GCP REQUIREMENT FOR HIGH-RESOLUTION SATELLITE MAPPING

Th. Toutin [a,] *, R. Chénier[b]

[a] Natural Resources Canada, Canada Centre for Remote Sensing, 588 Booth St., Ottawa, Ontario, K1A 0Y7 Canada – thierry.toutin@ccrs.nrcan.gc.ca

[b] Consultants TGIS inc., 16 chemin Pelletier, Chelsea, Quebec, J9B 2A6 Canada - rene.chenier@ccrs.nrcan.gc.ca

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ABSTRACT:

High-resolution images have to be geometrically and precisely processed with ground information, such as ground control points (GCPs) and digital elevation models (DEM) to generate accurate map products and 3D geospatial information. Consequently, the 3D multi-sensor physical model developed at Canada Centre for Remote Sensing for medium-resolution satellite images was adapted for these new high-resolution data, such as SPOT-5, EROS, IKONOS and QuickBird. To evaluate the impact of GCP accuracy in the geometric correction process of the highest resolution data available, QuickBird (0.61 m), different methods of collection were used with accuracies varying from 10 m to 0.10 m. Good quality results (4-5 m in both axes), as related to input accuracy, were obtained when using GCPs collected from 10-m accurate map. Medium quality results (3-4 m in both axes), as related to input accuracy, were obtained when using GCPs collected from 1-m pixel orthophotos (3-5 m positioning accuracy) These medium quality results are mainly due to differential errors caused by a lack of homogeneity between the orthophotos. High quality results (0.8 m and 1.4 m in both axes), as related to input accuracy, were obtained when using GCPs collected from differential GPS (0.20-m accuracy) and hand-held commercial GPS (2-3 m accuracy), respectively. These geopositioning accuracies meet the 1:5,000 to 1:10,000 mapping standard, respectively. Consequently, depending upon the positioning accuracy required by the user and their applications, the appropriate GCP collection method can be chosen to maximize scientific and managing aspects.

RÉSUMÉ :

La géométrie des images de haute résolution doivent être traitées avec précision en utilisant des données-terrain, tels des points d'appui(PA) et des modèles numériques d'altitude (MNA) pour créer des produits cartographiques précis et de l'information géospatiales 3D. Le modèle physique multicapteur 3D, développé au Centre canadien de télédétection pour les images satellitales de moyenne résolution, a été alors adapté à ces nouvelles données de haute résolution, tels SPOT-5, EROS, IKONOS et QuickBird. Pour évaluer l'impact de la précision des PA sur la correction géométrique des données de la plus haute résolution disponibles, QuickBird (0,61 m), on a utilisé différentes méthodes d'acquisition avec des précisions variant de 10 m à 0,20 m. De bons résultats (4 m dans les deux axes), par rapport à la précision des données d'entrée, ont été obtenus avec les PA d'une carte topographique de 10 m de précision. Des résultats moyens (4-5 m dans les deux axes), par rapport à la précision des données d'entrée, de la modélisation géométrique calculée avec les PA acquis d'orthophotos (3-5 m de précision), s'expliquent par des erreurs différentielles causées par le manque d'homogénéité entre les orthophotos. De très bons résultats (0,8 m et 1,4 m dans les deux axes), par rapport à la précision des données d'entrée, ont été obtenus avec des récepteurs SLDEG ("DGPS") (0,10 m de précision) et SLEG ("GPS") (2-3 m de précision) permettent d'atteindre la précision cartographique des échelles du 1 : 5 000 et 1 : 10 000, respectivement. Par conséquent, le choix de la méthode d'acquisition des PA dépend de la précision de la localisation requise par l'utilisateur et du type d'applications. Elle peut être alors sélectionnée pour maximiser les aspects scientifiques et de gestion de projet.

1. INTRODUCTION

High resolution images, such as Quickbird (0.61 m resolution), IKONOS (0.8 m resolution), EROS (1.8 m resolution), and SPOT-5 (2.5-5.0 m resolution), have to be geometrically processed with ground control points (GCPs) and digital elevation models (DEM) to generate precise map products before being used for extracting geospatial information. Consequently, the 3D multi-sensor physical model developed for medium-resolution sensors in the visible and infra-red (Landsat, SPOT, ASTER, etc.) as well as in the microwave (SIR-C, ERS-1, RADARSAT) at Canada Centre for Remote Sensing (CCRS) (Toutin, 1995) was adapted two years ago for IKONOS high resolution data and now for SPOT-5, EROS and QuickBird data (Toutin, 2004a).

This universal geometric model is to be used in the different mapping processes: operational automatic DEM generation, ortho-image generation, and 3D-geospatial information extraction on digital stereo photogrammetric workstation. Whatever the processes applied, a geometric correction method using the multi-sensor model has to be first computed. When accurate results (less than 5 m) are required GCPs have to be acquired to precisely compute/refine the parameters of the mathematical functions, which physically describe the acquisition system geometry (Toutin, 2004b). Generally, an iterative least-square adjustment process is applied when more GCPs than the

* Corresponding author.

minimum number required by the model (as a function of unknown parameters) are used.

The number of GCPs is a function of different conditions: the method of collection, the sensor type and resolution, the image spacing, the geometric model, the study site, the physical environment, GCP definition and accuracy and the final expected accuracy. If GCPs are determined *a priori* without any knowledge of the images to be processed 50% of the points may be rejected (Toutin, 2004b). If GCPs are determined *a posteriori* with knowledge of the images to be processed, the reject factor will be smaller (20-30%). Consequently, all the aspects of GCP collection do not have to be considered separately, but as a whole to avoid too large discrepancies in accuracy of these different aspects. For example, differential GPS survey should not be used to process Landsat data in mountainous study site, nor should road intersections and 1: 50,000 topographic maps to be used to process QuickBird images if you expect 1-2 m final accuracy, etc. The weakest aspect in GCP collection, which is of course different for each study site and image, will thus be the major source of error in the error propagation and overall error budget of the bundle adjustment.

In order to address some aspects of GCP collection (definition and accuracy) with high-resolution satellite data in operational environments, a collaborative project within Natural Resources Canada occurred. Scientists at the Centre for Topographic Information (CTI), the Geodetic Survey Division (GSD), and CCRS were evaluating the mapping potential of high-resolution satellite imagery using CCRS 3D multi-sensor physical model and QuickBird, the highest resolution satellite images available to the civilian communities in remote sensing/photogrammetry.

2. STUDY SITE AND DATA SET

2.1 Study Site

The study site is the National Capital Region of Canada (45º 20' N, 75º 45' W): Ottawa, Ontario in the south-east and the Gatineau Hills, Quebec in the north-west, separated by the largest half-frozen Ottawa River (East-West) (Figure 1). This study is mainly a residential environment on both sides of Ottawa River, and a forest environment in the Hills. The elevation range is between 50 m in Ottawa to 300 m in the Gatineau Hills.

2.2 Data Set

To test the CCRS 3D parametric model with QuickBird data, panchromatic and multispectral imagery products of Ottawa, were provided as a courtesy of DigitalGlobe™ (http://www.digitalglobe.com). The image (16 km by 15 km) was acquired February 17, 2002 with a low sun elevation angle of 19°. QuickBird image was provided as *Basic* imagery products, which are designed for users having advanced image-processing capabilities. DigitalGlobe also supplies QuickBird camera model information with each *Basic* Imagery product to permit you to perform photogrammetric processing such as orthorectification and 3D feature extraction (Robertson, 2003). This camera model is only useful for the users who do not have or develop 3D physical model. *Basic* imagery is the least processed image product of the DigitalGlobe product suite; only corrections for radiometric distortions and adjustments for internal sensor geometry, optical and sensor distortions have been performed on each scene ordered, and the image orientation approximately corresponds to a North-South direction.

Figure 1. QuickBird panchromatic image over the National Capital Region of Canada (16 km by 15 km; 0.61 pixel spacing).
QuickBird © 2002 and Courtesy DigitalGlobe.

To evaluate the impact of GCP accuracy in the geometric correction process, four methods of collection were used. Specifically:

1. Thirty points were collected from 1:50,000 topographic map. Points are mainly road intersections (Figure 2) with image pointing accuracy of few pixels (2-3 m). However, the predominant error comes the map accuracy of around 10 m;
2. Twenty points were collected from 1-m pixel spacing orthophotographs provided by the *Ministère des Ressources naturelles du Québec*. Points are mainly the same than with topographic map collection. However, the predominant error comes also the orthophoto accuracy of 3-5 m;
3. Fifteen points were collected using a hand-held Global Positioning System (GPS) receiver (WASS enabled). Points are precise features such as poles (Figure 3) with image pointing accuracy of one or two pixels (1 m). These poles were clearly distinguishable due to their long shadows on snow. However, the predominant error is the GPS accuracy of 2 to 3 m; and
4. Thirty-eight points were collected, using a differential GPS (DGPS) receiver in real-time kinematic and post-processing modes with better than 0.2 m accuracy. Points are mainly white lines on the ground (Figure 4) with image pointing accuracy of better than one pixel (0.5 m).

The rationale for the different GCP collection methods was that the larger number of GCPs would enable error propagation to be reduced in the computation of the 3D physical model by using an iterative least-square adjustment method. In fact, the more accurate the GCPs the fewer GCPs needed for modelling, and inversely when the accuracy is worse, the number should be increased depending also of the final expected accuracy (Savopol *et al.*, 1994).

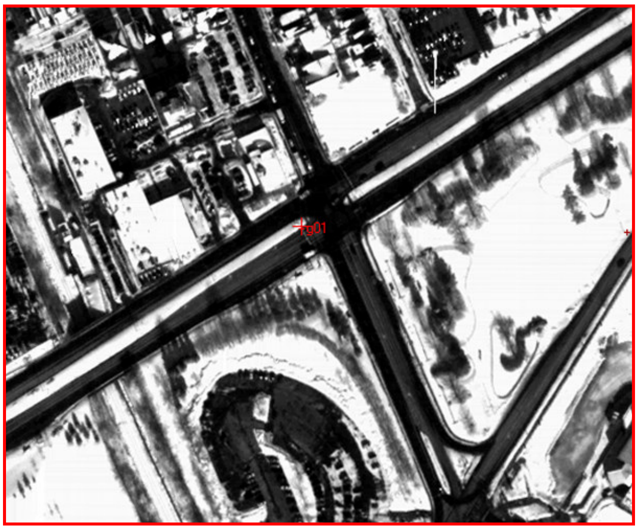

Figure 2. Example of GCP collected with topographic map: the road intersection.
QuickBird © 2002 and Courtesy DigitalGlobe.

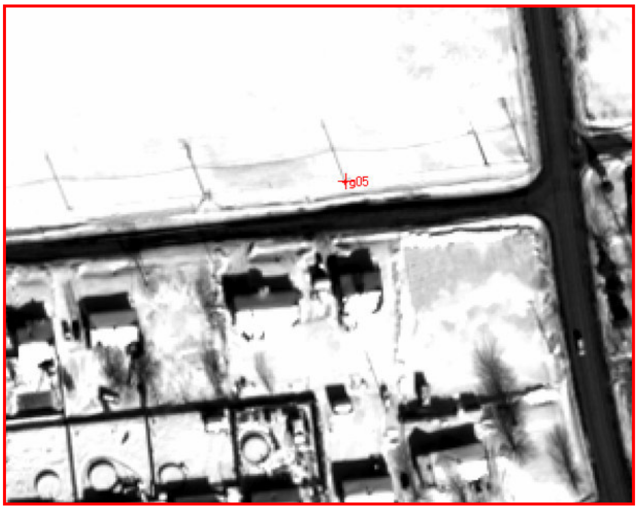

Figure 3. Example of GCP collected with hand-held GPS: the pole defined with its shadow. Even the shadow of the power line is visible on the snow.
QuickBird © 2002 and Courtesy DigitalGlobe.

Figure 4. Example of GCP collected with DGPS: the white stop line at the road intersection.
QuickBird © 2002 and Courtesy DigitalGlobe.

3. EXPERIMENT AND RESULTS

3.1 Experiment

The experiment deals with the computation of the parameters of CCRS 3D physical model using the four sets of GCPs. In the model computation, each GCP contributes to two observation equations: an equation in *X* and an equation in *Y*. The observation equations are used to establish the error equations for GCPs, which are weighted as a function of the accuracy of the image and cartographic data. The normal equations are then derived and resolved with the unknowns computed. In addition, conditions or constraints on osculatory orbital parameters are added in the adjustment to take into account the knowledge and the accuracy of the ephemeris. They thus prevent the adjustment from diverging and they also filter the input errors.

Since there are always redundant observations to reduce the input error propagation in the geometric models a least-square adjustment is used. Since the mathematical equations of the 3D physical model are non-linear, some means of linearization (series expansions) were used. A set of approximate values for the unknown parameters in the equations are thus initialized from the osculatory and sensor parameters. More information on least-squares methods applied to geomatic data can be obtained in Mikhail (1976). The results of this processing are:

- the parameter values for the 3D geometric model;
- the residuals in *X* and *Y* directions for each GCP and their root mean square (RMS) residuals;
- the errors and bias in *X* and *Y* directions for each independent check point (ICP) and their RMS errors;
- the computed cartographic coordinates for each point.

In the four tests, GCPs were spread at the border of the image to avoid extrapolation in planimetry, and cover the full elevation range of the terrain (lowest and highest elevations) to avoid extrapolation in altimetry. When more GCPs than the minimum theoretically required are used, the GCP residuals reflect the modelling accuracy. Additionally, the GCPs collected by the DGPS were also used as ICPs to obtain an unbiased validation of the collection methods' modelling accuracy.

3.2 Results

Table 1 gives for each collection method, the GCP accuracy, the number of GCPs and ICPs, the root mean square (RMS) residuals and errors (in metres) of the least-square adjustment computation for the GCPs and ICPs, respectively. GCP RMS residuals reflect modelling and GCP accuracy, while ICP RMS errors reflect restitution accuracy, which includes feature extraction error and thus are a good estimation of the final positioning accuracy of planimetric features. However, the final internal accuracy of the modelling of the 3D modelling will be better than these RMS errors. Consequently, it is thus normal and "safe" to obtain residuals from the least-squares adjustment in the same order of magnitude as the predominant GCP error.

Table 1 shows that RMS residuals/errors were generally in the same order of magnitude as the input data error, which is, depending of each collection method, a combination of image pointing error, *X-Y* planimetric error and propagation of Z-error as a function of the viewing angle. The analysis of the general results demonstrates that the 3D physical model is stable and robust over the entire stereo-images without generating local errors, regardless the GCP accuracy and number. These statements are mainly supported by the ICP errors, as an unbiased validation of the modelling. However, these ICP errors include both the cartographic errors and the extraction error (due to the image content) of ICP features, and are thus a good estimation of the restitution accuracy. The internal accuracy of the modelling is in fact better, in the order of pixel or sub-pixel.

GCP Method	GCP *X-Y* Accuracy	**GCP/** ICP	GCP RMS Residuals		ICP RMS Errors	
			X	*Y*	*X*	*Y*
1:50k Map	10 m	**30**/38	6.0	5.3	3.2	4.5
Photos	3-5 m	**20**/38	3.9	4.3	4.2	2.6
GPS	2-3 m	**15**/38	1.8	1.3	1.6	1.4
DGPS	0.2 m	**10**/38	0.2	0.2	**0.8**	**0.8**

Table 1. Results of the least-square bundle adjustment of the 3D physical model using the different GCP collection: with GCP accuracy the number of GCPs and ICPs, RMS residuals and errors (in metres) on GCPs and ICPs, respectively.

Presently there is no apparent explanation as to why the good quality results (6 m and 5.3 m), as related to input accuracy (10 m), were obtained with the GCPs from a 1:50,000 topographic map. The ICP error is in fact at least twice better than the input accuracy, with the cartographic coordinate error as the predominant error. A good potential reason is that the map has a good homogeneity and a good relative and internal accuracy (small random error), which are thus reflected in strong bundle geometry of the QuickBird image. The systematic error of the map is thus compensated by a translation in the image modelling. Care must be taken in the extrapolation of these results with other maps; however, these results have been confirmed in an unpublished CCRS study with QuickBird image over Voisey Bay, Newfoundland and Labrador, Canada.

On the other hand, the medium quality results (3.9 m and 4.3 m), as related to input accuracy (3-5 m), of the geometric modelling computed with the GCPs collected from the orthophotos are due to differential errors caused by a lack of homogeneity between the orthophotos. The ICP error is in fact almost the same than the input accuracy, with the cartographic coordinate error as the predominant error. These differential errors (even the systematic error) create local random errors in the different parts of the image, which cannot be fully compensated by the modelling.

The high quality results, as related to input accuracy, obtained with the DGPS system and the GPS meet the 1:5,000 to 1:10,000 mapping accuracy, respectively. The ICP error is in fact almost the same than the input accuracy: the cartographic coordinate error being the predominant error (2-3 m) for hand-held GPS collection method, while the 1-m image pointing error being the predominant error for the DGPS collection method. The DGPS results demonstrate that to achieve the best accuracy (sub-pixel) with QuickBird image, the predominant error in this GCP collection method has to be reduced by choosing well-defined GCPs (natural or artificial targets) in order to reduce the image pointing error to sub-pixel.

4. CONCLUSIONS

Different GCP collection methods were used for geometrically processing QuickBird image with CCRS 3D multi-sensor physical model: 10 m accurate topographic map to 0.2 m accurate DGPS. First, a larger number of GCPs has to be collected when their accuracy decreases to reduce the error propagation in the least-squares bundle adjustment. Then, positioning errors of few metres were achieved regardless the collection method: 3-4 m with 1:50,000 map and 3-5 m accurate orthophotos and around 1 m with 2-3 m accurate GPS and 0.20 m accurate DGPS. With the DGPS method, the predominant error came from the image pointing: natural and artificial targets should be used to further reduce the errors. Consequently, depending upon the positioning accuracy required by the user and their applications, the appropriate GCP collection method can be chosen to maximize scientific aspects such as input and processing, output and accuracy as well as better manage project aspects such as delivery time, efficiency, and costs.

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