COMPUTER GRAPHICS TECHNIQUES FOR GENERATING TERRAIN AND LANDSCAPE VISUALISATIONS

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ABSTRACT

A review of methods of generating computer visualisations using digital terrain and landscape modelling data is presented. Particular emphasis is placed on the procedures for rendering terrain and landscape models. The paper concludes by considering the role of photogrammetry in this field of activity.

1. INTRODUCTION

The representation of relief is a fundamental component of the cartographic process. A wide range of techniques for representing the topographic variations of the earth's surface on a two dimensional surface have been developed and these vary both in their symbolic content and in their degree of realism (Figure 1).

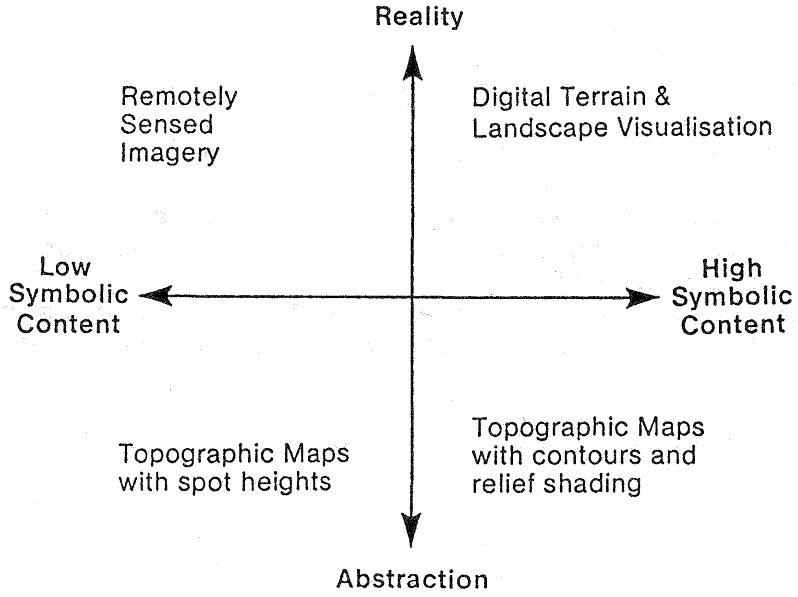

Figure 1 : Classification of Techniques for Visualising Terrain

Increasing emphasis has been directed recently towards the development of computer based display techniques which combine a high degree of image realism with a high level of symbolism. Where such techniques are used to describe the 3-D shape of the earth's surface and man made or other 'cultural' information, the process is referred to as digital terrain and landscape visualisation.

The input data for such a process will normally consist of a digital terrain model (DTM) to define the geometric shape of the earth's surface, together with further digital data to describe landscape features. For applications at small scales, this landscape information may be polygonal land use data, while at larger scales it may include explicit 3-D geometric descriptions of individual features or blocks of features. Although the photogrammetric acquisition of DTM data is well established and has been reviewed by Petrie (1987), to date, much less attention has been directed towards the photogrammetric acquisition of 3-D descriptions of significant objects on the terrain. Although the 3-D co-ordinates of features such as buildings may be observed, in many cases the Z co-ordinate values are deemed superfluous and do not form part of the recorded dataset.

While there is no shortage of techniques for general visualisation purposes, the characteristics of the earth's surface can significantly limit the applicability of many of the more general purpose techniques. Some of the more important differences between terrain and landscape visualisation and other forms of visualisation are that:

(a) natural phenomena are inherently more complex than man made objects and thus more difficult to model;
(b) the earth's surface is not geometric in character and cannot be modelled effectively by using higher order primitives such as those used in solid modelling CAD/CAM applications;
(c) the terrain and landscape model dataset sizes are considerably larger than the datasets in many other forms of visualisation;
(d) there are generally higher constraints on geometric accuracy than in many other applications;
(e) the scenes are not spatially compact and therefore the modelling may involve multiple levels of detail based on the object/viewpoint relationship;
(f) the optical model is more complex due to the effects of atmospheric refraction and earth curvature which are encountered in extensive datasets.

2. TECHNIQUES FOR DISPLAYING DIGITAL TERRAIN AND LANDSCAPE VISUALISATIONS

The degree of realism which can be achieved in the visualisation process is dependent upon several factors including the nature of the application, the objective of the visualisation, the capabilities of the available software and hardware and the amount of detail recorded in the model of the scene. At one end of the realism spectrum are relatively simple, highly abstract, static, monochrome, wireframe models while at the opposite end are sophisticated, highly realistic, dynamic full colour images. The former approach is currently more common for site specific, design purposes in fields such as landscape architecture and civil engineering, while the latter tend to more restricted to regional applications in military and flight simulation.

2.1 Display of 2-D Terrain Models

A number of relatively simple techniques have been developed for displaying DTMs on a computer graphics display. All are essentially extensions of the traditional cartographic process of representing relief on a 2-D surface. Probably the most common method which is used to indicate height variations on a 2-D surface is the contour. Colour graphics display devices may be used to portray contour lines, although colour variations are more commonly used to give an appreciation of the height variations rather than the traditional variable line widths. An extension of the colour coding of contour lines is to colour code the areas between contour lines as an aid to improving the appreciation of the topographic variations. Faintich (1984) discussed the use of a number of such techniques, particularly for the detection of gross errors in terrain data.

In addition to the display of contours, information such as slope and aspect can be derived from a DTM. By combining both attributes it is possible to replicate the technique of relief or hill shading. Scholz et al, 1987 have recently discussed the procedures adopted to automate the production of relief shading on 1:250,000 scale aeronautical charts.

These techniques are capable of meeting the display needs of many users. They do, however, suffer from a number of deficiencies including the production of a highly abstract view of the terrain from a fixed viewing position with little opportunity for including landscape features in the displayed image.

3. METHODS OF RENDERING 3-D TERRAIN AND LANDSCAPE MODELS

A number of alternative strategies exist for the transformation and display, or 'rendering' of 3-D terrain and landscape models onto a 2-D raster scan display. The first, and computationally the simplest, involves the use of a video digitiser to 'frame grab' a photograhic image. The position of new features may then be added to the model. The second, and computationally the most complex approach, is to mathematically define all features within the model. The basic elements of this approach are discussed in section 3.1. In some cases a hybrid approach may be adopted where photographic images are used to model complex natural phenomena and are combined with terrain and landscape features which are modelled by computer graphics.

3.1 Review of the Rendering Process

Having assembled the model of the terrain and associated landscape features contained within the required scene, the scene may then be rendered onto a suitable display system. The rendering process, however, requires a number of other parameters to be defined (Figure 2) including:

(a) the viewing position and direction of view of the observer;
(b) a lighting model to describe the illumination conditions;
(c) a series of "conditional modifiers", parameters which describe the viewing condition of the landscape objects (under wet conditions, for example, the surface characteristics of objects are quite different from dry conditions);
(d) a set of "environmental modifiers", parameters which describe atmospheric conditions and may model effects such as haze; and
(e) a sky and cloud model representing the prevailing conditions.

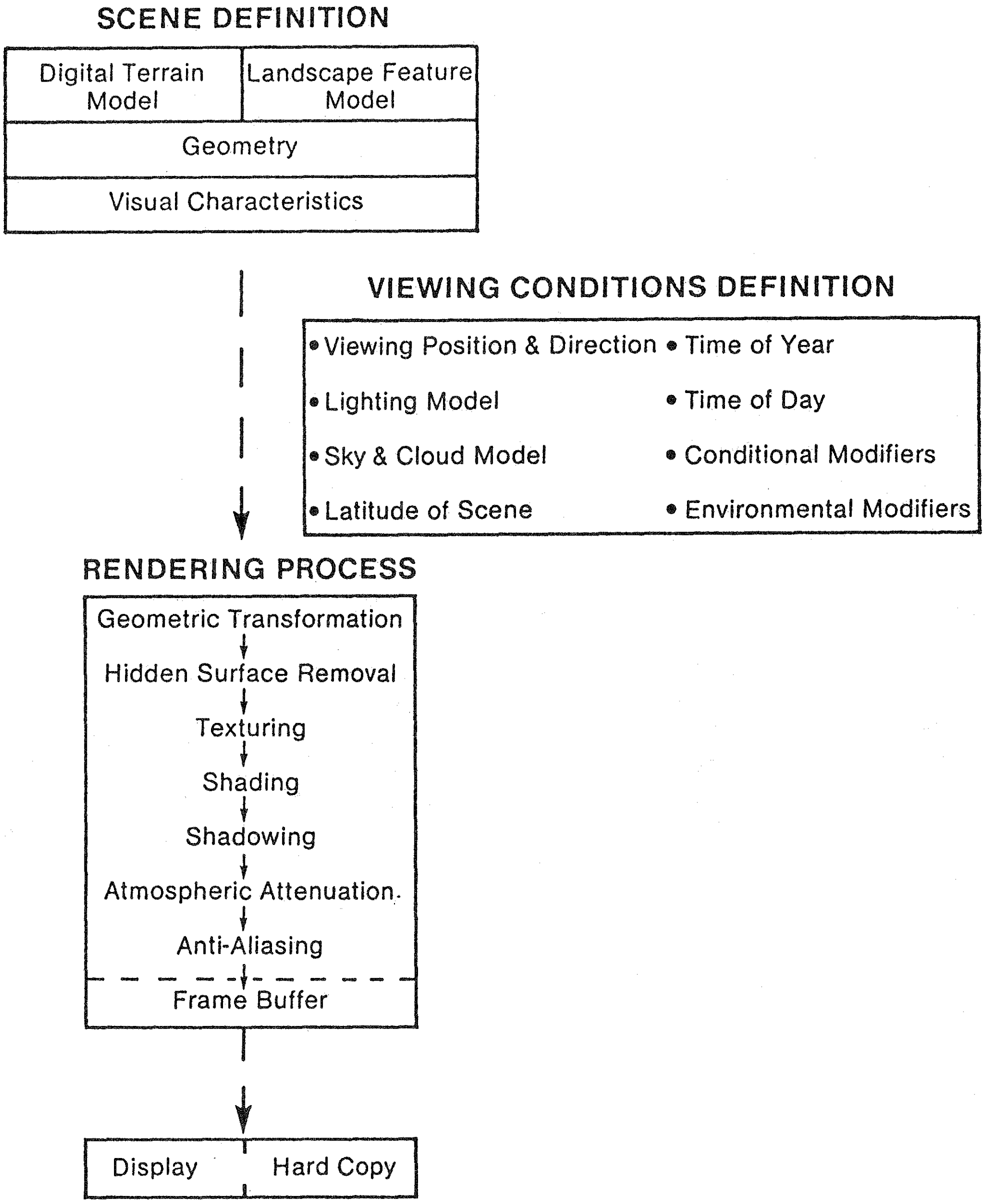

Figure 2 : Procedures Involved in the Rendering Process

All, or part, of the information may then be used by the scene rendering process to generate a two dimensional array of intensities or pixel values that will be displayed on the raster display device. The complexity of the rendering process is directly dependent upon the degree of image realism required by the user and an overview of the rendering process is shown in Figure 2.

3.1.1 Geometric Transformations

The 3-D terrain and landscape information is normally mapped into 2-D space by a perspective projection, where the size of an object in the image is scaled inversely as its distance from the viewer. The projection in effect models a "pin hole" camera. For site specific applications where the geometric fidelity of the rendered scene is of vital importance, for example the creation of a photomontage product in visual impact assessment, it may also be necessary to incorporate both earth curvature and atmospheric refraction corrections into the viewing model.

3.1.2 Depth Cueing

When a 3-D scene is rendered into 2-D space with any level of abstraction, an ambiguous image may often be portrayed. To compensate for this loss of inherent 3-D information, a number of techniques have been developed to increase the 3-D interpretability of the scene using depth cueing techniques that attempt to match the perceived computer generated image to our "natural" visual cue models.

Firstly, depth cues are inherent in the perspective projection used to create the 2-D image. When a projected object is known to contain parallel lines, then this type of projection is excellent at depicting depth, since parallel lines seem to converge at their vanishing points. This very effective visual cueing is highlighted when comparing the projection of a triangular DTM with its equivalent square grid derivative, in their wire frame forms. The depth cueing is pronounced in the square grid form due to the combined, convergent effect of parallel lines and the diminishing size of the uniform squares. The triangular form, with its lack of uniformity and randomness of triangular size, can present a very ambiguous and confusing image that requires further cueing techniques to allow adequate interpretation.

Although images formed by wireframe models with hidden edge removal are primitive images with no pretence at being realistic, they still portray form and geometric fidelity and provide an inexpensive technique for visualisation. Major advantages are the low overheads in their production and their ability to be output on standard vector plotting devices.

A second depth cue corresponds to the relative lighting intensities of objects. Through atmospheric attenuation, more distant objects lose contrast and appear dimmer than closer ones. If the sky is modelled in the scene, then this can also add to the depth cues by ensuring that the sky appears lighter overhead than at the horizon and thus conforms to reality.

Object simplification is a further form of depth cueing. As an object recedes from a viewer, it diffuses through several forms of apparent simplification until it eventually disappears from sight. This is due to the limited resolution of the eye's optical system and is influenced by atmospheric distortion and the shape and texture of the object. Computer graphics can also be used to generate stereoscopic images that provide a very powerful depth cue. Whiteside et al, 1987 discuss the production of simulated stereoscopic perspective views of the terrain using digitised vertical aerial photography and digital terrain elevation data (DTED) produced by the United States Defense Mapping Agency.

3.1.3 Hidden Surface Removal

Hidden surface removal techniques are employed to remove the edges and surfaces that are obscured by other visible surfaces. The implementation of the technique of hidden surface removal is computationally expensive, especially for complex landscape scenes, where the rendering process can involve hundreds of thousands of surfaces. Therefore the challenge has encouraged a wide variation of algorithms. These can be categorised into two fundamental approaches: Image Space and Object Space algorithms.

One of the most popular algorithms used is the Z-buffer or refresh buffer image space algorithm. This approach assumes that the display device has a Z-buffer, in which Z-values for each of the pixels can be stored, as well as the frame buffer in which the intensity levels of the pixels are stored. Each polygon is scan-converted into the frame buffer where its depth is compared with the Z-value of the current pixel in the Z-buffer. If the polygon's depth is less than the Z-buffer value then the pixel's frame buffer and Z-buffer values are updated. This is repeated for each polygon, without the need to pre-sort the polygons as in other algorithms. Hence, objects appear on the screen in the order they are processed.

3.1.4 Anti-Aliasing

Many computer graphics images displayed on raster display devices exhibit disturbing image defects such as jagging of straight lines, distortion of very small or distant objects and the creation of inconsistencies in areas of complicated detail. These distortions are caused by improper sampling of the original image and are called aliasing artefacts. Techniques known as anti-aliasing, which have their roots in sampling theory, have been developed to reduce their influence (Crow, 1977).

3.1.5 Shading

The next step towards the goal of realism is the shading of visible surfaces within the scene. The appearance of a surface is dependent upon the type of light source(s) illuminating the object, the condition of the intervening atmosphere, the surface properties including colour, reflectance and texture, and the position and orientation of the surface relative to the light sources, other surfaces and the viewer. The objective of the shading stage is to evaluate the illumination of the surfaces within the scene from the viewer's position.

The effectiveness of the shading algorithm is related to the complexity of the model of the light sources. Natural lighting models, in the case of landscapes under daylight conditions, are normally simplified by assuming that there is only a single parallel light source i.e. the Sun. Refinements to this light model have been developed by Nishita and Nakamae (1986), in which the lighting model is considered to be a hemisphere with a large radius that acts as a source of diffuse light with non-uniform intensity, thus simulating the varying intensity of sky lighting.

There are two types of light sources apparent in the environment: ambient and direct. Ambient light is light reaching a surface from multiple reflections from other surfaces and the sky, and is normally approximated by a constant illumination on all surfaces regardless of their orientation. This simplified model produces the least realistic results since all surfaces of an object are shaded the same. However, more complex modelling of the ambient or indirect component of lighting has produced enhanced realism using ray tracing techniques (Whitted, 1980) to model the contribution from specular inter-reflections and transmitted rays, and radiosity techniques (Goral et al, 1984) to account for complex diffuse inter-reflections.

Direct light is light striking a surface directly from its source without any intermediate reflection or refraction. This can be broken into two components: diffuse and specular, depending on the surface characteristics. The diffuse component is re-radiated equally in all directions while the specular component is re-radiated in the reflected direction. Both reflected components must be modelled to create realistic images. The diffuse component is simple to compute since it is independent of the viewing position. The specular component is however, more complex to model since real objects are not ideal reflectors, a portion of the light being reflected off the axis of the ideal light direction. Phong (1975) developed an empirical approximation which was subsequently refined by Blinn (1977) and Cook and Torrance (1982).

Having modelled the intensity of colour at a point, this must now be expanded to encompass a surface, normally defined by a polygonal mesh. In Gouraud's approach (Gouraud, 1971), the true surface normals at the vertices of each of the polygons are calculated. When the polygon is converted into pixels, the correct intensities are computed at each vertex and these values are used to linearly interpolate values across the polygonal surface. An alternative, but computationally more expensive approach, was developed by Phong (1975).

3.1.6 Shadows

Shadows are an essential scene component in conveying reality in a computer graphics image. A scene that appears "flat" suddenly comes to life when shadows are included in the scene, allowing the comprehension of spatial relationships amongst objects. Shadows provide the viewer with one of the strongest visual cues needed to interpret the scene.

The fundamental approach is equivalent to the hidden surface algorithm approach. The shadow algorithm determines what surfaces can be "seen" from the light source. Those surfaces that are visible from both the viewpoint and the light source are not in shadow. Those that are visible from the viewpoint, but not from the light source are in shadow. A variety of shadow algorithms have been developed and can be categorised into five groups (Max, 1986) : Z-buffer, area subdivision, shadow volumes, pre-processing and ray tracing.

3.1.7 Surface Texture Detail

Natural landscape scenes are characterised by features with a wide variety of complex textures. Computer graphics visualisations of landscapes can only achieve an acceptable level of realism if they can simulate these intricate textures. The "flat" shading algorithms, described in the previous section, do not meet this requirement directly since they produce very smooth and uniform surfaces when applied to planar or bicubic surfaces. Therefore the shading approach must be supplemented by other techniques to either directly model or approximate the natural textures.

The explicit modelling approach involves creating a more detailed polygonal and colour model of the landscape and surface features to enable a higher level of detail and texture to be visualised. For landscape visualisation, explicit modelling has so far proved impractical due to the size and intricacy of the model that would have to be created to reflect the required level of detail.

Texture mapping provides the illusion of texture complexity at a reasonable computational cost. The approach refined by Blinn and Newell, 1976 is essentially a method of "wallpapering" existing polygons with a user defined texture map. This texture map can for example, represent frame grabbed images of natural textures. A modification of the texture mapping technique is to utilise satellite remote sensing imagery to "clothe" the terrain model with natural textures.

A further approach for texturing terrain models involves the use of fractal surfaces. Fractals (Mandelbrot, 1982) are a class of irregular shapes that are defined according to the laws of probability and can be used to model the natural terrain. Simple models of the terrain are defined using quadrilaterals or triangles, which are subsequently recursively subdivided to produce more detailed terrain models. Some of the most successful examples of the use of fractals have been in the field of animation.

3.1.8 Atmospheric Attenuation

Due to atmospheric moisture content, objects undergo an exponential decay of contrast with respect to distance from the viewpoint. The decay converges to the sky luminance at infinity. This reduction rate is dependent upon the season, weather conditions, level of air pollution and time. The result is a hazing effect.

4. CONCLUSIONS

Computer generated visualisations of digital terrain and landscape scenes are now widely accepted in many application areas as efficient technical analysis, design and marketing tools. These applications range from visual impact analysis and urban design to military and flight simulation (Kennie and McLaren, 1988).

Visualisation techniques have tended to reduce the surveying industry's emphasis on 2-D methods of data presentation. In so doing, they have also highlighted the 3-D deficiencies in sources of data, in terms of availability and accuracy. Many large scale maps have minimal terrain elevation data and the majority ignore the 3-D aspects of surface features. This is currently inhibiting the wider application of these techniques although the increasing availability of national level DTM's is a promising trend. Photogrammetrists have an important role to play in the acquisition of both forms of data, particularly in urban environments. It is vital that they also become directly involved in the exploitation of these new data sources.

Despite the progress in this field, the visualisation of natural phenomena inherent in landscape scenes are still simplistic, forming "realistic abstractions". Many of todays landscape visualisation techniques use approximations such as photographs, frame grabbed images or texturing techniques to assist in the computer graphic synthesis of natural phenomena. Although the explicit modelling of many of these phenomena are currently prohibitive, they will become feasible with the increases in processing power offered by parallel processing architectures, minisupercomputer based workstations, high bandwidth links between supercomputers and workstations and the availability of customised VLSI for specific applications. The search for increasing realism will therefore continue to be a subject of importance for the future.

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