Photogrammetry in Focus

The Digital Hypsographic Model

BY STEPHEN M. PERKINS, O.L.S.

A digital map has more to offer than a conventional cartographic product. Where as map on paper uses symbolism and shading to depict terrain relief, a digital map can store and later process true three dimensional information.

It is easy to visualize the existence of three dimensional features such as buildings, roads and bridges within a digital map. These features are typically constructed with well defined linear or curvilinear boundaries. Harder to visualize is the definition of free-form surfaces such as ground terrain. Hypsography, the art of mensurating the continually changing elevations of the surface of the earth, is the branch of science that deals with these definitions.

Hypsographic modelling is used to allow free-form three dimensional surfaces such as the surface of the earth to be defined in a computer model. By definition, a hypsographic model must yield information such as elevation, slope and volume at any point within the model area. Engineering and architectural designers should be able to use these properties to design or modify projects that are linked to the surrounding hypsographic information. Hypsographic models can be stored efficiently in a digital format and can be used to detail accurate terrain information.

On a two dimensional piece of paper, the display of surface elevation was traditionally achieved through the use of contours. Webster's Dictionary defines contours as;

> *"lines that connect points on a land surface that have the same elevation".*

Traditional maps that depict hypsographic information show a series of curving lines that are annotated with an elevation. Figure 1 depicts a road intersection in planimetric view and includes contour lines at 25 centimetre intervals. The contour lines allow for the visualization of terrain relief on a two dimensional piece of paper. Typically, elevation text is shown on every fifth contour with the number reading 'up hill'. For this example, text was placed on all contours for clarity.

The difference in height between opposing contours is termed the contour interval. By definition, contour lines closer together depict a steeper slope of the terrain than contour lines further apart. In addition, an elevation for any point on the entire map can be extrapolated by determining its position relative to at least two contour lines.

There are two related drawbacks to the use of contour lines in a digital hypsographic model. The first is that accuracy inherent in the use of the contour lines to extrapolate hypsographic information anywhere on the model is limited. For example, if the contour interval in a model is one metre, terrain undulations in an amount less than one metre will not be stored in the model. Therefore, to be more accurate, a contour interval of a smaller amount would have to be used.

This would then exacerbate the next problem, model size and related computer storage space. Line strings in a computer model tend to take up a large amount of space and require more processing ability on behalf of the computer.

With digitally stored contour lines, a series of points of equal elevation are joined with small line segments. When viewed in its entirety, the line string appears as a smooth curving line. When viewed at close range, the single segments of lines are visible. If one line on

Figure 1

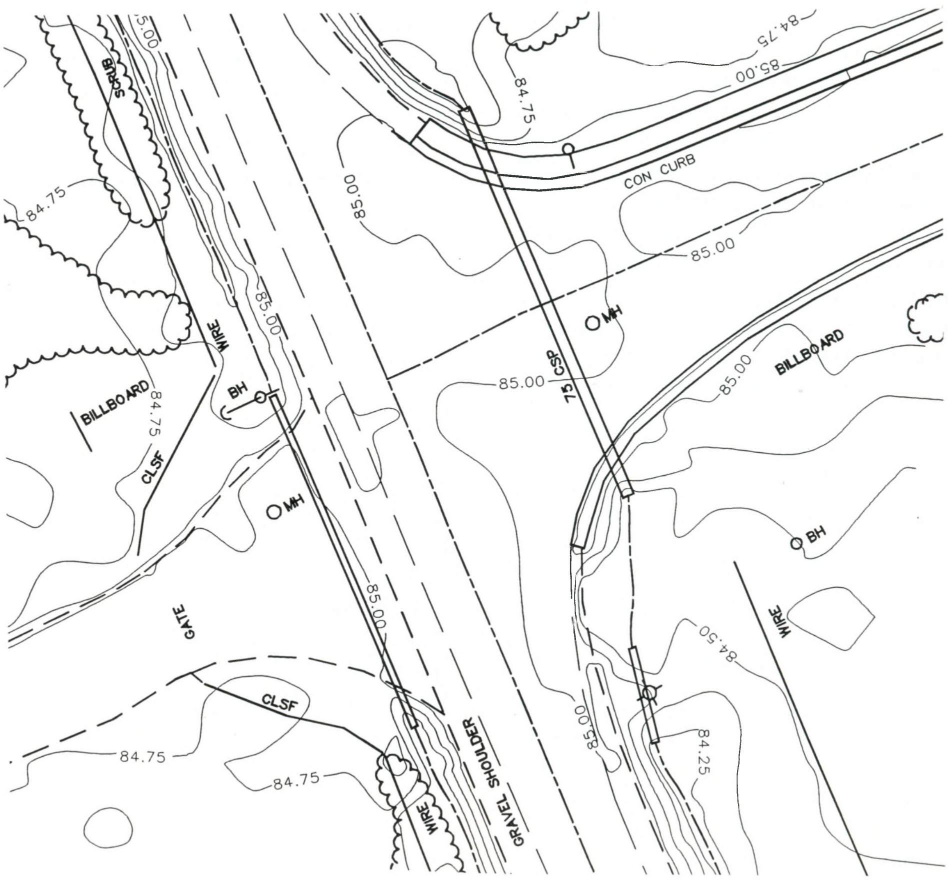
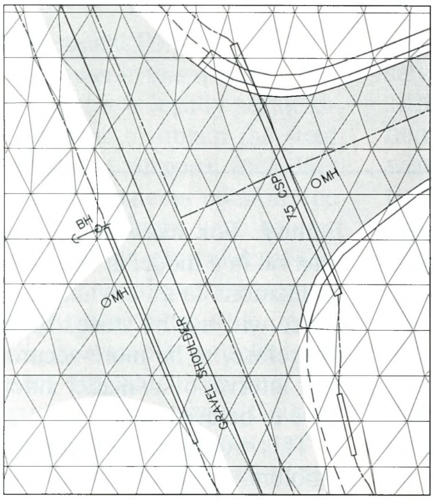


Figure 2 (a)



the line string is deleted, the entire line string will be deleted because all of the lines are connected.

The majority of computer applications that use hypsographic models work by laying three dimensional triangles onto the model surface. Triangles are used because the three vertices of the triangle define a single flat planar surface. These triangles are fit to completely cover the entire model area. Generally, the smallest triangle allowable will be fit between three opposing data points. These triangles can be analyzed by the computer to solve elevation and slope information at any point in the model. Also, the triangles can be used to construct contour lines for cartographic display. Unfortunately, when triangles are calculated relative to contour lines, each point on the line string is used. Therefore, the number of triangles is usually too numerous to be effectively probed for terrain information.

> *"'Bezier splines' are a class of mathematically defined curves and surfaces in three dimensional space."*

A more efficient way of modelling digital terrain information is with the use of three dimensional point data. This involves covering the model area with a grid of three dimensional points, each of which has a location (x and y), and elevation (z). Using photogrammetry, an operator can follow a grid pattern on the photograph and digitize a three dimensional point on the surface of the terrain. The predefined grid size is related to the size of the project area and the accuracy required in the terrain model. The resultant grid model can be 'triangulated' more efficiently than the contour model.

For reference, this modelling technique is described by two terms. Digital Elevation Model (D.E.M.) refers to the grid of points measured for the model. Digital Terrain Model (D.T.M.) refers to the elevation data contained in the D.E.M. The computer file containing the triangles used in processing is sometimes referred to as the 'D.T.M.'

Figure 2(a) depicts the same road intersection as in Figure 1, but instead of contours, shows triangles that have been 'fit' between three dimensional data points. In the computer, each vertex of the triangle is defined in x, y, and z. Using this data, each triangle can be probed to find elevation and slope information.

On its own, a grid of three dimensional points cannot depict terrain information entirely. In the middle of a field the model is adequate, however, where linear features 'break' the continuity of the terrain, or at the edges of area features, the model is not effective. Such is the case when a ridge in the terrain or an edge of pavement does not occur exactly on the grid line.

To complete the model, 'breaklines' are used. Breaklines are linear features depicted in the model using a series of points at a density greater than that of the regular grid. To be effective, the distance between points in a breakline are usually defined as one third the distance between grid lines. Using three dimensional breakline features embedded in a grid of points allow for the creation of triangles that accurately depict free-form surfaces broken with linear elevation changes.

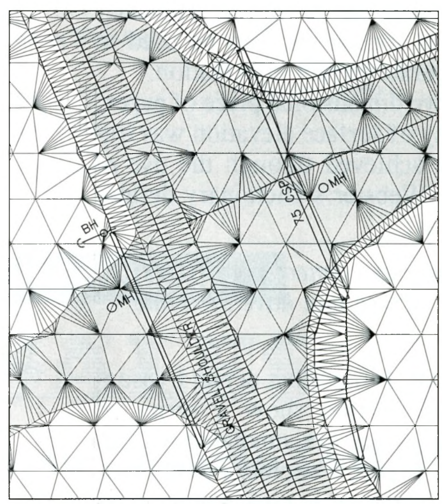
Figure 2(b) depicts the same model as in Figure 2(a) but with densified breakline information. Notice that there are many triangles fitted to linear features that also give elevation information in the model. The road centerline, road edge, sidewalk, and bottom of ditch have all been densified.

This model is more efficient than contour modelling, however it does have some drawbacks. Once again, the size of the data set is restrictive. Once breaklines are densified, there can be as many three dimensional points as in a contour model. To be fair to the D.E.M. though, it should be noted that data in this model is better organized and more descriptive than the contour data.

The solution to the size problem brings this discussion to the forefront of D.E.M. software technology. The solution offered by some leading edge D.E.M. processing software has been to replace the breakline information with linestring data. These three dimensional linestrings are acknowledged by the software as lines which cannot be crossed by triangles that are matched to the regular grid of points. What this does is reduce the amount of data points re-

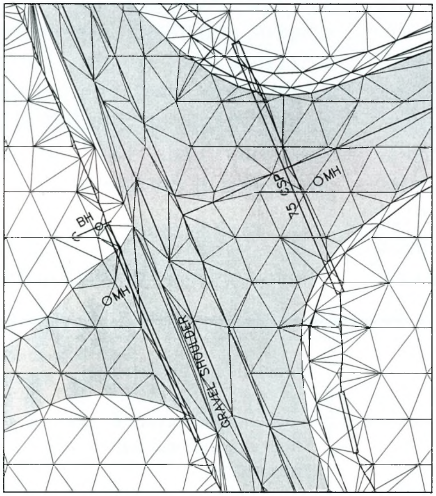
continued on page 47

Figure 2 (b)



continued from page 18

Figure 2 (c)



quired along a breakline by requiring points only where the linestring breaks up, down, left or right. A densified breakline requires points at predetermined and regular interval whereas collinear points on a line string are not required. The size of the D.E.M. using this technique can be reduced by over 60 percent in most cases.

Figure 2(c) depicts triangles that have been fitted to the grid of D.E.M. points while observing the linestring breakline data. Notice that no triangles cross over the linear features shown in Figure 1. There are fewer triangles in this model and yet the terrain is described as accurately as in Figure 2(b).

The other drawback to D.E.M. technology is that by definition, the model cannot depict vertical surfaces or two surfaces in the same model. For instance, when two breaklines are coincident in x and y when depicting a vertical retaining wall, or when a bridge surface obscures the surface below, the terrain software will not be able to fit triangles on the data set. This is because two points of different elevations cannot share the same positional value.

The solution to these problems may force current D.E.M. users to change to a surface definition by free-form three dimensional 'Bezier spline' surfaces.

'Bezier splines' are a class of mathematically defined curves and surfaces in three dimensional space. The idea behind bezier splines is that only a few 'control' points located in cartesian space define the location of the curve or surface that they represent. The control points for the surface do not necessarily touch the terrain that they approximate. By moving one or more control points, the definition of the free-form surface changes.

Currently, the problem with using bezier splines is that it is very hard to manipulate the free-form surface of the spline to conform to the surface of the hypsographic model. However, if modelling techniques become better defined, and if systems are developed to allow photogrammetrists to visualize both the terrain and the spline surface in the same viewing space, widespread use of bezier splines may be realized.

"With the latest developments in digital hypsographic modelling, designers are abandoning the practises of conventional two dimensional design and drafting techniques."

With the latest developments in digital hypsographic modelling, designers are abandoning the practises of conventional two dimensional design and drafting techniques. They are now free to pursue true three dimensional design work. In the future, this technology can be combined with virtual reality tools to improve current visualization methods. Projects can be designed and adjusted using inexpensive computer models saving time, materials, resources and therefore money. The digital hypsographic model has evolved from contour lines into a more precise and accurate definition of free-form surfaces because of the power of the computer and the software designed for them.

Stephen Perkins graduated from the University of Toronto with a B.Sc. in Surveying Science and received his OLS in 1992. He is the Geographic Systems Coordinator for the Surveys and Mapping Branch of the Regional Municipality of Ottawa-Carleton.