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Development of Three-Dimensional Spatial Displays Using a Geographically Based Information System

Three-dimensional space object data are displayed in two-dimensional perspective picture plane coordinates, and spatial information may be superimposed on that display.

Abstract: *A generalized three-dimensional perspective software capability has been developed at the NASA/NSTL Earth Resources Laboratory within the framework of a low-cost computer-oriented geographically based information system using the* Earth Resources Laboratory Applications Software *(ELAS) operating subsystem. This perspective software capability was developed primarily to support data display requirements at the NASA/NSTL Earth Resources Laboratory. It provides a means of displaying three-dimensional feature space object data in two-dimensional picture plane coordinates and makes it possible to overlay different types of information on perspective drawings to better understand the relationship of physical features. An example topographic data base is constructed and is used as the basic input to the plotting module. The example displays illustrate oblique viewing angles that convey spatial concepts and relationships represented by the topographic data planes.*

Introduction

The NASA/NSTL Earth Resources Laboratory (ERL) has developed several computer software programs and procedures (Junkin, 1979a; Junkin, 1979b; Pearson, 1977; Graham, 1977) within the framework of a computer-oriented information system (Whitley, 1975; Whitley, 1976) for the processing and analysis of data from disparate, geographically oriented base maps and from remote sensor aircraft and satellite systems. These different types of information are compiled into data bases which contain information on land use, elevation, slope, soil series, rainfall, population density, etc. The capability to manipulate, store, analyze, display, and disseminate the large volumes of data in these data bases has evolved through research efforts at the ERL (Whitley, 1975; Whitley, 1976).

Examples of several practical modular systems, with emphasis on low cost, are given in Whitley (1976). These systems, an example of which is shown in Plate 1 (page 581), consist of an image display system, a graphic digitizer, a small digital computer and an output recording device. All hardware components used in these low-cost data processing systems are off-the-shelf. The software consists of a Landsat multispectral scanner data reformatting program, a series of supervised and unsupervised spectral-pattern-recognition programs, a program to reference the image data to a map base, a data storage and retrieval program, and various applications programs.

The software support concept has evolved into an operating subsystem referred to as the Earth Resources Laboratory Applications Software (ELAS). This software system accepts as input a variety of data types, including topographic data tapes from the National Cartographic Information Center (NCIC). Users of these data require oblique viewing angles to convey spatial concepts and relationships represented by the topographic data planes.

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For example, the relationship of Landsat classification components to elevation may be visualized by perspective color mapping of the classification data plane onto the topographic elevation data plane. Other graphic information, such as aspect or slope, can be placed on the perspective plot to relate the data elements to the terrain profile. This article addresses the procedures involved in the development of a generalized three-dimensional perspective software capability to support the above display requirements and presents typical results using a topographic data base.

Three-Dimensional Graphics with Perspective

General Overview

There are several steps required to determine the two-dimensional perspective picture plane coordinates for the display of three-dimensional feature space object data (Newman and Sproull, 1973). First, the reference system coordinates of the feature space object are translated to the vantage point coordinate system. Then, the vantage point coordinates are rotated through two angles in order to align them with the vantage point line of sight passing through the origin of the reference coordinate system. Finally, a perspective transformation is applied to obtain the two-dimensional picture plane coordinates for the actual display on two-dimensional display devices (i.e., X-Y plotters or CRT screens). An integral part of this display is the removal of hidden lines on the other side of the object from the vantage point. Additional details of the software development for three-dimensional perspective display are given in Junkin (1980).

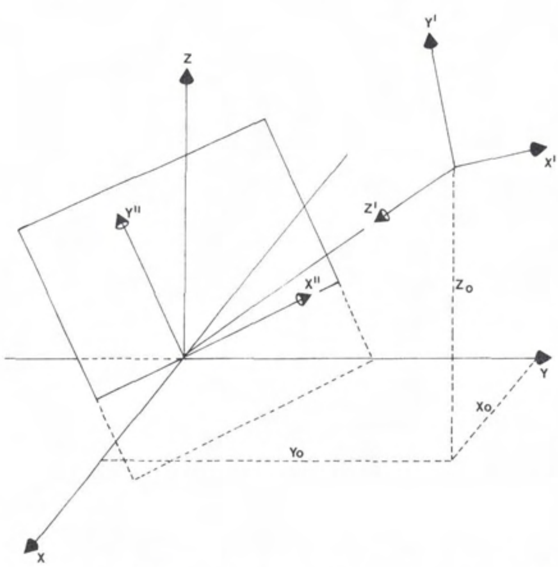

FIG. 1. Reference, vantage point, and picture plane coordinate systems.

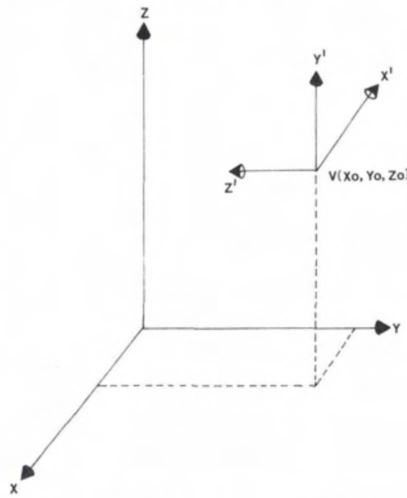

FIG. 2. Initial position of reference and vantage point coordinate systems.

Coordinate Systems

There are three rectangular coordinate systems involved in the derivation of two-dimensional picture plane coordinates. These are the reference coordinate system (X,Y,Z), the vantage point coordinate system (X',Y',Z'), and the picture plane coordinate system (X'',Y'').

A brief description of each follows:

(X,Y,Z) *Reference System.* This is a right-handed fixed system of axes. The coordinates of the vertices of all objects as well as the vantage point (X_0,Y_0,Z_0) are given in this system.

(X',Y',Z') *Vantage Point System.* The vantage point (X_0,Y_0,Z_0) specified in the reference system is taken as the origin of the vantage point coordinate system, in which coordinates are denoted as (X',Y',Z'). This is a left-handed coordinate system wherein the Z' axis goes from (X_0,Y_0,Z_0) through the origin of the (X,Y,Z) reference system. The X' axis is parallel to the X-Y plane of the (X,Y,Z) reference system.

(X'',Y'') *Picture Plane System.* This is a two-dimensional coordinate system which represents the plane of the actual perspective drawing. This plane passes through the origin (X,Y,Z) of the reference system and is chosen perpendicular to the Z' axis. The X'' axis is chosen to lie in the X-Y plane. These coordinate systems are depicted in Figure 1.

Coordinate Transformations

The transformation from the reference coordinates to the vantage point coordinates can be obtained by considering the geometry in Figure 2. This transformation is given by the following matrix equation:

$$\bar{\mathbf{X}}' = \bar{\mathbf{R}}_T\bar{\mathbf{X}} \tag{1}$$

where

$$\bar{\mathbf{X}}' = \begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} \quad (2) \qquad \bar{\mathbf{R}}_T = \begin{bmatrix} -1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & -1 & 0 \end{bmatrix} \quad (3)$$

$$\bar{\mathbf{X}} = \begin{bmatrix} X - X_0 \\ Y - Y_0 \\ Z - Z_0 \end{bmatrix} \tag{4}$$

Two rotations are now required in order that the vantage point coordinate system is so oriented that the Z' axis goes through the origin of the reference coordinate system. This is accomplished with a rotation about the Y' axis by the angle α, followed by a rotation about the X' axis by the angle β. The rotations about the Y' and X' axes are shown in Figures 3 and 4, respectively. The final rotation, shown in Figure 4, results in the Z' axis passing through the origin of the reference coordinate system. Thus, the total transformation can be written as

$$\bar{\mathbf{X}}' = \bar{\mathbf{R}}_X\,\bar{\mathbf{R}}_Y\,\bar{\mathbf{R}}_T\,\bar{\mathbf{X}} \tag{5}$$

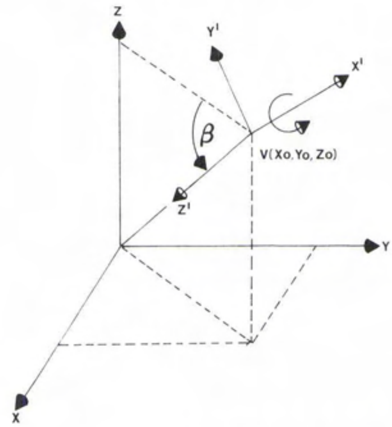

FIG. 4. Rotation through angle β about X' axis.

where

$$\bar{\mathbf{R}}_X = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\beta & \sin\beta \\ 0 & -\sin\beta & \cos\beta \end{bmatrix} \tag{6}$$

$$\bar{\mathbf{R}}_Y = \begin{bmatrix} \cos\alpha & 0 & -\sin\alpha \\ 0 & 1 & 0 \\ \sin\alpha & 0 & \cos\alpha \end{bmatrix} \tag{7}$$

Expanding Equation 5 yields

$$\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = \begin{bmatrix} -(X - X_0)\cos\alpha + (Y - Y_0)\sin\alpha \\ -(X - X_0)\sin\beta\sin\alpha - (Y - Y_0)\sin\beta\cos\alpha + (Z - Z_0)\cos\beta \\ -(X - X_0)\cos\beta\sin\alpha - (Y - Y_0)\cos\beta\cos\alpha - (Z - Z_0)\sin\beta \end{bmatrix} \tag{8}$$

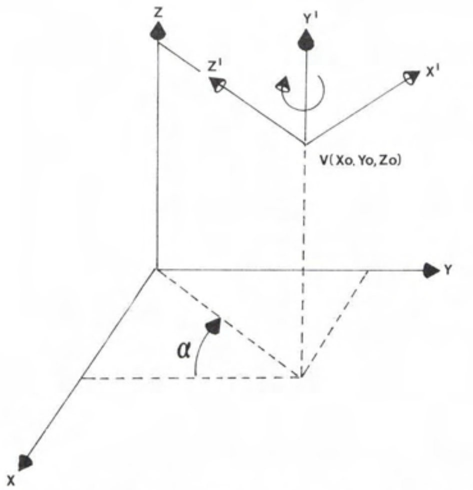

FIG. 3. Rotation through angle α about Y' axis.

From basic trigonometry, the following relations are obtained from Figure 3:

$$\sin\alpha = X_0/d \qquad \cos\alpha = Y_0/d \tag{9}$$

and, from Figure 5,

$$\sin\beta = Z_0/D \qquad \cos\beta = d/D \tag{10}$$

where

$$d = \sqrt{X_0^2 + Y_0^2} \qquad D = \sqrt{X_0^2 + Y_0^2 + Z_0^2} \tag{11}$$

PROJECTIVE TRANSFORMATION

Once the Z' axis is oriented to pass through the origin of the reference system, the three-dimensional coordinates (X',Y',Z') must be projected on-

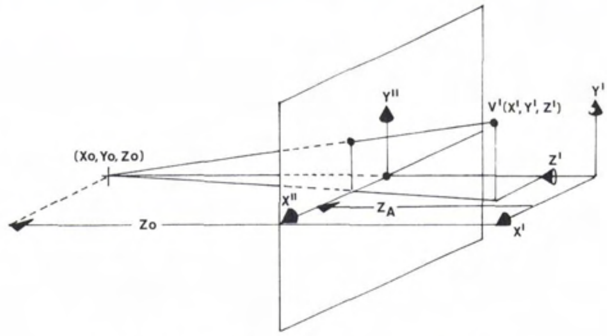

FIG. 5. Geometry for perspective projection.

to the X''-Y'' picture plane in order to generate the actual two-dimensional coordinates. This projection is shown in Figure 5. The point $V''(X'',Y'')$ in the picture plane is related to the point $V'(X',Y',Z')$ in the vantage point system by the following equations:

$$X'' = \frac{Z_0 - Z_A}{Z_0 - Z'} X' \qquad Y'' = \frac{Z_0 - Z_A}{Z_0 - Z'} Y' \tag{12}$$

HIDDEN LINE PROCEDURE

A two-dimensional representation of a three-dimensional surface can consist of line segments of a succession of curves. The basic approach used herein for removing hidden lines is to eliminate all of those line segments which are behind other surfaces and which would not be visible in a plot of the data in two dimensions. A lower boundary (or horizon array) for all lines is set up below which no line is drawn. Visibility arrays are set up and then the line segment points of the curve closest to the observer are tested. If the point is visible then it is inserted in the visibility array and becomes a point in the horizon array. If it is not visible, then the next point of the line segment is tested, and the process is repeated until all points along the curve have been tested. The visibility array now contains the points for plotting the first curve in the foreground. This logic is then applied to the line segment points of the curve next farthest from the observer. At each step the horizon array is also tested and updated. Other types of algorithms can be found in the literature (Wright, 1973; Williamson, 1972; Gottlieb, 1978; Loutrel, 1970; Potmesic, 1976).

SCALING

The final step before displaying the (X'',Y'') perspective data on a CRT screen or other display device is to scale the data to fit within display limits. Basically, this involves scanning the (X'',Y'') data to find maximum and minimum X'' and Y'' values for use in computing linear transformations of the form $\hat{Y} = A_0Y'' + A_1$. For elevation data obtained from contour profiles, we want A_0 and A_1 to be such that Y''_{min} is 0 and Y''_{max} is some value Z_{max}. Thus, we have

$$A_0 Y''_{min} + A_1 = 0 \qquad A_0 Y''_{max} + A_1 = Z_{max} \tag{13}$$

Solving for A_0 and A_1,

$$A_0 = Z_{max}/(Y''_{max} - Y''_{min}) \qquad A_1 = -A_0 Y''_{min} \tag{14}$$

The elevation data values are then computed from

$$\hat{Y} = \left[Z_{max}/(Y''_{max} - Y''_{min})\right] (Y'' - Y''_{min}) \tag{15}$$

DEVELOPMENT OF SOFTWARE ALGORITHMS

THREE-DIMENSIONAL SOFTWARE

The development of a three-dimensional perspective software capability to support the display requirements addressed earlier in this article has been accomplished under the ELAS operating subsystem. A functional diagram of this geographically based information system is shown in Figure 6. The three-dimensional program, as developed for running on the NASA/ERL computer system, is summarized in Figure 7. Various ELAS functional programs, such as CFSUB, RDWR, RIO, ILBYTE, and ISBYTE, were used in this development.

The program determines the two-dimensional perspective picture plane coordinates for the display of three-dimensional data and provides for the overlay of other types of data onto this perspective. It can be executed either in the demand (interactive) or batch mode of operation. The data are processed beginning with the surface profile closest to the observer. Each profile is read and scaled according to a previously determined scale factor. Overlay data are then extracted from the appropriate input. The (X'',Y'') picture plane data and the overlay data are then passed to the subroutines HIDLIN to determine if any portion of the line is visible. Visible segments of the line are then passed to the subroutine INTERP, which transfers the data to a disk file for subsequent plotting on an X-Y type plotter or for viewing on an image display device.

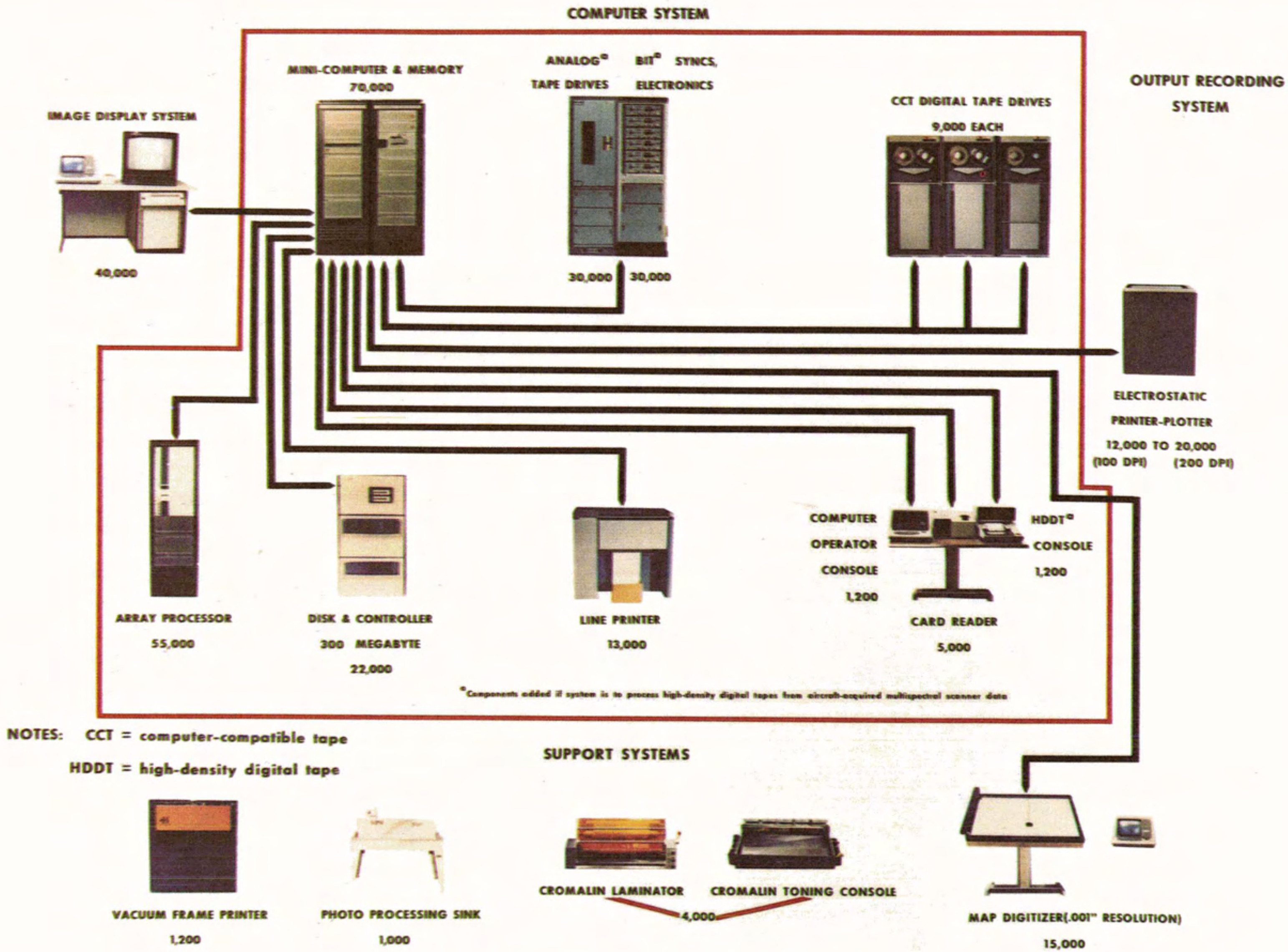

Plate 1. Example of low-cost data analysis system.

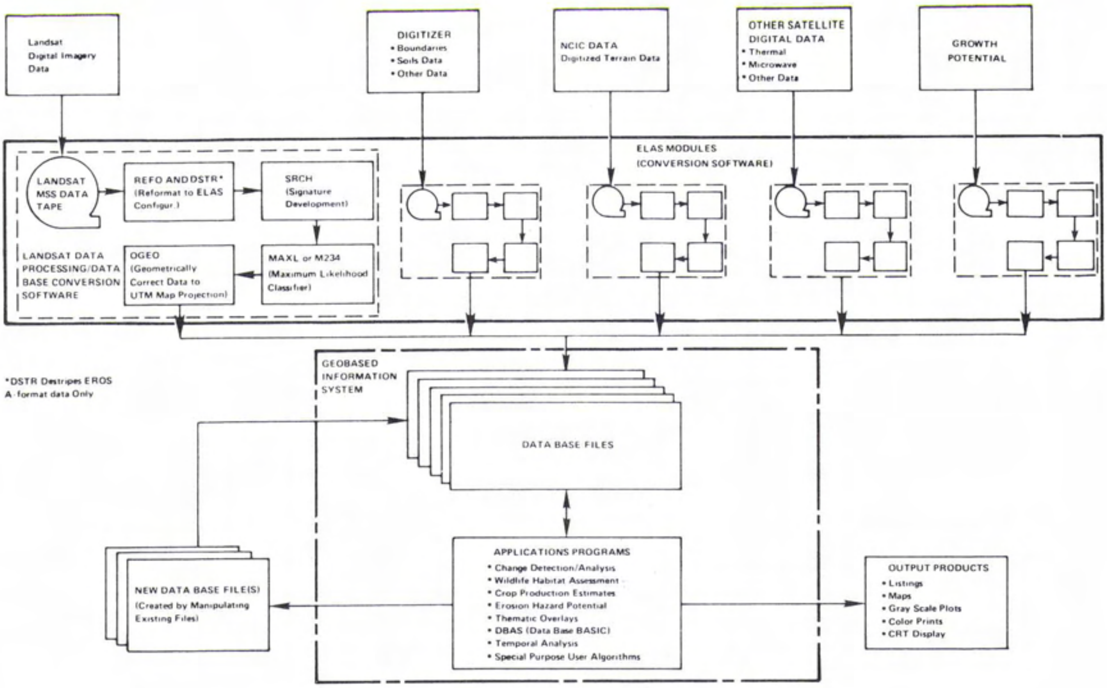

FIG. 6. Geographically based information system.

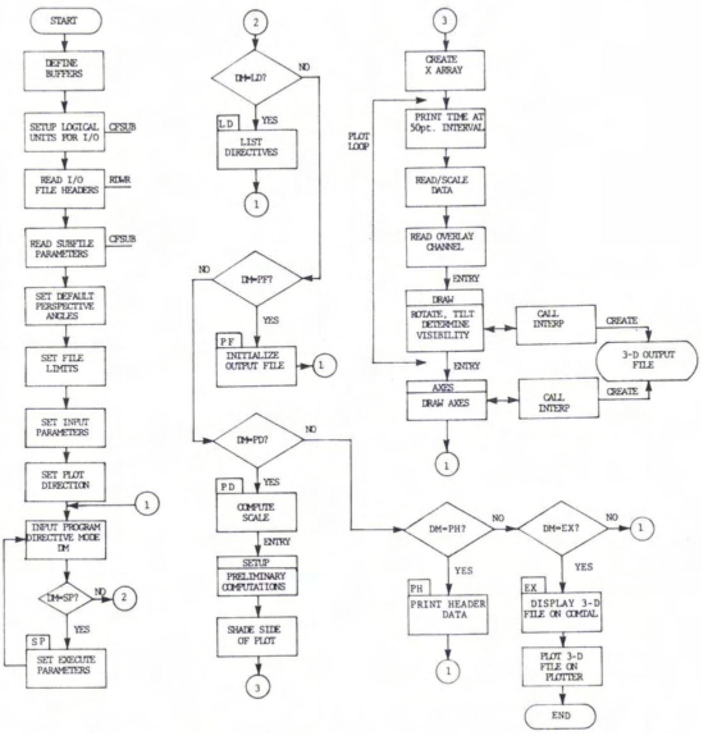

FIG. 7. Flow chart for three-dimensional perspective software.

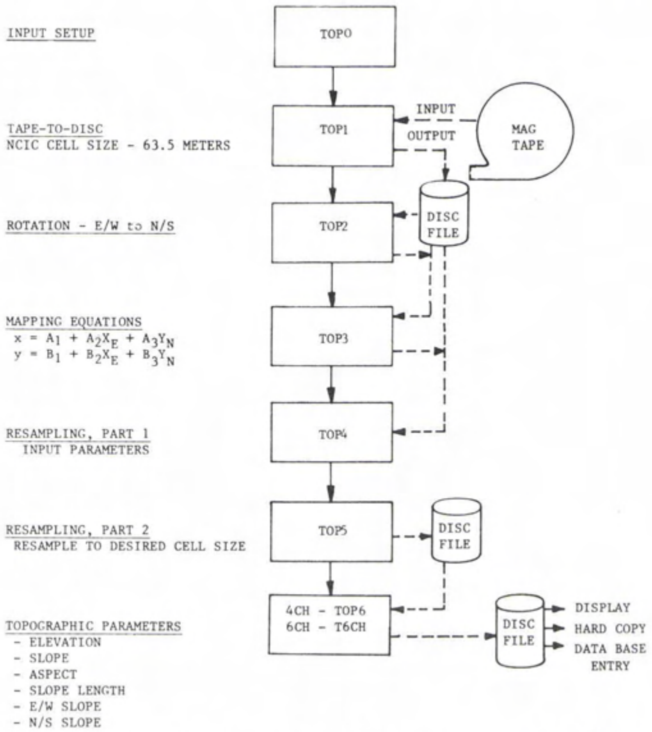

FIG. 8. NASA/ERL topographic data processing and analysis software overview.

The input is a standard ELAS data file, referred to as ID1. The output is another ELAS data file known as ODF. Two channels of data are used by the program—one to produce the plot and another to produce the overlay element along each line. As each element of data is plotted, the overlay value for that line segment is determined by the value corresponding to that element.

TOPOGRAPHIC DATA BASE SOFTWARE

The National Cartographic Information Center (NCIC) of the U.S. Geological Survey, Department of the Interior, provides a national information service to make cartographic data of the United States accessible to the public and to various federal, state, and local agencies. These cartographic data include geographical maps and charts, aerial and space imagery, topographic maps, etc. This type of data is used by the NASA/ERL as its primary source of topographic information and is available from the NCIC on 800 to 1600 CPI tapes. These data serve as input to a series of three topographic application modules for the construction of a topographic data base and subsequent input to the three-dimensional software.

The first module consists of six overlays: TOP0, TOP1, TOP2, TOP3, TOP4, and TOP5. A second module (TOP6) computes slope, aspect, and slope length on the output of TOP5. A third module (T6CH) computes the average north-south slope and the average east-west slope in addition to the four variables computed in TOP6. Basically, these modules reformat the NCIC data from tape into the ELAS data file format; rotate the data 90 degrees to a north-south orientation; compute mapping coefficients that relate transposed plane coordinates to UTM coordinates (eastings and northings); resample the 16-bit data to a UTM grid file; and then use this file to compute slope, aspect, slope length, and average slopes. These modules are summarized in Figure 8. A technical writeup of these procedures with a topographic data base example is in progress and will be published in the near future as a NASA TM (Technical Memorandum).

RESULTS USING A TOPOGRAPHIC DATA BASE

The TOPO application modules were used to construct a multichannel topographic data base file containing elevation, slope, aspect, and slope length parameters for the Olympic National Park in the State of Washington at a cell size of 50 metres by 50 metres. Another channel in this data base contains the results of classifying a Landsat MSS data set for this area which was subsequently improved by using elevation data. The park encompasses some one million acres and includes the Olympic Mountains. Elevations in the Olympic Park range from sea level to approximately 8,000 feet, with variations in vegetation corresponding

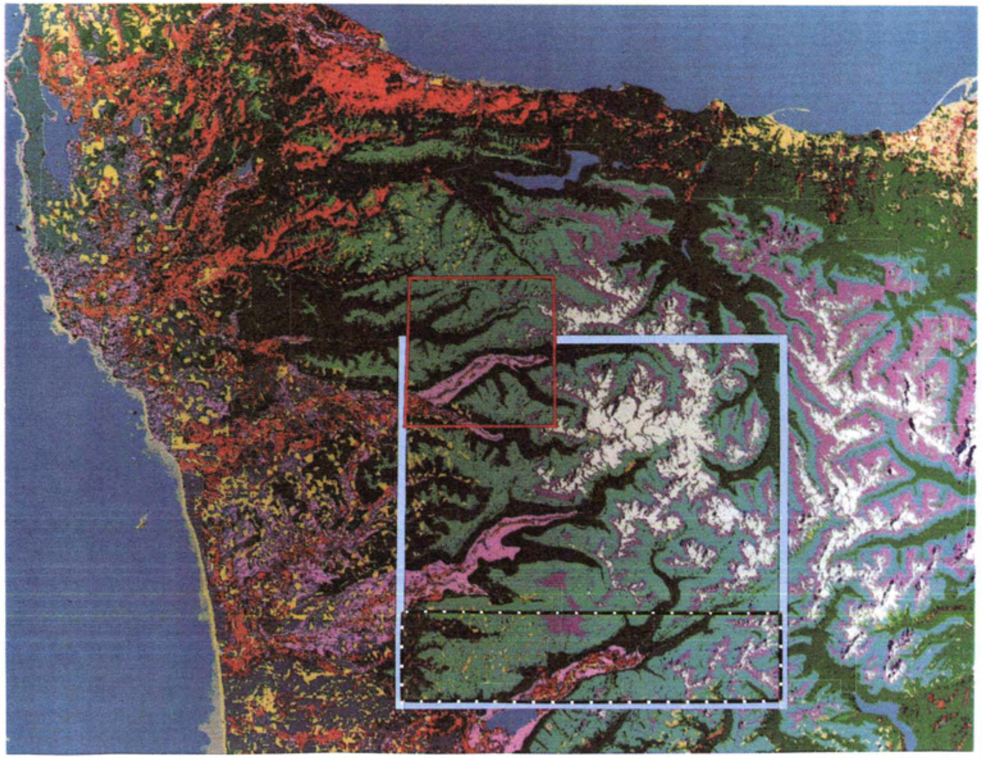

PLATE 2. Vegetation type land-cover classification derived from Landsat MSS data.

CLASSIFICATION	COLOR CODE	DESCRIPTION
1		WATER
2		HARDWOODS OR HARDWOOD/CONIFEROUS MIX
3		LOWLAND HARDWOOD OR HARDWOOD/CONIFEROUS MIX; MAY INCLUDE BRUSH OR SLASH
4		AGRICULTURAL FIELDS WITHOUT VEGETATION OR WITH VERY LITTLE (24); CLEAR CUT AREAS; SLASH; CLEAR CUTS WITH EARLY REGENERATION (c.a. 20-30% VEGETATION COVER OR LESS), CONCRETE, OTHER INERTS (INCLUDES SOME URBAN)
5		PASTURE & OTHER GRASSLANDS
6		BEACH, RIVER GRAVELS, WET SAND, DRIFTWOOD, MODERATELY DARK COLORED INERT MATERIALS
7		SHADOWS
8		SNOW, ICE OR GLACIERS
9		SCRUB; HIGH ELEVATION HARDWOOD; VINE MAPLE & SITKA ALDER
10		ALPINE MEADOWS (CLASS 44 WITH SPARSE VEGETATION)
11		SUB-ALPINE FOREST; SILVER FIR, MOUNTAIN HEMLOCK, SUB ALPINE FIR
12		WESTERN HEMLOCK, DOUGLAS FIR, SILVER FIR
13		WESTERN HEMLOCK, DOUGLAS FIR
14		LOWLAND WESTERN HEMLOCK, & SITKA SPRUCE
15		COASTAL HEMLOCK, CEDAR; SOME REGENERATION OF THESE SPECIES IS INCLUDED (41)
16		BARE ROCK, IN MOUNTAINS
17		HIGH ELEVATION BURN AREAS WITH PARTIAL REGENERATION
18		
19		HARDWOODS (RED ALDER) OR HARDWOOD/CONIFER MIX OF VARYING DEGREES
20		
21		

PLATE 3. Color codes for Olympic National Park vegetation classification derived from Landsat MSS data.

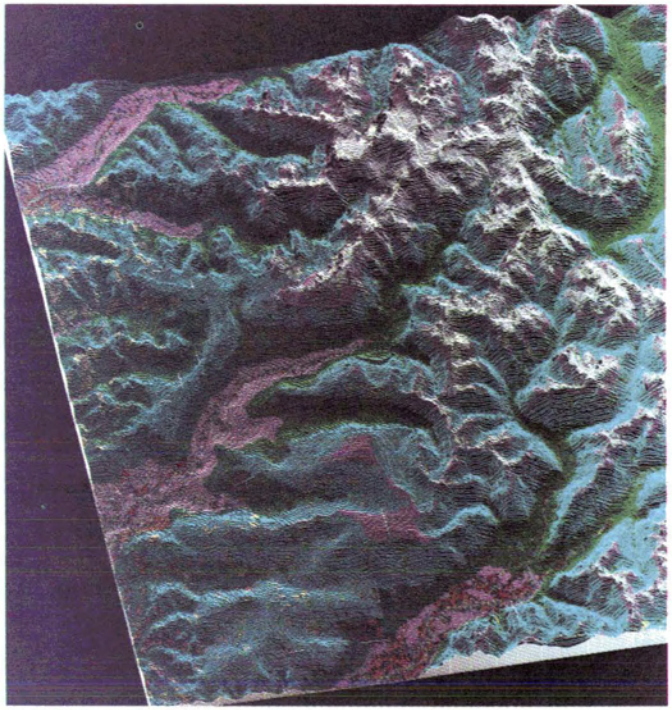

PLATE 4. Perspective relationship of classification to elevation for a rotation of −10 degrees and a tilt of 45 degrees.

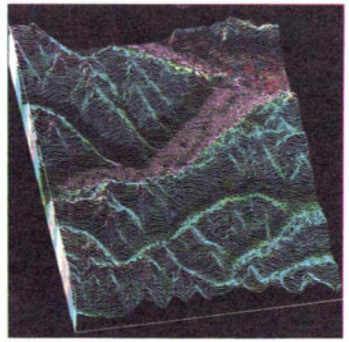

PLATE 5. A backside perspective view.

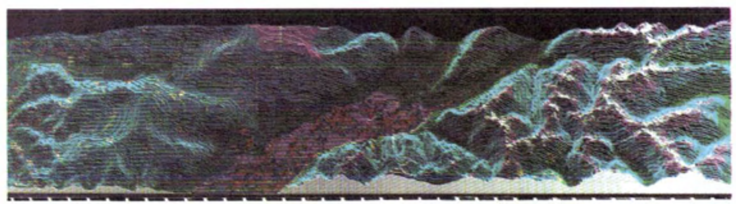

PLATE 6. Perspective relationship of classification to elevation for no rotation and a tilt of 60 degrees.

to severe changes in terrain and rainfall patterns within the park.

The Olympic Park vegetation-type land cover classification derived from the Landsat MSS data which is improved using NCIC elevation data is shown in Plate 2. Further details on the derivation of these results are given by Cibula (1981). The color codes for the 21 classes are shown in Plate 3. The relationship of classification components to the elevation components may be visualized from Plate 4, which contains the perspective color mapping of the classification data plane on the topographic elevation data plane. This perspective plot was obtained by using a viewing rotation angle of −10 degrees and a tilt angle away from the viewer of 45 degrees; it corresponds to the outlined area in Plate 2. A backside view of a northwest section of the elevation and classification data planes for this same area is shown in Plate 5. Plate 6 shows a south section of this same area with no rotation and 60 degrees tilt. These displays are but a few examples of how three-dimensional perspective graphics can be used to convey spatial concepts and relationships represented by topographic data planes.

Summary

A generalized three-dimensional perspective software capability has been developed at the NSTL/ERL within the framework of a low-cost computer-oriented information system using the Earth Resources Laboratory Applications Software (ELAS) operating subsystem. This perspective software capability provides a means for displaying three-dimensional feature space object data in two-dimensional perspective picture plane coordinates and makes it possible to superimpose disparate or spatial information on perspective drawings in order to better understand relationships of physical features.

Digitized topographic elevation data obtained from the National Cartographic Information Center are used as input to a series of topographic application modules for the construction of a topographic data base. These data base parameters are subsequently input to the three-dimensional plotting module and serve to illustrate one type of data base input. The relationship of a Landsat classification to elevation is illustrated by the perspective color mapping of the classification data plane onto the topographic elevation data plane. These example displays illustrate oblique viewing angles that convey spatial concepts and relationships represented by the topographic data planes.

Acknowledgment

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* These are NASA NSTL/ERL internal reports on open file.

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