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To demonstrate these capabilities, high-altitude infrared photography of the Fort Belvoir, Virginia, area was used for photo interpretation and digitization, supplemented by large-scale photography and field data. Landforms, surface

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TERRAIN ANALYSIS DATABASE GENERATION THROUGH
COMPUTER-ASSISTED PHOTO INTERPRETATION

Daniel L. Edwards
Center for Artificial Intelligence
U.S. Army Engineer Topographic Laboratories
Fort Belvoir, Virginia 22060

BIOGRAPHICAL SKETCH

Daniel L. Edwards is a 1981 honor graduate of Ohio State University with B.S./M.S. degrees in Natural Resources. He has served as a consultant to the Division of Reclamation, Ohio Department of Natural Resources regarding delineation of Ohio surface mines using Landsat MSS data. Currently, he is a physical scientist with the U.S. Army Engineer Topographic Laboratories (USAETL) involved in computer-assisted photo interpretation research.

ABSTRACT

The creation of digital terrain analysis databases through on-line photo interpretation has been the focus of computer-assisted photo interpretation research (CAPIR) at USAETL. An APPS IV analytical plotter equipped with stereo superposition linked to a minicomputer is used for photo interpretation and digitizing. Digital data is input in arc/node format with attributes and the points are stored in three dimensions; latitude, longitude, and elevation.

To demonstrate these capabilities, high-altitude infrared photography of the Fort Belvoir, Virginia, area was used for photo interpretation and digitization, supplemented by large-scale photography and field data. Landforms, surface drainage, soils, and vegetation were individually interpreted and digitized. Digital elevations, measured from stereo imagery, were used to produce contour and slope overlays. The resultant digital database was readily accessed and used as a basis for analysis and modeling. This paper briefly describes the hardware, software and methods used to generate a digital terrain analysis database.

INTRODUCTION

Three decades of advances in electronics have revolutionized the manner we store and process information. The way we gather information, in many cases, has also changed with the advent of multispectral scanners, thematic mappers, digital radar systems, and others. These new sensors have shown great promise in automating the data gathering process for many applications. However, both the diversity of the natural environment and the types of information required by man limit their use.

To date, existing sensors and processors can not satisfy the data requirements for a detailed terrain database at an

acceptable level of accuracy that can be achieved with a skilled photo interpreter, stereoscope, and stereo imagery. However, current methods of terrain feature analysis from aerial imagery are labor-intensive tasks requiring skilled interpreters to produce intermediate manuscripts and data lists (Lukes,1981). Manual digitization from X-Y tables of the manuscripts produces a digital format. Reviewing and editing are performed visually during and after digitization (Case,1981). Quality control, maintenance, revisions, and intensification follow the same labor-intensive schema. Increasing demands for digital cartographic data fueled by decreasing computer processing costs push for more efficient and increasing automation of image data extraction. Clearly issues arise from this apparent division between labor-intensive data extraction and increasing requirements for digital cartographic data.

Efforts at the U.S. Army Engineer Topographic Laboratories through a program in computer-assisted photo interpretation research (CAPIR) have focused on developing methods and tools which the photo interpreter can use to perform his task more proficiently, accurately, and expeditiously. An analytical plotter equipped with stereo superposition graphics and linked to a minicomputer has been matched with a geographic information system to establish the foundation of a system which can address these issues.

HARDWARE

In this study an APPS IV analytical plotter was used. It is a medium accuracy plotter (10 micrometers RMS after 6 parameter calibration) which is linked through a RS-232c interface to a host computer (Greves,1980). A series of microprocessors within the APPS IV plotter perform real-time control functions which reduce demands made of the host computer. The plotter is equipped with a stereoscope which has a continuous zoom magnification range of 6X to 36X with a 10X eyepiece.

The APPS IV analytical plotter has been equipped with several features which impact on terrain analysis. The first and foremost being stereo superposition (Greve,1981) which consists of two vector graphic displays installed in the rear housing of the plotter. Digitized information, displayed on both graphics, is projected through respective beam splitters into the optical path of the stereoscope where it is viewed by the analyst as being superimposed upon the stereo imagery. The graphics are updated ten times per second so that current digitizing is displayed real time and the graphics track the imagery as the analyst moves around the stereo model. A second hardware addition supports on-line extraction of digital elevation data by profiling. Elevation data can be collected as the photo stages automatically drive to sample points along a user-defined grid with the analyst controlling the elevation. Firmware has also been installed to demonstrate capability to triangulate and analyse synthetic aperture radar imagery.

SOFTWARE

The software system used during this study was the Analytical
Mapping System (AMS) and the Map Overlay and Statistical
System (MOSS) which was developed for the U.S. Fish and
Wildlife Service and extended for USAETL. It handles the
data entry, storage, retrieval, manipulation and display of
geographic information. Data input can be from maps using
a X-Y digitizing table or from stereo imagery using an
analytical plotter. Points are stored in geographic coordinates
(compressed form), thus making the data scale and resolution
independent.

The software consists of both a data entry system and a
spatial analysis system. The former being the Analytical
Mapping System (AMS). It is an interactive menu driven system
which allows one to aero-triangulate, digitize, edit, verify
and then database the results. Triangulation and block
adjustment can be accomplished with frame and panoramic
optical bar imagery. Digitization is executed in an arc/node
format with an arc (segment) required to begin and end on a
node. Attributes are input for the regions to the left and
right of the arc, and for the arc itself. Edit capabilities
can be exercised during digitization and verification. They
include deleting portions of or whole segments, modifying
attributes, and editing nodes or polygons. The verification
routine insures the arcs, nodes and subsequent polygon
formations are spatially consistent. Once corrected and
verified, the digital set can be databased into a permanent
file which can be retrieved later for updates or used for
spatial analysis.

The spatial analysis sofware is the Map Overlay and Statistical
System (MOSS) which is used for data manipulation and spatial
analysis. MOSS can store and manage point, line, polygon,
elevation, raster, binary bit and digital terrain data
(Reed,1979). Polygon data may also be transformed into raster
data and different data types can be combined for analysis
and display. There are nearly 70 different functions which
are used to structure, manipulate, query, display, and plot
different data types and files.

PROJECT AREA AND DESCRIPTION

Demonstrating these capabilities, high-altitude U-2 photography
of the Fort Belvoir,Virginia, area was used for photointerpretation
and digitization. The analysis was limited to the area
covered by the USGS 7 1/2 minute Fort Belvoir, Virginia,
quadrangle.

The study area is twenty miles south of Washington,D.C. The
land use ranges from typical urban (residential, commercial,
and industrial) to several different federal government
reservations (including Fort Belvoir) to a wildlife refuge
created for bald eagles. The Potomac River flows across the
southern section of the area and is fed by the Occoquan River
and several smaller streams which empty into numerous bays
and tidal flats. Ranging in elevation from sea level to

slightly over 300 feet, the terrain consists largely of
coastal plain terraces with the Piedmont Plateau rising on
the western boundary. Predominate vegetation categories are
grasses and deciduous forests with scattered sections of
conifers.

PROCEDURES

NASA U-2 color infrared photography (scale 1:130,000) was
used. Two stereo pairs were required to cover the study
area. Block triangulation was performed using field checked
and photo identified first and second order survey points
gathered from the National Geodetic Survey and a survey
established by USAETL personnel.

An initial cursory interpretation for each terrain overlay
was performed to develop terrain categories and general
spatial relationships. Areas difficult to interpret from
high-altitude imagery were checked with large scale photography
and/or field visits. Actual terrain category boundaries were
interpreted during on-line stereo digitization. Because two
stereo pairs covered the area, digitizing was performed to
the limits of coverage of the first stereo pair leaving nodes
at the margin. Then the second model was set up, the previously
digitized data was displayed via stereo superposition and
the digitizing resumed after connecting with the boundary
nodes. The digitizing was performed in point mode leaving
points at analyst determined distances.

TERRAIN ANALYSIS

The initial terrain analysis data extracted from the aerial
imagery of the Fort Belvoir study area was landforms. Three
levels of coastal terrace were delineated, as were tidal
flats, and an upland (Piedmont Plateau) category. The terrain
classes and elevation ranges follows:
1) Tidal Flat..............0-2 feet
2) Low Terrace.............0-100 feet
3) Mid Terrace............100 -170 feet
4) High Terrace...........170-240 feet
5) Upland.................100 - 310 feet
132 line segments forming 24 polygons were digitized requiring
approximately 12 man hours to digitize, edit and verify.

The next analysis was the surface drainage. The categories
were:
1) Main Stream Channels
2) Stream Tributaries
3) Open Water
4) Lakes/Ponds
720 line segments forming 573 polygons took approximately 32
man hours to digitize and verify this data set.

Soil categories were interpreted by analyzing relationships
between landform association, topographic position, drainage
pattern, and resident vegetation. Interpreted soil classes
were verified by on-site checks. The categories and their

percentage slopes are:

1) Well drained sands and gravels on moderate to steep slopes (10-70% slopes)
2) Moderately-well drained sands and gravels on level to gentle slopes (0-15% slopes)
3) Moderately-well drained sands and silts on level to gentle slopes (0-10% slopes)
4) Poor to moderately drained sands and silts on level slopes (0-4% slopes)
5) Moderately drained sands and silts on level to slightly sloping Piedmont Plateau uplands (0-10% slopes)
6) Well drained gravels, sands and silts on moderate to steep Piedmont Plateau slopes (10-80% slopes)

238 line segments forming 58 polygons required approximately 26 man hours to digitize and verify.

The study area landcover was interpreted and categorized in 15 groups which follow Defense Mapping Agency product specifications for terrain analysis databases (DMA,1982). The categories are:

1) Wetland vegetation
2) Grasslands
3) Grasslands with scattered trees and scrub
4) Agricultural cropland
5) Brushland and scrub
   a) nearly open to medium spacing
   b) medium to dense spacing
6) Coniferous Trees
   a) nearly open to medium spacing
   b) medium to dense spacing
7) Deciduous Trees
   a) nearly open to medium spacing
   b) medium to dense spacing
8) Mixed deciduous/coniferous trees
   a) nearly open to medium spacing
   b) medium to dense spacing
9) Bare earth
10) Excavated areas
11) Urban/builtup areas

518 line segments forming 310 polygons required slightly over 40 man hours to interpret, digitize and verify.

Digital terrain elevation data (DTED) was collected at 5 second spacing using the profiling capability of the APPS IV analytical plotter. Approximately 16 man hours were required to compile this data. Because the 7 1/2 minute study area was covered by two stereo pairs, separate digital terrain elevation files were combined during spatial analysis. Both contouring and slope algorithms were used on this elevation file to produce contour and slope maps.

SPATIAL ANALYSIS

The Fort Belvoir Quadrangle terrain data base consists of landform, surface drainage, soil, landcover, DTED, contour, and slope files which serves as a base for spatial analysis.

Through the use of the Map Overlay and Statistical System (MOSS), digital files were stored, various data summaries were gathered for terrain attributes, maps were overlayed, and boolean inquiries were made of the data base. Both base and composite maps were displayed and plotted.

In addition to the information that can be compiled during spatial analysis, simple overlaying of various terrain files can help to provide an additional check on the validity of the terrain data. Generally, for a given terrain feature or category one can predict certain relationships with other terrain categories in the same spatial region. When viewing overlays of different terrain categories and these expected relationships are violated, then one can return to the data source (imagery) to check for possible interpretation errors. An example of this could be inconsistent surface drainage patterns for a given landform or soil type. While this visual "logic" checking can be labor intensive, boolean inquiries of a database could assist in these checks. For example, one could query the database to list the land cover on slopes greater than 40 percent. Any man-made features or urban land uses on such steep slopes might be suspect and merit checking the data source for errors in the DTED or the land cover file.

DISCUSSION

Data entry was slowed because the arc/node format requires the analyst leave nodes for every additional arc that would intersect or join the existing segment. For instance, when digitizing a main stream channel, an analyst must leave nodes for each tributary that empties into it. This demands foresight and planning of the analyst, thus slowing the data entry.

The listed man hours required to compile each of the digital terrain analysis files are the total of the on-line interpretation, digitization, edit and verification tasks. The time spent on initial cursory interpretations to develop terrain categories and general spatial relationships were not included because efforts early in this study were often sporadic. The times are estimated since intermittent equipment failures and interuptions were very hard to quantify. Performance improved as the study progressed due to increasing experience and proficiency of the analyst. Future enhancements of existing hardware, software and techniques will continue to reduce compilation times.

The man hours required to generate this digital terrain analysis database compare very favorably with current manual methods. Labor estimates alone for the manual compilation of a slope map from a topographic map sheet often require 40-80 man hours as opposed to the roughly 20 hours required to compile the DTED and then generate a slope map from computer algorithms in this study. Digital collection and storage of cartographic information eliminates many of the scale and mapping problems faced with manual methods. This in part accounts for the often large time expenditure differences between manual and digital methods.

Several concepts are central to the process of generating and maintaining digital cartographic data. First, interpretation and digitization without the graphic feedback provided by stereo superposition would be severely limited except for the most simple data sets. Quality control is also enhanced since the stereo graphics validate the horizontal and vertical accuracy of the data. Secondly, because the digitized points are stored in geographic coordinates, digitized files can be displayed at any scale to overlay different imagery for checking, editing, updating or intensifying. This is crucial to maintaining the integrity of the digital files. Finally, direct data entry by the analyst during interpretation can increase efficiency and reduce the chances for error.

Enhancements of existing systems, such as stereo superposition and profiling, made the generation of this terrain database possible. Much more is needed. Several improvements currently being developed which will further advance the present system are:

1) Reduced magnification of the analytical plotter stereoscope since various interpretation tasks demand a wide field of view.
2) Voice data entry rather than computer terminal entry of digitizing parameters would increase operator efficiency.
3) Additional input to a terrain analyst supplied by a digital image processor would allow softcopy digital analysis of the stereo imagery and thus enhance the interpretation process.
4) The capacity to enter a node into an existing line segment during digitizing would simplify demands made of the analyst.

Long range developments are anticipated to include expert and knowledge-based systems which will serve as consultants to the photo terrain analyst.

CONCLUSIONS

The capability to generate a complete digital terrain database from a single interpreter using a single workstation certainly holds promise and flexibility. The marriage of an analytical plotter with a geographic information system allows one to gather, organize, store, and manipulate cartographic data while insuring the geographic accuracy. Existing manual terrain analysis methods are costly in terms of time, effort and efficiency. Use of these methods to meet future requirements is unrealistic. Augmentations of existing systems have made the generation of a digital terrain database possible and further improvements will serve to assist the analyst and simplify his task. This is demanded by increasing requirements for digital cartographic data.

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