ON-SITE GPS AND INTERACTIVE GEOMETRIC MODELING : A WINNING COMBINATION

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INTRODUCTION

The improvement in the speed and affordability of computers, the increased resolution of scanned airphoto and satellite images (5m and less), and the integration of cartographic features with GIS data (raster and vector) have revolutionized the process of topographic mapping. However, a growing number of applications still require an orthorectification process so that images can be accurately corrected to a ground reference system. Because they are planimetrically correct, the resulting orthoimages can be used as maps. Being able to correlate features on an orthoimage with what is observed on the ground is both time saving and cost effective.

Highly accurate ground control points (GCPs) are necessary to generate orthoimages. One method of collection is to use a GPS receiver. A high-quality GPS receiver with post-processing differential correction can yield GCPs with a horizontal and vertical accuracy of within 1m and 2m, respectively. The problem with post-processing differential correction is that the user cannot accurately plot the GCPs on-site. For example, if the GPS antenna does not have a clear path to the satellites, the user is not immediately aware of the error. A new service called real-time differential correction whereby the user can find out the coordinate of any point in real time is now available in many countries. This eliminates the post-processing differential correction step while yielding GCPs of comparable horizontal and vertical accuracy.

After the GCPs are collected, geometric modelling has to be applied to orthorectify scanned airphoto and satellite images. The polynomial method is the most common geometric modeling method used but it cannot reflect distortions during image acquisition. This deficiency limits its use to small areas with flat terrain.

Two products have been developed at PCI Enterprises to exploit on-site GPS and interactive geometric modeling. The OrthoEngine package is used for scanned air photos and GCPWorks is used for satellite images. Besides GCPWorks, an orthorectification and DEM extraction package based on a rigorous geometric modeling was also developed for satellite images. Both can be executed on most workstations and personal computers including laptops.

The uncorrected scanned airphoto or satellite image is loaded onto a laptop computer using OrthoEngine/GCPWorks. GPS points are collected in the field using a high quality GPS receiver with real time differential correction service. For each GCP collected, the user enters the *X*, *Y*, and *Z* coordinates into OrthoEngine/GCPWorks and finds the corresponding point on the uncorrected image. After three GCPs are collected, OrthoEngine/GCPWorks will use the built-in geometric model to calculate and report the

GCPs residual errors. Unlike other geometric modeling methods, OrthoEngine/GCPWorks takes into consideration errors of image geometry, for example, terrain, platform, sensors, earth and cartographic projection. Errors that occur during the GCP collection process can then be immediately detected and corrected on-site. This process saves the user time and money since the number of GCPs required is minimized., and the user do not have to come back in the field to measure again any erroneous point.

Furthermore, the satellite package has been tested at the Canada Centre for Remote Sensing (CCRS) and the Canada Centre for Topographic Information and meets the specifications of Canada's National Topographic Database to update digital topographic data at 1:50000 scale using SPOT panchromatic data.

GEOMETRIC MODELLING

OrthoEngine/GCPWorks use a geometric model based on collinearity conditions, which represent the physical law of the transformation between the image and ground space. For scanned airphotos, space resection by collinearity is the preferred method of determining the elements of exterior orientation. This is a purely numerical method that simultaneously yields six independent parameters that express the space position and angular orientation of a tilted airphoto. Furthermore, the calibrated focal length of the camera lens and a minimum of three control points with X, Y, and Z ground coordinates must be known. A redundant number of ground control points results from this method so that least squares computational techniques can be used to determine most probable values for the six elements. Also, the method can be extended to multiple blocks of photos by simultaneously using a bundle adjustment method.

For satellite images, the collinearity condition used is based on principles related to photogrammetry, orbitography, geodesy and cartography developed by Thierry Toutin at the Canada Centre for Remote Sensing. This model reflects the physical reality of the complete viewing geometry and reflects the following distortions that may occur during image formation:

(1) distortions due to the platform (position, velocity, and orientation);
(2) distortions due to the sensor (orientation, integration time, and field of view);
(3) distortions due to the Earth (geoid, ellipsoid, and relief); and
(4) distortions due to the cartographic projection (ellipsoid, and cartographic reference)

The greatest advantage of this satellite modeling method is that it has been applied to VIR data (Landsat, SPOT, IRS, MOS), as well as SAR satellite data (ERS, JERS-1, SIR-C and RADARSAT) and can easily be modified to support other satellite and airborne sensors. The model adjusts simultaneously if more than one input image is used, which improves the relative accuracy of the positioning of super imposed images. Based on good quality GCP coordinates, the accuracy of this modeling was proven to be one-third of a pixel for VIR satellite images and one resolution cell for SAR images.

TEST IMAGES

GCP collection tests were carried out using on-site GPS and the interactive geometric modeling computation to detect erroneous points. An eight channel Trimble Pro XL with TDC1 GPS receiver and a premium service DCI 3000 unit with real time differential correction were selected. By comparing the position to a known survey mark, the horizontal and vertical accuracies of the GPS receiver together with the real time differential correction service were within 1m and 2-3m, respectively.

For the airphoto, an 1:8000 scale airphoto of Richmond Hill, Ontario, Canada was used. The photo was scanned at 25mm resolution with a ground resolution of approximately 0.21m. The area has an elevation range of 190m to 210m.

For the satellite data, four different satellite images of Toronto, Canada were used.

- a raw panchromatic SPOT-HRV (10m resolution)
- a raw multiband SPOT-HRV (20m resolution)
- an orbit-oriented Landsat TM image (30m resolution)
- a georeferenced ERS-1 SAR image (12.5m pixel spacing)

The area has an elevation range of 80m to 210m.

GCPs were distributed uniformly over each image. Independent check points (ICPs) were also collected to test the accuracy of the results. The ICPs were collected inside the area bounded by the GCPs and were not used in determining the geometric model and its parameters.

AIRPHOTO RESULTS

Six GCPs and four ICPs were collected from the image. The RMS residuals and errors for the GCPs and ICPs are about 0.2m to 0.4m and 0.3m to 0.6m, respectively using the collinearity condition method. In comparison, the RMS residuals and errors for the GCPs and ICPs are 3.0m to 3.7m and 3.0m to 7.0m using the polynomial method. This is because the polynomial method, which is not rigorously modeled, corrects the GCPs locally, but distortions between the GCPs are not entirely eliminated. Conversely, the collinearity condition method globally corrects the entire image and also takes into consideration the distortions due to terrain. Due to the accuracy of the collinearity condition, witness to the examples given, it is possible for the user to verify the position of a GPS coordinate within two to three pixels when collecting points in the field.

During the GCP collection process, some points were inaccurate. One possible reason was that the GPS antenna did not have a clear path to the satellites. With the built-in geometric modeling, the erroneous points were detected on-site immediately. For example, because of the eroneous point, the RMS residuals of all GCPs increased to 2.1m and 2.4m in *x* and *y* directions, respectively when using the collinearity condition method. The residuals of the erroneous GCP were 3.3m and 4.7m in *x* and *y* directions, respectively, clearly indicating that this GCP was defective. By contrast, the RMS residuals of all GCPs were 1.5m and 2.6m in *x* and *y* directions, respectively when using the polynomial method. The defective GCP cannot be detected when residuals are 1.2m and 2.2m in *x* and *y* directions, respectively.

As a rule of thumb using the collinearity condition method, when a GCP has a residual that is at least two times greater than the RMS residual of all GCPs, it can be considered defective.

SATELLITE IMAGE RESULTS

Although the collinearity condition method requires a minimum of only four GCPs for VIR and seven GCPs for SAR images, 14 GCPs were used for each image to ensure consistency in the comparison of results between the collinearity condition and polynomial methods. There is no significant difference in residuals between the methods. As explained earlier, this is because the polynomial method corrects locally at the GCPs, but distortions between the GCPs are not entirely eliminated. This is confirmed by the results of Table 1 when using seven ICPs not used in determining the geometric models and their parameters.

Table 1 : Comparison of seven ICPs results from different satellite images of Toronto, Canada using Toutin's collinearity condition method and the second order polynomial method

Method	Error (meters)	SPOT 10*m*		SPOT 20*m*		Landsat 30*m*		ERS 12.5*m*	
		E*x*	E*y*	E*x*	E*y*	E*x*	E*y*	E*x*	E*y*
Collinearity Condition	RMS	3.8	4.4	4.6	6.9	6.3	8.3	11.0	8.6
	E*max*	5.4	7.1	5.1	7.6	9.9	10.9	13.7	15.0
2nd Order Polynomial	RMS	28.3	10.6	32.0	23.6	17.4	18.0	81.5	79.4
	E*max*	19.2	7.3	25.6	15.4	11.7	11.7	53.8	61.7

As Table 1 indicates, the accuracy of SPOT and Landsat images are within one-third of a pixel, and the accuracy of the ERS-1 image is less than one resolution cell. This confirms in an operational environment, previous results at CCRS.

When an erroneous point was included in the GCPs, the collinearity condition method was able to detect the error on-site immediately. For example, the RMS residuals of all GCPs were 4.7*m* and 12.9*m* in x and y directions, respectively using a SPOT 10*m* image with an erroneous point. The residuals of the erroneous point were -13.1*m* and -32.3*m* in x and y directions, respectively. When using the polynomial method, the RMS residuals of all GCPs were 5.6*m* and 11.1*m* in x and y directions, respectively. The residuals of the erroneous point were -2.9*m* and -11.1*m* in x and y directions, respectively, which are not an indication of any error. Again, the residuals of the erroneous point from the collinearity condition method were three times higher than the residuals of all GCPs and were detected and corrected on-site immediately.

Our results clearly support the superiority of the collinearity condition method over the polynomial method in areas of low relief, but most particularly in areas of high relief.

SUMMARY

In summary, the main advantages of this winning combination using on-site GPS and interactive geometric modeling based on the collinearity condition are :

- less GCPs are required
- more accurate results
- robustness and consistency of results
- capability to detect and correct erroneous GCPs on-site
- interactive GCP collection and computation save time and money.

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