

DIGITAL CARTOGRAPHIC DATA BASES: ADVANCED ANALYSIS
AND DISPLAY TECHNOLOGIES

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ABSTRACT

The Defense Mapping Agency produces digital data bases that describe the physical appearance of the surface of the earth. Using state-of-the-art display and analysis concepts in conjunction with sophisticated interactive computer graphics systems, a variety of geographic simulation and analysis displays are available. Applications include visual and electro-optical sensor simulations to support aircrew training simulators, mission and land use planning displays, trafficability analysis based upon terrain and surface cover, threat and survivability displays, airport radar installation analysis, and advanced convolution and digital Fourier analysis for quality control of the digital data bases.

BACKGROUND

The Defense Mapping Agency (DMA) produces digital data bases that describe the physical appearance of the surface of the earth. These data bases include, but are not limited to, terrain elevation, culture including landscape characteristics, and vertical features. This data is collected from digitized source maps, from optically or digitally correlated stereo-pairs of photographic imagery, and from digital multi-spectral sensor data. A dramatic impact has been made in the ability to analyze these digital data bases by applying state-of-the-art digital image technology processing and display concepts. These include a variety of color and/or black and white displays of not only intensity/color coded matrix data, but also image processed data using specialized convolution filters, texture discrimination, digital Fourier analysis, and special color representation techniques. In addition, computer generated visual and electro-optical imagery from these data bases serves as a final analysis tool.

For purposes of quality control and data base applicability investigations, DMA has developed the Sensor Image Simulator (SIS), a very high speed data base edit station and static scene simulator that allows for interactive

query and manipulation of individual features in the data base displays and/or simulated sensor scenes to determine the corresponding data base elements responsible for the simulated features. The SIS was installed at DMA in 1981, and plays a key role in determining the applicability of existing and prototype data bases for use in a variety of applications, as well as to ensure the quality of, and coherence between the various digital data bases prior to new data insertion into the master cartographic data base files.

DATA BASE CONTENT

The current DMA standard production data bases (Level I) contain large area cultural information, and digital terrain data sampled at a three arc second interval. The cultural data consists of point, linear, and areal features described by characteristics such as surface material category, generic identification, predominant height, structure density, and percentages of roof and tree cover. The cultural data is in lineal (planimetric boundary) format and, although feature sizes may vary depending upon local circumstances, reflects a resolution on the order of 500 feet. Smaller features are aggregated into homogeneous features described by predominant characteristics. The current high resolution (Level II) data bases contain small area cultural information, and limited digital terrain elevation data sampled at a one arc second interval. This translates to a resolution of about 100 feet, with smaller features aggregated. With the exception of some special products, DMA does not produce digital terrain elevation data sampled at one arc second intervals. The majority of Level II data produced contains Level II digital feature analysis data and Level I digital terrain elevation data.

The terrain elevation data is produced by contour digitization from charts or directly from stereo pairs of photographs using advanced analytical stereoplotters. The cultural data is produced from both charts and photographs with a much higher level of manual effort required in order to perform the complex feature analysis.

SIS CONCEPT

The natural evolution of sensor simulation at DMA led to the design and fabrication of the Sensor Image Simulator (SIS), a dedicated mini-computer-based image processing system capable of performing simulations in an interactive mode.

The Sensor Image Simulator performs five major functions:

1. Digital Data Base File Input and Output.
2. Off-Line to On-Line Data Base Transformation.
3. Sensor Simulation.
4. Interactive Data Base Editing.
5. Software Development and Maintenance.

The SIS brings together, in a self-contained integrated hardware/software facility, a significant capability to evaluate the digital data bases. All operations are conducted under interactive control. Both the software structure and operations sequence reflect a top-down implementation philosophy wherein principal control functions are resident at the top of the hierarchy and functions concerned with processing individual data elements are at the lowest. The system is implemented in such a fashion that future changes in processing can be accomplished at the highest level of system software support. Detailed information on SIS operations, hardware, and software has been previously published.

GENERAL LAND USE AND RESOURCE MANAGEMENT

Maps are perhaps the single most important tool for the solutions of the problems confronting the land use and resource manager. The proper map, viewed in the proper manner, can sometimes convey all that is needed. Yet, frequently, the maps that must be used are too general -- they cannot address themselves directly to the problem at hand. It is the ability to quickly customize presentations of digital cartographic data through interactive selections that give computer generated maps their advantage over conventional maps. The basic information contained in digital terrain and feature data bases can be manipulated in hundreds of different ways to produce the one electronic map or image necessary to address a specific problem.

Sometimes, a land use solution lies solely with terrain evaluation. One of the most common means of terrain analysis is through the use of a contour map. With digital terrain on an interactive system, contour vectors can be generated at the analyst's discretion. The analyst simply chooses the upper and lower limits of evaluation along with an interval for the contours. Perspective profiles are another type of vector display that can be easily generated.

To increase the analyst's comprehension of profile displays, the vectors can be color coded with a color spectrum scale. Using this technique, progressions of elevations from the lowest to the highest value correspond with vectors that are colored from violet to red. Color coding dramatically increases the analyst's understanding of a profile display by eliminating any ambiguity about relative vector heights. Matrix analysis of digital terrain is available by using displays of shaded relief, color elevations, and gradient magnitude.

The gradient magnitude operator is a useful function for producing a nonconventional type of terrain matrix image. The gradient magnitude image becomes a very useful method if identifying areas of steep slope is part of the solution to a land use manager's problem. The gradient is a vector function $\nabla f(x,y)$ that points in the direction of maximum slope and is defined by:

$$\nabla f(x,y) = \frac{\partial f}{\partial x} \vec{i} + \frac{\partial f}{\partial y} \vec{j},$$

where i and j are unit vectors.

Its magnitude is defined by:

$$|\nabla f(x,y)| = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2},$$

and represents the steepness of slope at every point. One of the specific applications in which a gradient magnitude image could be used is in the determination of drainage patterns in terrain of high spatial frequencies. Finding these same patterns using contours or shaded relief images is much more difficult.

If surface feature information is the primary concern in a land use problem, then feature boundary plots can be produced that use vectors to identify the outlines of feature data in geographic region. These displays are highly interactive and allow for the analyst to create displays of color coded vectors based on the surface material categories (i.e., metal, soil, etc.) of the feature data. If desired, the analyst can also display only certain features specified by combinations of surface material category, the feature type (i.e., residential, processing industry, commercial buildings), feature identification number, and feature length, width, height, and orientation.

If the combination of feature and terrain information is important, then the two data types can be displayed simultaneously in an image using color. Color is perceptually

defined in three dimensional space by its intensity, hue and saturation attributes. Each of these attributes can be independently controlled by a multi-dimensional data structure to generate representative colors. A raster geographic data base can be displayed in color such that for each cell, the feature component determines the hue, while the terrain data, through slope shading, determines the intensity. The result, when using conventional hues in association with general landcover classes, is a natural appearing color image clearly displaying the character of the landscape. Saturation may also be used in addition to hue and intensity to reveal a third data class, such as data accuracy levels or climatic conditions.

The computer generated intensity, hue, and saturation (IHS) display allows a great deal of flexibility to achieve a variety of capabilities through the manipulation of the digital data. The terrain shading condition of the image can be controlled to vary the direction and intensity of the slope illumination. This is used to create displays with optimum illumination conditions to enhance terrain characteristics or to provide desired aesthetic effects without changing the information presented by hue or saturation

The digital feature data base may consist of a variety of descriptors which can be selected for display. Normally, the basic surface material is used to determine hue, resulting in general land-use displays. Such information as predominate heights or tree types can be portrayed using hue to create thematic IHS images. The ability to relate various types of data to terrain in a single image makes the IHS display particularly useful to the analysis of the landscape. In addition, the rapid generation speeds for interactive computer generated map displays allows the user to quickly generate a variety of unique images to fully exploit the information available in the data base.

The IHS display contains the realism of aerial photography the planimetric control and generalization of a map, and the flexibility of a computer generated image. It can thus be used in place of, or to supplement, aerial imagery, conventional maps and less advanced computer graphics. Applications include the interpretation of geologic formations for mineral exploration, hydrology studies, civil land use assessment and planning, environmental research, route planning, inventory of natural resources such as timber or water, and a variety of other uses which can benefit from advanced digital geographic data displays.

MISSION PLANNING ANALYSIS

Digital terrain and feature data displays are particularly useful for mission planning analysis due to the realism,

efficiency, and flexibility possible with advanced processing and display technology. The geographic data can be rapidly processed into a variety of graphic forms best suited for specific needs.

Various data base displays have been demonstrated to be very effective for ground operation mission planning. During the planning process for a mountain climbing expedition, several computer generated displays, including shaded terrain, color height, gradient magnitude, feature and surface material IHS, were used to determine the optimal route to the top of Mt. Powell in central Colorado by visual inspection of the displays. Such images proved to be superior to conventional maps using contour coding by providing a variety of graphics which made it possible to better comprehend the actual landscape. When particular terrain conditions required greater clarification, the digital data displays were quickly manipulated to more appropriate images by changing the area, resolution, color, shading conditions, or the type of display. Color hardcopy was created of the most useful images for navigation and planning in the field. Since the digital data displays lacked symbology, conventional maps were required. However, this information can be added to digital images using graphics overlays. The climbing route selected from the digital data follows one recommended by the Colorado Mountain Club.

Perspective visual simulation is perhaps one of the most effective display methods since it creates a natural appearing image, allowing the user to closely associate geographic data with the real world. It is especially useful for airborne operation planning by providing a pilot's eye view of the landscape which will be encountered in an actual mission.

Perspective simulation employs the same IHS techniques used for surface material color coded shaded terrain raster map displays and thus may include similar flexibility. Surface material codes are used to determine associated conventional hues for natural color, general purpose simulations. This provides highly realistic out-of-the-window scenes with viewer position, attitude, and optics controlled by the simulation producer. Atmospheric effects such as haze or fog can be created using the saturation component of color. This is significant in indicating to the simulation user the possible visibility conditions as opposed to the theoretical scene based solely on feature and terrain data.

In certain situations it may be desirable to vertically exaggerate a perspective simulation to enhance the portrayal of terrain. This is often necessary for areas of low relief in which the vertical dimension is very small proportional to the horizontal dimension. Earth curvature may also be accounted for as a significant factor in visual simulation to produce a scene correctly portraying what can actually be seen by the observer.

In addition to surface material codes, other information significant to planning analysis may be portrayed using hue. One method is to code terrain elevation levels in the simulation using a spectral arrangement of hues such that higher elevations appear in hues towards the red end of the spectrum. This is useful in allowing the pilot to accurately determine ground elevations in perspective view for terrain avoidance planning or landing assistance. The predominate heights of only the feature data can also be displayed using the same technique to indicate vertical obstructions or structures which will cause shadowing and high returns of radar. Radar and electro-optical sensor potential reflectance can be calculated from feature data and portrayed in the visual simulation using a similar arrangement of hues. Such displays are significant for the planning of missions in which sensors will be used in navigation by indicating the various strengths and positions of sensor returns which will be encountered. The numerous types of data which can be portrayed using hue in perspective scenes can also be displayed in raster map images.

Specific radar and electro-optical sensors may be digitally modeled to produce sensor simulations using digital terrain and feature data. All aspects of the simulation, including radar parameters and aircraft position and attitude, can be controlled by the operator to produce scenes simulating various circumstances. Sensor simulations are valuable to navigation planning and may serve as enroute navigation check points.

In hostile tactical military environments, the ability to predict threats, such as surface-to-air missiles, is an extremely valuable tool. Techniques have been developed to place models of multiple threat acquisition parameters into the simulation data base to provide safe "pathways in the sky" displays for mission planning.

The capability to simulate electro-optical displays from the digital data led to a pilot study to support the Department of Transportation in planning the location

of airport radar systems. Of primary concern was the shadowing of ground vehicles by airport buildings. The flexibility of easily changing radar location and altitude with the resultant computer generated radar shadow mask proved the viability of this technique.

TRAFFICABILITY ANALYSIS

Trafficability analysis is concerned with the determining of movement costs and optimum routings over a selected set of data. By using digital terrain and/or feature data as inputs to imagery processes, it is possible to create cost of movement displays that can aid in this analysis. These cost of movement displays are created by using a cost matrix concept.

Cost matrices are arrays whose elemental values indicate the cost associated with moving through each particular element. These cost values can be considered in many different ways. For example, the costs could be in terms of speed of movement, danger of movement, combinations of the two, or in any other conceivable manner. These cost matrices consist of 256 levels. The terrain costs are produced by computing the gradient magnitude of the terrain data and using the value to assign a terrain cost of 0 to 127. The terrain cost, T_C , can be varied for different scenarios by changing a terrain cost multiplicative factor (α),

where: $T_C(x,y) = \alpha \nabla \text{Terrain}(x,y)$;

$$0 \leq \alpha T_C(x,y) \leq 127.$$

The feature costs, F_C , are produced using the thirteen different surface material categories present in the feature data (i.e., water, trees, soil). An entry cost value between 0 and 127 must first be selected for each surface material category. In the special case that a no entry condition is desired for any particular surface material category, a value of 255 is assigned,

where: $0 \leq F_C(x,y) \leq 127$;

$$\text{no entry: } F_C(x,y) = 255.$$

The feature data is then used by examining the surface material category at each location and assigning the cost matrix a feature cost value. By summing the terrain and feature cost values together at each location, a cost

matrix is produced and can be displayed using a color spectrum intensity mapping,

where:

$$\sum_{x=0}^m \sum_{y=0}^n C_m(x,y) = \alpha \sum_{x=0}^m \sum_{y=0}^n T_C(x,y) + \sum_{x=0}^m \sum_{y=0}^n F_C(x,y);$$

$$0 \leq C_m(x,y) \leq 255.$$

This use of a visual cost matrix technique on digital terrain and feature data, along with the ability to interactively change cost structures, gives an analyst the power to quickly solve many problems relating to trafficability. The cost matrix format could also readily lend itself to manipulation by software that would automatically select optimum routes based on the analyst's decision of cost structures for a given scenario.

DATA BASE QUALITY CONTROL

In order to perform interactive analysis of the digital files, digital terrain elevation data may be used to generate color coded contour plots and line profile displays. An alternative is to color code the matrix terrain data directly. While analysis of these matrix image displays is superior to trying to perform analysis by visual inspection of the data in printed numerical matrix format, they only provide for a low spatial resolution analysis capability. Shaded relief display with variable illumination adds additional information for analysis of all types of matrix data and is particularly meaningful for cartographic data because of the relationship to the physical world. Higher spatial resolution analysis of the shaded relief display may be gained by applying photogrammetric models to generate pseudo-stereo-pairs of images in which spike points are apparent under stereoscopic analysis. These techniques, used singly or in combination, allow for data base analysis far superior to techniques of a decade ago, but they are not enough.

In order to perform high resolution anomaly analysis of data bases for the purpose of either quality control or information gathering, advanced techniques are required. These techniques include convolution filtering, specialized color representation, digital Fourier analysis, and computer generated sensor simulation.

Convolution filters have been used very effectively to enhance matrix data to show processing anomalies as well as where data has been merged from different production equipment, different stereo models, different production

methods, variable requirement specifications, and even from different analysts. These types of filters are used extensively by the image processing community to detect edge differences, and then to reapply the differences to sharpen the original image. They also have been shown to be a powerful tool for the analysis of cartographic data bases.

For the purpose of determining compatibility between data types, such as between digital terrain and culture data, simple color coding and overlay in Red-Green-Blue (RGB) space may not be sufficient. A more powerful technique employs coding each data type along an Intensive-Hue-Saturation (IHS) axis and then converting from the IHS space to RGB space prior to display. Since the visual perception process can distinguish variation between IHS, the data types can be overlaid without a merging of colors, and therefore, without an information loss. Various cultural thematic displays may be overlaid on variably illuminated terrain displays.

The DMA is beginning to explore the potential of using digital Fourier analysis for filtering of the terrain data. The digital generation and interactive display of two-dimensional Fourier transformations of the terrain data in conventional frequency vs azimuth as well as profile displays have highlighted and isolated data anomalies that were previously extremely difficult to describe. A variety of digital pass and rejection filters have been applied to these transforms for anomaly removal.

Finally, and probably unique to cartographic data bases, is the technique of computer generating landform scenes as seen by various visual and electro-optical sensors. This allows for a final quality control analysis of information content, and also has been very valuable in the definition of data base requirement specification.

IMPACT

The impact of this interactive system and application technique development has been enormous. Not only is there a greatly increased capability for the degree and sophistication of quality control of the digital data bases, but also there is now a highly flexible and interactive tool for data base application studies which allows users to investigate potential methods for topographic information display to meet a wide variety of requirements.

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