Using a Geographic Information System for Forest Land Mapping and Management

Fred C. Martin
Montana Forest and Conservation Experiment Station, University of Montana, Missoula, MT 59812

ABSTRACT: Results are presented of a project to automate forest stand mapping and to evaluate the usefulness of a geographic information system (GIS) for forest land management. Electronic scanning was used to digitize photointerpreted forest stands, while digital terrain models and analytical photogrammetry permitted automated photo-to-map transfer. Linkages between an attribute management information system and a computer mapping system were constructed to form an integrated GIS. The GIS was tested in support of a number of standard timber management activities. Cost efficiency and the formation of a multifacet land information system make these methods a valuable tool for land managers and planners.

INTRODUCTION

As LAND AND RESOURCE values increase, the need for site-specific resource information becomes critical for efficient planning and management. Because of this increasing need, a USDA Cooperative River Basin Study was initiated. This study, titled the Montana Timber-Water Cooperative Study, had as its goals (1) the construction of a computerized geographic information system (GIS) for forested lands; and (2) the development of site-specific timber and hydrologic resource information on forest lands in western Montana. A general description of the history, organization, and results of the overall study is provided in Martin *et al.* (1983).

The objectives of this report are to

- Describe an automated approach for mapping photointerpreted forest stands, and
- Discuss the practical application of a computerized GIS for timber stand management.

THE MAPPING PROCESS

The techniques developed and used were designed primarily to provide an efficient and economical means for mapping forest stands. These techniques are, however, quite flexible and readily adaptable to a wide range of mapping and resource analysis applications.

A 600,000-hectare area encompassing two counties in western Montana was selected for mapping in the Timber-Water Cooperative Study. The USGS 7.5-minute quadrangle topographic map was chosen as the standard base map, with final products envisioned as photointerpreted forest stands overlayed onto 89 separate quadrangles.

The general procedures are outlined in Figure 1 and can be summarized as follows. Land ownership boundaries, a digital terrain model, and photogrammetric control data are entered into a computer system called DTIS II, Digital Terrain Information System (Gossard, 1978; USDA Forest Service, 1981). DTIS performs a single photo spatial resection and computes orientation and transformation parameters. Using the inverse solution of this resection along with the terrain model, the 7.5-minute quadrangle and ownership boundaries are computer-plotted as an overlay in the perspective of a quad-centered aerial photograph. This overlay, or photo collar, provides a guide for delineating photointerpreted forest stands on each quad-centered photo. Delineated stands are then drafted onto the collar overlay and scan digitized. Digitized forest stand boundaries are formed into closed polygons, entered into DTIS, and converted to true ground coordinates using the transformation equations developed from the photo resection solution. A 7.5-minute map overlay is then drawn of the forest stands. Data from an extensive forest survey are statistically expanded to each delineated stand and entered into a management information system. Queries on specified attributes are used to identify desired stands, which are then selectively drawn by DTIS as an interpretive map overlay.

Two sources of digital elevation data were used. The primary source was digital terrain models developed by the Defense Mapping Agency (DMA), having an approximate density of 13,000 points per 7.5-minute quadrangle. A computer system called TOPAS, Topographic Analysis System (USDA Forest Service, 1976), was used to reformat the DMA data from standard one degree format to the 7.5-minute quadrangle areas used in this study. For five quad-

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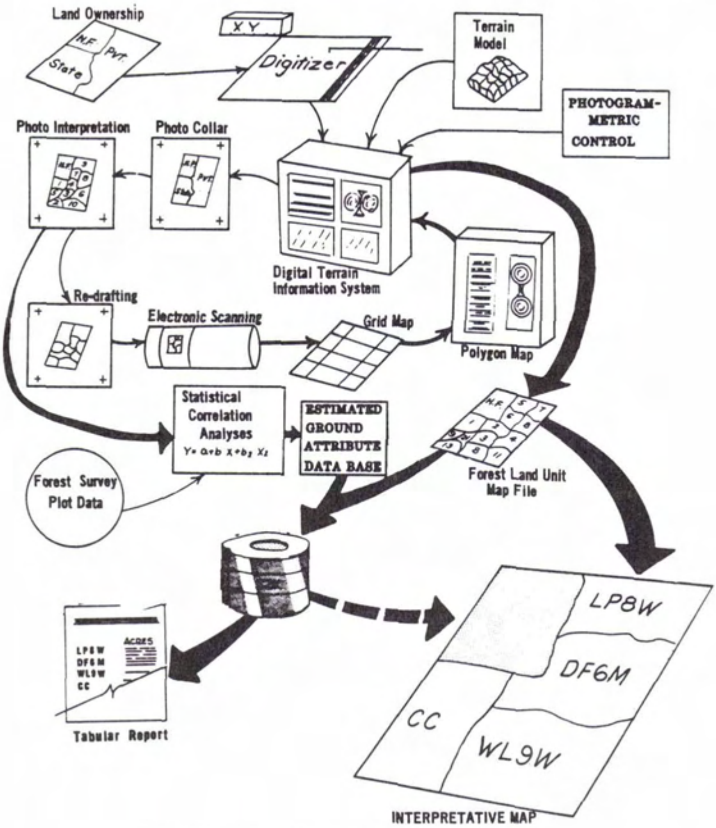

FIG. 1. Mapping process flow chart.

rangle areas, digital elevation models (DEMs) produced by the USGS were also used. The DEMs had a density of over 140,000 points per quadrangle. A system called MULDEM, Multiple Digital Elevation Model Grid Software (USDA Forest Service, 1983), was used to reformat the DEMs into DTIS compatible form.

Small scale (1:76,000) quad-centered USGS panchromatic photography was the source for photo-delineated forest stands. Control data for this photography were purchased from the USGS. Root-mean-square errors computed during photo resection showed an average horizontal error of less than two metres on 89 controlled photos. Because identical copies of the controlled USGS photos were used, measurement of control and pass points on the interpreted photos was unnecessary. Simply digitizing the fiducial marks on each interpreted photo provided registration for DTIS input and output operations.

A principal advantage of DTIS is that geographic information is stored in a three-dimensional format. That is, all geographic features, whether they be points, lines, or polygons, are stored as strings of actual X, Y, and Z ground coordinates. DTIS analytically converts geographic features digitized from different source documents into a common ground coordinate system.

A basic assumption in the operation of DTIS is that the slope of a line between any two adjacent terrain model points will conform to the actual slope of the ground. When geographic features are entered into DTIS, additional ground coordinates (horizontal and vertical) are computed whenever a change of slope in the terrain model is detected between digitized feature points. This coordinate computation occurs regardless of the source document, e.g., maps, aerial photographs, or ground survey measurements.

Ownership, political jurisdiction, and 7.5-minute quadrangle boundaries were digitized from maps and entered into DTIS and the actual X, Y, and Z ground coordinates were computed. These boundaries were then transformed by DTIS into photo coordinates and plotted as the overlay collar for each quad-centered photograph. Because new ground coordinate points were computed at each slope change, relief displacement along boundary lines was properly depicted in the photo perspective collar.

The quadrangle and ownership boundaries were traced from the overlay collar onto film transparencies of the quad-centered photographs. This collar identified the area to be photointerpreted and facilitated edge matching between adjacent photos. The photo collar also provided information about the ownership and political jurisdiction of each photointerpreted forest stand.

The film transparencies were stereoscopically photointerpreted under a zoom-stereoscope with a magnification capability from 2.5 to 20×. Delineation of forest stands consisted of recognizing distinct landscape units homogeneous in terms of both topography (slope, aspect, slope position, and contour curvature) and forest overstory conditions (crown canopy cover, tree height, crown size, tree distribution pattern, and crown texture), following procedures developed by Martin and Gerlach (1981). Average forest stand size was less than ten hectares, with minimum stand size set at four hectares, about 0.265 centimetres square at photo scale. A portion of an annotated film transparency, with the photo overlay collar superimposed, is shown in Figure 2. Note the effect of relief displacement on the quadrangle and ownership boundaries. Upon completion of photointerpretation, the delineated polygons were traced onto the photo collar to provide a "clean" medium for scan digitizing.

The 1:76,000 scale photo collar overlay was scan digitized using a Joyce Loebl Scandig Model 3 drum type microdensitometer at a resolution of 100 micrometres at photo scale. Conversion of the scanned data to closed polygons was performed using the Wildland Resource Information System (WRIS), recently renamed RIDS*POLY, Resource Information Display System - Polygon Processor (Russell *et al.*, 1975; Deschene, 1981; USDA Forest Service, 1982).

The forest stand polygons were transformed from the digitized photo coordinate system to ground coordinates using the transformation equations computed in DTIS. DTIS also calculated the acreage, the polygon perimeter length, the minimum and maximum horizontal and vertical ground coordinates, and the centroid label location ground coordinates of each polygon. These data provided quantitative spatial information about each forest stand.

The final mapping step was to link the photointerpreted characteristics and other inventory data on each forest stand with the computerized boundary information. The sequential label number for each forest stand, along with the acreage, length, minimum and maximum ground coordinates, and label location for each stand, were extracted from DTIS and entered into a management information system. The information system used was a general purpose data base management system called System 2000 (S2K), developed and marketed by MRI Systems Corporation, Austin, Texas. Photointerpreted topographic and forest overstory character-

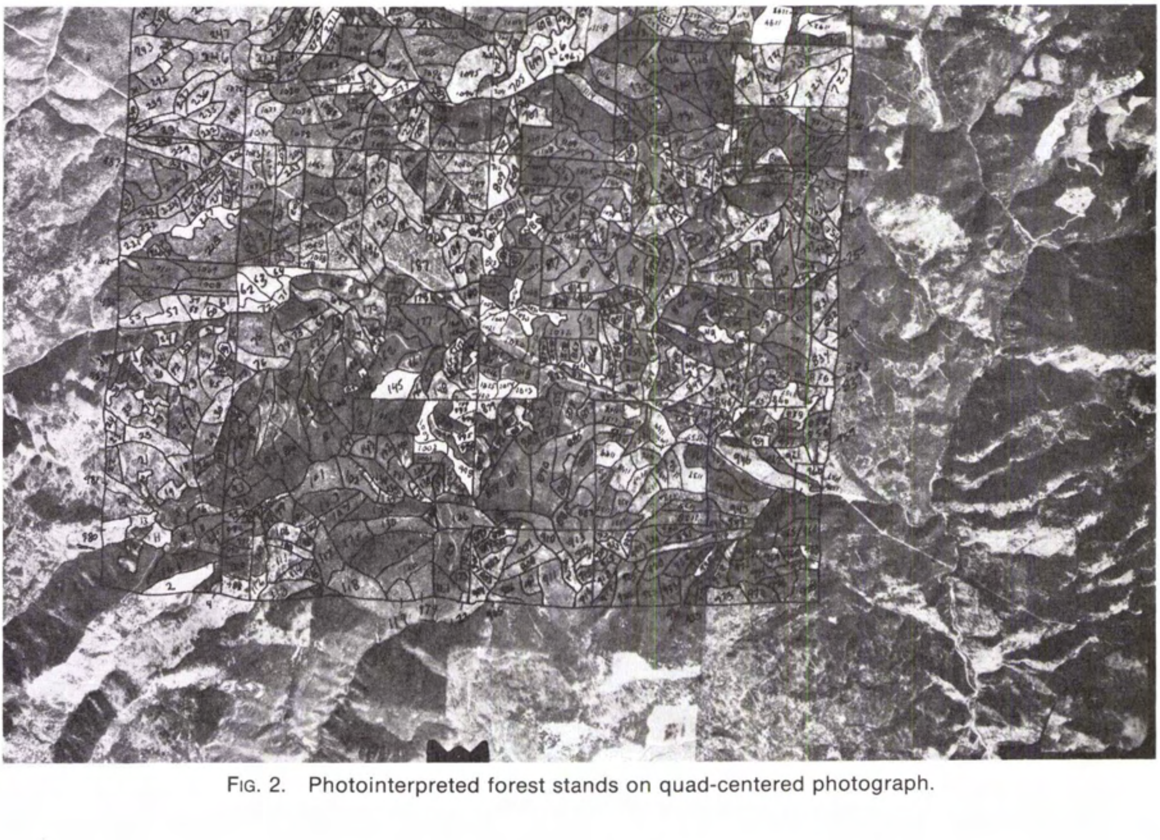

FIG. 2. Photointerpreted forest stands on quad-centered photograph.

istics, along with statistically estimated timber attributes for each forest stand, were also entered into System 2000. In this way a relatively small tabular file of location and forest attributes was created and linked to the larger stand boundary and terrain data files of DTIS by means of the stand label number.

Using the query capability of System 2000, forest stands can be quickly sorted by size, location, ground characteristics, etc., and identified by the forest stand label numbers. These label numbers are then read by DTIS to generate a computer-plotted interpreted map. Including timber type and volume attributes in the System 2000 data base permitted queries of total or average volume by forest type, and generation of a correlated plot showing forest stands having the desired volume and species combinations. An example of such an interpreted forest stand overlay produced by DTIS is shown in Figure 3. The area is the same as that shown in Figure 2.

As part of the mapping process, a test was conducted to determine differences in ground coordinates computed using the two different terrain models. Two forest stand map overlays were produced—one using a DEM and one using DMA terrain data. For one very mountainous and rugged 7.5-minute quadrangle area (relief exceeded 610 metres from valley bottom to ridge line), a visual comparison of the two 7.5-minute forest stand map overlays showed only minor differences at map scale (1:24,000) and only in the map corners (areas farthest from the photo center). Horizontal differences between the ground coordinates calculated using the DMA and a DEM terrain model averaged 15 to 25 metres in the map corners, with maximum differences of about 33 metres. These differences averaged less than five metres near the center of the map.

A test was also conducted to determine differences in contour maps generated by DTIS using DMA and DEM terrain models. A comparison of DMA contour lines at 200 foot intervals on two adjacent 7.5-minute quadrangles (40 foot contours) showed major discrepancies, often amounting to vertical differences of 600 feet between overlayed contour lines, representing a horizontal displacement of two centimetres and more at 1:24,000 scale. Forty-foot contour lines produced from DEMs for these same two quadrangles were overlayed onto the original topographic base maps. Visual inspection showed nearly identical contour positions, and in no cases were observed discrepancies greater than one-half contour interval.

GIS APPLICATIONS

To evaluate the usefulness of the DTIS and System 2000 data bases for timber management, these systems were tested in the conduct of normal forest management activities on a 2600 hectare area of industrial forest land. Management activities included inventory and map update, road and logging system design, and timber sale preparation.

As a prerequisite for this test, 1:12,000 scale normal color prints were obtained for the study area. Control point coordinates for these photographs were determined from the controlled USGS

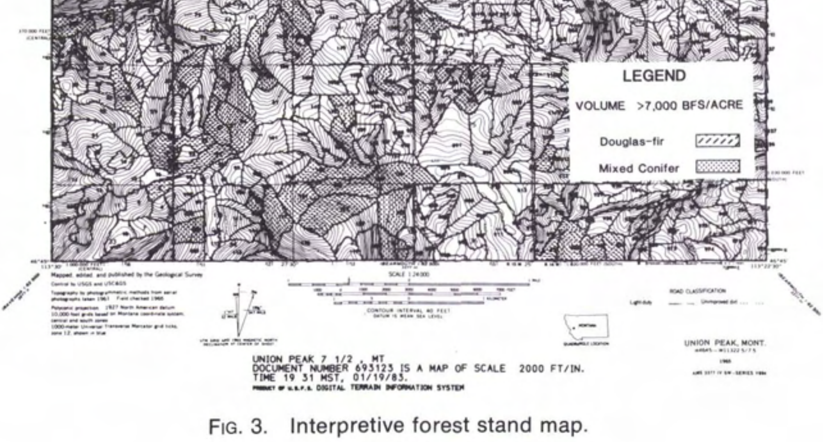

FIG. 3. Interpretive forest stand map.

quad-centered photos, using semi-analytical bridging techniques on a Zeiss C-8 Stereoplanigraph. Root-mean-square errors computed for ten 1:12,000 scale photos during DTIS resection averaged 4.5 metres. The terrain model for the test area was a USGS DEM.

A query of the System 2000 data base identified forest stands having timber volumes and species composition suitable for logging consideration. These forest stands, along with section lines and a uniform grid showing ground inventory sample plots, were plotted on overlays to the 1:12,000 scale photography. An inventory was then conducted to determine on-the-ground tree volumes and defect. Ordinarily, the grid points would be ocularly transferred from a topographic map to the photos and then field located by measuring angles and distances on the photographs from identifiable image points. Using DTIS, the grid points were precisely plotted in their true photo perspective. Further, field locatable image points on the photograph near each grid plot were digitized in the office and their ground coordinates were calculated by DTIS. In this way, much more accurate bearings and distances were obtained between the image points and the inventory plot locations. Upon completion of the field inventory, timber volumes were expanded for each sampled stand using acreages computed by DTIS.

In addition to obtaining actual ground inventory data, an up-to-date base map was needed. Existing roads and streams were manually digitized from the USGS 7.5-minute quadrangle, entered into the DTIS system, and then plotted as overlays to the 1:12,000 scale photos. New roads visible on the photos were digitized and entered into DTIS. Roads built since the date of photography could also be added by inputting construction traverse data. An up-to-date project map including contours, streams, old and new roads, ownership lines, and forest stands, all generated from DTIS project files, is shown in Figure 4 (1:15,840 original scale). Roads digitized from the air photos are shown as dashed lines, while old roads are shown as solid. The "stepped" solid lines are forest stand boundaries. Contour lines were generated from the DEM.

Forest stands found suitable for harvest were then examined for operability. Slope angles stored in the data base identified those stands that could be tractor logged. For steeper stands, slope profiles were generated by DTIS using the DEM terrain model. Examination of these profiles showed where skyline logging systems might be employed and slope break points where new roads might be required.

Examination of the project area map (Figure 4) and an interpretive map like Figure 3 showed those forest stands suitable for logging but lacking road

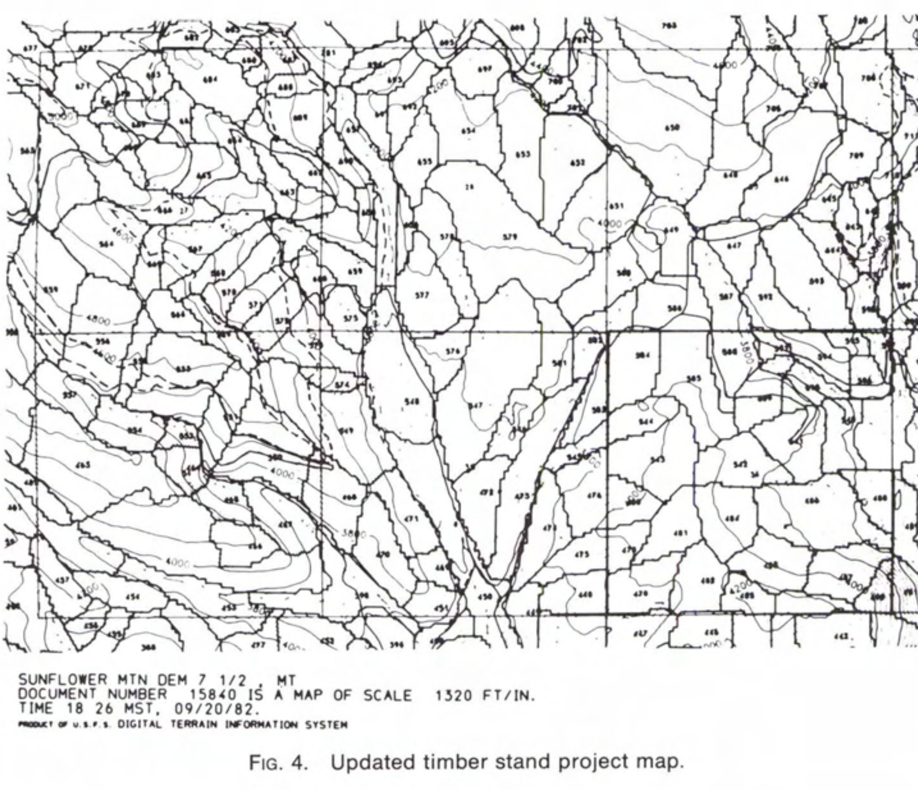

FIG. 4. Updated timber stand project map.

access. Proposed roads were sketched on the project area map, digitized, and entered into DTIS. Profiles of each proposed road and cross-sections at selected intervals were then produced by DTIS. A file of coordinates can also be generated by DTIS for input to road design systems to provide computation of preliminary earthwork volumes and traverse descriptions.

Figure 5 shows a number of features extracted from the DTIS data base. The proposed road locations are shown as white dashed lines, with section lines in solid white. Forest stands are the dark, fine-line numbered polygons—note the "stepped" lines, a remnant from scan digitizing of the 1:76,000 scale interpreted photos. The heavier black lines are existing roads. The mismatch between plotted roads and the photograph in the center left corner results from positional errors in the original 7.5-minute quadrangle, from which these roads were digitized.

The above activities form the technical base for timber harvest on both public and private lands. Photo overlays such as those in Figure 5 provide a means for facilitating field inventory and road and logging system layout. Maps such as Figure 4 can serve as sale area maps showing the location of sale units and proposed road developments. Information is also provided from the data base in terms of acreages, timber volumes, and earthwork requirements. Even aesthetic concerns can be addressed through three-dimensional perspective displays produced by DTIS which illustrate the visual impact of land management activities.

FIG. 5. Overlay in photo-perspective of selected terrain features.

COSTS AND ADVANTAGES

The cost for building the GIS used in this study is considered competitive with more traditional methods of forest land mapping. Cost for photointerpretation and construction of the DTIS and System 2000 data bases was twenty cents per hectare. Scott (1980) compared costs for producing a forest stand map overlay and acreage listing from quad-centered photography using two different methods. The first method employed a Kelsh plotter to map the overlay and an electronic planimeter for acreage measurement. Cost for this method was twelve cents per hectare. The second method used manual digitizing of the interpreted photo and subsequent DTIS processing. Cost for this second method was 27 cents per hectare. The use of scan digitizing reduced mapping costs in this study by at least 25 percent. Although costs in the present study were higher than Kelsh mapping costs, this study produced an operational GIS in addition to a map overlay and acreage tabulation. Costs to use this GIS for the forest management application test was an additional 25 cents per hectare.

Although use of a GIS approach for acquiring, storing, and manipulating forest resource information has numerous benefits, there are a number of disadvantages. First, a substantial amount of hardware must be available, including a digitizer and computer plotter, a photogrammetric triangulation instrument, and a relatively large-capacity computer. Second, although the automated mapping process used in this study required less total time than traditional manual methods, longer lead times and careful planning are required to link the many intermediate tasks into a completed data base. Third, these systems do not lend themselves to single-purpose operations. They are most efficient when creating a multifacet information base where the integration of several separate data sources is required. And finally, it is necessary that people from different disciplines, e.g., road and logging engineers, foresters, and system managers, work together in building and using a common data base.

The most significant advantage of the GIS employed in this study is the application of system-generated products for on-the-ground management. By providing tools, such as photo overlays, profiles, cross-sections, and traverse coordinates, that are then used to design forest improvements, the systems are "self" updating. That is, the data base can be quickly updated as proposed management activities are implemented. In this way, the GIS expands beyond a simple data storage and retrieval function and becomes a dynamic tool for documenting, planning, designing, and implementing forest activities.

This study has demonstrated that computer-assisted methods for forest land mapping can be executed in an operational environment and that they are cost effective. The big pay-off of these techniques is not, however, just cost savings. Forest landscape features and characteristics can be quickly queried and displayed in a multitude of ways that facilitate forest management. This ability also permits rapid update as timber stand and road development occur.

ACKNOWLEDGMENTS

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Forum

What is a Near-Vertical Photograph?

IN THE CONCLUSIONS of W. W. Carson's fine article (*PE&RS*, Vol. 51, No. 5, pp. 533-536) we found a statement which should be corrected, the statement that the *Stereocord* uses a linearized rotation matrix. This was true in 1975, when the Zeiss *Stereocord* was introduced using an HP 9810 calculator with very limited memory (Hobbie, 1976). However, since 1978 the *Stereocord* programs for the HP 9815 calculator make use of the trigonometric sine and cosine functions to calculate the rotation matrix elements (Mohl and Faust, 1978; Mohl, 1980) as do the *Stereocord* G 3 programs for the HP 85 and HP 86 calculators (Mohl, 1982; Schwebel, 1984; Schwebel and Mohl, 1984). The G 3 software certainly is not restricted to near-vertical photography as it can handle tilt angles of Ω and φ up to 45 degrees in any camera configuration (parallel, convergent, or skewed axes).

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—Hans W. Faust
Dept. for Photogrammetry
Carl Zeiss Oberkochen