Geometrically Corrected Digital Images For Resource Mapping And Precision Farming

Albert K. Chong, Chris Pearson

Department of Surveying

University of Otago. Dunedin, New Zealand

Email: chonga@albers.otago.ac.nz, chris.pearson@stonebow.otago.ac.nz

Presented at the 10th Colloquium of the Spatial Information Research Centre, University of Otago, New Zealand, 16-19 November, 1998

Abstract

This paper presents a overview of the benefit of geometrically corrected digital terrain images for resource mapping and precision farming. It provides a brief summary of the methodology used in the geometric correction of aerial and satellite imagery.

Recently completed projects were used to determine the cost involved in the acquisition of ground control; in the acquisition of digital terrain elevation data; and in the production of geometrical corrected aerial photographs. GPS techniques were used for the acquisition of ground datum control and digital terrain elevation data. Off-the-shelf geometric correction software was used for the production of the orthoimages.

Keywords and phrases: Differential GPS, geometric correction, Kinematic GPS, orthoimages, precision farming, resource mapping.

1 Introduction

The objective of this paper is to show that geometrically corrected digital images derived from aerial photographs and satellite imagery are an essential and cost effective information source for resource mapping and farm management. The paper also gives a summary of the various geometrical errors of aerial photographs and satellite imageries. It provides a brief discussion on the methodology used to geometrically correct and to geocode terrain images to obtain high accuracy orthoimages. The use of differential GPS and continuous kinematic GPS technique are discussed to highlight the simplicity of field work involved in the acquisition of digital terrain model (DTM) data of a typical farm.

A local farm was used to compute the cost to obtain DTM data for geometric correction and geocoding of a large format aerial photograph. The farm was used to estimate the cost of producing a high accuracy orthoimage for input into farm mapping and information management software.

2 An Overview of the Benefit of Geometrically Corrected Images

A digital geometrically corrected terrain image is commonly known as a photomap, orthomap, orthophoto, orthoimage, or ortho-satellite imagery. In this paper, geometrically corrected aerial photographs are referred to as orthophotos and any other combination of geometrically corrected terrain images are referred to as orthoimages.

2.1 Positional Correctness

Digital images can be geometrically processed to achieve high accuracy which would be comparable to cartographic maps of similar scale (Thorpe *et al*., 1994; Doyle, 1996). They can be geometrically corrected and geocoded using accurate methodology and accurate DTMs to represent terrain mapping units. For example, digital orthophotos can be produced to an accuracy that can satisfy most specification requirements of large scale resource mapping (larger than 1:5,000) and precision farming (1:1,000). A list of mapping accuracy specifications and their corresponding map scales is provided in FGDC (1998).

2.2 Completeness of Terrain Elements

Schiewe and Siebe (1994) indicated that orthoimages have high information content which are near-reality representations of the terrain. They further stated that orthoimages are suitable as master layers within GIS because of the ease of interpretability of image features for future overlay creation. Baltsavias (1996) and Shears and Allan (1996) qualified Schiewe and Siebe's comments by suggesting that orthoimages can be used to update existing overlays and to generate new overlays as data are needed. For example an overlay of existing farm paddocks can be extracted quickly. In addition other overlay data such as large holes, ditches, erosion, bare terrain, rock outcrops, weed infestation and livestock burial grounds can be mapped or updated accurately.

2.3 Advanced Radiometric Enhancement

The introduction of orthoimages into multi-function GIS is encouraged by the advancement in radiometric enhancement and image shadow removal techniques (Thorpe *et al*., 1994). Multi-function GIS in this context means the capability of a GIS to capture, manage, analyse, and present vector and raster data efficiently (Grenzdorffer, 1994). It is now possible to produce large, seamless orthoimages which are highly accurate regardless of the terrain relief and automated image feature extraction techniques have been developed to populate GIS database (*ibid*). The suitability of orthoimages for GIS is further strengthened by improved functionality in the areas of raster and vector data manipulation in multi-function GIS (Thorpe *et al*., 1994). For example improved radiometric enhancement techniques allow tree species, crops and weed infestation to be mapped accurately. Also yield maps, crop conditions and soil conditions can be obtained readily.

2.4 Cost Reduction in Image Acquisition

Spradley (1994) gave a detailed account on the cost of production of orthimages from aerial photographs and satellite imagery. Comparing the production costs with similar quality cartographic map such as topographic maps, it is apparent that the cost savings were mainly in the area of cartographic compilation (vector generation). Besides a significant additional cost in labour, photogrammetric compilation is also a slow process. On the other hand, automation results in fast digital image production (*ibid*) and, moreover, existing DTMs (e.g. Land Information New Zealand (LINZ) data) can be used to create new orthoimages as frequently as required, as well as quickly and inexpensively. Resource mapping and farm management require constant revision of terrain information. Cost reduction in the gathering of farm terrain information improves efficiency in land management.

2.5 Up-to-date Source of Information

A significant amount of digital cartographic data for resource mapping are obtained by digitising or scanning existing hardcopy line maps (Thapa and Bossler, 1992; Walsby, 1995). In many cases the compiled information on these maps was obsolete by the time it was available to the farmers. It is true that information created from these maps are outdated and also may contain substantial errors due to digitising, scanning and cartographic generalisation. In fact it would be very rare for existing line maps to have paddock boundaries in sufficient detail for farm management purposes. On the other hand, orthoimages can be produced accurately in a few hours. As a result, the latter are up-to-date and have fewer errors. For example when river courses or stream beds which have changed due to a flood or a storm an update is available within hours of this occurrence. For another example a quick update of an orthoimage may show a change in the landscape or reduction in pasture damage resulted from the release of RCD (rabbit virus) from one season to another the area of affected pasture can be determined instantly.

2.6 Multi-scale Orthoimage

Orthoimages are multi-scale. It is acceptable to merge a larger scale image to a smaller scale image as long as the resulting accuracy analysis is based on the latter. For example, a 1:10,000 orthophoto from the Otago Regional Council archive may be merged with a 1:25,000 orthophoto derived from aerial photographs taken in a farm aircraft to produce a 1:25,000 seamless image map without any degradation in radiometric continuities. For another example, a 10 metre resolution SPOT Panchromatic image may be merged with a SPOT MSS 20 metre resolution multispectral image to form a new image having a resolution of 20 metres.

2.7 A Design Tool

Orthoimages are excellent farm layout design base maps. Existing paddocks can be easily plotted and changed. New paddocks can be created on the same base map. Any obstructions, farm furniture or structures can be identified and relocated quickly.

3 Geometric Correction and Geocoding Techniques

Both aerial photos and satellite imagery have geometrical errors. Satellite imageries usually have many more errors than aerial photos. However, there are two major sources of error in digital terrain images. They are instrumental errors and environmental errors. Instrumental errors include errors caused by imperfections in instrument construction, or lack of adequate instrument adjustment or calibration prior to its use in data collection (Thapa and Bossler, 1992). Environmental errors are caused by variations in atmospheric conditions, variations in platform altitude, velocity and attitude, satellite ephemerides, earth rotation, earth curvature, variations of sensor timing and other minor sensor scan non-linearities (Richards, 1986). Fortunately, most major systematic errors of both electronic scanner sensors and photographic systems can be eliminated or reduced significantly (Richards, 1986). The process in which geometric errors are reduced or eliminated is known as geometric correction (also known as geometric rectification). In addition to provide for a correct geometrical relationship between remotely sensed digital terrain imagery or digital aerial images and the ground reference frame, a transformation process known as geocoding is carried out using co-ordinates of ground control points (Steinnocher, 1996). Geometric correction and geocoding are often combined in one process. As images are in raster format, each pixel will have a clearly determined position in the mapping reference frame after geometric correction and geocoding. The methodology for geometrical correction and geocoding varies according to: the type of digital terrain images used, ground control available, and the accuracy of the orthoimage required. Detail on published methodologies such as projective transformation, perspective transformation and enhanced perspective transformation may be found in Wolf (1983), Richards (1986), Novak (1992), Yang and Lin (1993), Pries (1995), Jayapalan (1996) and Fraser and Shao (1996).

It is essential to perform geometric correction and geocoding before an aerial photo or a satellite imagery can be used for resource mapping and precision farming. In this paper, discussion on this task is based on three levels of complexity. Typically, the level of complexity used is related to the accuracy of the final products. In addition the achievable accuracy of an aerial photo or satellite image is dependent on the imagery scale, pixel ground resolution, orthoimage scale and the corresponding mapping accuracy specifications (FGDC, 1998). An example is provided below.

A typical 1: 12,000 aerial photo taken at 6,000 feet altitude with a 152 mm camera was scanned at 600 dpi optical resolution. The pixel ground resolution is 0.5 m. However the ground control and DTM data is accurate to ± 1 m. The resulting orthophoto will have an accuracy no better than ± 1 m. That is, the best orthophoto scale is 1: 5,000 scale (Table 4 of FGDC, 1998). In fact the image may be scanned at 400 dpi optical resolution to achieve the same orthoimage scale with substantial saving in data processing and data management costs.

3.1 Minimal Geometric Correction

Generally, a minimal geometric correction is required for low accuracy resource mapping applications. This is especially true if low resolution satellite imagery or high altitude aerial photography is involved. Richards (1994) discussed two techniques that may be used in this situation. The first requires an intimate understanding of the source of geometric image distortions, such as earth rotation, curvature of the earth, variations in platform altitude and scanner imaging anomalies. A limited amount of geometric correction and geocoding is usually performed by the distributor of most satellite imagery (Reading, 1993). The second technique is based on a simple mathematical relationship expressed as a two dimensional transformation or low order polynomial between the addresses of pixels in an image and the corresponding co-ordinates of the same features on the ground (i.e. ground co-ordinates). In his paper, Pries (1995) pointed out that this technique works satisfactorily for the geometric correction of high-altitude photography of 1:40,000 or smaller, as well as SPOT MSS satellite images (refer to Table 1 and Table 2).

3.2 Geometric Correction Without DTM

A higher order of transformations such as projective transformation or perspective transformation are used to remove basic errors such as platform tilting errors, lens distortions and some relief distortion. Both transformation techniques describe the geometrical relationship between the image plane and object plane by means of rotational (w, f, k) and translational parameters (T_x, T_y, T_z) in all three axes (Wolf, 1983). These transformation techniques can be used for geometric correction and geocoding of aerial

Country Origin and Mission	**Sensor Type (including lens camera system)**	**Pixel Size (m)**	**Format Size (km)**
France			
SPOT 1, 2, 3 and 4	High Resolution Visible - CCD - stereocopic Panchromatic and Multispectral mode	MS = 20 Pan = 10	60-85
Russia			
RESURS-F	Multispectral image	160	600
USA			
LANDSAT -1 - 5	MSS	79	185
	Thematic Mapper ™	30	185
	SEASAT	25	100

Table 1. Current avaible Space-borne Imagery from Landcare Research. Imagery suitable for general farming applications (excluding conventional aerial photography). Other imagery may be available on request (e.g Synthetic Aperture Radar).

Imagery								
SPOT-MSS				*	*	*	*	*
SPOT-Pan		*	*	*	*	*	*	*
Lansat-MSS								*
Landsat-TM					*	*	*	*
Aerial Photography	*	*	*	*	*	*	*	*
scale per 1000	1	25	50	75	100	125	150	250

Table 2. Common imagery and their mapping scales

photography of flat terrain without DTM (Novak, 1992). Perspective transformation has an additional advantage because displacement due to relief is reduced significantly when the height of ground control points are known. This is an attractive alternative to the more costly DTM method if high accuracy and output image quality is not critical. However, this technique requires that the calibration parameters of the camera used to obtain the image are known (refer to Table 3).

3.3 Geometric Correction With DTM

A high accuracy geometric correction and geocoding technique using perspective transformation can be achieved with the introduction of a DTM of the terrain. A DTM is needed to correct for relief distortions. This method is suitable for geometric correction of most types of aerial and satellite images and for most types of terrain. Interpolation of the height for some image pixels is needed because the geometrically corrected image is always denser than the DTM (refer to Table 3).

Factors	Minimal	Without DTM	With DTM
Based on the type of imagery or photography			
Low resolution satellite, e.g. Landsat	*		
High resolution satellite Imagery, e.g. SPOT Pan	*	*	*
Spaceborne photography, e.g. Space Shuttle	*	*	
Small scale aerial photography	*	*	
Medium scale aerial photography	*	*	*
Large scale aerial photography	*	*	*
Based on proposed image scale			
Very small scale image (above 1:1,000,000)	*		
Small scale image (up to 1:1,000,000)	*	*	
Medium scale image (up to 1:100,000)	*	*	*
Large scale image (below 1:20,000)		*	*
Based on proposed image ground accuracy			
0 - 5 m *1 flat terrain		*1	*
5 - 30 m		*1	*
30 - 300 m	*		
above 300 m	*		

Table 3. Level of Geometric Correction and Geocoding of digital images

4 GPS Techniques For Dtm Collection

4.1 Differential GPS

Differentially corrected GPS is by far the most common surveying method to obtain low accuracy ground control or DTM data. In this technique, GPS pseudo ranges or distance to the satellites are corrected by reference to a base station with a known position, resulting in nearly two orders of magnitude increase in the survey accuracy as compared to autonomous GPS positioning. The technique is capable of giving positions accurate to ± 1.5 m at the two Standard Error level of confidence but accuracy of 3-5 m is more typical depending on the type of receiver used and the distance to the base station. The data is then processed to generate improved co-ordinates using proprietary software such as PATH-FINDER OFFICE and the resulting co-ordinates are transferred into an appropriate GIS or mapping software for final editing.

4.2 Continuous Kinematic GPS

The fastest and most efficient method to create a DEM is to use continuous kinematic GPS in a moving vehicle. The technique can give heights accurate to ±10 cm at the two Standard Error level of confidence. In the test case discussed below, Trimble 4000 SSI receivers were used. The instrument was set to acquire data at 10 second intervals while the vehicle in motion. This technique implicitly assumes that the antenna of the GPS receiver has a constant height above the ground. Clearly this is an approximation since spring compression or the tilt of the vehicle will both cause the actual height to vary and in steep or rough country these errors can become significant. The data was acquired using post-processed kinematic rather than the more usual real time kinematic or RTK techniques as our experience has shown that the savings in logistical effort and equipment rental plus the ability to record data while the initialisation process occurs more than compensates for the extra certainty due to the data being available real time. Obstructions due to trees and hedgerow are not usually a significant problem.

5 Pilot Projects

The test case for differential GPS involved a dairy farm near Outram on the Taieri Plain, Dunedin. The farm covers approximately 193.7 hectares and was subdivided into 62 paddocks with an average size of 3.2 hectares. The level of subdivision is typical of dairy farms in New Zealand. The farm was relatively clear of trees although some large trees and hedge-rows were present on site. Along with elevation data, all internal subdivisions of the farm were surveyed. Cost estimate for kinematic GPS are based on several projects in Southland and Otago.

5.1 GPS Surveys

The cost of using differential GPS and continuous kinematic for farm survey are summarised in Table 4 below. The cost of differential GPS was $5.30/ha or $16.50/paddock. Using continuous kinematic GPS we have been able to cover approximately 2-3 km^2 per day with a cost of $15 per hectare or $30/ paddock.

Type of expense	DiffGPS cost	Kinematic cost
Receiver hire	$ 150	$ 1000
Base station data	$ 80	$ 0
Field personnel	$ 192*[1]	$ 1200
Postprocessing @$50/hr	$ 600	$ 600
Total	$1022	$ 2800

Table 4 Cost of GPS Surveys *1 unskilled labour used

5.2 Geometric Correction and Geocoding

DMS Ortho-32, a Window95 high accuracy orthophoto production software, and Endeaour, a Window95 farm mapping and information management software were used in the pilot study. Large format (228 by 228 mm) aerial photographs were obtained from the Otago Regional Council and scanned at various optical precisions. The digital images were geometrically corrected and geocoded for input into Endeaour. Tests were carried out to estimate the production cost. The result is provided in Table 5.

Type of expense	Cost
Photo scanning	$ 45
Orthophoto production (3 hrs@$ 70/hr)	$ 210
Field check (optional, 3 hrs@$ 50/hr)	$150 *
Editing, data entry, archive (2hr@$ 50/hr)	$ 100
Software depreciation (@1%/day)	$ 25
Total cost per photo	$ 530* ($ 380)

Table 5 Cost of High accuracy Geometric correction and geocoding

6 Conclusions

The paper shows that orthoimage is an useful tool for resource mapping and farm management. Off-the-shelf geometric correction and geocoding software are readily available and are simple to use. DTM can be obtained cheaply and quickly using GPS techniques and the data can be used for many future updates. It is not essential to obtain highly accurate orthoimages for low density farming. In this case LINZ DTM data is satisfactory. The minimal geometric correction technique should not be used to produce orthoimages for medium and high density farming use because the ground accuracy is unpredictable.

Acknowledgements

The authors would like to thank Mr Xiaolun Wang for his assistance on the projects.

References

Baltsavias, E. (1996). Digital Ortho-images - a powerful tool for the extraction of spatial- and geo-information, *ISPRS*, 51:63-77.

Doyle, F., (1996). Thirty years of mapping from space, *International Archives of Photogrammetry and Remote Sensing*, Vienna, 31(B4):227-229.

Federal Geographic Data Committee, (1998). National Standard for Spatial Data Accuracy (NSSDA), FGDC-STD-007.3-1998: Washington, D.C., Federal Geographic Data Committee, 25p.

Foley, J., Dam, A., Feiner, S., and Hughes J., (1990). Computer Graphics: Principles and Practice, 2nd edition, *Addison-Wesley Publishing Company*, 1174 p.

Fraser, C., and Shao, J., (1996). On the triangulation of MOM-02 three-line imagery, *Geomatics Research Australasia*, 64:47-64.

Grenzdorffer, G. and Bill, R., (1994). Digitall Orthophotos for Mapping and Interpretation in Hybrid GIS-Environment, *Inter. Archives of Photogrammetry and Remote Sensing*, 30(4):467-475.

Jayapalan, K., (1996). Airborne GPS, International Archives of Photogrammetry and Remote Sensing, Vienna, 31(B3):377-383.

Novak, K., (1992). Rectification of Digital Imagery, *Photogrammetric Engineering & Remote Sensing*, 58(3):339-344.

Pries, R., (1995). A System for Large-scale Image Mapping and GIS data collection, *Photogrammetric Engineering & Remote Sensing*, 61(5):503-511.

Reading, M., (1993). Production Considerations for Satellite Image Maps, Conference proceedings, *EGIS'93*, Italy, II:1097-1105.

Richards, D., (1986). Remote Sensing Digital Image Analysis: An Introduction, second Edition, *Springer-Verlag*, 281p.

Schiewe, J. and Siebe, E., (1994). *International Society of Photogrammetry and Remote Sensing*, Munich, 30(3/2):724-731.

Shears, J. and Allan, J., (1996). Softcopy Photogrammetry and its uses in GIS, *International Archives of Photogrammetry and Remote Sensing* , Vienna, 31(B4): pp.70-73.

Spradley, L., (1994). Cost-effective data for regional GIS bases, *International Archives of Photogrammetry and Remote Sensing*, 30(4): 203-208.

Steinnocher, K., (1996). Integration of spectral and spatial classification methods for building a land use model of Austria, *International Archives Photogrammetry and Remote Sensing*, 31(B4):1-846.

Thapa, Khagendra and Bossler, John, (1992). Accuracy of spatial data used in Geographic Information Systems, *Photogrammetric Engineering and Remote Sensing*, USA, 58(6):835-841.

Thorpe, J., Thorpe, A., and Klimiuk M., (1994). The handling of large digital orthophoto raster databases in GIS, *International Archives of Photogrammetry and Remote Sensing*, 30(4):457-459.

Walsby, J.C., (1995). The causes and effects of manual digitizing on error creation in data input to GIS, Innovations in GIS 2, *Taylor & Francis*, UK, 257p.

Wolf. P. (1983). Elements of Photogrammetry, *McGraw-Hill Inc*, 628p.

Yang, X. and Lin, H., (1993). Digital Ortho Correction Using Pre-transformation Distortion Adjustment, *Proceedings of ASPRS/ACSM*, pp425-433.