DIGITAL MAP REVISION IN A HYBRID GEOGRAPHIC INFORMATION SYSTEM

Eugene Derenyi and Chee Hua Teng
Department of Surveying Engineering
University of New Brunswick
Fredericton, N.B. Canada

COMMISSION IV

ABSTRACT

It is advantageous to perform the updating of digital maps directly in a geographic information system (GIS). Through the research and development efforts at the University of New Brunswick, the Computer Aided Resource Information System (CARIS) has been equipped with an integrated digital image/map display and with orthoimage generation capabilities. Thus, map revision can be performed by on-screen digitization. Digital elevation models or piecewise rectification are used to correct for the relief displacement. Three map revision schemes were devised and then tested on 1:50 000 and 1:10 000 scale maps.

KEY WORDS: Map revision, Orthoimage, GIS, Rectification DEM, Registration, Integrated system.

1. INTRODUCTION

In the 1980s, imagery acquired by photographic and electronic sensors was utilized in a distinctly different manner. Photographic camera products were handled in hard copy form. Quantitative analysis was performed in various photogrammetric restitution instruments, where graphical and digital map manuscripts or orthophotos were produced. Qualitative information extraction was performed by visual interpretation. Data acquired by non-photographic sensors were mostly handled in digital form and evaluated in stand-alone digital image analysis systems. The results were then recorded on hard copy outputs. This decade was also marked by the proliferation of geographic information systems (GISs). Most of them were established by digitization of existing hard copy maps.

By the turn of this decade, GISs were widespread and firmly established; the conversion of hard copy images into digital form has become affordable and digital, soft-copy photogrammetry began to evolve as a viable alternative to analogue restitution instruments. It is imperative that the revision and updating process of maps and resource inventories stored in GISs reflects these new developments.

The updating of a GIS can be accomplished ineither off-line or on-line mode. Off-line means a data capture in a device, such as a stereoplotter, digital image analysis system or an optical transfer scope, which is not an integral part of a GIS workstation. On-line means that the revision takes place in the GIS workstation itself, using digital images. This approach requires a hybrid GIS, which has both vector and raster data handling capability. The Computer Aided Resource Information System with Raster Image Extension (CARIS/RIX) is such a system.

CARIS is a GIS marketed by Universal Systems Ltd. of Fredericton, N.B., Canada, while RIX was developed at the University of New Brunswick [Derenyi, 1991]. RIX supports the superimposition of vector data on a raster image backdrop, on-screen digitization, image classification, analytical photogrammetric operations and a variety of image processing and geometric registration tasks in interactive and batch mode.

Three map revision schemes were developed and tested in this environment:

- piecewise rectification,
- DEM corrected tracing, and
- digital orthoimage tracing.

All three schemes are applicable to monoscopic images.

2. MAP REVISION SCHEMES

2.1 Piecewise Rectification

This scheme is based on the assumption that all inherent distortions including the relief displacement of an image, can be reduced to an acceptable level by a two-dimensional transformation. This assumption is only valied in subregions of an image, where the magnitude of the relief displacement is below the tolerance set by the map accuracy standards. It is also assumed that the image and the map files are in a reasonably good registration.

The residual mis-registration errors evident in subregions of an image, caused by deficiencies in the data used for the registration and by the neglected topographic effect, is then corrected by localized incremental transformation. In this process the analyst interactively improves the map to image registration by matching well-defined points and features within a small segment of the data surrounding the area of interest. It is done by incrementally translating, scaling, rotating and skewing the map (vector) to the image (raster). Although the transformation parameters are operated on sequentially, their effects are accumulated to form an affine transformation. Once a satisfactory registration has been achieved, the digital map file can be updated by digitization and editing in the image display. The inverse transformation is then applied to the coordinates of the new map objects, to register to the original map.

This scheme is, in fact, the digital emulation of the technique used in Zoom Transfer Scopes. It is fast and simple. By temporarily warping the map to the image, the lengthy resampling operation of the raster data is avoided. This scheme is especially useful when changes in the planimetric content of the maps are concentrated in localized areas of the image.

2.2 DEM Corrected Tracing

This scheme requires a digital elevation model (DEM) in either a grid or triangulated irregular network (TIN) form. Based on this data, the relief displacement of points along the path of digitization is determined and their planimetric position corrected.

Interpolation in the DEM is performed according to an iterative algorithm developed by Masry and McLaren (1979) for computing the planimetric coordinates of features digitized in a single photograph. First the exterior orientation of the photography is acquired. Next, the collinearity equation is used to project the image points onto a plane set at the average terrain elevation to obtain object space coordinates X', Y'. The corresponding terrain elevation Z' is then found in the DEM which in turn defines a new projection plane. The procedure is repeated until the change in Z' is within a preset tolerance. The X, Y, Z values obtained at the last iteration are adopted as the object space coordinates of that particular image point.

2.3 Digital Orthoimage Tracing

The acquisition of planimetric object space coordinates from monoscopic images becomes a simple task if both the tilt and the relief displacements have been removed from the image prior to digitization; in other words, if the feature tracing is performed in an orthoimage.

Differential rectification of raster imagery is a straightforward process. First the exterior orientation parameters are acquired. Next an empty grid is created at the proper orientation and with a spacing that corresponds to the desired pixel size of the orthoimage. The elevation of each grid cell is then interpolated in the DEM, and is combined with the exterior orientation parameters in a transformation of the empty grid onto the uncorrected image. Finally, the grayscale value of each grid cell is determined by one of the resampling algorithms such as the nearest neighbour, bilinear or bicubic interpolation. As a byproduct of this scheme, the orthoimages can also serve as a companion to digital line maps. Images are a more complete representation of the real world than line maps.

3. MAP REVISION TEST

3.1 Test Material and Preparation

All three revision schemes were tested on a 1: 50 000 scale digital map sheet of the Canadian National Topographic System (NTS) series and on a 1: 10 000 scale digitial map sheet of the New Brunswick Geographical Information Corporation (NBGIC). To facilitate the evaluation of the results, various features were deleted in a copy of each map file to simulate an out-of-date map. These features were then re-established from the same black and white aerial photographs used for the original map compilation. The photo scale was 1: 40 000 and 1: 35 000 respectively.

The digital images were obtained by scanning the paper prints in a Hewlett-Packard ScanJet Plus document scanner at 300 dots per inch (118 dots per cm) which resulted in a 85 µm pixel size at image scale. The corresponding pixel size on the ground was 3.4 m and 3.0 m in the two photographs respectively. The radiometric values were recorded in 256 gray levels.

In preparation for the piecewise rectified digitization and the DEM corrected tracing, the image was registered to the map by perspective transformation. The orthoimage was produced by a rigorous pixel-by-pixel differential rectification, based on the collinearity equation. The cubic convolusion resampling was employed in all cases. Road intersections and other well-defined features were selected in the screen display of the digital maps as control for the transformation.

Both maps cover the City of Fredericton and vicinity. The downtown area which spreads along the shore of the St. John River is essentially flat ground at an elevation near sea level. There from the terrain has a steady incline and reaches an elevation of 130 m at the city limit.

3.2 Data Collection and Evaluation

Change detection was performed visually on the screen in a merged map and image display. The new features were then traced in the image by freehand cursor control and digitized. The features mapped included: highways, major thoroughfares, residential streets, river shoreline, power transmission line, racetrack, highway bridge, buildings and edge of forest. All features were digitized in point mode. Roads were digitized along the centre line.

The new features digitized in each of the three revision schemes were concentrated into the original map. The position of the features in the original map were used as the reference to ascertain the accuracy of the newly digitized values. Point features were tested by forming the coordinate differences. Line features were subdivided into sections at well identifiable breakpoints. Thereafter, X, Y coordinates were generated at equal intervals along the original and newly digitized path of the features. The deviations at corresponding point pairs were then computed.

Final assessment of the three map revision schemes was based on the degree of compliance with the map accuracy standards. The 1:50 000 NTS map was produced to meet the "A" rating in the classification as to accuracy of planimetry ("Circular Map Accuracy Standard") in the North Atlantic Treaty Organization (NATO) Standard System for the Evaluation of Land Maps, which states:

> *Planimetric position of 90% of well-defined features measured from the map (except those unavoidably displaced by exaggerated symbolization) will fall within... [25 m]... relative to their true planimetric position as referred to the geographic graticule or grid of the map.*

This accuracy criteria expressed in terms of measurements made on the map is 0.5 mm. The equivalent root mean square error (RMSE) in position is 16.5 m or 0.33 mm.

The 1:10 000 scale map was produced by the Maritime Land Registration and Information Service to satisfy the accuracy specification for the Urban and Resource Digital Map Base prescribed in the Land and Water Information Standards Manual, which states [NBGIC, 1991]:

> *Ninety percent (90%) of all "well defined features" must fall within the positional accuracy... [2.5 m]. Well-defined features are those whose positional accuracy is not adversely affected by vegetative cover. Accuracy of the digital data (point, line, area) can be defined as the difference between the position of the associated data in the digital file and the real position of the represented feature on the earth.*

The above requirement expressed in terms of RMSE in position is 1.6 m. It should be noted, that the accuracy assessment was based on the comparison of two digital products and not on measurements made on the ground. Therefore, the tolerance can be increased by a factor of $\sqrt{2}$ to account for the uncertainties in both data sets, which is equal to 3.5 m and 2.3 m for the 90% error and the RMSE respectively. The required 90% error and RMSE for a graphical plot produced from the digital map base are 5.0 m and 3.3 m respectively, or 0.5 mm at the publication scale.

3.3 Test Results

The results of the assessment are shown in Tables 1 to 3 for the 1: 50 000 scale NTS map and in Tables 4 to 6 for the 1:10 000 LRIS map. The type of features mapped, the number of points tested along each feature (No. pts.), the root mean square error in metres (RMSE) and the percent of test points where the coordinate differences exceeded a certain tolerance value, are listed.

4. ANALYSES OF RESULTS, CONCLUSIONS AND RECOMMENDATIONS

Three schemes were developed and implemented for detecting changes in the planimetric content of digital maps and for revising the changes. All operations are performed in a GIS environment, which has been equipped with vector/raster handling capability. This arrangement has a number of advantages:

- All operations are performed in a commercially available GIS workstation. No additional, special hardware is required.
- The revision process is an extension to the existing GIS functions, so that an operator can perform these tasks with no or very little additional training.
- The photogrammetric operations, which are incorporated in the processes, are largely transparent to the user and no knowledge of photogrammetry is required on the part of the operator.
- All measurements are monoscopic so that the ability of stereo vision is not a prerequisite.

The results obtained for the revision test of the 1: 50 000 scale map are entirely satisfactory for all three schemes. A total of 1476 points were tested and with the exception of four along the forest boundary, none exceeded the 25 m tolerance prescribed in the specifications. Forest boundary is not considered as well defined feature. This result was to be expected because the photo scale was larger than the map scale which left a larger margin for identification, measuring and instrumental errors. It is not uncommon to take photographs at such a large scale for 1: 50 000 scale mapping. The operating ceiling of most aircrafts used for aerial photography is 25,000 feet (7,625 m) and the photo scale obtained from this altitude with a wide angle camera is 1: 50 000 [Slama (ed.), 1980].

The results obtained for the 1: 10 000 scale map are less favourable. Out of the 1701 points tests 31%, 6% and 7% exceeded the 3.3 m limit and 10%, 0.4% and 3% exceeded the 5.0 m limit set for the 90% error using the piecewise rectification, the DEM corrected tracing and orthoimage tracing schemes respectively. The following explanations are offered:

- The pixel size of the digitized photograph is 3.0 m which is the same magnitude as the tolerance set for the map accuracy.
- The map accuracy standards set by NBGIC are considerably more stringent than the customary 0.5 mm tolerance at publication scale which would correspond to 5.0 m on a 1:10 000 scale map. With the exception of a few features in the piecewise rectification case, this standard was satisfied.
- Difficulties were encountered in some section of the image to find well defined features around the area to be revised for the rectification.
- This project was the first experiment for testing the three map revision schemes on real data. It was performed by a novice operator without the opportunity of gaining the necessary experience needed to generate consistent results.

Nevertheless, this experiment is a good preliminary indicator of the practical value of the proposed map revision schemes and points to certain modification to be made in the future. In particular the following conclusions and recommendations were reached:

All three schemes are feasible alternatives for the revision of digital maps. The orthoimage tracing provides the highest accuracy, followed by the DEM corrected tracing and the piecewise rectification. Data requirement (DEM) and preprocessing time are in direct relationship with the level of accuracy obtaineable and the cost incurred.

The piecewise rectification scheme, which is the simplest and most economical of the three is perfectly satisfactory for the revision of medium scale maps. For large scale maps the DEM correction or the orthoimage scheme are recommended. It is expected, however, that as experienceis gained, the piecewise rectification results will improve.

The piecewise rectification is a satisfactory method for the updating of resource inventory maps at all scale. Here the map accuracy standards are less stringent than in basic mapping.

It is recommended that for the revision of large scale maps the photo to map scale ratio be reduced to about 2.5:1 and the resolution of the digitization be increased to about 500 dots per inch or 0.05 mm. This resolution can still be achieved with medium priced scanners. The performance of scanners is steadily improving and the price is becoming more affordable.

More experimentation is needed to evaluate the full potential of the map revision schemes presented here, and to refine the procedures used. There are definite plans to do this.

ACKNOWLEDGEMENT

This research and development work is being funded under the Canada/New Brunswick Subsidiary Agreement on Industrial Innovation and Technology Development and by a National Sciences and Engineering Research Council, Canada grant in aid of research. The authors also wish to thank Universal Systems Limited for their collaboration.

REFERENCES

Derenyi, E. and R. Pollock (1991). "Design and Development of a Heterogeneous GIS." *CISM Journal ACGC,* Vol. 45, No. 4, pp. 561-567.

Masry, S.E. and R.A. McLaren (1979). "Digital Map Revision." *Photogrammetric Engineering and Remote Sensing*, Vol. 45, No. 2, pp. 193-200.

NBGIC (1991). "Province of New Brunswick Land and Water Information Standards." New Brunswick Geographic Information Corporation, Fredericton, N.B., Canada.

Slama, C.C. (ed.) (1980). Manual of Photogrammetry. 4th Ed. American Society of Photogrammetry, Falls Church, VA, U.S.A.

Table 1: NTS Map, Piecewise Rectification

Feature	No. Pts.	RMSE (m)	% > 25 m
Buildings	91	1.0	0
Roads	836	2.9	0
Race track	50	1.0	0
River shoreline	70	2.2	0
Transmission line	165	2.4	0
Forest boundary	236	4.9	0

Table 2: NTS Map, DEM Corrected Tracing

Feature	No. Pts.	RMS (m)	% > 25 m
Buildings	91	1.2	0
Roads	836	4.2	0
Race track	50	0.4	0
River shoreline	70	1.7	0
Transmission line	165	2.5	0
Forest boundary	268	7.2	3

Table 3: NTS Map, Orthoimage Tracing

Feature	No. Pts.	RMSE (m)	% > 25 m
Buildings	91	1.4	0
Roads	836	1.6	0
Race track	50	0.7	0
River shoreline	70	2.0	0
Transmission line	165	1.7	0
Forest boundary	264	5.3	1

Table 4: NBGIC Map, Piecewise Rectification

Feature	No. pts.	RMSE (m)	% > 5 m	% > 3.5m
Buildings	150	1.3	3	12
Four lane highway	74	0.4	0	1
Two lane highway	311	1.9	14	36
Highway interchange	138	1.0	0	8
Residential streets	438	2.1	26	52
Driveways	52	1.5	7	25
Access roads	26	1.0	3	11
Bridge	126	0.3	0	0
Racetrack	52	2.0	15	42
Transmission line	334	1.5	1	37

Table 5: NBGIC Map, DEM Corrected Tracing

Feature	No. pts.	RMSE (m)	% > 5 m	% > 3.5m
Buildings	150	1.4	4	14
Four lane highway	74	0.7	0	0
Two lane highway	311	0.6	0	0
Highway interchange	138	0.5	0	0
Residential streets	438	1.2	0	15
Driveways	52	0.9	0	3
Access roads	26	0.4	0	0
Bridge	126	0.5	0	0
Racetrack	52	1.3	0	34
Transmission line	334	0.7	0	1

Table 6: NBGIC Map, Orthoimage Tracing

Feature	No. pts.	RMSE (m)	% > 5 m	% > 3.5m
Buildings	150	1.4	4	10
Four lane highway	74	0.2	0	0
Two lane highway	311	0.5	0	0
Highway interchange	138	0.4	0	0
Residential streets	438	1.2	1	14
Driveways	52	1.1	7	28
Access roads	26	0.5	0	0
Bridge	126	0.5	0	0
Racetrack	52	0.3	0	0
Transmission line	332	1.2	2	11