System Integration Issues in Digital Photogrammetric Mapping

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Abstract

The recent development of the Terrain Information Extraction System (TIES) has provided the U.S. Army with an end-to-end digital photogrammetric mapping testbed. Using components developed by differing vendors, the system provides capabilities for scanning hardcopy imagery, photogrammetrically processing digitized or digital imagery and interacting with a geographic information system.

The process of assembling the components of TIES into a single, functioning system, has raised a number of key issues and provided valuable lessons learned concerning internal data exchange, networking and quality control. These issues, discussed independently, are analyzed and reviewed from a systems perspective.

Introduction

Currently, in photogrammetric mapping research and development there is a race away from the use of analog aerial film as source material towards the use of digital imagery as a replacement. Clearly, there is good reason for this. The manual, laborious nature of extracting mapping-quality information from aerial film imagery is unacceptably slow and costly. The promise of increasingly sophisticated computer-assisted extraction and processing of digital imagery is likely the only hope of meeting demands for spatial information in an increasingly dynamic world. However, research in digital photogrammetric mapping is embryonic with many issues to be resolved and additional technical developments to be made before digital mapping can become affordable and economically competitive. Research at the U.S. Army Topographic Engineering Center in developing a low-cost, end-to-end digital photogrammetic testbed, the Terrain Information Extraction System (TIES), has shown promise and raised many issues (Desmond and Edwards, 1989) (Brown, 1991). This paper reviews the basic TIES system design, recounts the lessons learned, and raises some of the unresolved technical issues.

TIES System Design

The basic components and data flows of the TIES are illustrated in Figure 1. The Image Digitizing System (IDS) is used to digitize positive and negative film transparencies or negatives and measure photogrammetric interior orientation parameters. The digitized imagery and ASCII header files are transferred over a computer network to the Digital Stereo Photogrammetric Workstation, DSPW, (Miller, 1992). Digital imagery, such as SPOT or Landsat, can be loaded directly via digital tape at the DSPW. Photogrammetric functions such as multi-image/multi-sensor triangulation, rectification and point mensuration are performed at the DSPW. Imagery can be reshaped based on ephemeral information, elevation data, or perspective views. Data compilation, review, and edit functions such as stereo correlation, spatial feature extraction and 3-dimensional wireframe modeling are resident on the DSPW. Feedback during data compilation and edit is accomplished through stereo graphic overlays superimposed on imagery displayed on the stereo monitor. The automated stereo correlation is based on a hierarchical relaxation strategy (Hellava, 1987). The interactive feature extraction produces 3-dimensional "spaghetti" vectors with attribution based on a user-defined data dictionary. Three-dimensional wireframe models can be produced for use in image perspective transformations.

Data produced by the DSPW are exported to a geographic information system (GIS) for further spatial analysis and modeling. Topology is created from the points and spaghetti arcs of feature data with the attributes stored in relational tables. Elevation data is used in terrain modeling programs. The GIS is also used as a data conversion medium to bring externally produced standard data (such as DMA ITD/TTD or USGS DEM), vectorized multispectral data classifications, or custom data from testbed computer-vision/knowledge-base systems into the TIES for use or review on the DSPW.

Image Digitization Issues

Two key issues relating to the digitization of aerial imagery are prominent; sampling resolution and geometric sampling accuracies. The sampling resolution affects not only the amount of spatial information retained from the original film, but also dictates the computer storage requirements. The IDS can sample imagery with spot sizes of 7.5, 15, 30, 60 and 120 microns. The digitization of an entire aerial 9.5 by 9.5 inch frame image at a spot size of 7.5 microns results in an unacceptably large one gigabyte digital file. Most commonly, conventional frame imagery is scanned at 30 microns, since using a 15 micron sample size only produces a modest increase in spatial information, but represents a four-fold increase in storage requirements. Other sensors, such as panoramic, are often sampled at finer resolutions.

The geometric sampling accuracy of the digitization process is also very important so that it does not introduce unknown photogrammetric errors into the digitized image. The stage used to move the imagery under the CCD during digitization on the IDS has an advertised geometric precision of +/- 2 microns MSE per axis across 9.5 by 9.5 inches of travel. This precision allows interior orientation to be performed as part of the digitization process which provides two additional advantages. First, because the fiducial/timing marks can be sampled independently in small digitized patches and at the 7.5 micron resolution, the resulting measurement can result in a more precise interior orientation. Secondly, through the process of sampling and measuring each fidicial/timing mark, a micron coordinate system is established, which permits scanning only that portion of the aerial image needed for mapping. This saves network transfer time, storage, and processing requirements. Normally, for a stereo pair of frame images, the fiducials are sampled/measured at 7.5 microns, and only the stereo overlap portion of each image is scanned at 30 microns. Coordinates of both the measured fidicials and the four corners of the digitized image patch are saved in an ASCII file with additional information. The digital patches of imagery surrounding each fidicials are not saved once the interior orientation has been measured. This information is transferred with the image file over the computer network to the DSPW and is used in the photogrammetric adjustment. The potential also exists to measure control points at the IDS for use in the exterior adjustment at the DSPW, though this has not been done to date.

Storage Issues

Storage represents a prominent issue for the DSPW. The storage of only the patch of imagery needed for mapping without having to store the entire image including fiducials helps conserve disk space. Image compression, implemented in hardware, could greatly alleviate this problem, though it is not implemented on the current version of the DSPW. With digitized aerial imagery, the sampling resolution is the primary method used to constrain storage requirements.

Photogrammetric Orientation

The digital domain offers many advantages and useful tools to perform relative and exterior orientation adjustments. The capability to view differences in measured and adjusted control points with the display cursor superimposed upon the imagery, in stereo or split screen, is extremely helpful. The ability to preposition points based on estimated/adjusted ephemeris can save time and is valuable for transferring control points image-to-image.

Other tools, currently not implemented on the TIES, would be useful. There is a need for more sophisticated blunder detection. Display of adjusted parameters such as control point residuals in a graphical Triangulated Irregular Network (TIN), where the z axis would register the residual error component(s), would be helpful for detecting blunders or systematic errors. The capability to use stereo correlation to produce passpoints, distributed appropriately through the sensor model, would save labor and improve results. The capability to orient photos based on lines or arcs also enhance production throughput.

Until affordable computers realize great increases in processing power, certain enhancements for digital photogrammetric systems capable of high volume data production need to be implemented in specialized hardware. First, a capability to rectify imagery in real-time is needed. Correlation requires epipolar rectification to aid in conjugate point matching. Currently, each stereo image pair must be rectified along epipolar using a software function. When using a stereo triplet, the middle photo gets rectified twice, once to the left photo and once to the right photo resulting in a doubling of the storage requirement of the middle photo. A hardware implementation of image warping/rectification would save considerable storage and time. Another useful hardware implementation would involve hardware zoom and minification, since analysis and measurement often require both magnified views and overviews. Currently, the DSPW computer calculates minified images using software and stores these on disks which adds roughly one-third to computer storage requirements. A third capability involves real-time image compression/decompression to alleviate the data storage problems discussed earlier. Currently, these real-time hardware capabilities only reside on high-end, expensive systems such as the Defense Mapping Agency workstation or the Digital Image Workstation Suite (Miller, 1992), and not on the DSPW.

Correlation

Testing, to date, has proven the current stereo correlation capability is reasonably robust under differing terrain conditions, image sensors and image scales. Some conditions, such as 1:12000 scale frame imagery taken during winter over forested, rolling glaciated terrain, have produced results that have required extensive editing of the elevation data. In the near future, correlation using "window shaping" operations along with an iterative orthophoto refinements methodology (Norvelle, 1992) is being implemented on the DSPW for testing and evaluation. At some point in the future, robust correlation programs will have to incorporate some knowledge-based processing capabilities. These will constrain correlation parameters based on an understanding of geomorphology and post-process the results based on an understanding of the effects that landcover conditions such as forests, water, or urban areas can have on the elevation data.

GIS

Existing GIS technology must mature in order to exploit the spatial information capabilities offered by emerging digital photogrammetric mapping systems. The GIS used in TIES stores only 2-dimensional (X,Y) coordinate data. Currently, the elevation coordinate is preserved by storing the X,Y,Z coordinates in a triangulated irregular network (TIN). Coordinate data (X,Y) being passed from the GIS to the DSPW must be intersected with the TIN in order to re-establish the elevation (Z) coordinate with the appropriate 2-dimensional coordinate pair. The X,Y,Z coordinate triplet is needed at the DSPW in order to superimpose spatial information onto the stereo image model. Not all spatial information systems are so limited, some GISs do store X,Y,Z coordinates. However, few, if any, GISs utilize spatial tools (except TINs) that use 3-d feature coordinates for spatial analysis or modeling. Functions such as route planning, hydrologic modeling and erosion analysis all would benefit if such detailed elevational information were used rather than relying on regularly gridded digital elevation models. Research in knowledge-based work such as geomorphic analysis of landforms would also benefit since this relies heavily on detecting subtle breaks in slope which are best observed in the 3-dimensional gradient of streams and gullies, and are not derivable from gridded elevation models.

As mentioned earlier, data generated at the DSPW is transferred and imported into the GIS. This connection, while simple, is not very efficient. Ideally, the GIS needs to be fully integrated with the DSPW. The entire feature extraction process would benefit tremendously by having the utility of a fully capable GIS available at the DSPW. The ability to query previously generated thematic layers, extract information/features, and use these during the current DSPW extraction would both save time and improve data quality. This eventually could be expanded to include the concept of feature compilation as an iterative analysis and extraction process based on a min/max strategy. Actual feature extraction would be kept to a minimum. Analysis of mapped features combined with local/regional/global terrain knowledge would be performed to its fullest extent to maximize data extraction through statistical analysis, mathematical models, knowledge-based models and inferencing (Edwards, 1988). This min/max strategy represents a long term goal of TIES. Currently, the DSPW is incorporating a limited query capability to somewhat alleviate this integrated GIS shortfall.

Data Formats

A major challenge in the development of TIES has been the definition of data exchange formats between the major system components of TIES. The IDS passes tiled image data and ASCII header data to the DSPW. The tiled image file contains only image data. The ASCII header file has a "keyword and value" type format (McDonnell, 1992) which includes such information as: image dimensions, tile size, measured fiducial coordinates, calibrated fiducial coordinates, image patch corner coordinates, and scan resolution. The DSPW utilizes this digitized data information or digital image data loaded directly from tape with input control points or ephemeral information, and generates 3-dimensional feature data with attributes, elevation models, and/or rectified imagery/orthophotos. Imagery exported from the DSPW can be either in a tiled image format or standard raster format. The ephemeral information and other support information is available in a keyword/value ASCII file. Compiled feature data is either exported/imported as spaghetti or closed polygons in an ASCII coordinate list format. Attributes are available in an ASCII table symbolically linked to the feature file of coordinates by a feature identification number. Correlated gridded elevation data is available in a DTED format (if certain boundary and spacing constraints are met) or as a binary matrix of elevations defined by an ASCII header record or as point feature data in an ASCII coordinate list. Controlled/rectified imagery, features with attributes, and elevation data are transferred to the GIS. Resident data is available for further analysis using available GIS tools or can be exported to testbed computer vision or knowledged-based analysis programs.

Future

In order for digital image-based mapping systems to be come truly viable, a "beginning-to-end" engineering approach is mandatory. For example, image digitization using a very small sample size is useless, if there is inadequate space to store the image on the computer. Likewise, a very fast stereo correlation algorithm means very little if it takes weeks to manually correct all the erroneous elevations. Similarly, real-time image rectification, minification, or zoom functions add very little to data production throughput if the analyst has inadequate interactive mapping and analysis tools at their disposal. Emerging digital photogrammetric mapping systems hold great promise, but both developers and users must let their actions be guided by careful analysis of the entire "cradle-to-grave" digital process.

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