A Prototype System for Light Propagation in Terrains

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Abstract

We present a prototype system for a simple version of electro-magnetic wave propagation prediction in rural areas, using a real-time exploration environment for very large topographic scenes. The wave propagation prediction algorithm is based on a simple line-of-sight approach, realized with a modified hidden surface removal algorithm. The system serves as a transmitter management tool, for interactively placing transmitters and studying the effects. Improvements according to the propagation prediction and automatic optimized placement of transmitters are current subjects of our research.

1. Introduction

In the current transition from a monopolistic to an open telecommunications market, more and more companies offer telecom services to the general public. Some of these companies face the problem of designing and setting up a network based on electro-magnetic wave technology, with transmission stations that cover the area to be serviced. Instead of having a company car drive around and measure signals, a virtual reality system that models wave propagation is by far less costly. We expect that powerful Virtual Reality based tools will soon help in network design, optimization and management in mobile telecommunication applications such as paging, cellular phone, mobile computing, and global positioning.

The design of a mobile telecommunication system strongly depends on the best possible placement of transmitters for given radiation power, transmission carrier frequency, propagation delays as well as population count and density. Yet, placement of transmitters that is optimum with respect to some objective function may not always feasible because of boundary conditions such as the government authorization of placing a transmitter that may be denied. Today, the procedure of optimizing a transmitter's position in space strongly depends on an experimental, extremely time consuming procedure: Signals are measured in the real world, and the recorded values are then marked on a conventional map or entered in a Geographical Information System (GIS).

The objective of our project is to provide a Virtual Reality tool that supports mobile telecommunication network system design, optimization and management. In this report we will concentrate on the implementation of physical models and advanced algorithms to perform numerically intensive wave propagation and visualization computations under interactive control.

2. Motivation

The system presented in this report has been implemented to visualize a 2.5-dimensional terrain related theme, the electro-magnetic wave propagation of transmitters. The navigation through large terrain data, held on disk, should work in a Virtual Reality manner. This means the following: First, the man-machine interface should be intuitive. Second, both visualizing the terrain and the theme should be fast and realistic. The first point is discussed in Section 3. The handling and visualization of large terrain data is then described in Section 4. And last, in Section 5 we describe a simple and fast approach of wave propagation.

3. System architecture

Market pressure dictates that we base our system on the Windows NT platform on a personal computer with a supplementary graphics acceleration board. Personal computers will meet our expectations in computer graphics and virtual reality in a few years. Our strategy is to use off-the-shelf software components as much as possible, and to develop new techniques and algorithms only where these cannot fulfil our requirements.

3.1. Man-machine interface

Using Visual C++ and WorldToolKit (WTK) we developed a man-machine interface to an interactive 2.5 dimensional terrain explorer. The terrain itself is formed by a textured Digital Elevation Model (DEM) and covers Switzerland. According to the resolution of the DEM, the amount of disk storage needed to hold the whole terrain is about half a gigabyte. In some computer systems it may be possible to load the whole terrain to the computer's main memory. In our project the main memory is too small to hold the whole terrain data. But it is large enough to load the parts of the terrain needed to visualize a perspective scene, where the viewpoint either lies on or above the terrain, but not higher than at a maximum height. To explore a special part of the terrain, e.g. a long valley, the user often changes her viewpoint. Therefore we need a strategy to fast exchange the data in the main memory with the new relevant data. In our project the terrain data is held on disk.

To reduce the amount of main memory needed to visualize a scene, and to reload new data from external storage, we implemented several mechanisms: Level Of Detail (LOD) management, multi-process scene paging for dynamic terrain data allocation and efficient data access techniques for retrieval. Besides the possibility of interactive navigation, e.g. walk-through or fly-over, the user may also request and update geographical and other information, such as population, altitude and transmitter parameters. Because it is easy to get lost in virtual worlds, the user can always watch her position on a small map. But still there are situations, where the three-dimensional view doesn't fulfil the user's need, so there is a possibility to switch between the three-dimensional pilot's view and the two-dimensional bird's eye-view.

4. Terrain data

The visualized terrain is a combination of adaptively triangulated digital elevation data and texture. The texture helps to better recognize known terrain parts and it therefore reduces the problem of being lost in space. But the visualization of texture data requires additional time. Thus, the user has the option to switch texture on and off. In our prototype the texture is extracted from remote sensing satellite data, but there is no reason not to use scanned topographic maps as well.

The Digital Elevation Model (DEM) of Switzerland is based on the Swiss Federal Office of Topography's data height model. The Swiss Federal Office of Topography offers two models. The older one, called RIMINI, has a 250-meter grid. This wide-meshed data set is suitable mainly for applications not requiring high accuracy. The newer model, called DHM25, is based on the height information of the National Map 1:25000 and the resulting interpolated heights are arranged in a 25-meter grid. This data set is suitable for applications calling for high precision. As mentioned in Section 3.1, we do not use the DEM in its initial form, but we use it to compute a multiresolution surface model.

4.1. Strict hierarchical multiresolution surface model

Multiresolution surface models offer the possibility of visualizing a terrain at different degrees of resolution: A coarse representation can be used in areas far from the observer, while high resolution can be used close to the point of interest. A multiresolution surface model is effective if its storage cost does not introduce a serious overhead with respect to a simple surface model at the maximum precision, and if its access and manipulation algorithms are kept efficient [2].

A hierarchical triangulation (HT) is a data structure containing different triangulations of the same terrain, where from top to bottom of the hierarchy the resolution increases. We call these triangulations hierarchical because one triangle or a small set of adjacent triangles is subdivided into a larger set of adjacent triangles, whose area covers the area of the former set. If we restrict ourselves on just each triangle alone to be subdivided into a set of triangles, then we call the HT strict, and we get a tree structure. Beside the multi-resolution representation we get in this way an efficient data structure to support point location queries.

The problem is the following: For a given minimum precision, we only want to subdivide triangles as much as required. Whether a triangle is subdivided or not depends on a measured error value between this triangle and the DEM in the corresponding area. If the error value is larger than a given maximum error value, then the triangle is subdivided. The way this subdivision is done follows a heuristic and also depends on the terrain.

The two major goals of our heuristic are to keep triangles fat, i.e. to avoid the generation of many triangles with small angles, and to keep the total number of triangles small. First of all, on each edge of a given triangle exactly one new vertex is inserted. The position of the new vertices shouldn't be determined by the part of the surface interior to the triangle, but just by the vertical cut of the terrain along the edge. This restriction is implied by the fact, that each of these new vertices is also used to subdivide the adjacent triangle. Normally, these three new vertices are connected to each other, leading to a subdivision into four triangles. Thus, a choice of the new vertices near the midpoints of the edges seems to be useful. In the case where the choice is restricted to the midpoints of the edges, the four new refined triangles preserve the shape of the initial triangle. Thus, in order to reach the goal of keeping triangles fat, it is sufficient to build a good triangulation at the top of the hierarchy. But there is a minor drawback of this strategy: Because we restrict the choice of the new vertices to a planar geometry driven criterion instead of a terrain driven one, we unnecessarily increase the total number of triangles.

In special cases, where the adaptability demands it, our heuristic allows the placing of a fourth vertex inside the triangle. These four new vertices together with the three corner vertices of the initial triangle allow a local Delauney subdivision into six refined triangles. In order to fulfil the criteria of fat triangles the new inner vertex must not lie near any of the triangle's edges.

4.2. Level Of Detail

Because of the limited computing power of today's personal computers we cannot visualize the whole scene in its full resolution and maintain a sufficient frame rate simultaneously. It is important to guarantee high resolution in areas close to the observer, while resolution can progressively decrease with distance to the viewpoint. This approach allows the rendering system to visualize a reduced number of triangles, while maintaining a high degree of visual realism. Thus, we are looking for a continuously increasing level of detail from background to foreground.

Typically, only a small number of surface models for a given area are defined, and the difference in the number of triangles in successive levels of detail may be quite large. When switching between two successive levels, the change in the number of rendered triangles may amount to a substantial fraction of the given rendering capacity, and may cause rapid fluctuations in the frame rate [8].

In our project we use the strict HT to blend the geometries of two successive levels of detail defined on the same area, resulting in a virtually continuous change in resolution over distance from the viewpoint to the mesh. To avoid gaps along the boundaries of two adjacent triangles of different levels, caution is taken to ensure that such gaps are smoothed out.

5. Simple wave propagation

So far, we described a common virtual reality based framework used to visualize large terrains in a interactive manner. In addition, we need a visualization of a 2.5-dimensional terrain related theme, the electro-magnetic wave propagation of transmitters.

First, we are considering a very simple physical wave propagation model, the line of sight (LOS) approach, where electro-magnetic waves propagate in exactly the same way as visible light. We disregard reflections, refractions and diffraction. Even though this physical model is hardly realistic for wave propagation used in mobile phone and pager networks, it serves as a starting point, since it models the behavior of waves of high frequencies reasonably well. Furthermore, it appears to be adaptable to the special characteristics of other interesting frequencies.

5.1. Line of sight approach

The line of sight (LOS) approach and more sophisticated approaches based on LOS are discussed in several papers [4, 7]. Most of them realize LOS computations with ray tracing methods. This is very time consuming, whenever there are many triangles in the transmitter's environment. Since efficiency is a major problem for the more complex wave propagation computations, we believe that it is necessary to develop more sophisticated data structures and algorithms from the very beginning, in order to understand the issues at more depth. We therefore developed a modified hidden surface removal (HSR) algorithm, where the viewpoint of the HSR algorithm corresponds to the transmission point of the antenna.

Object-space HSR algorithms meet our requirements, because they compute a discrete combinatorial representation of the view of the scene, whose complexity depends on the combinatorial complexity of the scene. [3] gives a survey on object-space HSR.

Early object-space methods have a running time of $O(n^2)$ (n is the number of triangles in the terrain), independent of the complexity of the resulting visible portion. Efficient methods, like the method described in [5], have a running time of $O((n\alpha(n) + k)\log(n))$ and use $O(n\alpha(n)\log(n))$ working storage for terrains viewed from a fixed point. (k is the complexity of the visibility map and $\alpha(n)$ is the extremely slowly growing inverse of Ackermann's function [1].) In the following subsection we describe our implementation of this HSR algorithm.

5.2. Modified HSR algorithm

To get an idea how this algorithm works, we summarize the major steps implemented in our prototype. We assume that each triangle 'knows its neighbors'; this information is stored in our HT, too. In a first step, we reduce the number of triangles needed to cover the active representation of the terrain, to the relevant environment of the viewpoint. In order to preclude misunderstandings of the term 'viewpoint', we define in this section that 'viewpoint' means the transmission point of an antenna, and not the viewpoint of the visualization component described in Section 3. This relevant region is determined by the power of the transmitter. The n triangles inside the relevant region can easily be found in time $O(n)$, given the triangle of the transmitter. In the same step we also get a depth order of the triangles according to the viewpoint. In the further steps, the term 'terrain' is abused for the relevant portion of the terrain.

In a second step, the terrain is divided into four quadrants, where the viewpoint lies on the z-axis of a Cartesian coordinate system. Triangles lying in more than one quadrant are cut at the quadrant borders and the resulting polygons are computed in the corresponding quadrant. The subdivision into four quadrants is done because the HSR algorithm operates on a perspective projection of the terrain. Actually it would be simpler to project the triangles to an x-y-plane, but vertices on the same height as the viewpoint would degenerate to infinity. In order to bypass this problem, we project all polygons of a quadrant to a vertical plane, e.g. the polygons of the first quadrant ($x \geq |y|$) are projected to the plane $x = d$, where $d > 0$. To simplify the next step, we don't project the polygons, but a collection of semi-unbounded vertical prisms instead, each consisting of all points lying below the corresponding polygon. Obviously the visibility map does not change by this transformation, but the complexity of it is reduced.

The third step is the HSR algorithm, applied on the perspective projected polygons of each quadrant. The algorithm involves two divide-and-conquer passes over the polygons ordered by depth from the viewpoint. First of all, the polygons are stored in this order in the leaves of a balanced binary tree τ, the nearest polygon in the leftmost leaf. For each node δ of τ we compute the following two maps:

- U_δ – the union of the projections of the polygons in the subtree τ_δ of τ rooted at δ.
- V_δ – the visible portions of U_δ, i.e. the subset of U_δ consisting of those points that are not contained in the projection of any nearer polygon (stored in τ to the left of δ).

Both U_δ and V_δ are monotone polygons, without holes, and it is easily checked that each of the Boolean operations (union, intersection, difference) on them performed by the algorithm can be done in linear time, using standard line-sweeping methods.

In the next and last step the four visibility maps are glued together and transformed back to the visible parts of the terrain. To allow an adequate back transformation not only the visible portions, but also the original triangles and its projections are needed.

6. Further work

Wave propagation in the VHF/UHF frequency range over natural terrain is strongly dependent on topography and morphography. The TIN we use in the terrain visualization sufficiently satisfies the requirements on a reasonable topologic model. The information about the morphology could be extracted from the remote sensing satellite data using standard computer vision methods.

As mentioned before, the LOS approach disregards reflections, refractions and diffraction. So we plan a stepwise refinement of the LOS approach to realistically model a reasonable electro-magnetic wave propagation in rural areas. How this refinement can be realized is a current subject of our research. There are different approaches to consider wave interactions. In [7], for example, wave interactions are described, like diffraction and scattering over the propagation path, by the uniform theory of diffraction and physical optics. A more empirical approach is used in [6]. It is also dependent on topology and morphology over the propagation path.

References

[1] R. Cole and M. Sharir. Visibility problems for polyhedral terrains. *Journal of Symbolic Computation*, 7(1):11–30, Jan. 1989.

[2] L. de Floriani and E. Puppo. Hierarchical triangulation for multiresolution surface description. *ACM Transactions on Graphics*, 14(4):363–411, Oct. 1995.

[3] S. E. Dorward. A survey of object-space hidden surface removal. *Int. Journal of Computational Geometry and Applications*, 4(3):325–362, 1994.

[4] D. W. Fellner. Funkwellenausbreitung (CARPET). Technical report, Universität Bonn, Oct. 1995.

[5] M. J. Katz, M. H. Overmars, and M. Sharir. Efficient hidden surface removal for objects with small union size. In A.-S. ACM-SIGGRAPH, editor, *Proceedings of the 7th Annual Symposium on Computational Geometry (SCG '91)*, pages 31–40, North Conway, NH, USA, June 1991. ACM Press.

[6] M. Krüger and R. Beck. GRAND – Ein Programmsystem zur Funknetzplanung. *PKI technische Mitteilungen*, 2, 1990.

[7] T. Kürner, D. J. Cichon, and W. Wiesbeck. Concepts and results for 3d digital terrain-based wave propagation models: An overview. *IEEE Journal on selected Areas in Communications*, 11(7), Sept. 1993.

[8] P. Lindstrom, D. Koller, W. Ribarsky, L. F. Hughes, N. Faust, and G. Turner. Real-Time, continuous level of detail rendering of height fields. In H. Rushmeier, editor, *SIGGRAPH 96 Conference Proceedings*, Annual Conference Series, pages 109–118. ACM SIGGRAPH, Addison Wesley, Aug. 1996. held in New Orleans, Louisiana, 04-09 August 1996.