Extending a GIS to Support Image-Based Map Revision

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ABSTRACT: The Computer Aided Resource Information System (CARIS) has been extended with on-screen, hybrid, and correlation-based digital map-revision environments to support the revision of digital maps using imagery acquired from airborne and satellite sensors. The on-screen environment is an implementation of the now-familiar integrated raster-image/vector-graphics display (within the existing CARIS map-editing environment), but with a novel raster image organization scheme. The hybrid environment has an integrated raster-image/vector-graphics display for visual change detection, while supporting highly accurate manual digitization from hardcopy aerial photographs and relief displacement correction using a digital elevation model (DEM). The correlation-based environment includes relief displacement correction of digitized points without a DEM when overlapping photographic coverage is available. The hybrid and correlation-based environments are being generalized to accomodate imagery from the SPOT and Landsat satellites.

INTRODUCTION

THIS PAPER DESCRIBES extensions to the Computer Aided Resource Information System (CARIS), a GIS developed and marketed by Universal Systems Ltd. (USL) of Fredericton, New Brunswick, to facilitate the revision of digital map data from digital and analog imagery. These extensions are in the form of three separate map-revision environments: on-screen, hybrid, and correlation-based. The different environments are suitable for different accuracy requirements, and for using elevation data from different sources when correction for relief displacement is important. Software for this project has been implemented on a Sun workstation with an 8-bit-per-pixel color display.

CARIS was initally designed and implemented to store, display, and manipulate point-vector data and to interface with a commercial database management system that manages the associated lexical data (Lee, 1983; Masry, 1982). CARIS has since been extended to handle, in a similar fashion, map objects that are stored as 1-bit-per-pixel raster data and to convert between raster and vector formats (Reedijk, 1990). The capabilities described in this paper are a subset of those that were developed for storing, displaying, and processing multiple bit-per-pixel raster image data within CARIS.

ON-SCREEN MAP EDITING ENVIRONMENT

The CARIS map editing module, CARED, was extended with raster-image display capabilities that allow users to edit a vector-based map file through a workstation screen display of the map data on a raster-image background. All of the pre-existing CARED operations work as they did before the extension, including those for changing the display window and scale.

RASTER-IMAGE DATA ORGANIZATION

A major objective in the design of this extension was to provide an environment in which displays could be created from a wide variety of raster-image data with as few pre-processing steps as possible. This objective was met through the use of a flexible raster-image data organization scheme.

In most software systems that display and process raster imagery, particularly remotely sensed imagery, the raster-image data are organized as collections of layers where each layer is assumed to be a rectangular array of pixels from a single source. An example of a raster-image layer in such a system is a single channel of a Landsat MSS scene. Layers that are often combined in color-composite displays or for multispectral machine processing may be collected into distinct data sets. Typically, layers in such sets are required to have the same raster definition (pixel-depth, pixel-size in ground units, and geographic position) and extent (number of rows and pixels-per-row). This scheme facilitates multispectral machine processing but is restrictive with respect to image display. For example, a user of a system that conforms to this scheme who wishes to view a color-composite display of a SPOT panchromatic scene and two Landsat Thermatic Mapper (TM) channels would have to first resample the TM channels into new rasters that have the same raster-definition and extent as the SPOT raster.

In CARIS, a raster-image layer is a set of one or more *regions*. A region corresponds to a layer in the scheme described above. Multiple regions that belong to the same layer are not required to have the same raster definition, and a region may belong to more than one layer (Figure 1). As in conventional systems, a layer represents the data that controls a single color in color-composite display. Layers that are intended to be used to create various backdrop displays for the same map are collected together in a single raster image. The CARED raster-image display system supports this scheme, which means that data from different sources may be displayed together in a monochromatic display or as a single color in a color-composite display without requiring the user to first resample the data to a common pixel size and physically merge them into the same file.

For any given map display on a window-based display system, the window's drawing surface (or canvas) represents a certain geographic extent, depending on the scale at which the data are drawn on the screen and the geographic location that the data represent. Furthermore, each pixel in the canvas represents a certain area and location. Thus, the canvas may be thought of as having a raster definition for which the pixel size, raster dimension, and location parameters are set by the display scale and location. When displaying raster imagery as a backdrop to a digital map, CARIS obtains the canvas raster definition parameters as set by the map display and automatically resamples (by nearest neighbor) the image-region data to that raster definition when transferring the data from disk to main memory (Figure 2). Because of this resampling, the dimensions of the canvas only influence the spatial resolution of the raster image display, and not the extent of an image region that can be displayed at any one time. Also, for each image region in the display, only the part that intersects the geographic extent of the display is read from disk. When reading a layer that is composed of multiple overlapping regions from disk, CARIS arbitrarily selects one region to be visible in the overlap area.

A current raster image that has been input into CARIS consists

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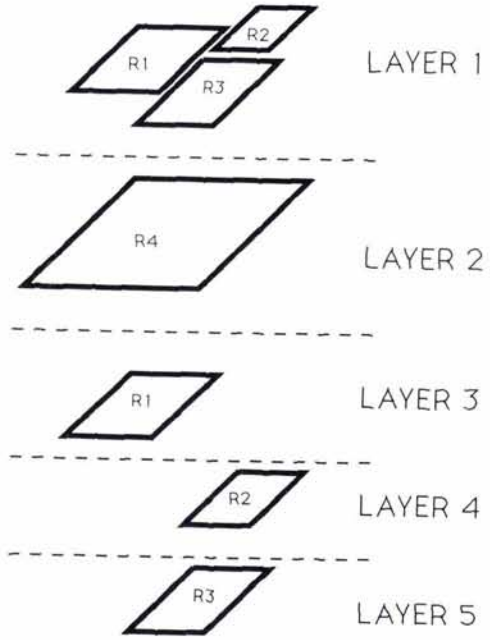

FIG. 1. A schematic example of a raster image in CARIS composed of four regions (R1-R4) and five layers.

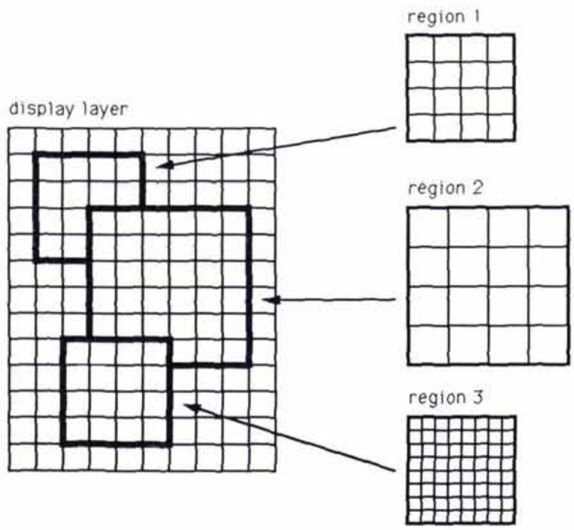

FIG. 2. Regions comprising a single layer are dynamically resampled to a uniform raster definition when displayed.

of ten single-region layers of geophysical data having a 250-metre pixel size, seven single-region layers of Landsat Thematic Mapper data having a 30-metre pixel size, and one multiple-region layer that was created by scanning adjacent aerial photographs to a 7-metre pixel size (one region per photo). Color-composite displays of any three layers may be created at any scale.

In the current implementation, the descriptive data for layers and regions are stored in tabular form in an ASCII text file and the actual pixel values are stored in one or more separate binary files as unstructured strings of bytes. The descriptive data for a region includes the data needed to impart a structure to the stored image pixel values, as well as the parameters of each region's raster definition. This implementation allows all of the descriptive data to be read and modified using a text editor. Also, it would be easy to use the relational database management system that is currently coupled with CARIS to manage these data.

RASTER-IMAGE ENHANCEMENT OPERATIONS

When a raster-image display is created, the resampled data for each layer are loaded into a buffer of eight-bit values in main memory, and a bitmap for each layer is created which discriminates the "non-null" display pixels for each layer. (Display pixels are "null" if no image data are read for them, and they occur when the raster-image data do not cover the entire extent of a display window.) In addition, a frequency histogram of the values of the non-null pixels that are displayed from each loaded layer is automatically compiled. These features support in-memory raster-image enhancement operations. Such operations may be required for clarifying details in a raster-image backdrop during an on-screen mapping session.

The currently available image enhancement operations are histogram equalization, direct histogram specification, neighborhood averaging, bi-directional gradient, and the intensity-hue-saturation (IHS) to red-green-blue (RGB) color space transformation. The color space transformation is useful in creating an effective display with one layer containing high spatial resolution data and two others containing low spatial resolution and high spectral resolution data. An in-memory enhancement operation is performed on data in one or more of the layer buffers for the current display, and the frequency histogram for each effected buffer is automatically recomputed during the operation. The null-pixel indicator bitmaps allow null pixels to be recognized and excluded from the operations and the frequency histogram recomputations. The exclusion of null-pixels from a frequency histogram, and the fact that a histogram represents only the subset of the raster-image date actually being displayed, optimizes the results from operations that use this information (such as histogram equalization). The opportunity to recognize and skip null pixels can also significantly increase the execution speed of an operation.

RASTER-IMAGE/MAP REGISTRATION

The on-screen map-revision system requires that raster-image regions be in registration with the digital maps with which they are to be displayed. In many cases, the raster-image data cannot be obtained already transformed to the desired coordinate system. A raster-image/map registration package has been implemented in order to handle this situation.

One component of this package is a tool for manually selecting ground control point (GCP) locations in a digital map and a raster image which are simultaneously displayed in separate windows (Figure 3). This capability is required in cases where sensor orientation parameters are not available or sufficient for registration. A file of GCP coordinate pairs is output. The user can check the residual error for any GCP according to a projective transformation function or a polynomial transformation function of a specified degree and reject any GCP with unacceptable residual error. This package makes use of a facility implemented at USL for establishing interprocess communication between a CARED process and a second process. In this case, the second process displays the uncorrected raster image, controls the overall GCP collection procedure, and computes the residuals and root-mean-square errors. The CARED process can display raster imagery that is already registered to the map, and this may be useful for establishing further GCP locations.

A second system has been implemented to geometrically transform the raster imagery on the basis of GCP data or directly provided orientation parameters (in the case of scanned aerial photographs). Conventional projective and polynomial (up to

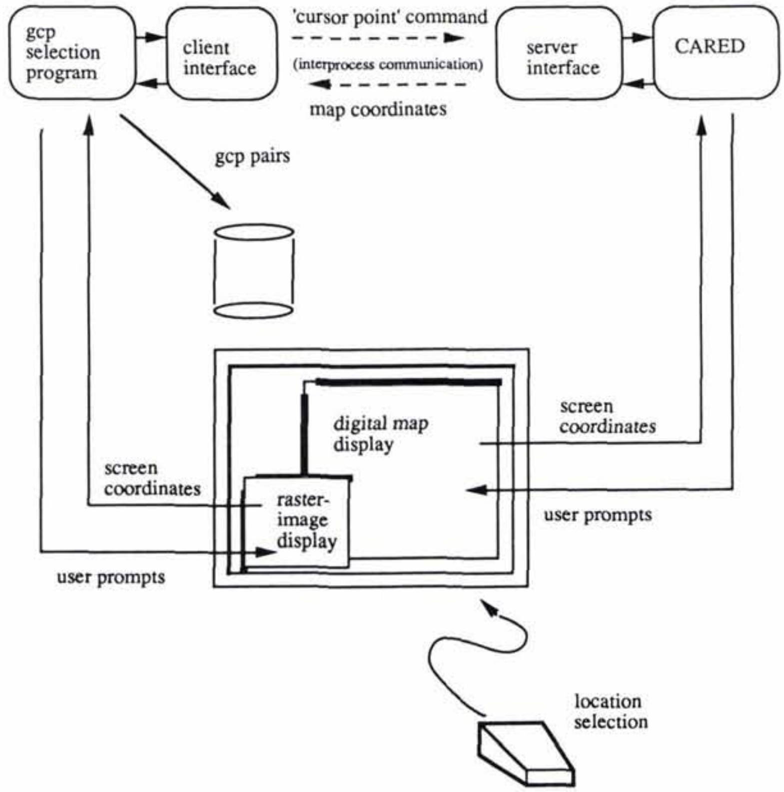

FIG. 3. GCP selection system.

degree 5) transformations have been implemented, in addition to a transformation based on surface splines (Goshtasby, 1988). This system can also use a digital elevation model (DEM) in grid or triangulated irregular network form in order to apply a correction for relief displacement to rasterized aerial photographs and produce an orthographic image. This system is being extended for use with data from non-camera sensors for which orientation parameters are available.

LOCAL REGISTRATION IMPROVEMENT

Even though good overall registration may be achieved with the raster image/map registration package, an unacceptable degree of mis-registration in some subregions of the coverage may remain. This may often happen when a DEM is not available to correct for relief displacement error in rasterized aerial photographs of hilly terrain, or in subregions lacking distinct points that could be used as GCPs. In order to address this problem, an incremental geometric correction module has been implemented within CARED that allows the user to interactively improve the registration of the map to the raster-image display without having to select GCPs. This is done by incrementally translating, scaling, rotating, and skewing the vector-based map graphics, which are redrawn on top of the raster-image backdrop after each adjustment step. Although the different types of adjustments are performed in separate steps, their effects accumulate to provide a full affine transformation capability. Once the desired registration improvement is obtained, the user can edit the "warped" map graphics. When new points are digitized on the display (using the mouse and standard CARED commands), their coordinates are put through the inverse of the registration improvement transformation before being written to disk. This causes newly digitized vector-based map objects to be in registration with the uncorrected map graphics (Figure 4).

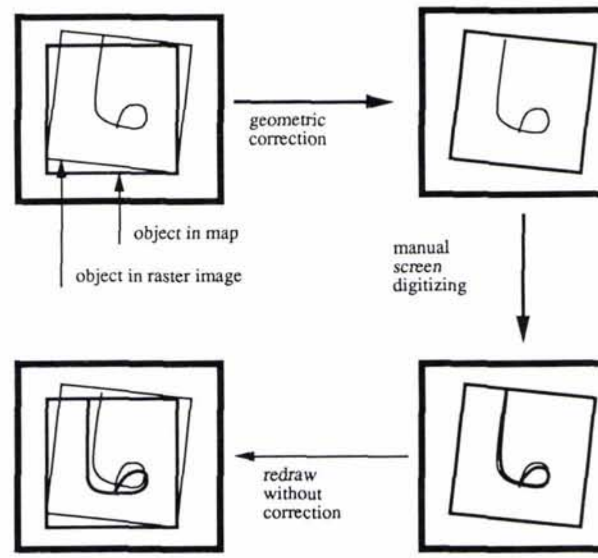

FIG. 4. Map objects digitized after local registration improvement are automatically registered to the uncorrected map.

HYBRID MAP-REVISION ENVIRONMENT

The task of manually selecting out-of-date features in a map is facilitated in the CARED environment when the map is displayed on top of recently acquired raster imagery. However, new map features may be more accurately digitized from hard-copy images than their rasterized counterparts. This is particularly the case when aerial photography is the source of image data. In order to obtain a digital version of a photographic print having comparable resolution, high-cost scanning equipment must be used and the disk file that is produced may be extremely large. This has led to the development of a hybrid map-revision environment in which aerial photographs that have been digitized with low-cost document scanning equipment at a modest resolution (e.g., 70 points-per-inch) are displayed in CARED as a backdrop to the digital map that is to be updated, but in which new features may be digitized from the photographic print on a digitizing table. The raster image/map display allows for convenient visual change detection, while features may be more accurately digitized from the photographic print. Enlargements of the photographs may allow even higher digitizing accuracy, up to the level of second-order photogrammetric restitution instruments (Faig *et al.*, 1988).

Two approaches to using a DEM to correct for relief displacement when digitizing from photographic prints are being implemented for testing (a technique for correcting for relief displacement when a suitable DEM is not available is described in the following section). The *iterative* approach (Masry and McLaren, 1979) involves projecting the image point onto a plane set at average terrain elevation to obtain approximate map-space coordinates which define a new projection plane. The procedure is repeated with successive projection planes until the change in the elevation coordinate is within a preset tolerance. The *direct* approach involves a preliminary operation in which an image DEM is created by projecting the map DEM onto the image plane, with respect to an arbitrary elevation datum, and then calculating the relief displacement at each image DEM point and storing it in place of the terrain elevation. When digitizing, the relief displacement at any digitized image coordinate is obtained by linear interpolation and applied as a correction, and the corrected image coordinates are reprojected onto the selected elevation datum to obtain the planimetric map space coordinates.

The iterative approach has the advantage of not requiring a preprocessing step but the number of computations required while digitizing may create a bottleneck. The direct approach requires fewer on-line computations but instead requires a significant pre-processing step.

CORRELATION-BASED MAP-REVISION ENVIRONMENT

This scheme is useful when significant relief displacement occurs in the imagery and no DEM is available to correct for it, but the imagery has stereoscopic coverage and elevation data exists for selected ground control points. The imagery must be in digital form. The current system is suitable for use with aerial photography that has been scanned using an inexpensive document scanner. Typically, the scanning is done at 300 points-per-inch.

First, at least three GCPs are selected for each image using the GCP selection tool described earlier. An elevation value is required for each GCP and, if this cannot be obtained from the digital map data, then it must be operator-input. The GCP coordinates are used in a space resection routine to compute camera parameters for each image.

Features are digitized in a screen display of one of the images of the stereo pair. The corresponding points in the other image are located by digital correlation techniques which make use of the pre-computed camera parameters. The computation of the parallax and the elevation of the points follows, and the planimetric position of the digitized points is corrected for the relief displacement.

Image correlation is accomplished by an area based matching algorithm (Rosenholm, 1986; Hannah, 1989). Specific points with known coordinates in one of the images are matched. Because the relative orientation parameters are known, it is a simple matter to pre-calculate the approximate location of the corresponding point in the other and keep the search window of the correlation small. Most planimetric map objects are well defined points, or have well defined boundaries in the imagery and matching is usually readily performed. With this approach, there is likely to be more success in locating the corresponding image point as compared to the approach of generating a DEM by correlation over a large area. Also, elevations are generated primarily for removing the effect of the relief displacement and not for DEM production. Therefore, the accuracy requirements can be relaxed. Nevertheless, this approach has the potential to produce height information as well. The accuracy of the relief displacment correction and height measurements obtained from this system has yet to be evaluated.

An integrated raster-image/vector-graphics display may be used for visual change detection, as in the hybrid environment. This is useful even when there is noticeable image/map misregistration due to the unavailability of a DEM in the registration process.

CONCLUSION

A Variety of environments for manual digital map revision have been implemented as extensions to the CARIS GIS. These provide options that are suitable for different accuracy requirements, and for the use of elevation data from different sources when correction for relief displacement is important. The on-screen map-revision environment is suitable when relief displacement is not significant, or if an orthographic image has been generated to compensate for relief displacement. The hybrid map-revision environment is suitable when high digitizing accuracy is required and a DEM is available for relief displacement correction. The correlation-based map-revision environment allows for relief displacement correction when a DEM is unavailable, but the imagery provides stereo coverage and elevation data for select ground control points is available. The correlation-based environment is appropriate when the digitizing accuracy of the hybrid environment is not required. The hybrid and correlation based environments are currently limited to use with scanned aerial photographs but are being generalized to accomodate imagery from the SPOT and Landsat satellites.

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