GPS Control for 1:50,000-Scale Topographic Mapping from Satellite Images

Abstract

Ortho-images from digital SPOT satellite data were generated to test their application in production and updating of 1:50,000-scale Canadian National Topographic Maps. The orbital parameters were modeled with Ground Control Points (GCP), and the transformation between image and geographic coordinates was defined. Successful production and update of digital map files, or GIS feature extraction from base images, requires knowledge of the total error budget in the ortho-image process. The errors were found to include the GCP geographic position error, the pointing error for GCPs in image coordinates, DEM error, and transformation and resampling errors. GCP error was studied using GPS technology, and photogrammetric and map coordinates with variances in both precision and efficiency in a production environment. Ortho-image chips were studied through correlation for residual errors between the varying factors. The results show that control points acquired through differential GPS technology with average precision handheld receivers would be sufficient to meet planimetric accuracies for 1:50,000-scale map production.

Introduction

The Canada Centre for Geomatics developed under the SINAPS Project a digital approach for topographic data extraction and map revision at 1:50,000-scale with SPOT satellite data (Begin, 1991). Furthermore, this approach confirmed the need for rigorously corrected satellite imagery for topographic data integration within a GIS environment. Tests were conducted in Qubec's Eastern Townships on the Sherbrooke Data Set (Lasserre and Lemieux, 1990). Among the various tasks, image rectification software was developped jointly with the Canada Centre for Remote Sensing (Toutin and Lemieux, 1991) and ground control point (GCP) acquisition was investigated for image geocoding (Clavet, 1991). Results of this investigation revealed that, in order to produce an ortho-image meeting positional topograpical data accuracies of 10 m at a 90 percent confidence level, a 4-m planimetric accuracy was needed for the control points.

Unanswered questions were: Which cost efficient control point source meets the required accuracy? Are there alternate sources and at what cost? A project with the objective to determine a cost-efficient approach for GCP acquisition in ortho-image generation at 1:50,000-scale topographic accuracies was defined, and the results are detailed in this paper.

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In the next section, methods to collect GCP coordinates for various acquisition sources are given. Two GPS procedures are detailed and compared to other GCP sources. This is followed by results giving cost estimates for various GCP sources and showing precisions obtained on a point by point basis, and ortho-image precisions estimated according to a Total Error Budget (TEB) or obtained from ortho-image residuals or from image correlation.

Methods

The Sherbrooke Data Set includes an area which can be referred to as the southern half of the National Topographic System, NTS map sheet 21E/5 SHERBROOKE and the northern half of NTS map sheet 21E/4 COATICOOK, thus representing a land coverage of approximately 26 km by 40 km (Figure 1). In order to produce an ortho-image of this area, a SPOT PLA image acquired in June 1987 at a view angle of 29.29° was utilized. The raw SPOT scene is presented in Figure 2 showing the 31 ground stations serving either as control points or as check points in the image rectification model. Maximum distance between stations was approximately 30 km. Positions were determined at the center of road intersections for each station. As suggested by Toutin and Carbonneau (1990), an *a posteriori* method of GCP acquisition was followed. Choosing easily identifiable linear feature intersections on the image before acquiring ground coordinates minimizes image coordinate reading errors.

For each GCP station, image coordinates were determined on a raster/vector display system by drawing vectors over the raster linear features and then by reading, at the intersection of the vectors, the line and pixel values to a 1-m resolution. The image coordinate reading error is 0.5 pixel when utilizing this method on easily identifiable features (Clavet, 1991).

GPS GCP Source

Precise station positions were determined by the Canada Centre for Surveying using Global Positioning System GPS Ashtech M-XII receivers. The observation period for each station was 2 hours, and road intersection centers were obtained by the antenna swapping method (Remondi, 1986); when this was not possible in heavy trafic, intersection center coordinates were determined by angle and distance measurements from a fixed station on the roadside. Relative planimetric precision was within 50 cm when compared to first-order geodetic network control (Clavet, 1991). Having to deal with data accuracies greater than 5 m RMS, these coordinates are considered as being highly accurate, and were des-

Photogrammetric Engineering & Remote Sensing,
Vol. 59, No. 1, January 1993, pp. 107–111.

0099-1112/93/5901-103$03.00/0

ignated as absolute values to which other source coordinates are compared.

Less accurate GPS observations were determined with Magellan NAV 1000 PRO receivers. These receivers are handheld, requiring a laptop computer and related software. In some cases where obstructions could occur (trees, passing traffic, etc.), the antenna was mounted on a 3-m extension rod fixed on a tripod. This single channel GPS receiver utilizes C/A (Clear Access or Course Availability) code to measure pseudo-ranges between receiver station and satellite station. The horizontal coordinate accuracies, with *a priori* knowledge of elevation to ±1 m, are better than 15 m (RMS) in autonomous mode and better than 5 m (RMS) in differential mode according to Magellan Systems Corporation (1990).

Figure 3 illustrates the steps that were followed for the GPS survey with the Magellan receiver (Lasserre and Pouliot, 1990). Site reconnaissance was made on ground stations previously marked for the GPS Ashtech survey; only 20 of the 31 stations were found to be obstruction free for the Magellan receiver, antenna, and satellite constellation specifications. Observation periods were chosen with a Horizontal Dillution Of Precision (HDOP) ≤2, HDOP being a scalar representing the changing geometrical strength of the satellites in GPS technology (Wells, 1986). This geometrical strength can be achieved in most parts of the world; however, at high latitudes (> 55°) a slight degradation of accuracy in height will occur in 3D mode operation (Lachapelle, 1991). At each station, observations were made in autonomous mode and coordinates were obtained by the averaging of 32 readings with one roving receiver. These observations were processed in differential mode through deploying a second receiver, recording throughout the observation period at the home station. The receiver roving on the stations and the home receiver recorded coordinates time synchronously. This method utilized two home stations in order to minimize distances between home stations and the roving receiver (less than 15 km). Of the 20 stations, only 11 were considered in the final results due to a gross error (> 5 m) in elevation introduced at one of the home stations during calibration; this resulted in abnormal discrepencies. Although Magellan GPS coordinates were acquired in both autonomous and differential mode, the autonomous mode coordinates were rejected on an operational basis because of Selective Availability (SA). If SA is set on, this could introduce random errors in coordinate readings. Post-processing of the data was accomplished on a PC system with Magellan and SAS statistical software packages. At this time coordinate values irregularly different were eliminated. These generally appeared at the beginning and end of the observation periods. Emphasis was put on insuring the accuracies in datum conversions from the GPS data in North American Datum NAD83 to NAD27 May 76 adjustment for the topographic data.

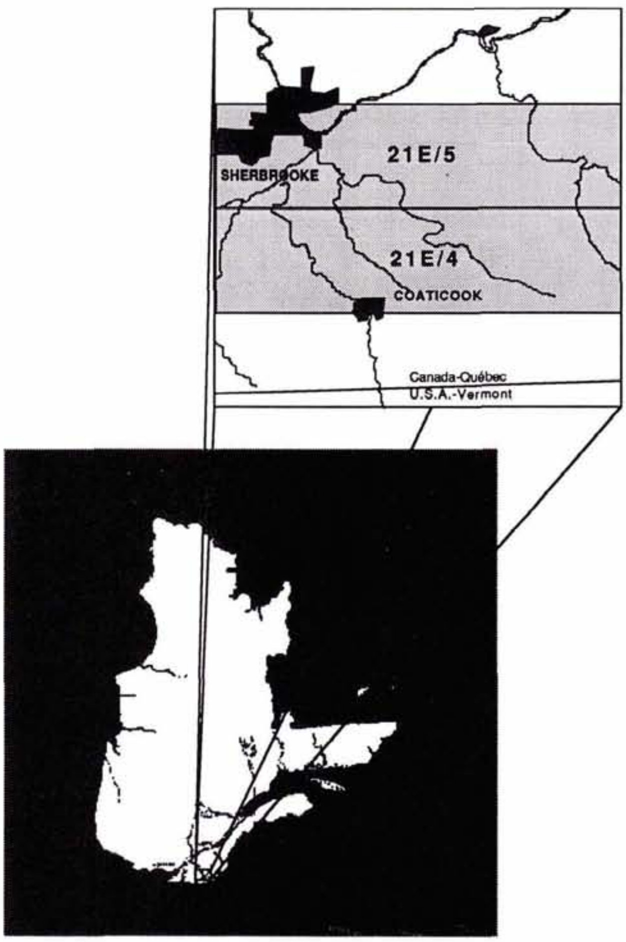

Fig. 1. Sherbrooke Data Set location.

Other GCP Sources

Positions were also determined photogrammetrically for each station by stereoscopic model readings based on digital aerotriangulated data, with a first-order stereodigitizer. When comparing photogrammetric with the absolute coordinates, the planimetric accuracy of an aerotriangulation block was determined. The aerotriangulation data were adequate for the

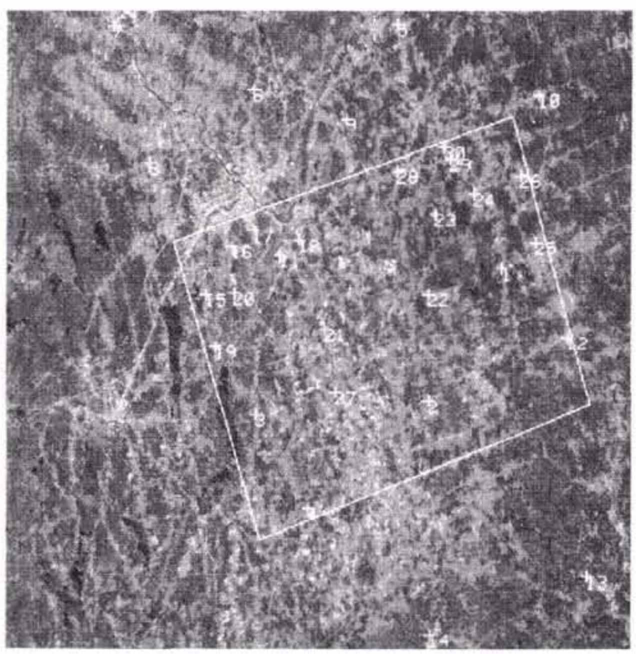

Fig. 2. Raw SPOT PLA, Ground Control Point stations, and Data Set perimeter. ©SPOT Image copyright 1987, CNES.

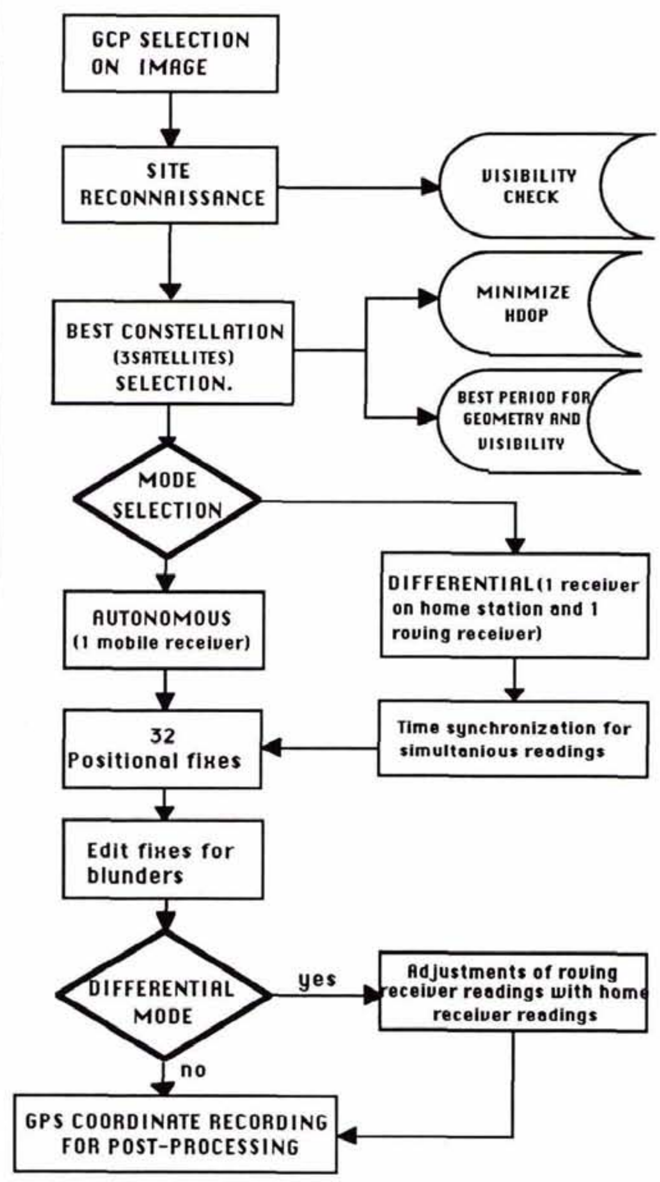

Fig. 3. Flow procedure for GCP acquisition with GPS Magellan.

production of NATO A1, 1:50,000-scale maps specifications (NATO, 1983), and the NTS maps used in this project were of A1 standard.

Maps being the conventional source of GCP acquisition for image geometric corrections, cartographic positions were determined by reading coordinates from the NTS map sheets with a digitizer cursor. Cartographic positions were also determined by reading coordinates from a digital topographical data file produced by stereo-digitization, these data being more accurate than map data. These stereo digitized GCP coordinates were rejected on an operational basis because of various uncontrolable errors (i.e., false elevation setting, etc.) that could have been be introduced during data capture.

Table 1. Time and Cost Estimates for GCP Acquisition Sources for the Sherbrooke Data Set.

GCP Source	Acquisition	Processing	Cost (Cnd $)
GPS Ashtech	15 days; team of 6	5 days	$800/station
GPS Magellan Dif.	3 days; team of 2	3 days	$115/station
Photogrammetric	1 day; 1 operator	3 hours	$15/station
Cartographic	4.5 hours; 1 operator	3 hours	$8/station

Ortho-Image Generation
GCP coordinates and image coordinates were modeled within the geometric correction software package (Toutin and Carbonneau, 1990, in press). This software models orbital parameters related to the scene center and resamples the image according to calculated coordinates. It utilizes general image information such as longitude, latitude, time and view angle, satellite ephemeris such as satellite velocity and position, and attitude data related to angular velocity along the three axes. Image resampling utilizes a Digital Elevation Model (DEM) to produce an ortho-image. For each GCP source, image coordinates were computed and the SPOT PLA was resampled to produce an ortho-image.

Analysis
In order to determine the optimum type of ground control, ortho-images were produced for each GCP type and accuracies were determined by either comparing ortho-image residuals or by image correlation. For the analysis of residuals, values are based on the same 11 stations for control points in model generation, and 16 GPS Ashtech stations served as check points for all GCP sources. Residuals were obtained by comparing check point adjusted coordinates with the GPS Ashtech coordinates.

Ortho-image correlation was done by comparing the photogrammetric, Magellan GPS, and Cartographic GCP ortho-images to the Ashtech derived ortho-image. This study utilized image chips in which pixel displacement between image pairs was measured (Guindon, 1985) in order to determine their accuracy.

Results
Results are given in terms of logistical efforts (time and cost estimates) and in terms of accuracies before geometric correction on a point by point basis. After geometric correction, estimated and calculated ortho-image residuals were determined from check points.

Logistics
With the GPS Ashtech, 31 station coordinates were determined for a SPOT scene, in 15 days by a team of six experienced operators. It took five days to process the data (network compensation, datum conversion, and formatting).

With the Magellan in differential mode, the survey took two days with one operator at the home station and two operators on the roving receiver. Handheld receivers like the Magellan are designed for use by non-specialist operators and require lower overhead costs in operations and supervision. In an operational mode, the roving receiver would require only one operator. Data processing (formatting, datum conversion, editing, and differential processing) was accomplished by an operator in three days.

When determining photogrammetric GCPs, one experienced operator took one day to read the coordinates on a stereodigitizer and three hours to process the data (datum conversion and formatting).

When determining cartographic GCPs, one operator took half a day to read the coordinates on the map sheets and three hours to process the data (datum conversion and digital formatting).

Cost estimates are given in Table 1 for each source of the GCPs. They include personnel salary and travel expenses, and amortized values of equipment or rental prices. Computer time is not included, nor is the pre-processing phase which is similar in cases of GPS surveying. Estimates do not include the acquisition of frame photography for photogrammetric GCPs.

Accuracies

Accuracies obtained with the different GCP sources are given in Table 2. Values for photogrammetric and cartographic GCP sources are based on 31 stations, while for the Magellan source 11 stations were utilized. Planimetric accuracies (CCSM, 1984) are given in terms of

CSE or Circular Standard Error (confidence level = 39%),

$$\text{CSE} = \sqrt{\sigma X^2 + \sigma Y^2} * 0.7071$$

where σ is the standard deviation.

MSEP or Mean Square Error in Planimetry (confidence level = 63%),

$$\text{MSEP} = \text{CSE} * 1.4142$$

and CMAS or Circular Mean Accuracy Standard (confidence level = 90%).

$$\text{CMAS} = \text{CSE} * 2.1460 = \text{MSEP} * 1.5174$$

Estimated ortho-image accuracy is obtained from a Total Error Budget (TEB) formula expressed as a CMAS value:

$$\text{TEB} = \sqrt{m^2 + p^2 + e^2 + c^2} * 1.5174$$

where

m is a model error of 1.0 m (Toutin and Carbonneau, 1990),
p is an image coordinate reading error of 4.0 m (Clavet, 1991),
e is a planimetric error induced by the DEM of 4.0 m (Clavet, 1991), and
c is the GCP source error.

Based on the MSEP (Table 2) values, the following TEB is given for different GCP sources:

Photogrammetric = 10.0 m
Magellan Diff. = 12.4 m
Cartographic = 39.0 m

Ortho-image accuracies were also determined from the geometric correction model residuals and by ortho-image correlation.

Ortho-image accuracies are given in Table 3. CMAS values at check points indicate that Ashtech precise GCPs do not produce better ortho-images than the less accurate photogrammetric or Magellan GCPs. Errors introduced in reading image coordinates or errors in the DEM, both being greater than GCP precision, have an overriding effect on ortho-image accuracy. GCP precision would have a direct influence on ortho-image acuracy only when it is less accurate then the other parameters involved in the mathematical model, as in the case of cartographic GCPs.

Furthermore, influence of GCP precision on ortho-image accuracy was tested by cross-correlating ortho-image chips. Results in Table 4 indicate that Photogrammetric and GPS Magellan GCP ortho-images were best correlated with the Ashtech ortho-image. Although cartographic GCPs produced an ortho-image with similar standard deviations to the reference, offsets of 7.5 m were encountered.

Table 2. Accuracies (in metres) for Various GCP Sources.

GCP Source	Bias X	Bias Y	Std Dev. X	Std Dev. Y	MSEP P=63%
Photogrammetric	−1.2	−0.3	2.0	2.6	3.2
Magellan Dif.	−0.6	−0.1	4.5	3.8	5.8
Cartographic	−4.7	−8.7	19.0	16.8	25.1

Table 3. Ortho-Image Accuracies (in Metres) According to Various GCP Sources.

GCP Source	Bias X	Bias Y	Std. Dev X	Std. Dev Y	CMAS (P=90%)
GPS (Ashtech)	1.1	0.5	3.5	5.9	10.2
GPS (Magellan)	−2.9	0.2	4.1	6.3	11.3
Photogrammetric	2.6	−0.9	4.8	5.9	11.5
Cartographic	−1.3	6.9	3.5	10.0	16.0

Conclusions

Digital topographical data can be extracted from SPOT imagery when introduced through a rigorous geometric correction model utilizing orbital data, an accurate DEM, and good quality GCPs. In order to obtain good ground control, sites must be chosen on the image and then measured on the ground. Coordinates must be read accurately on the image with a maximum error of 0.5 pixel. To obtain an accurate ortho-image requires a minimum of six GCPs (Toutin and Carboneau, 1990). It was found more reliable in a production environment to use a minimum of ten GCPs (Savopol and Leclerc, unpublished data, 1991) in order to strenghten model computations, thus minimizing extrapolations in the ortho-image.

For the Sherbrooke Data Set, photogrammetric source coordinates based on precise aerotriangulated data and accurate DEM produced ortho-images that met 1:50,000-scale planimetric accuracies. This is the cost efficient and accurate method of acquiring GCPs. The main drawback is that it requires existing aerial photography, an experienced operator to read coordinates on a stereodigitizer, and precise aerotriangulation blocks which are not always available.

When no photogrammetric data are available or they are of doubtful quality, GPS coordinates are sufficient. GCPs obtained with an average precision handheld GPS receiver produced topographically accurate ortho-images. This method has the advantage over the previous approach of being accessible to the non expert in GPS technology. When utilizing this type of receiver in the presence of potential SA, it is suggested that autonomous mode coordinates not be used but that one should rely on differentially obtained coordinates. When initializing the receiver for two-dimensional fix recording, elevation data must be accurate to one metre for best results. It is also recommended that test readings be run at known points a day before the projected survey to calibrate the receiver, satellite constellations, and HDOP expectations.

Cartographic GCP coordinates read on A1 standard topo-

Table 4. Correlation Results in Fractions of a Pixel (10 m) Displacement between Image Pairs.

	Bias X	Bias Y	Std Dev. X	Std Dev. Y	Corr. Coef.	Remarks
Ashtech/Ashtech	0.00	0.00	0.01	0.01	1.000	to test roundoff
Asthech/Photog.	0.03	0.03	0.02	0.02	0.999	
Asthech/Magellan	−0.15	−0.16	0.06	0.02	0.993	
Asthech/Cartog.	0.07	−0.65	0.05	0.06	0.988	max. adjust −.75

graphic map sheets are not recommended to generate ortho-images utilized for the production of 1:50,000-scale topographic data.

It was also demonstrated that, with image coordinates and DEM errors not exeeding 4 m, ortho-image accuracy was not increased with GCP accuracy greater than 3 m and that the ortho-image meets planimetric precision for topographical data when GCP source error does not exceed 6 m. This becomes an impetus for the use of handheld GPS receivers similar to those utilized in the present project for GCP acquisition and ortho-image generation applied in 1:50,000-scale topographic data production and manipulation.

Acknowledgments
The authors would like to thank Robert Duval from the Canada Centre for Surveying for his involvement in the GPS Ashtech survey. From the Canada Centre for Remote Sensing, Bert Guindon for having supplied the software for the image correlation study. From the Canada Centre for Geomatics, Florin Savopol for the geometric correction aspects, and the SINAPS team for their judicious comments in reviewing this article.

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(Received 10 February 1992; Accepted 14 July 1992; Revised 10 August 1992)