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COMPUTER MANIPULATION OF A DIGITAL TERRAIN MODEL (DTM) OF AUSTRALIA

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Images of the topography of Australia (DTM) have been created from a digital data file of about 320 000 topographic spot heights measured during the gravity survey of Australia, resampled on a regular grid, and manipulated with a Comtal image analysis system to enhance topographic features. Three manipulations: pseudo-colour transformations, bit-plane images, and synthetic reflectance images are illustrated and discussed to give an idea of the range of computer techniques that can be used to enhance continental topography for geologic or related study. Improvements are inevitable in this new technique, which is applicable to any regional data that can be digitised, such as magnetic, gravity, or radiometric data.

Introduction

The topographic data that have long been used in geomorphological and geological research have been displayed in several ways, including contour maps, three-dimensional scale models, stacked (coulisse) profiles, stereoscopic models projected from aerial photographs, line-scanner images from space vehicles, and, more recently, computer-generated stacked profiles and isometric drawings.

Last year a black and white image and a coloured map of digital terrain data of the conterminous USA were published by Kane (1981) and Godson (1981), respectively. On the cover of this issue of the BMR Journal there are the first published examples of coloured images of the topography of Australia created from a digital data file and photographed from the screen of the Comtal image analysis system at the Bureau of Mineral Resources (BMR). The display approach used was similar to Kane's, but was developed independently, and, in addition, colour and various image analysis techniques were employed to specifically enhance topographic features so that their geologic or geomorphic significance could be more easily studied.

The Digital Terrain Model (DTM)

The basis of this work is the rather novel display of elevation data on a regular grid as a digital image. (A digital image is simply a digital representation of what is normally called a picture, and its smallest independent unit is the picture element or pixel). The image display system used in the study at BMR allows an image with 512 lines and 512 pixels per line to be displayed on a 48 cm colour television monitor.

The elevation data came from a continent-wide grid of spot heights used to correct gravity readings during the production of the 1979 Gravity Map of Australia (Anfiloff & others, 1976). The grid for the DTM, on a spacing of 6 minutes of latitude and longitude, was sampled from a 3 minute grid of about 320 000 points. This grid is held in the Australian National Gravity Repository data bank at BMR. The spot heights are not necessarily a representative sample of the extreme heights in any district, because the techniques of gravity surveying require observations to be made at sites that are locally level.

The gridding process involves the formation of a mathematical surface of minimum curvature passing through the spot heights and interpolated on to the regular grid by an iterative process, as described by Briggs (1974). When the grid was produced, the data bank had not been checked systematically for errors. Individual incorrect point values occur throughout the data, and in some districts whole blocks of data are in error. Consequently, the grid is not reliable enough to be made generally available at present, but we do not consider the errors significant for the purpose of this note. The gravity data bank is currently being checked systematically with the aim of producing a corrected grid of heights at 3-minute spacing.

Image quantisation

Because pixels have a limited range of values, before a DTM can be displayed as an image, it must be scaled down by a process termed image quantisation. For this investigation, it was necessary to quantise or scale the DTM so that the elevation data could be represented by pixel values in the range 0-255 (for an 8-bit image).

There are several ways of performing this process (Rosenfeld & Kak, 1976; Pratt, 1978), but, in this case, a simple linear quantisation was used. Bathymetric data were included, and depths of 1270 m or more below sea level were set to pixel value of zero. Heights of of 1280 m or more above sea level were set to 255. Intermediate points were scaled linearly between 0 and 255, so that sea level, for example, was quantised to pixel value 127.

After quantisation the DTM can be displayed as a monochrome (black and white) image in which a pixel value of 0 (−1270 m) is black and 255 (+ 1280 m) is white, with 255 grey level steps in between (Fig. 1). The image contrast in Figure 1 is poor because of the method of quantisation, but digital image enhancement techniques can be applied to compensate for the method of quantisation and to improve the image contrast. In this investigation, the digital image processing technique known as histogram equalisation (Hall & others, 1971; Hummel, 1975; Gonzalez & Fittes, 1977) was found to give the best result (Fig. 2).

Pseudocolour transformation

The human eye can distinguish differences in any of the three visual coordinates of hue, saturation, and intensity (luminance). In black and white images the eye responds only to differences in intensity, over the grey-scale range of black to white. If, however, the monochrome image is converted to colour, all three of the visual coordinates can be used to detect subtle variations in image values. This can be done with a pseudocolour transformation (Miller & Badler, 1977;

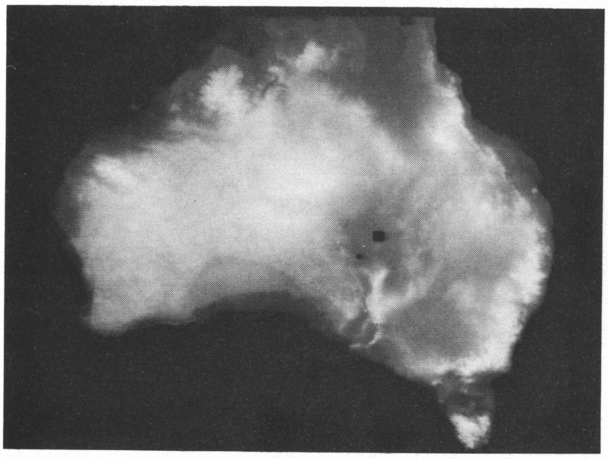


Figure 1. Initial monochrome image created from gridded spot heights and bathymetric data.
Black squares are areas where incorrect data have been removed.

Figure 3. Image of topographic gradient (west to east).

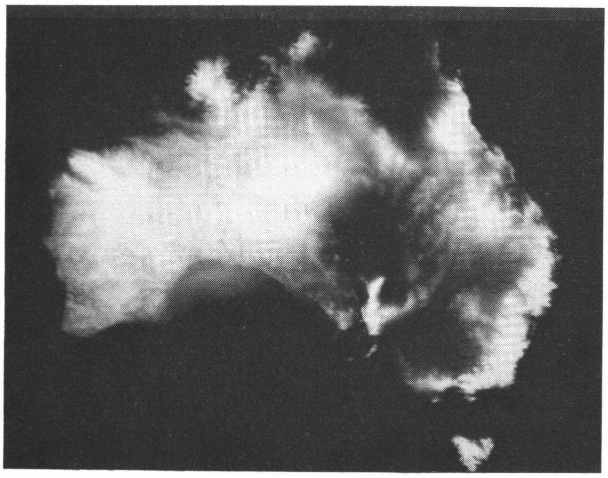


Figure 2. Image of Figure 1 data enhanced by histogram equalisation.

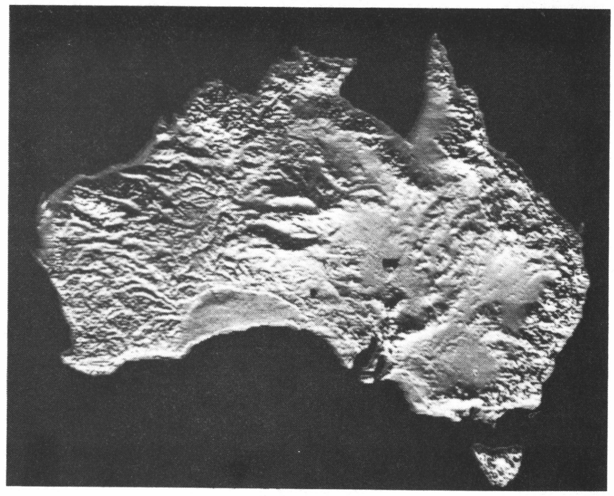


Figure 4. Image of topographic gradient (south to north).

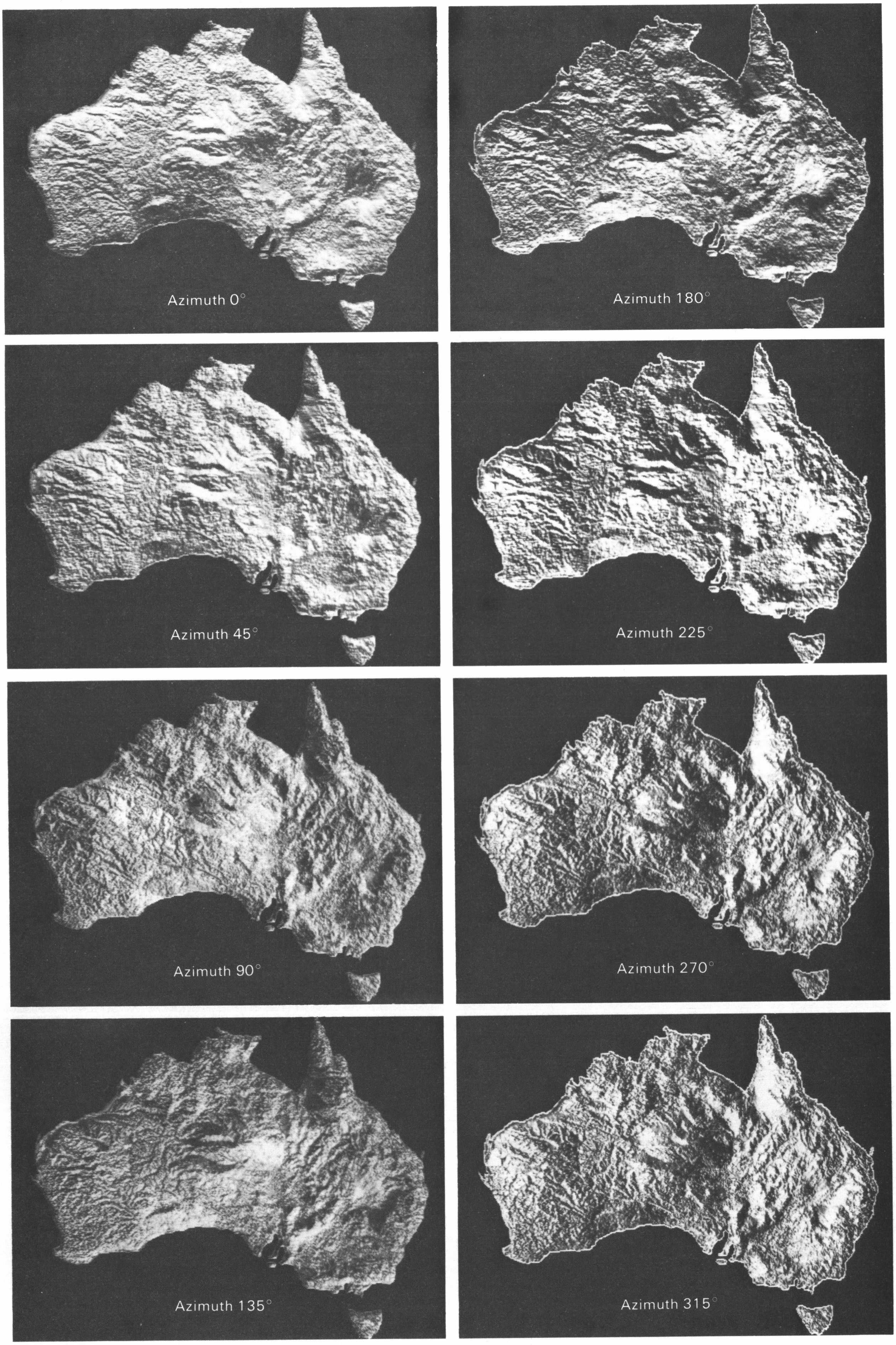
Gonzalez & Wintz, 1977), which is incorporated in BMR's image processing system. The transformation simply assigns a colour to every pixel value in the range 0 to 255, using 256 colours. The assignment of colours can be changed for different purposes, but a maximum colour contrast between adjacent pixel values is normally desirable. The pseudocolour transformation can be equated to colouring the contour intervals on a topographic map. The top and bottom-left images on the front cover of this journal show the effects of two different pseudocolour transformations of the enhanced monochrome image shown as Figure 2. Hundreds of other pseudocolour transformations are possible and can be obtained easily on the TV monitor. Owing to the way in which digital data are displayed on the square pixel arrangement of the television monitor, a distorted projection is presented. All illustrations in this note approximate a rectangular display of meridians and parallels, and the coastline and geographic coordinates were generalised and added independently of the digital data files.

The bottom-left coloured image also shows the effect of selected colour assignment: only topography higher than 120 m above sea level is displayed in colour, all levels below 120 m being assigned to black. The level to which black is assigned on such a display can be increased in real time to give the effect of progressive 'continental flooding'.

Bit-plane images

Once a digital data set has been quantised and loaded into a digital image analysis system, a variety of manipulations can be applied to enhance the image. One technique is to look separately at each of the bit-planes that are normally stacked together to make up the total stored image. This technique can be likened to the effect of performing spatial frequency filtering. The least significant bit-plane (bit 0) shows the greatest variation and is very noisy; it shows the odd and even image values. The most significant plane (bit 7 in an 8-bit image) shows the least variation and can be likened to an over-smoothed image. These two extremes, bit 0 and bit 7, have limited value when displayed as a binary image, but several of the intermediate planes show features (particularly lineaments) more readily detectable than in other DTM manipulations (Harrington & others, 1982).

Figure 5. Synthetic reflectance images for simulated sun elevation of 15° and various sun azimuth directions.


Azimuth 0°
Azimuth 180°
Azimuth 45°
Azimuth 225°
Azimuth 90°
Azimuth 270°
Azimuth 135°
Azimuth 315°

Synthetic reflectance images

The detection of lineaments with topographic expression is often facilitated by the presence of shadows, and this principle is used in terrain interpretation of aerial photographs, satellite images, and side-looking radar imagery. A constraint on its usefulness, however, is that lineaments with topographic expression aligned parallel to the illumination direction have no shadows. The strongest shadows are formed by features oriented perpendicular to the illumination. Using reflectance map techniques, synthetic images for any given conditions of sun illumination can be generated from topographic gradient data derived from a DTM (Horn & Bachman, 1978; Horn, 1981).

The reflectance of a surface element for given illumination conditions is a function of its gradient, and a reflectance map shows the relation between the apparent brightness of a surface element and its gradient in the west-to-east and south-to-north direction. Hence, for any given conditions of sun illumination (defined by azimuth θ and elevation ϕ), a synthetic image of apparent brightness at each point on the DTM under discussion can be derived and displayed as a monochrome image.

In defining the reflectance map, the topographic gradient for each surface element in the DTM must be calculated as an intermediate step. The gradient of a planar surface has two components along two mutually perpendicular directions. If the surface height, z, is expressed as a function of two coordinates, x and y, then the two components, p and q, of the gradient are defined as the partial derivatives of z with respect to x and y respectively. In this case, if the x-axis points east, the y-axis points north, and the z-axis is up, then p is the slope of the surface in the west-to-east direction and q is the slope in the south-to-north direction:

$$p = \frac{\partial z}{\partial x} \qquad q = \frac{\partial z}{\partial y}$$

One estimate of the gradient for a DTM is derived using first differences:

$$p \simeq (z_{i+1,j} - z_{ij})/\Delta$$
$$q \simeq (z_{i,j+1} - z_{ij})/\Delta$$

where $(z_{i+1,j})$ is the point immediately to the east of (z_{ij}) and $(z_{i,j+1})$ is the point immediately to the south of (z_{ij}); Δ is the grid spacing. This simple approximation was found to be sufficient for this application and has the advantage of being easy to calculate. These two intermediate gradient data sets can be displayed as monochrome images, as shown in Figures 3 and 4. In these illustrations dark areas show low (negative) gradients and light areas show high (positive) gradients, the overall impression being of illumination from the west and south, respectively.

Treatment of the DTM for a west to east gradient (Fig. 3), for example, shows a series of northwest-trending lineaments across central and western Australia, which are not so obvious in the south to north gradient image.

After derivation of the two-component gradient for each surface element in the DTM, apparent brightness, as observed looking down the z-axis (i.e. perpendicular to the plane of the DTM), can be calculated for each surface element using:

$$\Phi p,q = \frac{(1+p_s p+q_s q)}{\sqrt{1 + p_s^2+q_s^2}\,\sqrt{1+p^2+q^2}}$$

where $p_s = \sin\theta \cot\phi$, and $q_s = \cos\theta \cot\phi$

Using this equation, after Horn & Bachman (1978), a series of synthetic monochrome images was displayed in which sun elevation (θ) was maintained at 15° and the sun azimuth (ϕ) was changed in increments of 45°. It should be noted that the surface albedo was assumed to be 1 (i.e. perfect reflector) and that, since the reflectance map gives reflectance as a function of the local surface gradient only, it does not take into account effects of the position of the surface element, such as mutual illumination of surface elements and cast shadows.

The images are shown in Figure 5, and for comparison are positioned so that opposing illumination directions are adjacent. The mind is not conditioned to seeing apparent relief illustrations with illumination from the south, and the illusion of inverted relief can sometimes occur. The illustrations were photographed from the TV screen and in this paper are reproduced at a very small size. Despite this, the potential of such images for studying continental structures, both linear and circular is apparent. For example, on several images a broad lineament can be seen extending from Spencer Gulf to the bottom of the Gulf of Carpentaria. Several comparable features noted in the DTM are discussed by Harrington & others (1982).

The types of display and manipulation discussed above are applicable not only to topography, but to any digital data sampled on a regular grid, for example gravity, magnetic, and radiometric data. Data can also be superimposed as multiple sets, and there is considerable scope for the development of these new techniques for structural analyses of large regions.

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