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FEATURE MAPPING IN A PHOTOGRAMMETRIC GIS

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ABSTRACT

The U.S. Army Corps of Engineers Topographic Engineering Center (TEC) has assembled a Terrain Information Extraction System (TIES). The TIES uses photogrammetric Geographic Information System (GIS) technology for digital image-based mapping (Brown, 1991). The TIES is a modular system for generating digital terrain data (Desmond, Edwards, 1990). Components of the TIES exchange Digital Topographic Data (DTD) by a Feature Map Exchange Format (FMEF). The TIES-FMEF is described.

SCOPE

The Terrain Information Extraction System (TIES) accomplishes digital image-based mapping by exchanging Digital Topographic Data (DTD) between a digital-photogrammetric system and an attributed-vector Geographic Information System (GIS). The TIES Feature Map Exchange Format (FMEF) data characteristics and processing procedures are described.

TIES-FMEF DATA CHARACTERISTICS

Digital Topographic Data (DTD) are a set of identified objects which form the map of a surface. Photogrammetric Geographic Information System (GIS) technology processes the DTD by digital stereo image-based mapping. The Terrain Information Extraction System (TIES) digital-photogrammetric system, called the Digital Stereo Photogrammetric Workstation (DSPW), and a commercial attributed-vector GIS exchange DTD between themselves. They affect the Feature Map Exchange Format (FMEF) data characteristics.

Digital Topographic Data

Each identified object in the DTD is either a point feature, line feature, area feature, or volume feature. Spatial and attribute data identify objects. Spatial data delineate each object. Attribute data describe each object. An attribute "dictionary" describes the attribute items.

Spatial Data. One or more records of coordinates delineate each DTD object. Each record contains a list of [X,Y] or [X,Y,Z] coordinates. An elevation grid can add vertical [Z] values to the horizontal [X,Y] coordinates for mapping in stereo imagery.

A pair of coordinates is a vector. A list of coordinates is an arc. The coordinates are sequentially pair-wise connected to form the connected vectors of an arc. Nodes are the endpoint coordinates of each arc. The attributed-vector GIS creates nodes at spatial arc intersections. All those criteria create "arc-node" topology where each object may be many arcs or a single arc.

Table I: Object-Oriented Spatial Data Record

OBJECT$_i$				
C O O R D I N A T E S	1	X_1	Y_1	Z_1
	...	...	...	...
	k-1	X_{k-1}	Y_{k-1}	Z_{k-1}
	k	X_k	Y_k	Z_k
	k+1	X_{k+1}	Y_{k+1}	Z_{k+1}
	...	...	...	...
	r	X_r	Y_r	Z_r

Each "i" object is a record of "r-1" vectors formed by pair-wise connections of "r" coordinates. The $\{[X,Y,Z]_{k-1}, [X,Y,Z]_k\}_i$ *and* $\{[X,Y,Z]_k, [X,Y,Z]_{k+1}\}_i$ *coordinate pairs are two of the connected vectors forming the arc. The first and last coordinate are equal in the combined coordinate list for connected arcs of an closed area feature polygon edge.*

A single coordinate is a point feature. Or a pair of identical coordinates, called a "degenerate" arc, is a point feature. An arc is the centerline for a segment of a line feature, and/or the shared edge of two adjacent area features. The closed polygon formed by connected arcs is an area feature. Associated area features may form the volume feature "surface-shell" of a solid object.

Horizontal arc intersections form nodes in two-dimensional topology. Horizontal arc intersections form vertically "stacked" nodes in two-and-a-half-dimensional topology. Surface facets of a solid object are area features which form a volume feature in three-dimensional topology.

<u>Attribute Data</u>. A record containing a list of attribute item values describes each delineated DTD object. Each related record of spatial and attribute data contains an identical object number for associating the delineation and description data.

A tabular text file describes objects in a single "coverage-class" of the FMEF. Each row is a record containing a list of attribute item values for a single object. Each column is a particular attribute item. Each cell in the table is an attribute item value of a particular object (see Table II). The object number is an attribute item value in the attribute data record.

Table II: Object-Oriented Attribute Data Records

		ATTRIBUTES				
		$item_1$	...	$item_j$	...	$item_n$
OBJECTS	1	$value_{11}$	...	$value_{1j}$	...	$value_{1n}$
	...	...	...	...	...	...
	i	$value_{i1}$	...	$value_{ij}$	...	$value_{in}$
	...	...	...	...	...	...
	m	$value_{m1}$	...	$value_{mj}$	...	$value_{mn}$

The attribute data table contains an attribute item value (cell) for every object record (row) and every attribute item (column) in a particular coverage-class.

Attribute Dictionary. A dictionary describes the attribute item values. The dictionary consists of "extraction-specification" and "code-list" text files. The extraction-specification describes the format of the attribute item values for each attribute item column in the attribute data table. A code-list shows valid values for each attribute item.

TIES Mapping Methods

Several mapping methods exist for delineating and describing area features with the photogrammetric GIS. Computerized processing displays feature vectors on imagery, and their related attribute data records, for digital stereo image-based mapping at the DSPW. Those processes affect the DTD and FMEF characteristics.

Polygon Delineation. "Spaghetti" mapping quickens delineation in the imagery by reducing topological constraints and is used extensively in the TIES. The operator-analyst describes the identified objects without distractions from arc-node topology during imagery delineation. The redrawing of the shared edge between adjacent polygons isn't necessary during spaghetti mapping. That reduces delineation time, allowing more time for accurate descriptions of objects mapped at the digital-photogrammetric system.

An incidental arc intersection occurs when two vectors intersect without a node. An operator-analyst doesn't worry about putting a node at an incidental arc intersection during spaghetti mapping. Separate "clean" and "build" processing by the attributed-vector GIS creates nodes at incidental arc intersections, and it creates arc-node topology after finishing spaghetti mapping at the digital-photogrammetric system. A specified "extend" and "dangle" distance can remove the "overshoot" or "undershoot" at an intended arc intersection when the attributed-vector GIS forms the arc-node topology from the delineation.

The digital imagery resolution should determine the precision of the arc coordinates when the delineation occurs. The attributed-vector GIS specifies a distance called "fuzzy tolerance" to remove "sliver" polygons between adjacent polygons by removing one of two nearby coordinates. An operator-analyst specifies the distance during the attributed-vector GIS clean of the spatial data. It should be more than two picture-elements (pixels) of the digital image grid to remove sliver polygons between two adjacent image pixels. The specified overshoot and undershoot distance also should be at least two image pixels.

An attributed label point within a horizontally closed polygon describes the enclosed area feature. That allows spaghetti mapping of an area feature. The combined coordinate lists of the connected arcs form the closed polygon edge of the area feature. The attributed-vector GIS recognizes a "label error" when there isn't a label point within each area feature polygon while building arc-node topology.

Attributed polygon edges can describe an area feature without a label point. The DSPW operator-analyst can draw the shared edge between two adjacent area feature polygons twice. There are DSPW functions that automatically close an area feature polygon. There also are DSPW functions that "snap" onto already delineated coordinates. The later function allows redrawing (called "tracing") of the shared edge between adjacent area feature polygons by following already delineated coordinates. That allows the mapping of one-arc-per-polygon (without sliver polygons) instead of spaghetti mapping. Those functions reduce delineation speed at the DSPW, discouraging their use.

Polygon Attribution. A label point within the polygon describes the enclosed area feature. The label point $[X_0, Y_0]$ coordinate is within the area feature when satisfying the equation for the polygon edge coordinates (see Equation 1). A label point is outside the area feature polygon when that equation equals zero degrees. Label points aren't necessary to describe line and point features.

$$\left| \sum_{i=1}^{r-1} \cos^{-1} \left[\frac{(X_i - X_0)(X_{i+1} - X_0) + (Y_i - Y_0)(Y_{i+1} - Y_0)}{\sqrt{(X_i - X_0)^2 + (Y_i - Y_0)^2}\ \sqrt{(X_{i+1} - X_0)^2 + (Y_{i+1} - Y_0)^2}} \right] \right| = 360^\circ \quad (1)$$

Arcs forming the closed polygon edge may describe the area feature without a label point. That requires two separate descriptions from one arc being used as a shared edge between the two adjacent polygons. The operator-analyst must be aware of the arc direction during delineation to identify each polygon on both sides of the arc. Otherwise, the operator-analyst must redraw each arc for the shared edge of two adjacent polygons, where each identical arc separately describes one adjacent area feature polygon. Delineation time increases by doubling the amount of spatial data coordinates for each shared edge segment. Both cases complicate the arc-node topology during the TIES mapping of the area feature data.

Stereo Imagery Delineation. Aerotriangulation accuracy and the pair-wise image rectification method affect vertical depth perception in the stereo imagery at the DSPW. Depth perception from stereo imagery allows measurement of attributes in both the horizontal and vertical dimensions. But the attributed-vector GIS two-dimensional clean and build of the three-dimensional arcs created from stereo image spaghetti delineation is difficult. Vertical errors in depth perception can lead to horizontal error in seeing intended arc intersections in the stereo imagery at the DSPW. That may cause horizontally unclosed area feature polygons in the stereo imagery at the DSPW during delineation. The attributed-vector GIS will report label point errors when unclosed area feature polygons are present. An operator-analyst should be aware of those problems when deciding the distances (precision and shoot) during stereo imagery delineation.

Volume Features. The DSPW operator-analyst delineates the volume feature shell in stereo imagery by using area features as surface facets. The combined edges of the associated area features are the "wire-frame" of the volume feature.

Each associated area feature facet of the volume feature surface-shell has an identical object number. But each associated area feature has a unique "element" number allowing different attribute item values between different facets. The object and element numbers are separate attribute item values in each attribute data record.

Each closed polygon edge separately describes its area feature facet of the volume feature. That allows different attributes such as surface-material-codes at each area feature facet. The surface material of a building wall may be different from its roof for example.

Delineation of volume features in the DSPW stereo imagery allows spatial data of [X,Y,Z] coordinates. A two-dimensional attributed-vector GIS usually disallows elevation surface discontinuities at horizontally identical coordinates. That complicates processing of the volume feature data by making spaghetti mapping of volume feature data impossible.

There isn't a DSPW spaghetti mapping process for volume features. Each associated polygon facet is a single coordinate list digitized in a particular direction. That affects direction of the vector which is perpendicular to each polygon facet of the volume feature surface-shell. The vector must point out from the volume feature surface-shell for image perspective transformations.

Automatic Feature Mapping. Current TIES procedures require the presence of an operator-analyst to accomplish feature mapping. The TIES will have automatic feature mapping added in the future to reduce operator-analyst interaction with the digital image-based mapping process. An image analysis system and raster GIS for Multi-Spectral Imagery (MSI) will add supervised feature mapping. A raster-to-vector conversion of the feature grid will allow display and verification of identified features in stereo imagery at the DSPW. Anticipated developments may add automatic methods of cartographic feature extraction, intelligent analysis and update of spatial data bases, and MSI feature extraction methods to the TIES. A contractor is developing those methods for the Defense Advanced Research Projects Agency (DARPA) through a TEC contract. Another contractor is developing a method for automatic three-dimensional wire-frame modeling from stereo imagery of built-up areas. That will support Image Perspective Transformations (IPT) of urban terrain at the DSPW.

TIES-FMEF PROCESSING PROCEDURES

The Terrain Information Extraction System (TIES) includes a Digital Stereo Photogrammetric Workstation (DSPW) and a commercial attributed-vector Geographic Information System (GIS). A contractor developed the digital-photogrammetric image-based mapping system called the DSPW according to government specifications. Both systems are available as commercial products (GDE, 1992) (ESRI, 1992). The Topographic Engineering Center (TEC) Geographic Sciences Laboratory (GSL) developed processing procedures and accompanying software for Digital Topographic Data (DTD) exchange between those two systems.

FMEF Procedures

The TEC-GSL developed the FMEF procedures for digital image-based mapping by the TIES. The DSPW processes feature maps of DTD on digital imagery. An attributed-vector GIS further processes the DTD. Those recognized attributed-vector GIS capabilities determined the FMEF. Government-developed GIS software exchanges the DTD between the DSPW and the attributed-vector GIS.

Each area feature polygon contains a label point treated as a point feature. A line feature is an arc. The arc endpoints called nodes are point features. A single coordinate is a point feature.

Each polygonal facet of a volume feature surface-shell is an area feature. Area feature facets of solid three-dimensional objects are a coverage-class of line features. There is one attributed arc per closed polygon edge during mapping. The area feature edges forming the volume feature wire-frame have an identical object identification number.

The code-list for valid attribute item values is a text file. The existence of the text file creates an "enumerated-type" at the DSPW, where the operator-analyst can only use attribute item values from the code-list for each attribute item.

The United States Geological Survey (USGS) can do "DLG Photo Revision" with the same TIES components used at the TEC. Some FMEF software changes allow image-based revision of USGS Digital Linear Graphics (DLG) map data. Area features are line features of one attributed arc per closed polygon edge. The polygon edge can have attributes different from the label point within the enclosed area feature. Point features are in a coverage-class file separate from the coverage-class of all other features.

FMEF Software

The government-developed software joins attributed-vector GIS functions together for exchanging DTD between the digital-photogrammetric system and the attributed-vector GIS. C-software translates between the DSPW and the attributed-vector GIS extraction-specifications.

A file naming convention determines whether each coverage-class is either area, line, or point features (see Table III). The file name is the coverage-class called "*cover*" and the file name extension is the type of area, line, or point feature.

Table III: FMEF File Names

FILE NAME	DESCRIPTION
cover.pnt	spatial data records for coverage-class of point features
cover.arc	spatial data records for coverage-class of line features, or point features of two equal coordinates
cover.lin	spatial data records for coverage-class of area feature polygon edge lines
cover.lab	spatial data records for coverage-class of label points within area feature polygon edge lines
cover.pol	spatial data records for coverage-class of one arc per area feature polygon edge or wire-frame facet
cover.nod	spatial data records for coverage-class of arc endpoints
cover.*.atr	attribute records for coverage-class of "*" feature
cover.*.itm	extraction-specification of attribute items for coverage-class of "*" feature
cover.*.*attitem*	code-list of valid values for particular attribute item (*attitem*) in the coverage-class of "*" feature

Where "*" = {"pnt", "arc", "lin", "lab", "pol", or "nod"}.

The operator-analyst specifies the directory-path, coverage-class file name, and tolerance distances while running the FMEF software. The type of feature (volume, area, line, or point) determines the file name extension. The operator-analyst specifies whether a coverage-class of area features will be one attributed arc per closed polygon (*cover*.pol) or many segmented arcs with a label point per closed polygon (*cover*.lin and *cover*.lab).

CONCLUSION

The Topographic Engineering Center (TEC) developed the Feature Map Exchange Format (FMEF) procedures and software for the Terrain Information Extraction System (TIES). The TIES uses the FMEF to exchange Digital Topographic Data (DTD) between its digital-photogrammetric system and its attributed-vector Geographic Information System (GIS). An assembled modular photogrammetric GIS can use the TIES-FMEF for digital image-based mapping.

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