rho_0} & \frac{\delta F_2}{\delta \kappa_0} & \frac{\delta F_2}{\delta \rho_{to}} \end{bmatrix}$$

$$A = \begin{bmatrix} A_1 & & & \varnothing \\ & A_2 & & \\ & & \bullet & \\ & & & \bullet \\ \varnothing & & & A_n \end{bmatrix} \qquad B = \begin{bmatrix} B_1 \\ B_2 \\ \bullet \\ \bullet \\ B_n \end{bmatrix}$$

The condition equation can be written as: $Av + B\psi = f^0$

where v is the vector of measurement residuals, ψ are the corrections to parameters which are initially given as approximate values, and f^0 are misclosures using observed values. Formulated in this way, the equation could be singular in a poor GCP configuration (Gugan 1987, Westin 1990), mainly due to the high correlation between parameters (mainly phi and platform motion). It could be stabilised by padding with 'fictitious' equations, taking this shape

$$\begin{bmatrix} A & 0 \\ 0 & I \end{bmatrix} \begin{bmatrix} v \\ v_p \end{bmatrix} + \begin{bmatrix} B \\ -I \end{bmatrix} \psi = \begin{bmatrix} f^0 \\ 0 \end{bmatrix}$$

where vp are corrections to approximate values of unknown parameters. Simply, unknowns could be treated as fictitious observations with associated weights. These weights are usually set from experience and fine-tuned by trial and error. Using weights to effect the stability articulated above, the solution by Mikhail (1976), if **Q** is the apriori cofactor matrix for the measurements and **Wpp** is the apriori weight matrix for the parameter estimates, is:

$$\psi = (B^T (AQA^T)^{-1} B + W_{pp})^{-1} B (AQA^T)^{-1} f^0$$

v can always be calculated after a convergence has been achieved from a few iterations.

$$v = A^T (AQA^T)^{-1} (f - B\psi)$$

3.1 Software

The need for simulations and analyses of an optimal SPOT system required that this SPOT modelling software was developed. This has been done in an analytical-plotter environment, with a specially developed real-time system supporting profiling and image superimposition.

The software has been developed under Microsoft Visual C++ system, making use of this operating system's substantial programming resources driven by the Microsoft Foundation Classes (MFC). Windows file serialisation system, for example, ensures data permanence allowing a project to be continued exactly from where it was stopped; on start-up the system automatically loads the last project exactly where it was discontinued. The software has been programmed towards Windows-NT compatibility and runs well under Windows-95.

3.11 Inner Orientation: The four corners of the image would normally be used for inner orientation. Where analogue prints are used in an analytical plotter it is now possible to use prints with specially marked image corners for easier identification. The corners have image co-ordinates of ±39 cm in both x and y as defined by the characteristics of the SPOT panchromatic camera (3000 x 13μm), and the image centre has co-ordinates of 0,0.

3.12 GCP Management: This allows for input of both geographical and Cartesian co-ordinates. The module supports several possible choices of ellipsoidal parameters and map projection systems for the input data and the output of results. It also provides for needed transformations between the Cartesian, geographic, earth's geocentric and inertial geocentric systems.

3.13 Bundle Resection: A single image bundle resection is done initially. If tie points are needed for a good relative orientation, they could be measured after this computation. This initial orientation assures that reliable approximate values for these tie points are calculated. Linear array models are highly sensitive to the quality of approximate co-ordinates attributed to tie points. After tie points are measured, a two step adjustment is done, initially a single image bundle adjustment of each of the two images, and finally with a block adjustment of both images together. Typically, this bundle adjustments takes about 20 seconds on a 486-50MHz PC.

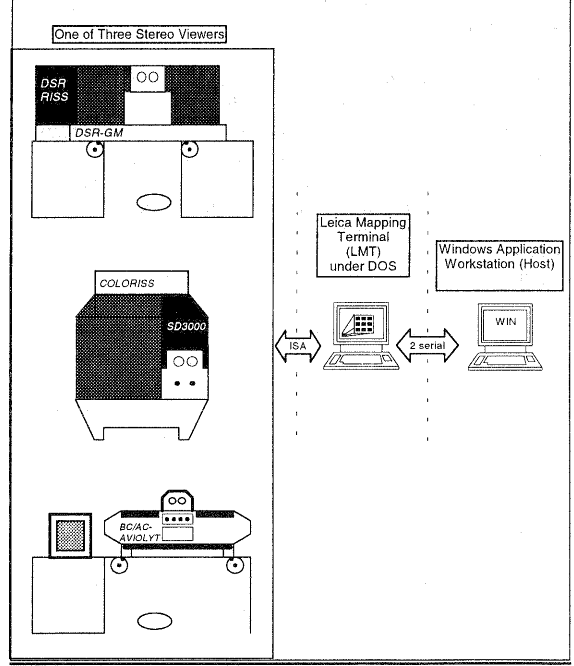
4.0 THE REAL-TIME SYSTEM

The concept of the Leica Photogrammetric Workstation, which is realized on SD2000 and SD3000 instruments as well as on upgrades of DSR and Wild AC/BC instruments (see figure 2.0, refer also to *Cogan, Hinsken 1992* and to *Hinsken, Meid 1993*), is completely unchanged by the implementation of the spot model. Mapping or GIS applications work in the same way as they do with perspective models. Some of the main characteristics of this Workstation are

- It is an open system, i.e. any application like mapping, GIS or DTM collection on any compute platform may be connected to it.
- All Leica analytical plotters can be controlled by the real- time processor software (RTP) on the LMT computer: PDP- based Kern DSR as well as DATA General- or UNIX-based WILD AC/BC instruments can be upgraded to it;
- The real-time software on the LMT computer provides some photogrammetric features and controls the superimposition system without any duplication of real-time computations.

In addition to the perspective model, which had been originally implemented, a new sensor model had to be introduced in order to support a SPOT orientation software. This sensor model had to fulfill the following conditions:

Figure 2: *The Leica Analytical Photogrammetric Workstation*



the mapping/GIS application interface had to remain unchanged, i.e. applications must be enabled to receive information and to control the instrument including superimposition, based on coordinates which are equivalent to those of the perspective model. The perspective sensor model maintains one model coordinate system, which on the one hand defines the movement directions of the instrument encoders (hand-wheels etc.) and which, on the other hand, holds the model coordinates which applications receive and use to control instrument movements. Applications normally would derive ground coordinates from model coordinates using a transformation matrix which is also provided by the RTP.

Since the real-time movements of the spot sensor model are performed in a different coordinate system (see chapter "Mathematical Aspects of the Real-Time System"), additional RTP internal computations had to be implemented to compute model coordinates which can be used in the same way as described above. In fact, these model coordinates are ground coordinates; consequently, the transformation matrix for deriving ground coordinates is a unit matrix.

The definition of the ground coordinates (TM, UTM and Lambert) can be given by the user during the orientation. The desired output system, TM, UTM or Lambert, is also specified during orientation so that the RTP considers this system of ground coordinates and delivers the appropriate information to applications.

- the mono and stereo superimposition system had to be supported; this has been no concern at all, because the integration of the superimposition into the RTP is such that any sensor model is supported without any necessary changes for the superimposition.

4.1 Mathematical Aspects of the Real-Time System

A real-time analysis of SPOT has been done by KRATKY (1987). For clarity, the 'model' system refers to the co-ordinate system in which the orientation is calculated, in this case the inertial geocentric system. **x'y'** refer to the left image co-ordinates, and **x"** and **y"** refer to the right image co-ordinates. Real-time model panning on a photogrammetric plotter requires that the plate position be updated at a high frequency; 25 Hz is known to be adequate.

The orientation parameters of a dynamic system change with time and is different for every scan-line (x-image co-ordinate). A RTP for SPOT, if driven by encoder-input in ground units, would require an iterative computation as the x-image co-ordinates are required (and not known) to calculate the orientation parameters. In six iterations, this could result in more than 500 floating point (FP) multiplications per image which is about 20 times the required number in a perspective RTP system. This would be difficult to achieve on typical CPUs of the day like an INTEL 486/66 MHz.

An SD operator expects the same feel as a model based on the perspective geometry. Thus, encoder-input devices must respond in similar fashion and the floating mark should move in the same consistent direction when the encoder input-devices eg. handwheels are operated. RTPs for conventional photogrammetric models are driven by model co-ordinates with axis almost aligned to the photo-co-ordinate system.

To achieve the same effect, image co-ordinates (x'y') would be the logical choice of encoder input for a linear array RTP system. There may be a misalignment of X- and Y-axis from the expected movement of the floating mark due to the placement of the image in the SD.

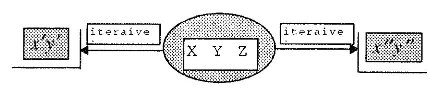
This problem is solved in an analytical plotter by using the kappa rotation from the inner orientation matrix of the left image to transform the basic encoder input. After model set-up, the right image could be rotated in kappa (as necessary) to ensure correspondence with with 'DOVÉ' prisms in an analytical system but in a digital photogrammetric system this is compounded by the need for image resampling image resampling (and re-display).

Accordingly, the operator expects the floating mark to move at right-angle to the plate when the foot disk is displaced as is the situation in conventional photography. This requires that the height (h) be the choice of input for the third encoder. This height should refer to the local geodetic system and would, therefore, compound the implementation because orientation is done in the geocentric system.

A compromise is to have encoder input in x'y'H. The height allows for scale to be solved in the collinearity model and thus the transformation to the model system is accomplished in one step without iterations. Then the calculation of x"y" proceeds iteratively. Less than 300 FP calculations per cycle are achievable here, but this may still not be fast enough.

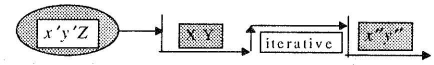
Figure 4: Optimisation drill for the RTP of SPOT

step 1:



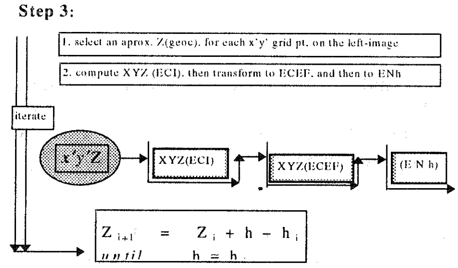
This requires many iterations and, therefore, takes too long.

step 2:



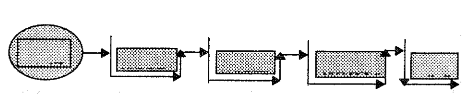
This is faster but the Z-floating mark may not move vertically to the image plane.

Step 3:



Then fit to Kratkys polynomial coefficients

Z = F(x, y, h); after collection of terms

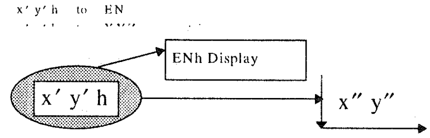


This should work well but can still be further optimised

Step 4:

similar polynomials could be calculated linking the following:

x' y' h to x"y" (not implemented in the Leica system)
x' y' h to EN



This is the full optimisation

A further optimisation is to have the encoder input-devices driven by **x'y'H** and to compute two polynomials linking **x'y'H** to Eastings, and Northings (EN). This could be done using three levels of H from a 5 x 5 grid covering the whole left image. A third polynomial links **x'y'h** to the Z-geocentric co-ordinates. Kratky (1987) has presented two suitable second-degree polynomials, one for either Eastings or Northings, and the other for the Z-geocentric co-ordinates; experience shows that these are very accurate. To calculate these polynomials, the Eastings and Northings must be iteratively calculated for all the selected image grid points.

Proper grouping the terms of these polynomials would result in not more than 11 FP multiplications for the calculation of each Eastings or Northings value. Figure 4 shows the optimisation steps for this real-time system.

5.0 TEST RESULTS

Tests were done using the OEEPE points field in Aix-en-Provence, France. 20 GCPs were used, but two were considered in gross error and removed. These GCPs are known to have a determination RMS. error of less than 5 meters in planimetry, and 2 meters in height, but identification errors could add another 10 metres (Dowman et. al. 1991). Therefore, a combined RMS. error of 10 metres in planimetry and 5 metres in height is assumed.

Commercial SPOT-image prints were used with image written on film at 25 microns for a pixel. Measurements were done on a Leica SD3000 (Walker 1994) analytical plotter by a student. Usually, the measuring accuracy of the SD3000 is between 2 and 5 microns using a grid plate. This is a summary of results.

No of GCPs	No of Check Points	RMSE GCPs (m)	RMSE Chk Pts (m)
18	0	0.97	nil
14	4	0.89	1.3
10	8	0.75	1.25
7	11	0.51	1.40

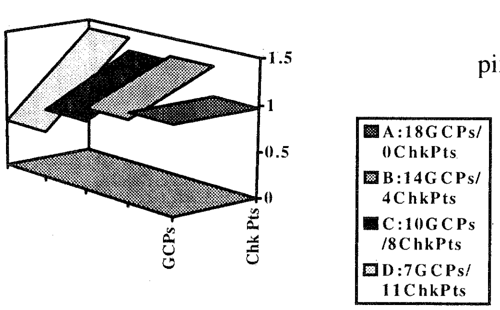


Figure 5-a: Aix_Model I; This model, not tested with tie points, shows a general conformist trend of having higher residuals at check points.

No of GCPs	No of check points	RMSE GCPs (pixels) 1-with tie pts 2-No tie pts	RMSE chk. Pts (pix) 1-tie pts 2-No tie pts
17	0	0.92	nil
		0.92	
13	4	0.90	0.99
		0.86	1.01
11	6	0.83	1.27
		0.92	0.85
9	8	0.80	1.36
		0.75	0.89
7	10	0.78	1.25
		0.73	1.35

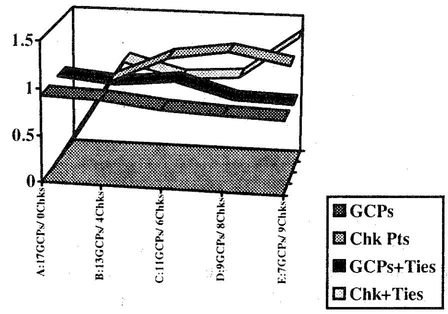


Table and graph 5-b: Aix_Model I, tested with tie points, showed slightly better results than without ties.

No of GCPs	No of Check Points	RMSE GCPs (m)	RMSE Chk Pts (m)
26	0	0.96	nil
15	11	0.82	1.2
9	17	0.76	1.2
7	19	0.58	1.3

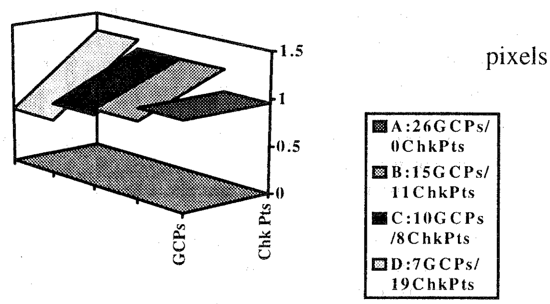


Figure and graph 5-c: Aix_Model II, no tie points, is also conformist.

No of GCPs	No of Check Points	RMSE GCPs (m)	RMSE Chk Pts (m)
26	0	0.89	nil
15	11	0.70	1.2
9	17	0.62	1.2
7	19	0.45	1.3

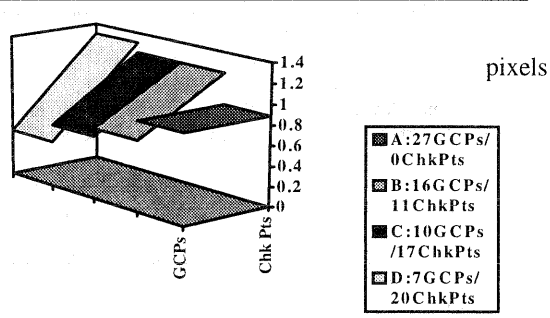


Figure and graph 5-d: Aix_Model III, no tie points, is also conformist

6.0 ANALYSIS AND CONCLUTIONS

Tests were done using the OEEPE points field in Aix-en-Provence, France. 27 GCPs were available. These GCPs are known to have a an accuracy of less than 5 meters in planimetry, and 2 meters in height, but identification errors could add another 10 metres in planimetry (Dowman et. al. 1991). Therefore, a combined RMS. error of 10 metres in planimetry and 5 metres in height is assumed. Measurements were done on a Leica SD3000 (Walker 1994) Leica SD3000 analytical plotter (acc. 2-3 µms) by a student.

1) The Westin model with 7 parameters as originally articulated is not adequate in modelling the SPOT dynamic system. Severe disturbances were noticed in a points field of more than 17 GCPs. After excluding all other options for the source of this problem, an extra parameter was added. A linear parameter in phi showed the highest sensitivity, removing the misfits to the points field. Incidentally, this was the only linear rotational parameter used in the model developed by Gugan.

2) Using seven well spaced control points, this model consistently showed RMS errors just above one pixel pixels at check points. With more GCPS this stabilizes in the one pixel region (see figures and tables 5a-5d above). When corrected for the error in the control network, RMS errors is below one pixel. Misclosures have been calculated using a single bundle resection without employing the stereo view; a stereo intersection could substantially dilute the misclosures and hide disturbance in the points field.

3) While the integrated attitude measurements taken from the SPOT header may not model platform attitude adequately, removing these measurements from the model consistently resulted in a slight deterioration of results.

4) It was also found that components of a 2nd-degree phi are present in the SPOT model, but to a lesser extent. The best results were achieved using a linear and quadratic rates of change for Phi but subtracting the attitude changes in phi calculated from the integrated attitude velocities recorded in the SPOT header files; and adding kappa and Omega attitude changes. This approach was inspired by Priebbenow.

5) When results are compared with earlier work , it would seem that less than 8 parameters are inadequate to model SPOT precisely. This SPOT model is robust and converges rapidly in 4 iterations.

6) Using the same control points on the two stereo images gives the best stereo viewing; this may not always be feasible for images with small overlap areas. Relative orientation is no problem using a large number of good quality, well spread, GCPs (>12) (that are not the same on each image) covering the images.

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