SIMPLIFIED SCENE MODELING USING CURVED SURFACES AND TEXTURING

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ABSTRACT

Constructing a scene data base for current computer image generation systems is a costly and time-consuming task. Thousands of edges must be defined by positioning the end points, or vertices, of each edge. In addition, edges bounding a common surface or face must be linked in a list. Data for each face must include information for a normal vector, and data for faces representing curved objects must include information for normal interpolation to simulate smooth shading across the object. This paper describes a more efficient scene model that is easier to construct and yet produces a more faithful representation of the real world. Scene geometry is modeled by quadric surfaces bounded by planes. Scene detail is modeled by a mathematical texturing function which modulates surface shading intensity and translucence. The paper describes how the new model simplifies modeling terrain, cultural features, moving targets, and special effects.

INTRODUCTION

The problem of constructing a computer model representing the complexity of a real-world scene and allowing real-time image generation is a formidable one. Two decades ago, computer image generation (CIG) pioneers attacked this problem by applying a time-honored engineering axiom: "be wise - linearize." The linear scene model that they produced was defined by efficiency of image computation rather than by efficiency of modeling. Over the past 20 years, impressive developments in CIG techniques based on this model have reinforced its use. Over the same period of time, however, the sophistication and complexity of training missions have created new demands on CIG technology. Ironically, it is the past successes of CIG that have enabled training to move forward to the point where it can make these demands.

Current training requirements call for the capability to model extensive gaming areas and to represent scene detail with enough fidelity to support nap-of-the-earth (NOE) flight and ground based operations. The asymptotic progress of edge CIG technology indicates that these requirements can be satisfied only by a new, more efficient approach to scene modeling.

A NEW SCENE MODEL

In developing a new scene model, Grumman studied the problem from the top down, choosing the most efficient data base to represent the full range of scene features needed for today's training. These features include terrain, vegetation, cultural features, moving targets, clouds, smoke, and weapons effects. We determined that the most significant limitations in edge technology for modeling these features were due to its inability to model surface curvature and textural detail efficiently. We therefore focused our scene model development on devising efficient representation of these two features.

Surface Curvature

Quadric surfaces are mathematically the simplest form of curved surface and can represent individual scene features as individual volumes. This allows modeling many scene features, such as a bush or a boulder, by a single ellipsoid. Modeling such features in this way is much simpler than using edges because very few parameters are required to define a quadric surface, and these parameters relate directly to the shape and position of the feature being modeled.

Many scene features can not be represented by a single quadric surface alone. To allow more flexibility in our scene model, we include the capability to bound a quadric surface with planar surfaces[1]. This allows us to model a wide variety of curved and linear scene features in a very simple manner. For example, we can model an aerodynamic surface using a thin elliptical cone bounded by two planes. A gun barrel or tree trunk can be modeled by a cylinder bounded by two planes. We organize our data base as a set of such geometrically defined "objects," with each object defined by one quadric surface and up to six bounding planes. Complex scene features, such as targets, are modeled by multiple objects. A glance at Fig. 1 will show how this parametric approach

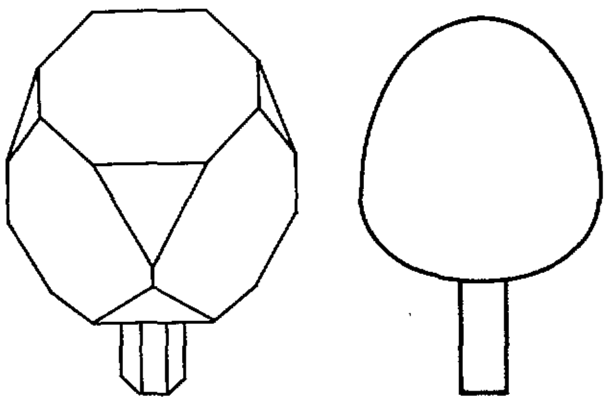

Fig. 1 Comparison of Two Tree Models

simplifies scene modeling compared to edge modeling. Using edges, the foliage for a single tree would require the positioning of many vertices, with lists linking vertices, edges, and faces. Using quadric surfaces, we need specify only three dimension parameters, three rotation angles, and three position coordinates for an ellipsoid, in addition to three rotation angles and three position coordinates for a bounding plane. The tree trunk can be modeled similarly by a cylinder and two bounding planes. Thus, the modeler will be required to define fewer data values, and these values will have a direct relation to the geometry of scene features he is modeling.

The significance of this simplification lies in the fact that any realistic scene will contain hundreds or even thousands of such features. Automated as well as manual scene modeling will benefit from this simplification since less data is involved, and the parametric nature of the data base allows straightforward definition of shape, size, and position.

Textural Detail

Most of the visual detail in real world scenes is due to minor topographical variations that would be very costly to model with a geometric data base. Such detail can be efficiently modeled using texture patterns mapped to the appropriate geometric surfaces. In studying various approaches to texturing, we developed a mathematical function that modulates surface shading intensity as the image is generated[2]. The texture function maps the pattern directly to scene surfaces with true perspective validity because its independent variables are the scene coordinates. This approach produces a very compact data base because only 25 function parameters define complex patterns covering large scene areas. In addition, many scene features can be textured using the same set of parameters. Because the pattern depends on the scene coordinates, each feature will look different from all the others. In this way we can model an unlimited number of individual trees or hills using a single set of texturing function parameters. Because the function parameters can be related to the spectral content of the texture pattern, modeling can be based on Fourier analysis of images of real-world features. Thus, the texture function has the potential for automated modeling.

One of the greatest advantages of the texturing function technique is the ability to control the function parameters on-line during image generation. This permits eliminating any high-frequency content of the pattern that would cause aliasing. Related to this feature is the ability to vary the detail of the pattern as a function of range. This provides a very efficient means of varying level-of-detail (LOD) without changing the geometric data base. Control of the function parameters also allows us to vary translucence across the surface of an object to enhance the modeling capability by simulating irregular boundaries and holes. Finally, by varying the parameters dynamically, we can simulate motion, such as tree leaf agitation and smoke rising.

In summary, the texture function simplifies modeling of scene detail by employing a minimal data base that can be related directly to the visual characteristics of specific real-world features. In addition, the texture function allows an efficient means of modeling irregular features, such as trees, clouds, and smoke, with dynamic capability.

SCENE MODELING WITH TEXTURED, QUADRIC SURFACES

Although quadric surfaces have been recognized as potentially useful for modeling a limited set of cultural features[3], they have generally been considered too simple to model the wide range of features required for combat training[4]. We have found that the limitations of quadric surfaces are greatly minimized by the addition of texturing, and that the combination of quadric surfaces and texturing provides an efficient data base for modeling the full range of features required for training, including cultural features, terrain, and special features.

Cultural Features

Many cultural features can be modeled by a single bounded quadric surface. Cylinders can be used for oil tanks and poles; spheres can be used for fuel tanks, lights of finite size, and radar domes. More complex cultural features can be modeled by sets of objects each consisting of a bounded quadric surface. Thus we can use a single object to model a wing, a canopy, an engine pod, a refueling boom, a tank turret, a gun barrel, a smoke stack, a wheel, or even a helicopter rotor disk. Complicated curved bodies, such as an aircraft fuselage, can be either approximated by a single object or modeled more accurately by multiple objects. In the latter case, care must be taken to fit abutting objects without noticeable surface discontinuities. The simplicity of the mathematics of quadric surfaces provides the potential for automated modeling aids to alleviate this problem. The simplicity of modeling cultural features typical of training scenes is demonstrated in Fig. 2, which shows how a tank can be modeled

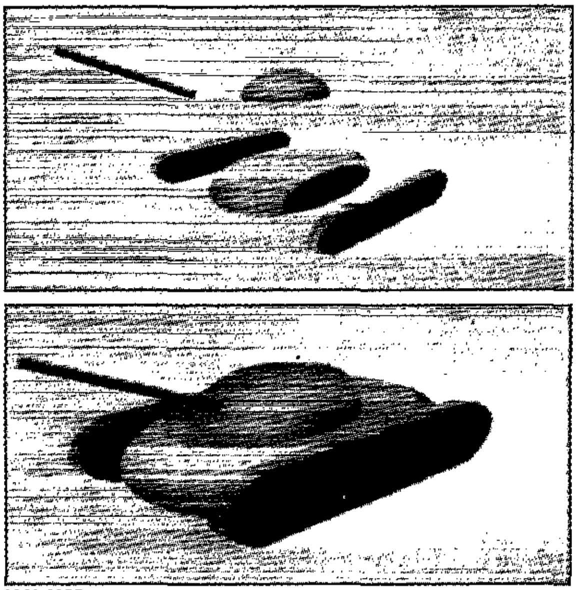

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Fig. 2 Tank Model Compressed of Five Bounded Quadric Surface Objects

efficiently with only five objects. Figure 3 shows a high LOD version of the tank using 51 objects.

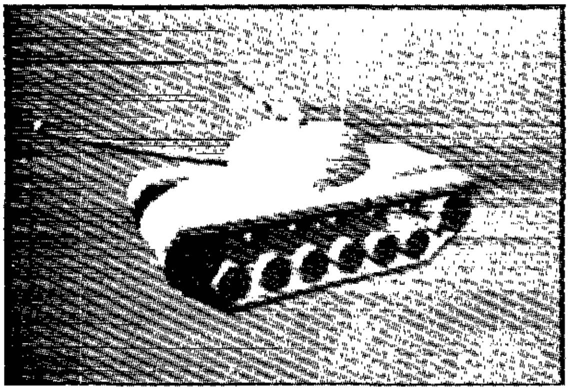

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Fig. 3 High Level-of-Detail Tank Model Composed of 51 Objects

Because each of our objects can include up to six bounding planes, they can be used to model linear, as well as curved, cultural features. To model complex linear features such as factories, we developed a program called "BLOCK," which creates buildings of arbitrary complexity using simple linear objects as building blocks. The building blocks are rectangular solids simply defined by three position and three dimension parameters.

Our texture function can be used to add detail to a cultural feature model. This detail can be linear, as in stripes on building walls, or non-linear, as in camouflage markings on targets.

An important consideration in modeling large gaming areas is implementation of the Defense Mapping Agency (DMA) cultural data information. Because this information defines features in generic terms only, it will be necessary to construct a library of generic cultural features which can be accessed, scaled, and positioned in the scene in accordance with the DMA data. The efficiency of our object modeling will facilitate the construction of such a library, and the parametric nature of the modeling will simplify scaling and positioning the features.

Terrain

The task of modeling arbitrary terrain has generally been approached by treating an extensive region as a single, complicated surface that can be approximated by a large number of planar patches. Because a linear model is so inefficient for modeling complex curved surfaces, an unacceptable number of edges would be required for a realistic representation. As a result, real-time edge systems must limit the edge allocation and produce primitive terrain images dominated by sharp linear boundaries.

A more efficient and effective way to model terrain is to represent it as the eye perceives it, as a set of individual topographical features, such as hills, mountain peaks, and ridges. Quadric surfaces lend themselves to this approach because each major feature can be modeled by a single curved surface free of linear artifacts. The quadric surface can be defined by 10 parameters specifying its shape and orientation in the scene. Although isolated quadric surface objects can be used to model some terrain features, in general, clusters of abutting objects will be required to provide a satisfactory representation of arbitrary terrain. This requires determining appropriate bounding planes to provide continuity between adjacent quadric surfaces. Figure 4 shows schematically how single or multiple quadric surface objects can be used to model terrain features.

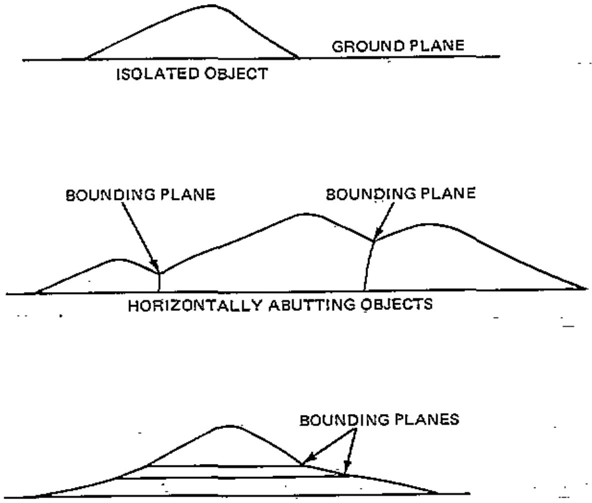

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Fig. 4 Examples of Terrain Features Modeled by Single and Multiple Bounded Quadric Surface Objects

Modeling the significant terrain features with quadric surfaces will produce a very compact data base free of linear artifacts, but will not by itself provide enough scene content for training. Our texturing function will produce the textural detail required to model the secondary topographical detail common in real-world terrain. A single texture pattern, defined by one set of texture function parameters, can be used to texture all surfaces, including the ground plane, within a defined region of arbitrary size. This provides a great deal of scene content with a minimal data base. In addition, the texturing enhances the appearance of surface continuity in the scene. Because we model major terrain features individually, we can also assign different texture patterns to different features. This will allow us to represent grass-covered hills, rocky mountains, and forest areas in the scene.

To satisfy the requirements of training missions involving low-level flight and ground-based operations, we must be able to model ground features, such as trees and rocks, with a fair amount of realism. Trees have been a particular stumbling block in edge modeling because edges define features in a very explicit manner. Thus, hundreds or even thousands of edges would be required to represent the complexity of a tree's foliage. Using quadric surfaces, we can model a tree with one or two textured objects. The parametric control inherent in our texturing function provides the irregular surface and boundary detail necessary to represent the essence of tree foliage without explicitly modeling each branch and leaf. An added advantage to this approach is the fact that the texture intensity is added to the quadric surface shading intensity. As a result, the overall shading of the model is representative of the illumination source, with "leaves" on the underside darker than those on top. In a similar manner, rocks and boulders can be modeled accurately by a single textured quadric surface for each.

To take advantage of quadric surface modeling of terrain features, we developed a computer program called "CNGEN" which generates clusters of hills, trees, and rocks. CNGEN operates on a very compact list of feature clusters. The data for each cluster include:

(1) coordinates and dimensions of a rectangular region on the scene ground plane and a grid spacing for positioning individual cluster features in the region,

(2) shape, and relative position parameters for template objects representing a typical cluster feature,

(3) an index to a list of texture function parameter sets,

(4) a set of three color parameters (RGB), and

(5) a translucence value.

For each cluster in the list, CNGEN adds pseudo-random increments to the grid position, color, and shape parameters of each individual feature and stores the features in a scene data base list. CNGEN greatly simplifies creating a terrain model of a large gaming area, and editing the scene is facilitated by the capability to change the position, extent, or character of a large number of objects at once. Different texture patterns or colors can be specified as well as different shapes and sizes for cluster features. Because of the efficiency of quadric surface modeling, the computation involved in CNGEN is minimal, suggesting the feasibility of on-line scene generation.

The simplicity and effectiveness of textured quadric surface modeling are demonstrated in Fig. 5

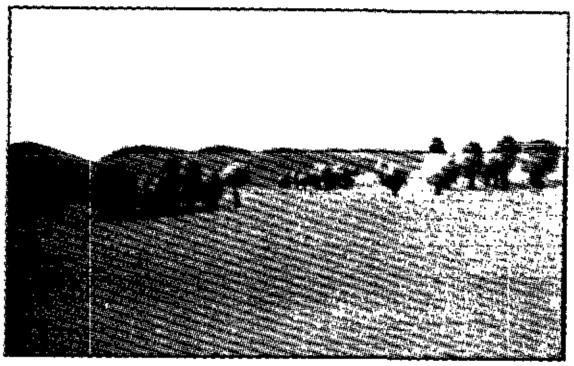

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Fig. 5 Terrain Scene Composed of 173 Bounded Quadric Surface Objects Without Texture

and 6. Figure 5 shows a terrain scene composed of quadric surfaces without texturing. Figure 6 shows the same scene with texturing. This model was generated by CNGEN from a list of 18 feature clusters defined by a total of 400 data values. The texture parameter file included data for seven texture patterns defined by a total of 175 data values. The final model included 173 objects, many of which are not visible in the image. We generated a dynamic sequence of NOE flight through this scene which confirmed the perspective validity of the modeling approach and demonstrated excellent flying cues produced by the high scene content.

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Fig. 6 Terrain Scene Composed of 173 Bounded Quadric Surface Objects with Scene Detail Produced by Texturing Function

To provide full terrain modeling capability for today's training requirements, we will have to use the DMA elevation data as a primary source. We have performed preliminary research in this area and have developed an approach to modeling the DMA data with textured quadric surfaces. This approach includes the following steps:

(1) Determine major terrain features by low pass digital filtering of the DMA elevation data.

(2) Isolate major features in the filtered data using digital image processing and pattern recognition techniques.

(3) Fit a single quadric surface to the original DMA data corresponding to each isolated major feature.

(4) Determine appropriate bounding planes for each feature to maximize continuity between adjoining surfaces.

(5) Determine appropriate texture function parameters by Fourier analysis of the original DMA data.

Under a National Science Foundation (NSF) grant we investigated the feasibility of our approach by means of a two-dimensional analysis in which we filtered profiles of actual digitized elevation data, isolated peaks, and fit conic section curves(5). The success of this work provides a firm basis for extension of the techniques to three dimensions. Terrain models generated in this fashion will produce a realistic, nonlinear data base that will greatly compress the information contained in the DMA elevation files. Our CNGEN techniques will then be extended to enhance the terrain elevation model by adding trees, rocks, and other surface objects.

Special Features

Although the great majority of scene objects can be modeled as solid objects with clearly defined boundaries, today's military training scenarios include scene features, such as weapons blasts, smoke, dust, and clouds, which can not be represented in the same explicit manner and must be treated as special features. These features are characterized by a lack of solidity and by amporphous shapes with irregular and poorly defined boundaries. In addition, they are generally dynamic, with constantly changing structure. Although these features are serious stumbling blocks for edge modeling, they are very efficiently modeled by textured quadric surfaces. Just as we modeled the foliage of a tree using a single textured quadric surface with variable translucence, so we can model a column of smoke, an atmospheric cloud, a dust cloud, or a weapon burst. Control of the texture function parameters allows the variable translucence required to simulate an amorphous shape. In addition, we can vary the parameters from frame to frame to agitate the texture pattern to simulate motion. The simplicity of quadric surface shape definition even allows us to create expanding weapons bursts.

Some of the possible special features that quadric surfaces can model effectively are shown in Fig. 7 and 8. Figure 7 shows smoke from chimneys on a factory. The clouds in the sky are modeled by mapping texture onto a plane in the sky. Figure 8 shows tanks with dust clouds. We generated a dynamic sequence of this scene which demonstrated the realism of the motion of the dust. The effect was produced by moving the quadric surfaces assigned to the dust clouds with the tanks, while moving the texture pattern on the dust objects at a slower speed. Figures 7 and 8 also demonstrate the modeling of textured linear features (the factory), textured targets (the tanks), rolling terrain, rocks, and bushes.

ADDITIONAL ADVANTAGES OF THE NEW SCENE MODEL

The sophistication of modern training scenarios places stringent demands on scene modeling for CIG systems. Viewable scene content must be carefully managed to prevent system overloads due to excessive computation loads during image generation. Specific enemy targets must be modeled with enough fidelity to allow recognition at reasonable distances, and provision must be made to allow targets to move arbitrarily in the scene.

Scene Management

Modeling scene features in multiple levels of detail has proven to be an effective means of controlling scene content. But this technique impacts the scene modeling task by requiring features to be modeled several times. Modeling with textured quadric surfaces simplifies the implementation of LOD modeling in three ways.

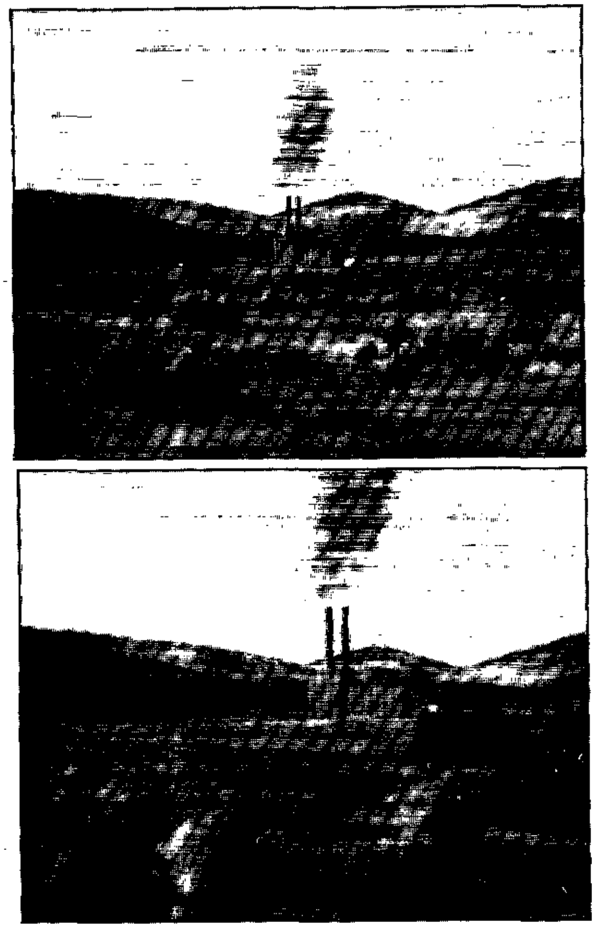

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Fig. 7 Terrain Scene Including Factory and Smoke Modeled by Bounded Quadric Surface Objects and Texturing Function

First, many scene features can be modeled in a single LOD using a single textured quadric surface. Control of the texture function to eliminate high frequency detail that would produce aliasing automatically provides LOD management. Thus the same model can be used regardless of the viewing range. Second, large clusters of individual scene features, such as groups of trees, can be modeled in just two levels of detail, a high LOD model consisting of objects representing the individual features and a low LOD model consisting of one object representing the cluster. By inserting a moveable bounding plane at a fixed distance from the viewpoint, we can continuously truncate the low LOD object as the viewpoint approaches, while smoothly inserting the high LOD objects in front of the bounding plane. As shown in Fig. 9, this technique will be effective for low altitude approaches that would not lend themselves to a simple fading of the low LOD object by increasing its translucence. This technique has the added advantage that translucence need be applied only to the high LOD objects near the bounding plane to smooth the LOD transition. In addition, texturing will greatly enhance the effectiveness of both LOD models. Finally, the simplification in modeling provided by textured quadric surfaces will apply to all levels of detail. Thus even features requiring more than two levels of detail will be easier to represent.

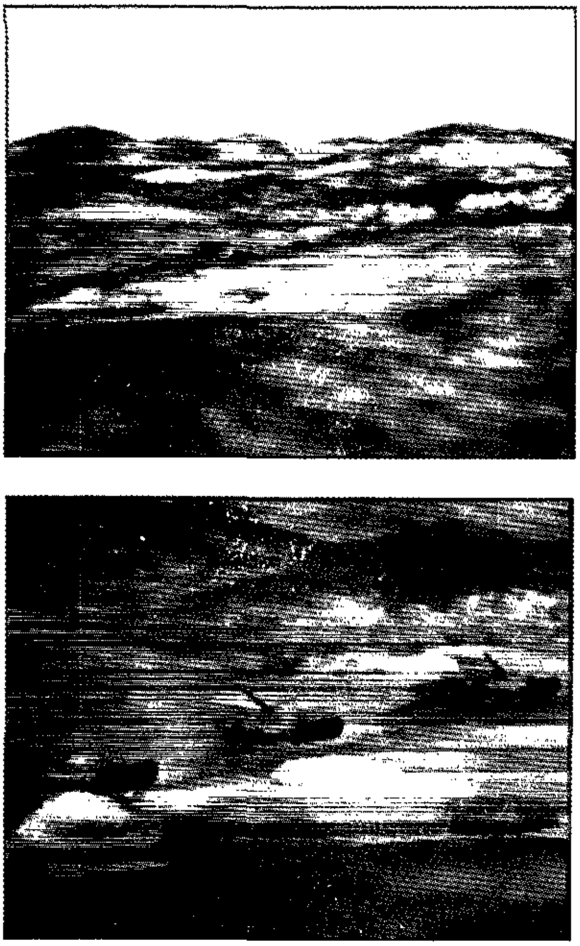

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Fig. 8 Camouflaged Tanks with Dust Clouds in Rolling Terrain Modeled by Bounded Quadric Surfaces and Texturing Function

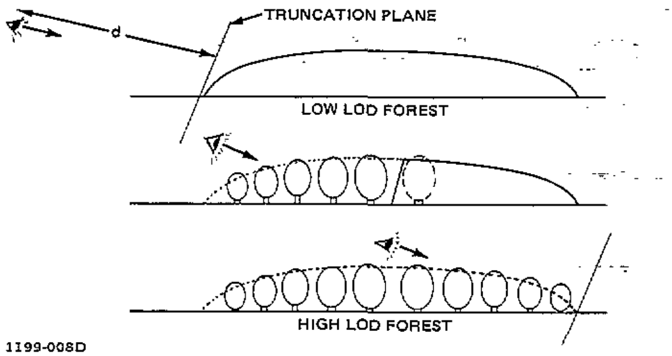

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Fig. 9 Transition Between Low and High Level-of-Detail Models of a Forest Using Bounded Quadric Surface Objects

Target Modeling

In order to provide a trainee with the capability for target recognition in a cluttered gaming area, we must represent all potential targets with a reasonable amount of fidelity. This includes friendly as well as enemy vehicles. Modeling such vehicles with edges requires the positioning of many vertices using a physical model or engineering drawings. Quadric surfaces can simplify modeling because they are closely related to the mathematical information used in engineering design. Engineering line drawings are generally produced from cross-sections, or stations, defined along a longitudinal axis. Each station is defined in terms of conic sections, and surfaces between stations are defined by second-order variations in the conic sections. Conic sections are identical to sections of intersection between quadric surfaces and planes, and quadric surfaces have second-order variation. Thus, a modeler can use this information to define quadric surfaces, and the potential exists for automated construction of quadric models using standard engineering design data.

Moving Targets

Modeling a moving target is no different than modeling a stationary scene feature. It must be kept in mind, however, that any model data parameters defining position will have to be changed on-line to reposition the model for each image frame. In edge modeling, all data parameters, including vertex coordinates and surface normals, relate to position. In quadric surface modeling, the shape parameters are not position dependent and therefore need not be changed. In addition, quadric surface modeling produces a much more compact data base than edge modeling, so fewer surfaces will have to be moved. This is particularly important in implementing moving models with moving parts, where multiple transformations of coordinates are involved.

Ground following targets present a particularly difficult problem for real-time CIG. The biggest part of this problem is to determine on which surface a target lies, so that its orientation can be adjusted to fit the surface slope. Quadric surface modeling alleviates this problem because it produces fewer terrain surfaces upon which a target can lie. In addition, structuring the terrain model as a set of individual objects allows the capability of testing all objects in parallel for the presence of a target.

FUTURE EFFORT

We have demonstrated how textured quadric surfaces will solve many scene modeling problems. However, we have only discussed how this approach can be applied to other scene modeling problems. The next task will be to test and refine our solutions to these remaining problems.

The most important problem remaining is to develop techniques to automatically model the DMA elevation data with textured quadric surfaces. To do this we will extend our profile analysis techniques to three dimensions. Next we will extend the scene modeling techniques used in our CNGEN program to place trees and rocks on terrain surfaces other than the ground plane.

We will also develop modeling aids to facilitate the modeling of cultural features, such as targets. We will use these aids to construct a library to be used in conjunction with the DMA cultural file to supplement the terrain elevation data.

It has become clear to us that efficient scene modeling will require the inclusion of two-dimensional feature models. We plan to adapt our basic bounded quadric surface model to two dimensions in the form of linearly-bounded curves. We will then be able to model and image such features as roads, rivers, and lakes more simply.

We will develop and test our LOD management techniques, and, finally, we will investigate the feasibility of our CNGEN and BLOCK techniques for on-line generation of scene features.

CONCLUSIONS

We have described a new scene model, composed of bounded quadric surfaces and texturing, which simplifies scene generation compared to edge techniques. The new scene model is defined by a parametric data base which is directly related to the size, shape, and position of scene features. In addition, the new scene model produces a much more compact data base because fewer surfaces can be used to model nonlinear features, common in the real world. The effectiveness of the new model is underlined by its capability to model efficiently such irregular features as trees, smoke, and clouds, which are serious stumbling blocks for edge modeling.

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