VISUALISATION TECHNIQUES AND APPLICATIONS WITHIN GIS

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ABSTRACT

The recent advances in computer graphics rendering techniques coupled with the availability of digital terrain model information have opened up new possibilities in viewing and analysing spatial information within a GIS environment. Terrain and landscape visualisation techniques ranging from simple wire-frame models through to photorealistic rendering approaches such as ray tracing and radiosity are reviewed. The techniques are then placed within the context of a variety of GIS applications including: spatial analysis, urban planning, architectural design, cartography, highway and traffic engineering, and environmental impact assessment.

INTRODUCTION

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 geometric and descriptive data to define 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 and its subsequent management within a GIS environment is well established, to date, much less attention has been directed towards the acquisition and management of 3-D geometric and visual descriptions of significant objects on the terrain. Normally, the 3-D co-ordinates of features such as buildings are observed during photogrammetric measurement, but in many cases the Z co-ordinate values are deemed superfluous and do not form part of the recorded dataset. This is primarily due to the inadequacy of GIS to handle data structures associated with volumes. Hence the more sophisticated visualisation techniques are currently being performed on CAD/CAM oriented systems.

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, especially those found in the advertising and entertainment industries, 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.

These inherent complexities of natural phenomena have inhibited the wider use of available computer graphic tools. However, recent advances in the sophistication of the rendering algorithms, the lowering in cost of high performance imaging systems, the emergence of PC based rendering platforms, and the arrival of standards such as RenderMan will help these visualisation techniques to filter down to low-cost systems, adding another valuable technical as well as marketing component to the GIS toolkit.

METHODS OF RENDERING 3-D TERRAIN AND LANDSCAPE MODELS

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.

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 photographic 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 2.1. 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. This is described in section 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 1) 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.

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 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. 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.

Depth Cueing When a 3-D scene is rendered into 2-D space with any level of abstraction, the result is often ambiguous. 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 and are emphasised when the scene contains parallel lines. 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.

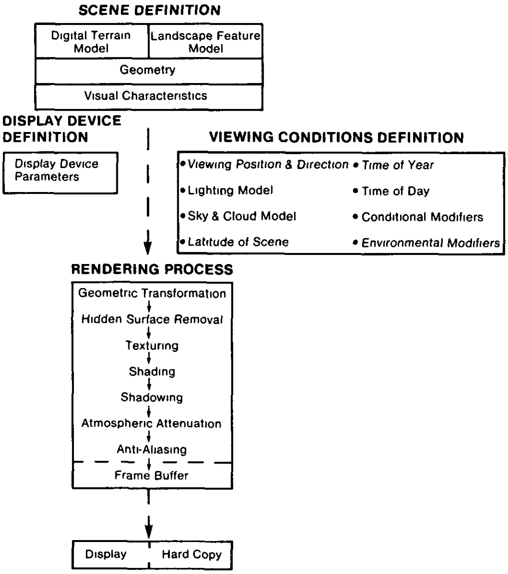

Figure 1 : Procedures Involved in the Rendering Process

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. 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 Defence Mapping Agency.

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. In this application area one of the most popular algorithms used is the Z-buffer or refresh buffer image space algorithm.

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).

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. Direct light is light striking a surface directly from its source without any intermediate reflection or refraction while Ambient light is light reaching a surface from multiple reflections from other surfaces and the sky. A number of levels of sophistication in the modelling of light are available. The more complex modelling of ambient 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.

When shading DTMs, the intensity of colour is calculated at each of the vertices of the polygonal mesh and then expanded using interpolation techniques to encompass the surfaces. This is achieved by interpolating using the Gouraud approach (Gouraud, 1971), or alternatively the computationally more expensive approach developed by Phong (1975).

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. A variety of shadow algorithms have been developed and can be categorised into five groups : Z-buffer, area subdivision, shadow volumes, pre-processing and ray tracing.

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. This is one of the more common methods in small scale GIS applications.

A further approach for texturing terrain models involves the use of fractal surfaces (Mandelbrot, 1982) where simple models of the terrain are defined using quadrilaterals or triangles, which are subsequently recursively subdivided to produce more detailed terrain models.

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.

APPLICATIONS

The use of visualisation techniques for both military and civilian applications is currently an area of significant growth. Some of the more prominent GIS applications are described in the following sections.

Landscape Planning - Visual Impact Analysis

Growing public awareness of environmental issues has been recently strengthened by the European Community's Directive on the "Assessment of the Effects of Certain Public and Private Projects on the Environment". This Directive will force certain proposed changes to the landscape to be publicly assessed for environmental impact. A component of this environmental audit is a statement on the visual intrusion of proposed landscape changes. Consequently, projects such as road construction, transmission line routing and open cast mining as well as more dynamic phenomena such as forestry will need to be visually judged.

Traditionally, landscape visualisation techniques have involved the building of physical models or the creation of artist's impressions. However, these are time consuming to create, and are inherently inaccurate and inflexible once created. In order to more accurately quantify the level of visual intrusion, computer graphic modelling and visualisation techniques are increasingly being used in the planning and design of landscape projects. These new approaches allow more accurate visualisations and more analytical assessments of visual intrusion to be determined. Due to the flexibility of the approach, many more proposed designs can be evaluated, resulting in a more refined design solution. Turnbull et al (1986) pioneered the development of a Computer Aided Visual Impact Analysis system (CAVIA) that has been used, for example, to provide evidence at public inquiries related to electricity transmission line routing through environmentally sensitive landscapes. Projects are typically performed at the sub-regional level with areas up to 40 x 40 km being analysed. The approach uses DTMs, landscape features and proposed design objects to produce an estimate of the visual intrusion. This visual intrusion toolkit includes intervisibility analysis to produce levels of visual impact, dead ground analysis, identification of the portions of the landscape forming a back-cloth for the design object, situations where the design object appears above the landscape horizon and the identification of optimal locations for vegetation screen placement.

One of the visualisation techniques used by CAVIA and other landscape planning systems is Photomontaging. A Photomontage is a physical or image composite of photographs of the existing landscape with a registered computer generated image of the proposed design object(s).

In this approach only the proposed design objects have to be rendered, avoiding the rendering of the intricate terrain and landscape detail. However, to achieve total image fidelity, the computer rendered portion of the image must effectively "merge" with the photographic image. Therefore, the atmospheric and distancing effects apparent in the photographic image must be inherited by the computer generated image. Nakamae, (1986) has developed techniques for merging image components to compensate for fog and aliasing effects. Future solutions to this problem will use a hybrid approach to rendering a photomontage image, incorporating ray tracing, frame grabbed images and textures, image processing and pixel painting techniques.

Road/Traffic Engineering

Visualisation has found a number of interesting applications in the field of road design. Many road engineering design systems are now offering visualisation capabilities. These form an integral part of the design process and allow the design to be subjectively assessed and refined for safety and visual intrusion in the context of its environment. The Transport and Road Research Laboratory of the UK have developed a system to model and visualise road designs. Applications of the system include;

(i) Road Lighting Scheme Design. In complex road designs or under environmental constraints, the design of an efficient road lighting scheme can be enigmatic. This is the perfect design environment for the application of visualisation techniques where the designer can directly examine the results of his design under a variety of atmospheric conditions.
(ii) Road Safety. Visualisation tends to imply aesthetic appearance. However, in this application, visualisation is concerned with the perceptual problems encountered by road users. Factors contributing to potential perceptual problems could be line of sight difficulties, incorrectly positioned street furniture or poor lane markings. In accident prone sites, the system can be used to identify possible contributing factors and to evaluate solutions.
(iii) Street Furniture Design and Placement. New designs for road signs and street furniture and their optimal positioning can be evaluated. This application has been taken one step further by the West German car manufacturer, Daimler-Benz, who have added dynamics and created a car simulator. The driver can experience driving a range of cars under a variety of driving conditions.

Architecture and Urban Design

In recent years urban renewal has become an activity increasingly exposed to and controlled by public and Royal opinion. Architects, in an attempt to alleviate public fears of a continuation of the "Kleenex Box" era, have turned to computer generated images to convince the public of the merits of their proposed building designs. Computer generated visualisations have become a fashionable marketing tool.

Although the architectural industry was one of the first application areas where Computer Aided Design (CAD) techniques were applied, it is only recently that tools for creating high quality visualisations of the resulting building designs have been made available. This capability is a natural extension of the CAD process and many CAD system vendors are now supplying this capability as an integral part of their system or as an interface to foreign visualisation packages.

Typically, architectural visualisations are not just isolated previews of the proposed building, but also include the contextual surroundings to allow appraisal of its applicability to the existing character of its urban environment. This usually involves the creation of a three dimensional model of the terrain, streets, street furniture and buildings in the immediate vicinity of the site. This approach was recently followed by Arup Associates in their submission for the development of Paternoster Square in London. The computer model of the development was created on a McDonnell-Douglas IGS system and supplemented with the surrounding urban details through photogrammetric measurement and direct input from the Ordnance Survey's digital map series.

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. Visualisation techniques have released the world from its traditional two dimensional approaches to display and in so doing, have highlighted the three dimensional deficiencies in our sources of data in terms of availability and accuracy. Indeed it is the lack of data that is currently inhibiting the wider application of many of these techniques.

Despite realism being a distant target, it acts as a convenient measure of our techniques and understanding and will continue to be relentlessly pursued to our continuing benefit. Continued increases in processing power through highly parallel architectures and customised VLSI will encourage the pursuit of the ultimate solution through the simulation of the phenomena based on the laws of physics. The present techniques of approximating or faking will be displaced by progressive refinements of the simulation model. This approach has been endorsed by the McCormick et al (1987) initiative on Visualisation in Scientific Computing.

In the GIS environment, visualisation techniques are recognised as an invaluable system component, aiding in the interpretation of spatially related phenomena and complex data analyses that takes the GIS a step beyond two dimensional polygonal overlay analyses. Many of the GIS vendors are including this capability in their systems to help cope in our understanding of the "fire hose" of data being produced by contemporary sources such as satellites.

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