SATELLITE IMAGE RECTIFICATION USING CONTROL TRANSFERRED FROM DIGITIZED AERIAL TRIANGULATION DIAPOSITIVES

M.A. Chapman, A. P. Tam
M. Boulianne, J.A.R. Blais
Department of Surveying Engineering
The University of Calgary
Calgary, Alberta, CANADA T2N 1N4

Commission IV

Abstract

The revision of digital topographical maps using satellite imagery requires an appropriate rectification procedure for the satellite imagery. An abundance of control information for the rectification process is readily available in the aerial triangulation photography originally used to produce the digital maps. Using a digital camera, the neighbourhoods of these control points and entities can be digitized on the aerial diapositives for subsequent cross correlation with the satellite imagery. Once sufficient control information is transferred to the satellite imagery, a rectification model will transform the satellite imagery in a manner compatible with map revision requirements. Such a procedure would greatly facilitate the revision of existing topographical maps using any available satellite imagery with appropriate resolution.

Introduction

In order to maintain the timeliness of the information contained in conventional and digital topographical maps periodic revisions are required. Digital satellite imagery with a ground resolution in the 10 to 20 m range may contribute to the revision process of small and medium scales maps provided that the distortions in the satellite imagery can be corrected. Satellite imagery has already been used for topographical mapping, hydrographic-surveying and -mapping purposes [e.g., Rochon et al, 1986] and with the improved resolution and the stereo coverage of SPOT imagery and the advances in image processing, the possibilities in mapping applications are promising [Borgeson et al., 1985; Colvocoresses, 1986].

Some of the problems associated with satellite image rectification are the resolution and identification difficulties associated with natural features of interest. In addition, distortions often remain after the usual geometric and radiometric corrections have been applied. The appropriate filtering and enhancement of the digital imagery can greatly facilitate the process of localizing the natural and artificial features of interest. Once found, control point information can be transferred from the digitized aerial triangulation diapositives to the satellite image. Upon estimating the corresponding distortions at a number of control points and features, a rectification or ***rubber-sheeting*** procedure is required to ensure that the digital imagery agrees with the topographical map in an optimal manner.

For the purpose of conventional topographical mapping, aerial triangulation diapositives are prepared with all the necessary information for the map compilation process. Normally, at least nine control points per photograph are known in the ground reference system as a result of adjusting the photogrammetric block and the available geodetic information. Patches centred on the control points or entities found on these aerial triangulation diapositives can be digitized using a digital camera (see Figure 1). Subsequently, cross-correlation procedures can be applied to find the best matching patches on the satellite imagery and hence the corresponding distortions. Following rubber-sheeting transformations of the satellite imagery to best agree with the topographical map, the latter can be revised using the satellite imagery information.

The experimental use of a digital camera of the Charge-Coupled Device (CCD) type to digitize the patches on the aerial triangulation diapositives is described in the sequel. Details of the digital camera system used for digitizing the aerial triangulation diapositves used in this study have been presented in Blais et al [1987] and Boulianne et al [1988].

Variations of two cross-correlation procedures are then presented to estimate best matching patches on the corresponding Landsat imagery following some appropriate preprocessing of the information. Practical considerations are included to emphasize the research and development aspects of this project which is still in its first phases.

Calibration and Accuracy Implications

For any precise measuring operation, the measuring device must be calibrated at one point to ensure reliable results. The purpose of this process is to establish the geometric properties of the measuring instrument and its stability over a period of time. The high stability of CCD cameras is well known although, this aspect of the system does not appear to be critical in the map revision project.

When a digital camera is used for digitizing purposes, a full geometric calibration is not required. More specifically, precise information concerning the interior orientation parameters such as the focal length and exterior orientation parameters such as the perspective centre position is not crucial. This is due to the fact that the object (aerial diapositive) being digitized and the CCD sensor doing the digitization can both be effectively considered to be

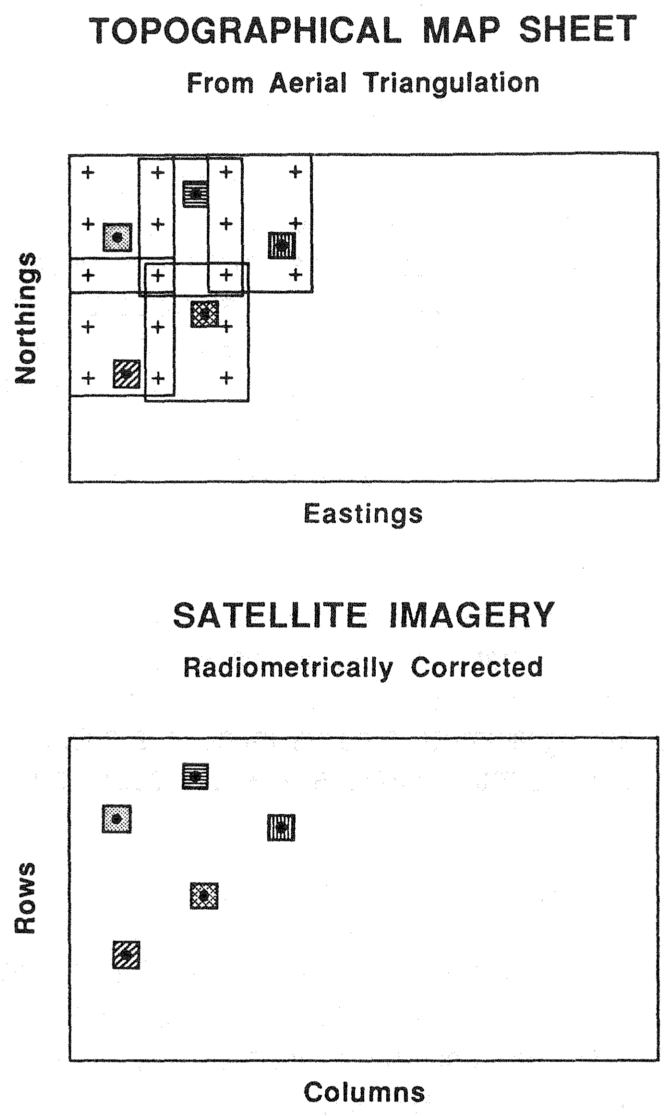

Figure 1: Digitized Neibourhoods of Control Points

planar. Thus, only the parameters expressing the relationship between the actual pixel locations on the CCD sensor and the corresponding stage locations are required for the subsequent data processing.

An initial examination suggests that several linear mathematical models such as a similarity, an affinity or a projectivity can be used for the intended transformation. Since the optical axis of the camera is not necessarily normal to the object (aerial diapositive), the most appropriate linear model appears to be a projectivity. However, for near-normal imaging geometry and considering the camera resolution a similarity or an affine model may be adequate. In cases where the residual errors with linear models are not tolerable, nonlinear mathematical models may very well be warranted.

Normally the calibration is carried out by digitizing a calibrated grid which contains a certain number of points precisely located in an arbitrary coordinate system. The pixel coordinates of these same points are subsequently measured on the display monitor using a cursor that is positioned by means of a mouse, for example. Following the measuring operations, the transformation parameters are estimated using least squares since some redundancies are available in the process. More recently, image matching techniques have been used to precisely locate well-defined grid intersections or crosses (Luhmann, 1986).

For most photogrammetric applications, a preliminary grid transformation is required to remove any arbitrariness in the position and orientation of the calibrating grid. This preliminary step is not necessary in the current project as the entity in the patch to be digitized is assumed to have known ground coordinates from the photogrammetric adjustment or a subsequent compilation of the stereomodel. Such simplifications are obviously not appropriate for other applications.

The calibrating standard used in this mapping project is a precise grid plate with grid spacings of 1 cm in two orthogonal directions. In total, nine points were used in the calibration process. Each grid point had a standard error of less than 1 μm. After the projective transformation, the standard error of the residuals for the transformed coordinates was of the order of 50 μm due to scale of digitization and the pixel resolution.

Practical Considerations

In the current project, the primary task involves the matching or cross-correlating of conjugate points or entities represented in digitized aerial photographs and digital satellite imagery. In general, these two types of imagery have many different geometric and radiometric characteristics or attributes. As a result, several complications may arise when attempting to match such different data types. The most evident difference between the two images is the variation in scale. The satellite image has a scale about twice as small as the digitized aerial photography used in this project. Consequently, some rescaling of the digitized aerial photographs will be required to ensure that the two images are compatible, especially when using standard algorithms (eg. correlation coefficient, sum of absolute differences) for cross-correlation.

Radiometric differences can be attributed to variations in the sensor spectral responses, changes in illumination, changes in surface reflection due to different times of acquisition and variable atmospheric conditions.

Consequently, a normalization scheme is suggested in order to make the two images as radiometrically similar as possible. A uniform normalization can be achieved by first removing the mean image grey value from each pixel and subsequently dividing every grey value by the standard deviation of the grey values for the entire image. The resulting grey values are then shifted to ensure that only positive values remain. Alternately, a non-uniform grey value modification can be imposed using histogram equalization or specification algorithms.

Another consideration involves the choice of an appropriate image matching procedure. Since point-wise correlations are not practical, a window of a specified dimension must be employed. The size of window will influence the pull-in range of the correlation algorithm and must be chosen in consideration of the local image texture. In many cases, an inappropriate window size can lead to "lost" conditions for the correlation process thus requiring a recovery mechanism to be present in the procedure.

Image Matching Strategies

Many image matching algorithms have been proposed in the literature [e.g. Gambino and Crombie, 1974; Blais and Gibson, 1987]. These methods can be generally categorized as those suited for images which are translated replicas of each other and those which can accommodate higher order differences as present in stereo pairs of perspective images. Three matching algorithms were tested in this study: maximum correlation coefficient, minimum sum of absolute differences and an adaptive least-squares method.

The maximum correlation coefficient method uses a popular objective function since it is relatively straightforward to implement and has been found to be reliable for similar images. Image matching using this algorithm is realized by computing several correlation coefficients between two sets of finite data sequences of grey values taken along homologous epipolar lines in the two images. In practice, one of the two images is held fixed (master) while the other (slave) is incrementally shifted in a systematic manner until a maximum correlation coefficient is achieved for the entire search region. Both one- and two-dimensional versions of this algorithm can be employed. The data sequences are normally of the same size with their extent referred to as the window size. Optimal window sizes are data dependent and can have a significant impact on the success of the matching procedure in some cases. Once a maximum correlation coefficient is found, the centres of the two windows are deemed to represent the conjugate image points. Sub-pixel matching is realized by subsequently interpolating in the vicinity of the point of maximum correlation. Any higher order variation in geometry between the two images can preclude an accurate solution by this method since only linear shifts are assumed to exist.

The second matching algorithm tested in this study is based upon the minimum sum of the absolute differences (SAD) between two data sequences. Once again, windows are used such that the point of interest occupies the central position of the window. In a manner similar to the correlation coefficient method, one of the two data sequences is held fixed with the other permitted to shift. A one-to-one correspondence between the two windows enables absolute differences of the corresponding grey values to be computed until a minimum solution is found for the entire search area indicating a best match. The requirement for grey values to be compared in a one-to-one fashion, however, makes this method unsuitable for image pairs with significant geometric differences.

Finally, an adaptive algorithm employing an iterative least-squares solution was tested. This method also searches for a minimum difference in grey values between two image windows but can accommodate some geometric and radiometric variations. More specifically, the slave image is transformed into the master image using a user-defined transformation model. Experience has shown, however, that a six-parameter affine transformation yields acceptable results when two-dimensional correlation is used [Gruen and Baltsavias, 1985]. The affine model permits differential scales for the pixel rows and columns as well as skewness of the axes and row and column translations. The possibility of modelling such elementary geometric distortions makes this method particularly attractive for the treatment of perspective imagery. Good initial approximations to the match location have been found to be necessary when using this technique.

Test Results and Analysis

For the purposes of this preliminary study, a test area centred over the Upper and Lower Kananaskis Lakes (located adjacent to Banff National Park, Alberta) was chosen since Landsat imagery and aerotriangulated diapositives were available for this region. The Landsat image consisted of the first principal component derived from four bands of the original image and resampled to a 50 m by 50 m grid. A subscene corresponding to the study area was extracted from the complete Landsat scene. The subscene has a mean grey value of approximately137, standard deviation of 8 and a minimum and maximum grey values of 102 and 147, respectively. Due to the scanning mechanism of the Landsat sensor, the imager has only approximately perspective geometry for every six line swath.

The same area located on an 1: 40 000 aerial diapositive was then digitized with a CCD camera. A subscene of this digital image was used for subsequent correlation testing. Within this subscene, a mean and standard deviation for the grey values of the pixels were determined to be approximately 96 and 60, respectively. An unequal pixel dimension for the digitized image yielded a terrestrial footprint for each pixel of 28 m (column-wise) by 23 m (row-wise).

Since the Landsat image and the digitized aerial photograph had incompatible pixel dimensions, a subsequent resampling was warranted. To this end, software was written to scale the Landsat image such that each of the original pixels were divided into four pixels with an equivalent ground dimension of 25 m by 25 m. After rescaling the Landsat image, a pixel dimension ratio of 1: 1.12 (horizontal) and 1: 0.92 (vertical) existed between the digitized aerial photograph and the Landsat image.

In order to evaluate the matching algorithms, a 19 pixel by 19 pixel area approximately centred on an island located in the Upper Kananaskis Lake was extracted from both images. A total of three sets of images were used where the original (or raw) image pair comprised the first data set and a normalized image pair represented the second data set. Image normalization was achieved by subtracting their respective means and, subsequently, dividing each by their corresponding standard deviation. A third data set was produced by filtering and thresholding the normalized images to produce a binary pair of images. Filtering was accomplished by using a modified Sobel edge operator while the thresholding operation utilized the mean value of the two images to create the binary images. Using these three image pairs, various window sizes were used in conjunction with the three matching algorithms to determine an optimal match location between the two images.

Three square window sizes varying from 7 by 7 pixels to 11 by 11 pixels were tested using the correlation coefficient and sum of the absolute difference methods. The results of these tests are presented in Table 1 where ρ corresponds to the correlation coefficient and SAD represents the sum of the absolute differences. As seen in Table 1, relatively consistent matching results were obtained for the correlation coefficient method for all tested window sizes. The sum of the absolute difference method produced similar results when using the normalized and binary data sets but yielded shifted values for the raw data sets. However, both of these image matching techniques only yielded integral row and column optimal pixel match values. Fractional pixel positions can only be obtained from these methods by using a subsequent interpolation scheme.

Table 2 lists the results for various square and rectangular window sizes used in conjunction with the adaptive least-squares method of image correlation. Only the normalized image pair was used since experience has shown this to be the most successful data type for this method. Results consistent with the other two matching techniques were obtained for this method except for the 5 by 5 and 5 by 7 window sizes. The adaptive least-squares method, however, yields sub-pixel shift values as a direct product of the solution. Also, this method can accommodate elementary image shaping, making it quite appropriate for the unequal pixel dimensions in the two images.

	Matching Window Size					
	7x7		9x9		11x11	
	ρ	SAD	ρ	SAD	ρ	SAD
Raw Data Sets	9,8	11,12	9,8	11,12	9,8	11,12
Normalized Data Sets	9,8	9,8	9,8	9,8	9,8	8,8
Binary Data Sets	9,9	10,9	9,9	9,9	9,9	9,9

Note: tabulated values correspond to the row and column pixel match locations in the slave image

Table 1. Summary of Results for Island Area using Correlation Coefficient and Sum of Absolute Differences Methods

	Window Size	Match Point Location
Square	5x5 7x7 9x9 11x11 13x13	8.4, 10.1 8.9, 8.8 8.7, 8.7 8.9, 8.8 8.8, 8.5
Rectangular	5x7 7x9 9x11	8.4, 10.0 8.9, 8.6 8.8, 8.9

Note: tabulated values correspond to the row and column pixel match locations in the slave image

Table 2. Summary of Results for Island Area using Adaptive Least Squares Method

Conclusions

Preliminary tests involving the use of a digital CCD camera to digitize aerial triangulation diapositives for cross-correlation purposes with satellite imagery have been carried out. Using appropriate image matching procedures, control can be transferred to the satellite imagery for the necessary rubber-sheeting operations. With Landsat or similar satellite imagery in best agreement with the digital topographical map, features can then be transferred for any revisions of the map.

The calibration of the digital CCD camera has been carried out using a precise grid plate and a linear projective transformation. Such a calibration procedure, although much simpler than a conventional photogrammetric calibration, must be repeated whenever the digital camera or the stage is moved. The level of accuracy achieved with the projective transformation from stage to CCD sensor has been about 50 µm.

Following some preprocessing of the digitized patches on aerial triangulation diapositives, three image-matching algorithms, i.e., the maximum correlation coefficient, the minimum sum of absolute differences and an adaptive least-squares method have been used experimentally. The last of these has proven to be the most appropriate with aerial triangulation diapositives of Kananaskis and Landsat imagery. Although the preliminary results are quite acceptable, much investigation remains to be done, especially in the area of scale-,orientation- and radiometric-invariant matching algorithms. For possible production applications for topographical map revisions, the digital camera should be mounted on a digitized transport system so that following the registering of the fiducials, the camera could automatically visit the control point entities to be transferred to the satellite imagery. For the rubber-sheeting of the satellite imagery, strategies such as described in [Chapman and Blais, 1987] can be implemented. With SPOT imagery with 10 m resolution, the approach offers real potential for the revision of digital topographical maps and other similar map products.

Acknowledgements

The authors greatly appreciate the financial support of the Alberta Bureau of Surveying and Mapping, Department of Forestry, Lands and Wildlife. This study was also partially supported by a Pilot Project grant from The University of Calgary to the last author.

References

Blais, J.A.R. and J. R. Gibson [1987] Digital Image Correlations, Lecture Notes in Digital Mapping and Land Information, Department of Surveying Engineering, The University of Calgary, Calgary, Alberta, pp. 78-98.

Blais, J.A.R., M. Boulianne, A.P. Tam and M.A. Chapman [1987] Digital Correlations for Revision of Digital Topographical Maps Using Satellite Imagery, Proceedings of the Fall 1987 URISA Conference, Calgary, Alberta, November, pp. 71-83.

Borgeson, W.T., R.M. Batson and H.H. Kieffer [1985] Geometric Accuracy of Landsat-4 and Landsat-5 Thematic Mapper Images, Photogrammmetric Engineering and Remote Sensing, Vol. 51. No. 12, pp. 1893-1898.

Boulianne, M., M.A. Chapman and J.A.R. Blais [1988] Assembling a PC-Based Image Processing System: Some Practical Considerations, Archives of the 16th Congress of ISPRS, Commission VI, Working Group 7, Kyoto, p. 10.

Chapman, M.A. and. J.A.R. Blais [1987] Integrating Digital Map Files, Proceedings of the URISA Spring Conference, Edmonton, pp. 133-144.

Colvocoresses, A.P. [1986] Image Mapping with the Thematic Mapper, Photogrammetric Engineering and Remote Sensing, Vol. 52, No. 9, pp. 1499-1505.

Gambino, L.A. and M.A. Crombie [1974] Digital Mapping and Associated Digital Image Processing, Proceedings of the Annual Meeting of the American Society of Photogrammetry, St. Louis, Missouri, March, pp. 99-111.

Gruen, A.W. and E.P. Baltsavias [1985] Adaptive Least Squares Correlations with Geometrical Constraints, Proceedings of SPIE, Vol. 595, Cannes, pp. 72-82.

Luhmann, T. [1986] Automatic Point Determination in a Reseau-Scanning System, Proceedings of the Symposium: Real-Time Photogrammetry - A New Challenge, Ottawa, June, pp. 400-408.

Rochon, G., T. Toutin, S.R. Haja and A. Leclerc [1986] Spatial Remote Sensing to Land Management, Proceedings of IGARSS' 86 Symposium, Zurich, September, pp. 1291-1296.

Shlien, S. [1979] Geometric Correction, Registration and Resampling of Landsat Imagery, Canadian Journal of Remote Sensing, Vol. 5, No. 1, May, pp. 74-89.