The Digital Transferscope

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Abstract

A simple scheme is presented for the real-time geometric co-registration of digital maps and images, in support of transferring planimetric details from image to map. The essence of this scheme is to transform the vector-based map graphics by incremental translation, scaling, rotation, and skewing to fit the raster-image backdrop, within a segment of the image at a time. The newly digitized features are concatenated with the base map by an inverse transformation. This scheme, in fact, emulates digitally the operation of a Zoom Transferscope. The utility of the scheme has been tested in a map revision experiment with satisfactory results.

Introduction

Single image photogrammetry, or monoplotting as it is often referred to, has been successfully employed throughout the history of photogrammetry for extracting planimetric details from photographs, mainly in thematic mapping and map revision. In these applications the existing base maps provide a framework of map objects to control the restitution of the images.

During the analog photogrammetry era, instruments built on the *camera lucida* principle, such as the Sketch Master and the Zoom Transferscope, as well as optical projectors, such as the Procom-2 optical image transfer instrument (Gregory and Moore, 1986; Turner and Stafford, 1987), facilitated monoplotting. Digital monoplotting systems using hardcopy images were also developed and are described by Masry and McLaren (1979), Oestman (1986), Sorensen and Nokleberg (1986), Molenaar and Stuiver (1987), Naithani (1987), Konecny *et al.* (1988), Warner and Carson (1992), and others.

Monoplotting is also applicable in softcopy mapping, when both the image and the map are in digital form. In fact, a fully digital system provides a better environment for the compensation of tilt and relief displacements, and other geometric anomalies inherent in images, than do simple analog restitution devices. A simple and inexpensive technique was recently developed and tested at the Department of Geodesy and Geomatics Engineering, the University of New Brunswick (UNB), to facilitate softcopy monoplotting, which is the subject of this paper. It has been designed specifically to serve the needs of resource mapping and the updating of digital maps and data bases.

Softcopy Monoplotting

A digital graphics workstation, equipped with both vector graphics and raster image handling capability and with on-screen digitization tools, is the basic requirement for soft copy monoplotting. It is advantageous to perform the operation on a geographic information system (GIS) workstation, which holds both the digital image and the map covering the area of interest and where the new information will also be stored.

The actual mapping process is very simple. The image is displayed as a backdrop for the map to be revised or used as a base for adding thematic information. The operator visually locates the details to be extracted from the image and traces these with the cursor. The digitized features are then stored in a file for further processing. Of course, the image and map must be in matched superimposition or, in other words, properly co-registered for this operation. This is the challenging element of monoplotting.

For satellite images, the standard method of co-registration is to fit the image to the map by a polynomial or spline transformation based on ground control points. For scanned aerial photography, the favored means of satisfying this requirement is orthoimage generation. This product assures a proper fit of the image to the map, and on-screen digitization can commence in the display without any further image processing.

Both the polynomial transformation and the orthoimage generation are complex and computationally demanding operations. They must be performed with utmost care and are best left to the specialists in image processing or photogrammetry. Image to map registration includes the following major steps:

- acquisition of ground control data from maps, by aerotriangulation or field survey;
- acquisition of a digital elevation model (DEM), in the case of orthoimage generation;
- measurement of the image coordinates of the ground control points;
- computation of the transformation parameters, usually by least-squares adjustment; and
- transformation of the image data, which includes the computation of new radiometric values for each image pixel by resampling.

A good illustration of the magnitude of this operation is that four hours of processing time were spent to resample a full Landsat Thematic Mapper scene (approximately 36 million pixels) in a Sun SPARCstation 2, and 45 minutes were needed for the transformation and resampling of 5 million pixels in a Sun SPARCsystem IPX, to generate an orthoimage. A bicubic interpolation was used for the resampling in both cases. Additional time and cost is involved in completing the other steps of the registration process.

In the author's opinion, such a major image processing task should only be undertaken when the georeferenced image is put to repeated multipurpose use. It is probably uneconomical to execute it in support of a one-time selective retrieval of information scattered over a large geographic area. An alternate solution is the temporary transformation of the vector graphics to fit the raster image, which is a much simpler task.

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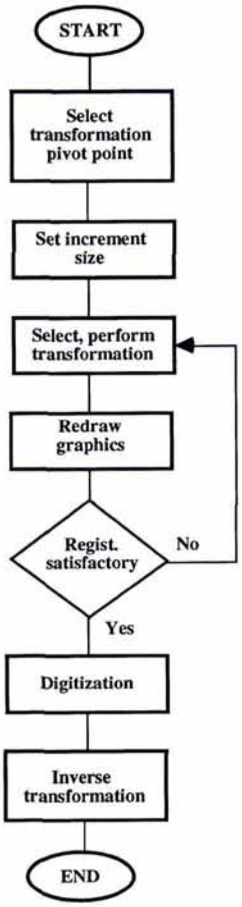

Figure 1. A schematic of the cartographic information extraction process from digital images with the aid of the digital transferscope.

Incremental Geometric Registration

In the registration scheme devised at UNB, the vector-based map graphics is adjusted to the raster-image backdrop, within a segment of the image at a time, by incremental translation, scaling, rotation, and skewing. The digital tracing of the planimetric details of interest follows. Thereafter, the newly digitized features are concatenated with the base map by an inverse transformation. This scheme, in fact, emulates digitally the operation of a Zoom Transferscope.

Procedure

Incremental registration is intended for correcting only small misregistrations. Therefore, it is assumed that a reasonable overall match already exists between image and map. It is not difficult to achieve this relationship, because the approximate orientation of the image coordinate system with respect to the reference system of the map is usually known, or can be determined with the help of the image and map coordinates of two corresponding points. A four-parameter similarity transformation of the vector graphics, performed in batch mode, can then establish an approximate match. Alternately, new aerial photography may be flown in an east-west direction in anticipation of map-to-image registration, or the photographs can be digitized with the scan lines running parallel to the map grid.

The registration and digitization is performed in subregions of the image at a time. The step-by-step procedure, based on the current implementation in the Computer Aided Resource Information System (CARIS) GIS, is as follows (USL, 1992):

The operator interacts with the CARIS registration module through the following two level menu:

Level 1	Level 2
Quit	*Quit*
Locate origin	*Erase old*
Return to original display	*Compare with original*
Set increment size	*Translation*
Make correction	*Scaling*
	Rotation or skew

"*Quit*" at Level 1 returns the control to the main CARIS menu while "*Quit*" at Level 2 returns the process to Level 1. Entry from Level 1 to Level 2 is through the "*Make correction*" command. Figure 1 is a schematic of the cartographic information extraction process.

The first step in using the module is the "*Locate origin*" option, which allows the operator to define the pivot point in the display around which the rotation and skewing occurs. The default location is at the upper left-hand corner of the display.

The second step is "*Set increment size.*" An integer in the interval 1 to 9 defines, in pixel units, the magnitude of the change that is introduced with each adjustment increment. The default is 5, which is a reasonable initial value. A larger increment is selected when the image/map fit is very poor. The operator can later return to this option to set a smaller increment size for fine adjustment.

The third step is "*Make correction*" to enter Level 2. At this level the operator can select any one of the following three types of transformations: "*Translation*" shifts the graphics independently in x and y directions with respect to the image. "*Scaling*" stretches or compresses the graphics independently in x and y directions. "*Rotation and skew*" changes the orientation and the shape of the graphics. These adjustments can be introduced iteratively in any sequence. The effects and the values of the adjustments are accumulated. The graphics are automatically redrawn after each adjustment step so that the operator can decide on the next appropriate move. All incremental changes, other than the most recent one, can be cleared by the "*Erase old*" command. At any time, the original map graphics may be redrawn by selecting "*Compare with original*," and the operator can assess the progress of the registration. "*Erase old*" will delete the original graphics. The "*Back to original display*" erases all the adjustments made. All adjustments will also be erased automatically if the pivot point is relocated.

When satisfactory map-to-image registration has been achieved, the operator can switch to the on-screen digitization routine in CARIS to commence the mapping. All map graphics are drawn in the image coordinate system. An inverse transformation is automatically applied to all coordinates of the newly digitized points so that the proper registration to the original map grid is assured. The "*Back to original display*" command then shows the original map and the new information combined in the proper reference system. If the results are satisfactory, a new image segment may be selected for registration and digitization. After all the pertinent information has been extracted from a particular image, the "*Quit*" command returns control to the CARIS main menu. Cartographic editing of the newly digitized features can then be performed if necessary.

Application

Incremental geometric registration is an inexpensive and simple solution for combining digital map and image data. It avoids the expensive process of orthoimage production when preservation of a georeferenced image is not essential. Very little if any preparatory work is required. The sensor orientation parameters (interior and exterior orientation) do not have to be known. Thus, imagery recorded by any kind of sensor and metric or non-metric camera can be handled with ease. Control points with known coordinates are not needed, which represents a significant saving in cost. DEM or any other kind of elevation data are not required either. A general familiarity with the topography is, however, helpful for the segmentation of the image.

The principal application of the incremental geometric registration is in map revision, in updating databases, and in thematic mapping, such as forest inventory, soil survey, geological mapping, land-use study, etc. It could be useful to relate historic photographs to current maps or, conversely, old maps to current photographs in order to observe and record changes that occurred over time. Relationship between land use, ground cover types, and topography can be easily studied by quickly overlaying a contour map on the image. Plans showing proposed developments such as new subdivisions, industrial sites, transportation and communication lines, etc., can be easily overlaid on images for a preliminary visual assessment of their impact on the environment and to facilitate the engineering design process. These are only a few examples which demonstrate the advantages of the digital transferscope scheme.

A limitation of this scheme is that the combination of transformation steps only amounts to a six-parameter two-dimensional geometric transformation, an affine transformation to be exact. This first-order transformation function may not be able to model adequately the random displacements caused by rugged topography and by the effects of tilt. Therefore, this scheme is applicable only when the residual displacements after transformation within a subimage can be tolerated. The magnitude of these displacements increases towards the edge of an image, and, thus, the utility of this scheme can be increased by judicious selection of segment locations.

Some mismatch and discontinuity may occur when features cross sub-regions or extend into neighboring images. These problems can be corrected using the cartographic editing tools available in the CARIS GIS.

The applicability and accuracy of this registration scheme also depends on the availability of well-defined planimetric features. Ideally, these features should be distributed throughout a segment so that an overall best fit of the map and image can be established within the subregion.

The procedure of incremental registration is easy to learn and follow. No formal training is needed in photogrammetry. It is an intuitive, trial-and-error process rather than an analytical solution. Thus, the necessary skills can best be acquired through experimentation.

Map Revision Experiment

The incremental geometric registration scheme was tested on the revision of a 1:50,000-scale digital map sheet of the Canadian National Topographic System (NTS) series and on a 1:10,000-scale digital map sheet of the New Brunswick Geographical Information Corporation (NBGIC) (Derenyi and Teng, 1992). 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. From there, the terrain has a gradual incline to reach an elevation of 130 m at the city limit. Basic rather than thematic maps were selected for the test to provide reliable data for the evaluation of the results. A duplicate map file was created, and various features were deleted in six regions of each map to simulate missing information. These features were then re-established from the same black-and-white aerial photographs used for the original compilation of the 1:50,000- and 1:10,000-scale maps. The photo scales were 1:40,000 and 1:35,000, respectively. The tilt of the photos was around one degree.

The digital images were obtained by scanning the paper prints in a Hewlett-Packard ScanJet Plus document scanner at 118 dots-per-cm (300 dots-per-inch) resolution, which resulted in an 85-µm pixel size at image scale. The corresponding pixel size on the ground was 3.4 m and 3.0 m for the two photo scales, respectively. The radiometric values were recorded in 256 gray levels. The reason for selecting paper prints, an inexpensive document scanner, and low image resolution was to prove the simple and affordable nature of this scheme.

Road intersections and other well-defined features were selected as control for the transformation of the map to the image. The features missing in the map files were then traced in the image by freehand cursor control and digitized. The features mapped included a highway, major thoroughfares, residential streets, river shoreline, power transmission line, a racetrack, a highway bridge, several large buildings, and the edge of forest . All features were digitized in point mode. Roads were digitized along the center line.

The digital files containing the new features were concatenated into the original map file by inverse transformation. 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 measuring the coordinate differences. Line features were subdivided into sections at well defined breakpoints. Thereafter, X, Y coordinates were generated at equal intervals along both the original and newly digitized path of the features, and the deviations in position at corresponding point pairs were computed. The root-mean-square error (RMSE) of the deviations at 1212 checkpoints in the 1:50,000-scale map was 2.6 m. The RMSE in the 1:10,000-scale map was 1.5 m based on 1701 check points. In comparison, the tolerances set in the map accuracy standards for an "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, are 16.5 m and 3.2 m, respectively.

The results are entirely satisfactory. In both maps, the RMSE indicates sub-pixel accuracy and is well within the tolerances set for basic mapping although simple equipment and low resolution image data were used. It is therefore a reasonable expectation that the less stringent demands imposed on the positional accuracy in thematic mapping can also be met with this registration scheme as long as sufficient control exists.

Conclusions

Incremental geometric registration is a simple yet effective method for overlaying digital maps and images in preparation for selective extraction of cartographic information from an image to a map by on-screen digitization. No ancillary data, such as ground control, a DEM, or sensor orientation parameters are needed, and no mathematical computations are performed, which renders this method very economical to use. It is applicable to any kind of digital image. The registration is performed in real time, which makes a rapid response to urgent mapping needs possible. Neither advanced photogrammetric knowledge nor stereo perception is a prerequisite. The outcome of the map revision experiment indicates that the digital transferscope scheme is a valid alternative to the rigorous image-to-map registration in map revision and thematic mapping.

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Forthcoming Articles

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Eduardo Brondizio, Emilio Moran, Paul Mausel, and *You Wu*, Land Cover in the Amazon Estuary: Linking of Thematic Mapper with Botanical and Historical Data.

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