DIGITAL ELEVATION MODEL IMAGE DISPLAY AND EDITING

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BIOGRAPHICAL SKETCHES

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ABSTRACT

The display, manipulation, and editing of digital elevation models, prior to their entry into the National Digital Cartographic Data Base, using an Image Display and Editing System are addressed. Visual inspection and verification are readily performed by computer processing the DEM data to create color-banded-elevation displays, shaded-relief displays, and anaglyphic stereodisplays, and observing the displays on an image display cathode ray tube. Histogram equalization and pseudocolor enhancement techniques can be applied to the elevation points.

The imagery is derived from DEM data on the host computer and transferred to an interactive display system. Areas needing editing are outlined into graphic image overlays, which are then used with DEM editing programs. For individual point editing, the overlay degenerates into a single point. The display techniques are implemented in a combination of FORTRAN and Assembler languages on an LSI 11/23 computer.

Publication authorized by the Director, U.S. Geological Survey, on December 18, 1984. Any use of trade names and trademarks in this publication is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

INTRODUCTION

The U.S. Geological Survey has undertaken the creation of a spatial topographic data base for the United States, and the task of defining, generating, and maintaining this data base has been assigned to the National Mapping Division (NMD). In response to this assignment, the NMD has created the National Digital Cartographic Data Base (NDCDB). The NDCDB will contain thousands of digital elevation models (DEM), one of the basic categories of the data base and the need for comprehensive interactive display and editing of DEM data has been recognized.

The display, manipulation, and editing of DEMs before and after their entry into the NDCDB provides a powerful and efficient tool for error detection, error correction, and quality control. This capability is provided by the DEM Image Display and Editing System (IDES) described herein. The system provides for visual inspection and verification by computer processing the DEM data to create color-banded-elevation displays, shaded relief and slope displays, and anaglyphic stereo displays, which can be viewed on an image display cathode ray tube (CRT). Image enhancement techniques such as pseudocolor and histogram equalization can be applied to the elevation data.

Interactive editing techniques can also be applied to the elevation data, including single point, editing based on either simple point replacement or sophisticated neighborhood averaging, and area editing, based on either a priori information or on data collected from an online map digitizing capability.

REQUIREMENTS

Design of the IDES was determined by consideration of seven basic factors:

- Low cost,
- Effectiveness in a production environment,
- Compatibility with the NDCDB data structure,
- Capability to display data from a standard 7 1/2-minute quadrangle,
- Capability to display data from a standard 7 1/2-minute quadrangle in the Gestalt Photomapper (GPM) format,
- Capability to interactively edit individual points, and
- Capability to interactively edit areas, i.e., collections of points.

Applications at several points in the production process were envisioned for the IDES, and it was determined that in order to be cost effective, the system cost should not exceed $100,000. The production environment dictated relatively unskilled operators, high throughput, and an easy-to-use system. The National Mapping Division DEM tape specifications determined the software format for the system, while the need to display standard 7 1/2-minute quadrangles was the controlling factor on system display memory requirements.

The need to perform effective editing was basically driven by three factors: an interactive technique with an efficient and easy-to-use operator-machine interface; editing of isolated points; and editing of water body errors.

The average Gestalt Photomapper DEM contains approximately 614,400 points, requiring a memory of 1,228,800 bytes for full storage. The GPM data may contain errors which must be corrected before further processing is applied. After the errors have been resolved, the GPM data are processed with a resampling algorithm which produces a relatively sparse DEM in the NDCDB format. After the resampling process, the average DEM contains approximately 164,000 elevations, which require a memory of 328,000 bytes for full storage. DEM data which are currently in the NDCDB may also contain both isolated point elevation errors and water body elevation errors (areas) which require further processing for correction. Therefore, the system must handle data in both GPM and NDCDB formats.

SYSTEM DESIGN

Design tradeoffs among cost, user training, speed, and memory requirements led to a system based on the Digital Equipment Corporation (DEC) LSI 11/23 microcomputer system. The system configuration is shown in figure 1. The LSI 11/23 is an MOS/LSI technology machine which brings the functional power of the PDP 11/34 minicomputer to the microcomputer level.

The Comtal Vision ONE/10 Color Graphic Image Display System forms the nucleus of the DEM viewing capability. It is an interactive system which provides a wide variety of image manipulation and display functions in a combination of well-designed firmware/software capabilities. Chief among these are such functions as a four-to-one hardware zoom factor; full image roaming; complete random addressing to a single pixel element; nondestructive superimposition of images, and combinations of image addition, subtraction, division, and multiplication.

In addition, a 24-bit color representation can be obtained in a configuration which provides address space for 8 image planes of 24-bit color. The Comtal is linked to the LSI 11/23 via a Direct Memory Access (DMA) channel to provide high image transfer rates, which enhances operational speed. Standard DEMs are input to the IDES via the magnetic tape drive, and a 30-megabyte (MB), Winchester-type magnetic disk drive provides ample storage for the various display files, applications programs, and the DEC RT-11 operating system programs.

Operator input to the Comtal is through use of an alphanumeric keyboard and a track-ball cursor control unit. Operator input to the LSI 11/23 is provided through a

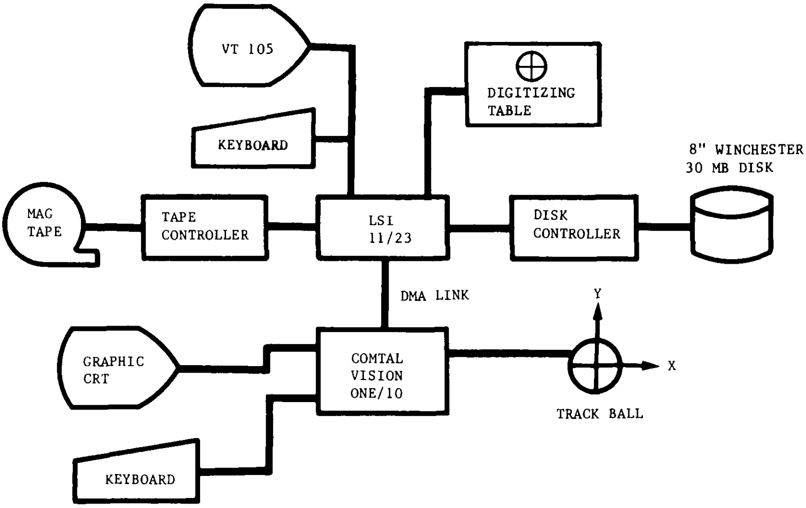

Figure 1.—DEM image display and editing system.

standard CRT terminal. Digitized map point and line data are entered directly into the LSI 11/23 via a manual digitizing table.

DISPLAY DESIGN

The main purpose of the IDES is to detect errors and anomalies in the DEM data. These errors may be classified as substantive or cosmetic and may be due to a number of causes, e.g., missing or inaccurate data, datum shifts, correlation failures in the case of automatically scanned imagery, overlooked data in the case of manually scanned maps, abberations due to software logic, software faults, and others. The following displays were selected as having the best potential for highlighting these errors:

- Color-banded-elevation,
- Shaded relief, and
- Anaglyph stereo.

Finite memory size is the driving element of display software design. The LSI 11/23 has an 18-bit extended memory space, which allows for only 262,144 bytes of real memory space. Conversely, the set of DEM images on the Comtal consists of four 512 x 512-pixel arrays of 8-bit points, which translates into 524,288 16-bit words (generally written as 512K words). This means that two Comtal images would require four times the entire address space of an LSI 11/23 if it were processed at one time.

To overcome this obstacle, each DEM tape data file of approximately 328,000 bytes (representing a standard 7 1/2-

minute quadrangle) is reformatted into a series of 512 x 512-pixel arrays or image planes, with separate image planes provided for the upper and lower bytes. As shown in figure 2, each array is partitioned into 16 smaller arrays, each consisting of a 32 x 512 x 2-byte array. Each of these smaller arrays is manipulated rather nicely within the LSI 11/23 address space. For DEMs which do not fill a particular subarray, the remaining points are zero filled. The successive 32-kilobyte subarrays are then stored on disk as a partitioned subimage matrix. This disk file is used by the display generation applications programs to process the various displays. Successive subimages are then linked together to form the 512 x 512-pixel image planes for the IDES, thereby allowing display of a full 7 1/2-minute quadrangle. The display image planes are stored back on the same disk, where they can be transferred to the Comtal Image Display System.

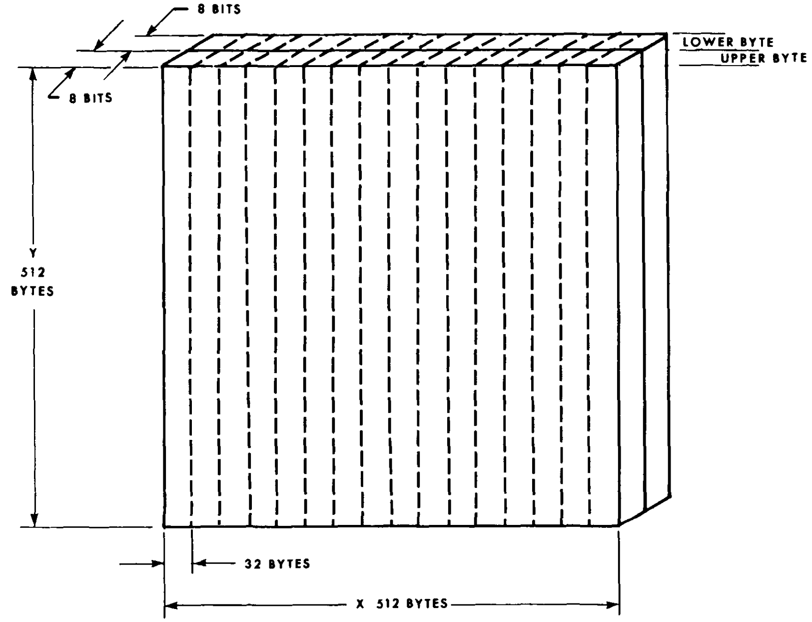

Figure 2.—DEM data partition array.

Color-Banded Elevation Display

The color-banded-elevation display uses point elevations to modulate a color intensity function. The function has a 24-bit range, with 8 bits assigned to each color. Point elevations are contained in the DEM so the color banding is straightforward. The major advantage of this display is to show slope irregularities, since contours of equal height should be of the same color. In addition, the display gives the experienced observer a feeling for the real appearance of the terrain.

Shaded-Relief Display

The shaded-relief display uses the slope between points to modulate an intensity function of a monochrome image. The intensity function is further modulated by an illuminance function, which represents sunlight coming from the north-west. Figure 3 shows the typical shaded-relief computational model. The amount of light striking a unit surface, S, on a horizontal map plane is related to the slope angle, Θ_s, of the terrain, and the elevation angle, Φ, of the light source (Monmonier, 1982). A surface sloping away from the light source will receive and reflect less light than one facing the light source. The amount of light, L, impinging on this surface is a function of the inclination angle, Θ_s, of the surface facing the light source and the elevation angle, Φ, of the light source above the horizon. L can be computed as $L = S \text{ SIN } (\Phi + \Theta_s)$. In this manner, an intensity value is calculated for each point in the DEM. The intensity value is then translated to a display brightness value via a software table lookup function.

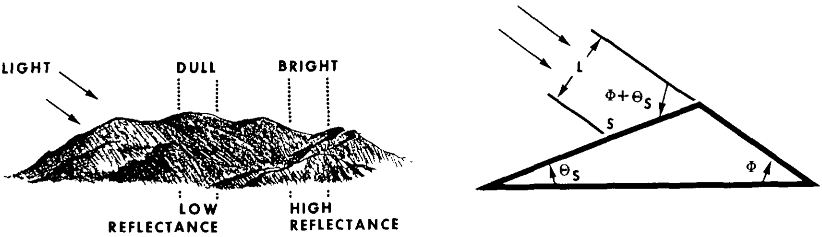

Figure 3.—Shaded-Relief computational model.

Figure 4 shows a typical DEM for which a shaded relief is computed, The shaded-relief display overcomes the limitation of the color-banded-elevation display by providing an approximate view of the terrain. However, it still provides no direct elevation information. Despite this rather undesirable result, it does provide the major advantage of displaying the terrain shape. The GPM correlation algorithm is deficient in water bodies and other poor contrast areas. The computer program which corrects these deficiencies rounds off all elevations to within plus or minus one meter. The resulting mismatch tends to show as a series of lines on the display.

Anaglyph Stero Display

The anaglyph stereo display is one which uses two superimposed images, each with a slightly different view of the same surface. Each image is generated in a different color, one red and one cyan. The viewer wears a pair of filter glasses, of which each lens transmits only one color, and the viewer thereby perceives a three-dimensional view.

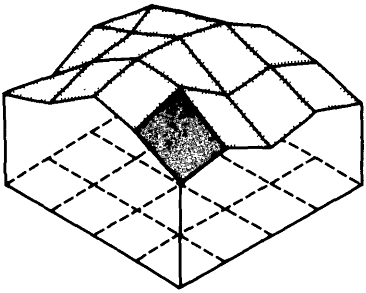

Figure 4.—DEM for shaded-relief computation.

The geometry of the anaglyph stereo display is based on well-known photogrammetric principles. In order to generate a stereopair which is perceived to have elevation, one image is shifted away from the position where the eye would normally find the unelevated image to the intersection of a line of sight through the elevated image and the ground surface (Monmonier, 1982; Slama, 1980). Figure 5 illustrates this principle.

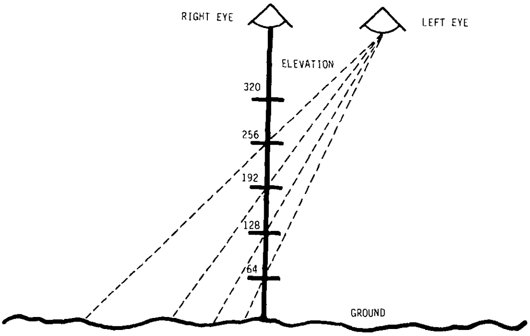

Figure 5.—Anaglyph stereo-display principle.

Since a CRT is composed of fixed-interval pixels, the anaglyph principle previously stated must be modified. This is accomplished by three simplifying procedures.

First, a shaded-relief image is calculated and held constant. Second, parallax is introduced into the first image in order to create a second image. Each corresponding pixel in the second image, relative to the first, is shifted one pixel for each 64-meter increase in elevation. This produces a somewhat less exaggerated three-dimensional image than a comparable true stereoscopic model, but one which, nevertheless, is quite acceptable to the eye. Finally, the intensity values for the shaded-relief image are assigned to the three 8-bit color planes precisely as if each image were a standard shaded relief. The left image is assigned to red, while the right image is assigned to both blue and green to yield cyan. The resulting display has the appearance of a full anaglyph stereo terrain model. The major advantage of this display is that an operator can rather easily identify elevation and slope errors.

EDITING

The IDES brings the power and simplicity of interactive processing to the task of editing. Editing needs can be essentially divided into two classes, cosmetic and substantive.

Cosmetic editing may include such functions as eliminating systematic tilt in GPM patch-derived data, smoothing of shoreline data around water bodies, and edge-matching of GPM patches. Substantive editing may include adding missing profile points based on nearest neighbor algorithms and correcting water-body elevation errors through interactive graphic polygon-fill methods. The latter problem is particularly prevalent in GPM data due to its inability to correlate images of areas which have poor contrast or are homogeneous in reflectance values, such as water, snow, and certain crops. Substantive editing also includes elimination of gross errors at isolated points, which singly would have little effect on the root-mean-square error of the DEM, but are troublesome to users during data applications.

Three basic editing capabilities have been provided for both point and area elevations:

- o Averaging,
- o Replacement, and
- o Increment/Decrement.

Averaging replaces the value of a point with a weighted average computed using the eight nearest neighbor points. The weighting factors are interactively entered into a 3 x 3 matrix. Figure 6 illustrates the weighting matrix.

W1	W2	W3
W4	W5	W6
W7	W8	W9

Figure 6.--Weighting Matrix

The replacement capability simply replaces the value of a point with an operator-selected value, which is entered interactively. The Increment/Decrement capability incrementally adjusts a point value by plus or minus 1. The system operator interactively selects which capability is to be used for a given editing task.

Single point editing is accomplished interactively using the Comtal display screen and the system console CRT. Using the track ball, the operator selects a point to be edited by moving the Comtal screen cursor to the desired point on the elevation display. The software uses the Comtal cursor position to define a 64 x 64-pixel processing window and moves the window data from disk to memory. An independent 10 x 10-pixel display window, initially centered around the selected point, is created for display on the system console CRT. The elevation of each point within the 10 x 10-pixel window is displayed on the console CRT, with the current cursor position being highlighted on the display. In effect, this window displays a 10 x 10-pixel matrix of elevations about a point. Figure 7 illustrates the matrix of elevations display.

```
2149  2161  2175  2190  2204  2215  2225  2238  2248  2258
2144  2157  2172  2184  2195  2204  2214  2224  2236  2247
2135  2149  2163  2175  2183  2192  2201  2211  2223  2234
2127  2137  2149  2161  2169  2178  2189  2200  2211  2221
2115  2125  2134  2143  2155  2165  2176  2187  2198  2208
2100  2111  2120  2129  2138  2150  2162  2173  2185  2195
2085  2095  2104  2113  2123  2136  2149  2160  2172  2181
2069  2077  2086  2096  2107  2122  2135  2146  2158  2168
2057  2058  2066  2078  2093  2108  2121  2133  2145  2155
2045  2046  2052  2063  2079  2094  2106  2118  2131  2141

      X POSITION          13        Y POSITION        254
    ENTER COMMAND (AVERAGE, INCRMENT, REPLACE, OR EXIT)
```

Figure 7.—Matrix of elevations display.

The result of the editing is shown on the 10 x 10 matrix of elevations display and on the Comtal elevation display. As the operator moves the cursor around the display, a new 64 x 64-pixel window and the corresponding 10 x 10-pixel windows are calculated and stored in memory, as appropriate. Each modified 64 x 64-pixel block is then written to disk, as necessary.

Area editing is accomplished by having the system operator use the Comtal track ball to outline an area on the Comtal display screen. The display may be a color-banded-elevation or a shaded relief. The software transforms the operator-defined area into a graphic overlay. The graphic overlay is scanned and the operator-selected algorithm is performed on each point within the overlay. After the scan is completed, the display is updated with the new information.

The location of map features from published maps, map separates, or orthophotos can be transferred to the IDES using the digitizer table. The outline of the feature is traced on the digitizer and transferred to the IDES, where it is loaded into a graphic plane. A map registration program is used to align the graphic plane boundaries with the stored DEM data. After the editing is completed, the display is again updated with the new data.

CONCLUSION

The IDES provides a practical and cost-effective means for viewing and editing DEMs formatted as 7 1/2-minute quadrangles. A powerful image processing system, coupled with interactive software, provides a significant error detection and correction capability. These capabilities can be used for both substantive and cosmetic editing. In addition, its wide color range affords a significant ability to detect slope irregularities. The IDES also provides anaglyph stereo and shaded-relief displays comparable in quality to those generated on high-powered and more expensive minicomputers. A configuration comparable to that shown in figure 1 can be reproduced for approximately $65,000. In all, the combination of a low-cost microcomputer, a state-of-the-art display system, and an innovative, interactive software design provides powerful image display, manipulation, and editing capabilities for use in a production environment for error detection and correction, and quality control of digital elevation models.

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