THE MULTI-DISCIPLINARY APPLICATIONS OF DEMS

D. R. Catlow

Laser-Scan Laboratories Ltd.,
Science Park, Milton Road,
Cambridge CB4 4FY

ABSTRACT

Digital Elevation Models (DEMs) are becoming increasingly familiar digital mapping products. A large number of different applications for DEMs may now be distinguished. The utilisation of these datasets crosses many discipline boundaries. This widespread use has important implications for the data structure devised to hold the DEM, and for the development of techniques to generate and exploit the elevation data.

INTRODUCTION

A Digital Elevation Model (DEM) may be described simply as a digital representation of the earth's surface. Most frequently the term is used to refer to a set of elevation data recorded on a regular rectangular grid, although a variety of other formats based on other regular meshes and non-regular representations may also be distinguished (Yoeli 1983). Whatever the data format, DEMs represent a convenient way of storing elevation information, and of making such information available to applications programs. As a result the utilisation of DEMs is becoming increasingly important, and their generation has become a major area of production for many national cartographic organisations, particularly in North America where Defense Mapping Agency and United States Geological Survey lead the way.

What characterises the present use of DEMs is their widespread and varied application in many situations. Their use, in much the same way as map based information, crosses many discipline boundaries. This situation, as will be discussed below, has important implications for DEM resolution and data structure.

DEM PRODUCTS

The widespread use of DEMs and the importance they have assumed in many situations, derives from the basic elevation data they hold, the information on slope, aspect and visibility that may be computed from the elevation model, and from the benefits that result from the integration of the DEM with other geographic information. Derived measures such as slope and visibility may be obtained from digital elevation data stored in a vector format obtained by the digitisation of map contours, but the algorithms required are often complex, and computation times are high. A DEM that provides data in a raster or grid format, lends itself to the development of software that is able to efficiently exploit the elevation information, often using relatively simple operations repeatedly applied to the data, and achieving relatively high processing rates.

A number of DEM products that form part of the output from the majority of terrain modelling and exploitation systems may be identified.

Slope and Aspect

Slope information may be readily derived from a DEM, particularly if the elevation information is stored on a regular grid. Faced with this arrangement, slope values may be computed by applying a local operator. A 3 by 3 matrix is generally used. The local gradient in both the x and y direction is calculated and subsequently combined to provide an estimate for slope for the central matrix point. In most cases the slope class interval, and slope limits may be specified, while often the slope calculations may be restricted to a particular area of interest or a particular direction eg along the line of a proposed road. As part of the same operation, and employing a similar local operator, slope aspect ie. the direction of maximum slope, may also be computed.

Shaded Overlays

The slope and aspect information may be combined to model the effect of illuminating the surface. Using this information, a conceptual light source, and a model that describes the reflectivity of the terrain surface, a shaded overlay may be produced. Conventionally the light source is placed in the northwest at a zenith angle of 45 degrees, although the user is usually free to vary both the azimuth and zenith angles. The degree of illumination received by a point on the surface, and therefore the grey value used to represent the point on the shaded overlay, is related to the angle of incidence. Slopes normal to the light source appear brighter than slopes facing away from the source of illumination. The resulting shaded overlay is an effective way of presenting elevation data to a viewer, enabling him to perceive rapidly the form and particularly trends in surface relief.

3-Dimensional Views

A product frequently produced from the DEM is a 3-dimensional view of the terrain surface. Either a parallel projection to produce an isometric model, or a perspective projection may be employed. Most viewing programs use a a simple profiling technique, which involves sampling the DEM on a line or column basis, and enhancing the model by hidden line removal, the overlay of a grid, or the use of colour. More sophisticated viewing programs employ either surface or solid modelling techniques, and achieve a degree of realism by shading the terrain surfaces according to aspect, colouring according to depth, or by modelling shadows and surface texture.

Attention is currently being turned to the registration of the elevation data to other datasets to enable their combined viewing in 3-dimensions. A number of commercially available viewing programs now allow data on surface features eg. roads and rivers, to be presented on the 3-dimensional terrain base. Work is also being performed that allows the DEM to be registered to satellite imagery for 3-dimensional viewing. The resulting images are visually striking and enable the viewer to quickly assimilate the information contained in the remotely- sensed data.

Visibility

The visibility status of a point on the surface with respect to another point either on or above the surface, may be determined by a consideration of the elevation values that lie between these two points. A large number of line of sight algorithms now exist. For the simplest applications eg. is a watch tower visible from another watch tower?, a single line of sight is considered. For other applications eg. radar, radio transmission, and observer positioning, a large number of lines of sight calculations need to be performed, in order that visibility within a particular cone or circle of vision may be determined. For many applications it is often necessary to modify the algorithms to take into account such factors as the curvature of the earth, atmospheric refraction, or in the case of radio propagation studies, the characteristics of the transmitter.

THE APPLICATION OF DEMS

It is not proposed in this short paper to describe in detail all the applications to which DEMs are currently being placed. Rather a number of brief descriptions which emphasise their multi-disciplinary and varied use are presented. In the majority of cases it is the products derived from the DEM, rather than the elevation data themselves, that are of relevance.

Cartography

On small scale maps hypsometric layering and hill-shading have traditionally been used to present relief information to the user. These techniques provide either an alternative to contour lines, or function as an additional aid to the perception of relief. The shaded overlay is particularly difficult to produce by manual cartographic means, requiring considerable artistic and geographic skill on the part of the cartographer.

The use of a DEM, a slope and aspect algorithm, and one of the numerous reflectance models as described above, now enable shaded images to be produced rapidly, according to a wide range of cartographic design specifications. The production of a layered relief map from the DEM, coloured according to any hypsometric colour scheme and at any desired vertical interval, is a straightforward operation involving the simple allocation of each DEM value to the relevant height band. These facilities are available on most cartographic systems that utilise DEMs, and are gaining increasing relevance in the map production environment by the availability of suitable hardcopy output devices.

Contouring operations are frequently applied to DEMs. A large number of contouring algorithms have been developed (see Gold 1978, Grassie 1982). They offer the cartographer considerable flexibility in terms of output contour interval, contour smoothing and generalisation. In most cases contouring may be applied to the derived DEM products as well as the elevation data.

Geomorphology
Geomorphology is a specialist branch of the Earth Sciences concerning with the form and development of the earth's surface. DEMs may be utilised in both the applied and pure applications of this subject. They offer the opportunity to produce 3-dimensional models of the surface allowing a worker to visualise surface form under different viewing conditions, and to calculate the local gradient and aspect of points on the terrain surface, in order to provide input into predictive and analytical models. Also of relevance are the algorithms that have been developed to extract form lines (ridges, valleys etc.) from the DEM.

Geology and Energy Exploration
The utilisation of DEMs and associated modelling and display techniques is of considerable importance in these disciplines. The graphic presentation of seismic, and geological information as 3-dimensional displays enables complex structures to be rapidly understood, and such displays are often the basis of many important planning decisions.

Civil Engineering
Civil engineers use a DEM for volume calculations, in connection with such developments as road and reservoir construction, and in order to generate sections and profiles between points of interest. The ability to view the impact of a particular development by means of 3-dimensional modelling techniques greatly facilitates the design and planning stages. Such displays also have a role to play in presenting the development to the public at the enquiry stage. In related disciplines eg. landscape architecture and mining, 3-dimensional views allow the visual impact of a development, eg. open cast mining, to be previewed and assessed.

Military
An appreciation of the terrain is vital to many military operations. Using DEMs and associated visualisation and line-of-sight software a commander may see in advance the terrain over which he may be travelling or fighting, and calculate the best position to site observers, communication equipment and sensitive military hardware. The generation and presentation of a series of 3-dimensional views, enables a pilot to preview a flight plan, while in similar, but more sophisticated applications, elevation information from the DEM are used for radar simulation, and to generate terrain scenes within aircraft and other simulators. DEMs are being increasingly utilised in guidance systems for advanced weapons, and in scene-matching navigation systems for manned and unmanned aircraft.

Communications
The determination of areas of hidden or 'dead ground' is vital in

the siting of communication equipment such as radio and television transmitters, and in the setting up of communication networks. A large number of algorithms which take into account the nature of the transmitter (the refraction of the propagating waves etc.) have been devised. When these algorithms are applied to the DEM, areas of hidden ground may be calculated with respect to one or more static or moving stations, and areas of 'dead ground' overlap may be determined.

Satellite Image Processing and Analysis

The use of ancillary data for both image rectification and to build additional control and knowledge into image analysis operations is becoming increasingly important. Most image analysis systems are now designed to accommodate both remotely sensed data and digital geographic data such as elevation and derived data in the form of a matrix.

The DEM information may be used in its primary form to correct radiometric and geometric effects in the image due to terrain variation over the image area. This is particularly important when dealing with non-vertical imagery. In analysis the elevation data may be used to stratify an image into height bands prior to the applying of classification algorithms, while information derived from the DEM on slope and aspect may be utilised to modify classification algorithms, and build in 'a priori' knowledge. For example we may know that a particular type of vegetation is only associated with a particular aspect and range of slopes. Research using contour data, and more recently DEM information indicates that a considerable improvement in classification accuracies result from using such a technique.

A point to note in connection with image processing and analysis is that many of the algorithms applied to the processing and particularly enhancement of satellite imagery are equally applicable to the DEM information. Spatial filters to produce smoothing or edge enhancement, histogram equalisation and pseudo-colouring are likely to become increasingly applied to the elevation data and DEM derived measures as image analysis and combined map-image processing systems become more widely available.

Geographic Information Systems

DEMs are essential to many Geographic Information Systems. In such systems the elevation data and derived measures gain increased importance when they are combined with other geographic information on surface and sub-surface characteristics. Many Geographic Information Systems that exploit DEMs, particularly in disciplines concerned with the natural environment now exist, and examples of GISs concerned with forestry management, hydrographic modelling and land-use analysis may be found in the literature.

This review of DEM utilisation is far from exhaustive. The use or potential use of DEMs by other disciplines eg. urban planning, agriculture and forestry, meteorology, and even the leisure industries (orienteering, landscaping of sporting courses are possible examples), may also be cited. Some of the implications of this pattern of use, and current trends in DEM design and exploitation are discussed below.

TRENDS IN DEM USE

The increased utilisation of DEMs and their varied application has important consequences for the structure of the DEM itself. It is now recognised that the adoption of a data structure appropriate to a given application is vital. For example, the requirements of a DEM that will be utilised in a simulator system, differ from those that may be used as a component in a Geographic Information System. In the former case access to the data in a way that will enable its rapid display, and therefore in a form that is most compatible with the architecture of the display and associated hardware, is the dominant requirement. In the second case a data structure that will enable queries to be efficiently answered, other thematic data to be computed from the elevation data, and will allow elevation data to be combined with other geographic information, is of prime importance.

Similarly in certain situations eg.on-board navigation systems, data quantity is a major consideration. In these cases the need to reduce the physical size of DEMs by the adoption of efficient data compression techniques is vital. For other applications eg. radio propagation, a structure that will accommodate data at different resolutions according to geographic area (eg. high resolution in urban areas, and a lower resolution in rural areas) is desirable.

As a result of these requirements, considerable research is now directed towards the development of data structures and data compression algorithms for DEMs. The most common data structure is still the regular rectangular grid, but this is not the most appropriate in many situations. The major difficulty is data redundancy. A regular grid representation means that a grid of sufficient size to hold information on the smallest features of interest must be adopted, and must also be applied to features of less relevance. The current trend of a move away from the rectangular grid with its inherent data redundancy, towards data structures based on triangulated irregular networks or a quadtree structure is likely to continue. (Mark 1979, Cebrian 1985). This trend will become more important as applications demand access to DEMs covering larger geographic areas and with greater spatial resolution.

The exploitation of DEMs is likely to be considerably affected by current hardware developments. The utilisation of parallel processors and transputer based computer systems is likely to have a major impact on the processing of grid based datasets. This is demonstrated for example by Laser Scan's current involvement in a Government assisted research and development programme addressing real-time 2.5D vision systems, based on the multiple input, multiple data stream (MIMD) parallel architecture of the INMOS transputer. Such architectures are particularly suited to a situation where a single operation or set of operations eg. gradient calculation, need to be repeatedly applied to the dataset, or where it is necessary to process a large number of objects simultaneously eg. terrain facets for view simulation. Contemporary developments in storage hardware eg. optical disks, will enable greater amount of data to be utilised in the modelling processes in the future.

Together these hardware and software developments will mean that the required operations will be performed more efficiently on the data, and the results of any operation will be displayed to the user at faster rates. As a result more sophisticated algorithms, that are capable of utilising higher resolution DEMs and taking into account other important ancillary data, are likely to be developed.

This contrasts to the present situation where many applications are forced to use relatively unsophisticated datasets, not at the ideal resolution or in the most appropriate data structure. In turn this leads to the simplification of applications software. For example in the majority of applications the impact of surface features is generally ignored either because the data on such features does not exist, is not available in a suitable form, or cannot be accommodated within a combined format. The applying of line-of-sight algorithms that additionally take into account such factors as the curvature of the earth and atmospheric refraction, are often nullified by the fact that surface features such as areas of urban development and areas of woodland are not involved in the calculations.

CONCLUSION

In 1979 Peucker (Peucker 1979) concluded that 'the different disciplines interested in Digital Terrain Models are moving the topic in the right direction.' The intervening years have seen the increased availability of DEMs, the development of a large number of systems to produce and utilise DEMs, the design of efficient exploitation algorithms, and considerable research activity in topics such as data structure and data integration. Given this situation, and related activities in the design of processing architectures, there is no reason why this statement is not still valid.

One area of concern however may perhaps be identified. The multi-disciplinary nature of DEM use, makes its particularly difficult for users to get together to discuss mutual problems and requirements for elevation data. As a result there is a real danger that a great amount of effort is expended on duplicating data capture and generation, and in reinventing basic processing algorithms. This is particularly the case in the United Kingdom where in contrast to the United States no national organisation has yet given a lead in the production of DEMs, or in the specification of data standards. The commercial and non-commercial potential for DEM exploitation makes it desirable that mechanisms whereby both users and producers of DEMs may benefit from mutual experiences in this area, and from current research activities, should be developed.

REFERENCES

Cebrian, J.A. et al (1985) Analysis and display of digital elevation models within a quadtree-based geographic information system. Procs. of Auto Carto 7, Washington 55-63

Gold, C.M. (1978) Common-Sense Automated Contouring - Some Generalisations, Cartographica, 21 2 121-129

Grassie, D.N.D. (1982) Contouring by Computer: Some Observations, BCS Special Publication No 2, 93-116

Kikuchi, L. et al (1982) Rapid display of digital elevation models in a mini-computer environment. Procs. of ISPRS Commission IV Symposium, 24-IV 297-307

Mark, D.M. (1979) Phenomena-based data structuring and digital terrain modelling, Geo-Processing 1 27-36

Peucker, T.K. (1979) Digital Terrain Models: An Overview, Procs. of Auto Carto 4, 1 97-107

Yoeli, P. (1983) Digital Terrain Models and their Cartographic and Cartometric Utilisation. The Cartographic Journal, 20 1 17-22