THE FEATURE POINT TRIANGULATION METHOD FOR SPATIAL SUBDIVISION

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Abstract

In this paper we describe the geometric and topological requirements of the triangulation scheme used to model the earth’s surface by spatial subdivision. The triangulation scheme that we developed is called the feature point triangulation method and it used Earth Modeler to represent the Earth’s surface. The feature point triangulation has markedly better resolution of features than other triangulation methods. The feature point method represents the terrain within each subdivision with four triangles oriented in three-dimensional space so as to approximate the surface contour of the section being modeled. Features of the earth’s surface are represented by a total of sixteen different triangulation patterns. The triangulation patterns are described and examples are given of their use in representing a variety of cultural and natural features on the earth’s surface, such as, roads, lakes, erosion cuts, and building. We describe the enumeration of spatial subdivision and triangles representing the Earth’s surface and show how the method is used to represent a single surface or multiple subterranean surfaces. We demonstrate the capabilities of the feature point method in representing multiple levels-of-detail and finite element mesh generation.

Introduction

The feature point triangulation is a method that has been developed’ for representation of surfaces in 3D-space by spatial subdivision. The method was developed to be used by Earth Modeler[z], a modeler that is based on the spatial subdivision using a quadtree data structure’” and is capable of generating and displaying a three-dimensional model of the earth’s surface at multiple levels of detail. The earth’s surface is modeled in one degree square sections. Each section is successively subdivided into quadrants and sub-quadrants. This process is continued until the smallest subdivi sion is about ten feet square. The terrain within each subdivision is modeled by four triangles oriented in three-dimensional space so as to approximate the surface contour of the section being modeled.

Domaratz[2] reviewed the various data input methods that represent a surface terrain. The methods he described using the concepts of discrete point surface sampling methods, and the theory of cartographic objects, attributes and relationships, are the irregular point methods, the linear methods, regular grids methods and irregular grid methods. Irregular point structures suffer from the lack of implicit or explicit descriptions of the spatial relationship between the sample points. Linear structures, such as contour and profile, implicitly define the spatial relationships between the points on the same line but fail to define them for points on different lines. Regular grids implicitly define the spatial relationships between neighboring points and are easy to use but they have a large number of redundant points in smooth regions. Although irregular grids define the surface specific points and lines, explicitly define the spatial relationships between the different points, and provide an accurate model of the surface, they have a more complex structure and a high storage because of the large number of pointers needed to be stored.

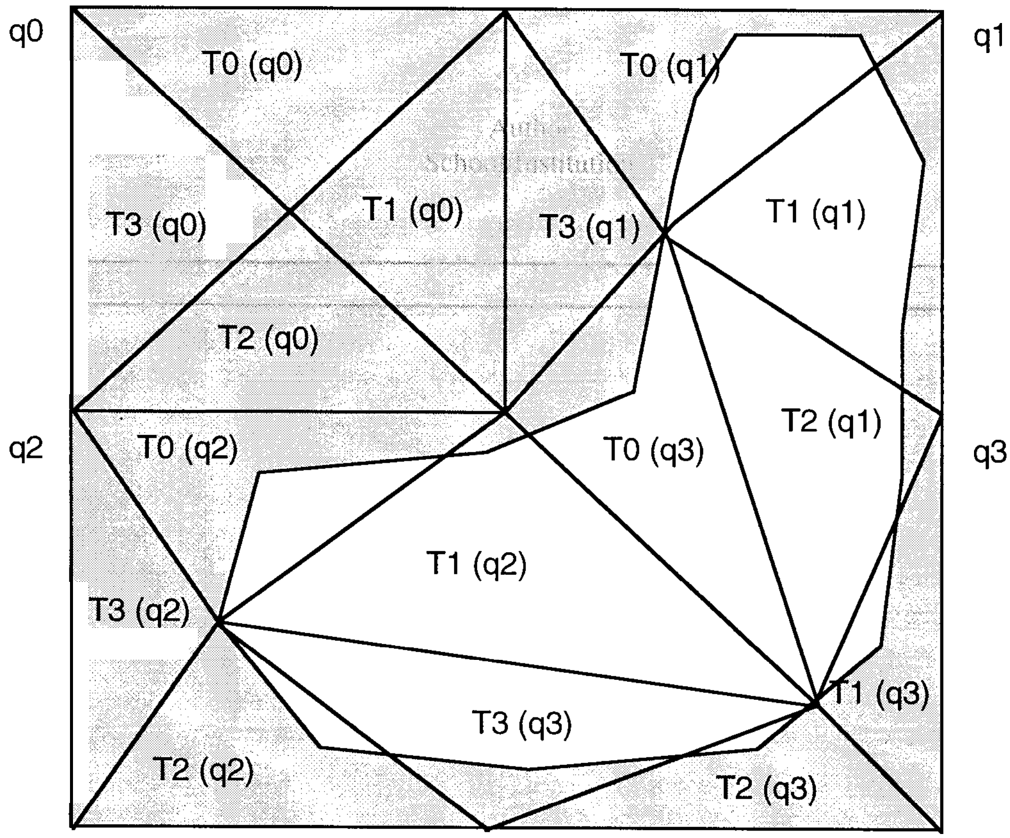
Irregular grids are unsuitable for representation of multiple levels of detail. The selection of any of the previous methods should depend on the requirement of the application. The Earth Modeler can take any of the previous input methods to generate its triangulation scheme. Furthermore, the Earth Modeler can overcome the disadvantage of each method and add capabilities to it. For instance, the Earth Modeler can define the missing spatial relationships between the points in the irregular point methods and the linear methods such as: contours and profiles. Or, as another example, the Earth Modeler can get eliminate the redundant points in the regular grid methods and deal with the complexity of the irregular grid structures.

Peucker and others* note that there are two major classes of implementation of these types of input data structures. These classes are differentiated by the amount of the given topological information about the surface. In the first type, facets formed by triangles with explicit pointers used to identify the points defining a facet and to identify the three facets bordering that facets. An example of this type of implementation is the Area Design and Planning Tool "ADAPT" [5,4]. In the second type, the identity of the points neighboring a particular point is explicitly defined in a clockwise or counterclockwise direction around the point. The triangular facets defined by these points are described implicitly by the order of the neighboring points. An example of this type of implementation is the First Data Structure of the Triangulated Irregular Network "TIN" [7,8]". Although these methods can accurately represent surfaces, they lack to a global relation between all the triangles. Besides, moving across the terrain and among the different levels of detail are not addressed. The Earth Modeler, on the other hand, gives a precise and accurate representation of the terrain and the associated contour. Furthermore, it gives a global relation that can define and relate the different neighboring regions in multiple levels of detail.

Feature Point Triangulation Method (FPT)

The Feature Point Triangulation (FPT) method works in concert with spatial subdivision using a quadtree data structure to accurately represent the boundary of features. In this method, points that are closest to the center of the quadrants in the quadtree data structure are determined and used to form four triangles per quadrant (polygon) that are in turn used to develop the triangle lists (Figure 1). If the quadrant is empty of feature points, the center point of the quadrant is chosen. The four triangles are then formed by connecting the center point to the quadrant four corner points. If two chosen point in two neighboring quadrants that share a side line lies on the same feature, the shared side will not be connected and instead the two chosen points are connected producing two triangles that belong to different quadrants so that the same number of triangles per quadrant (four) maintain constant. In addition, the chosen point is connected to the quadrant four corner points to form four triangles. This process is repeated for each level-of-detail. Sixteen different triangulation patterns are required in order to represent all possible feature boundaries.

In case of an inadequate number of measured feature points in the map data base, additional feature points are generated using linear interpolation until the adjacency requirement is met. Interpolation is carried out between consecutive points if they do not lie in adjacent quadrants. Different schemes are followed for



q = quadrant
T = triangle

Figure 1. Triangle Lists in Four Neighboring Quadrants

area and linear features. The scheme for areas ensures vertex adjacency and minimizes the number of points on boundary. The scheme for linear features ensures both vertex and edge adjacency and ensures straight edges. For area features, the following scheme is used: if the two quadrants containing the two consecutive points are in the same horizontal level, the line of horizontal quadrants between them is generated (Figure 2a).

If these two quadrants are in same vertical level, the line of vertical quadrants between them is generated (Figure 2b) or else a 45^o inclined line of quadrants is generated (Figure 2c). Feature points in the generated quadrants are chosen in the center of each quadrant.

For linear features, the scheme is proposed to overcome the problem of saw-like representation of linear edges. Intermediate points are chosen so that they lie exactly on the linear edge of the feature (Figure 3). Although this scheme increases the number of points generated from interpolation, it ensures straight edges of linear features.

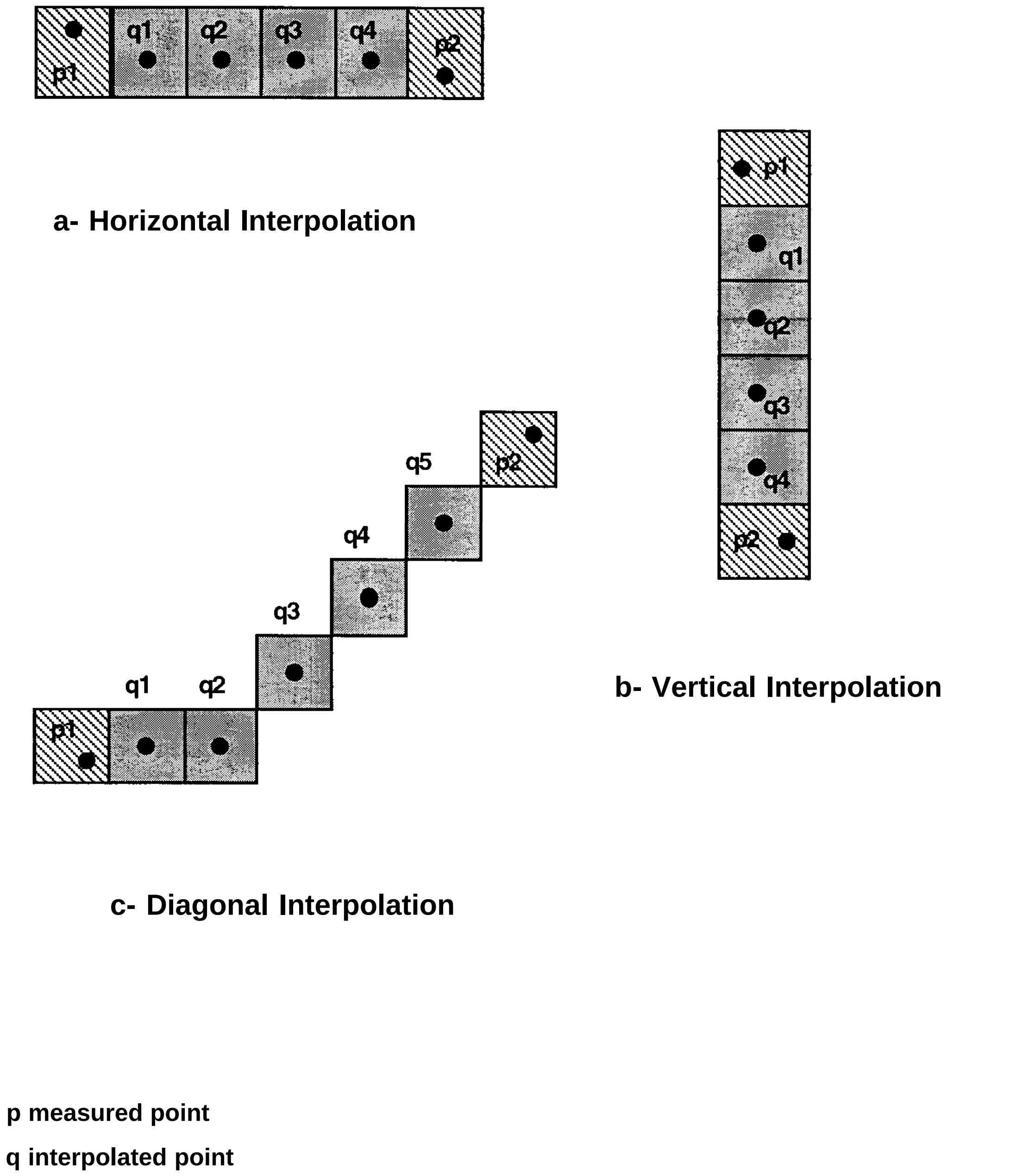


Figure 2. Interpolation of area features.

Generation of Triangle Lists

A list of four triangles per quadrant is generated through the entire quadtree. First, an intermediate point in each quadrant is found. If the quadrant is empty, its center point is chosen to be the intermediate point. Then, the four triangles are formed by connecting that center point to the quadrant four corner points. The background color is given to those triangles. When a quadrant has a point or more inside, the point that is closest to the center of the quadrant (a features), or the one that lies on the feature edge (linear features), is

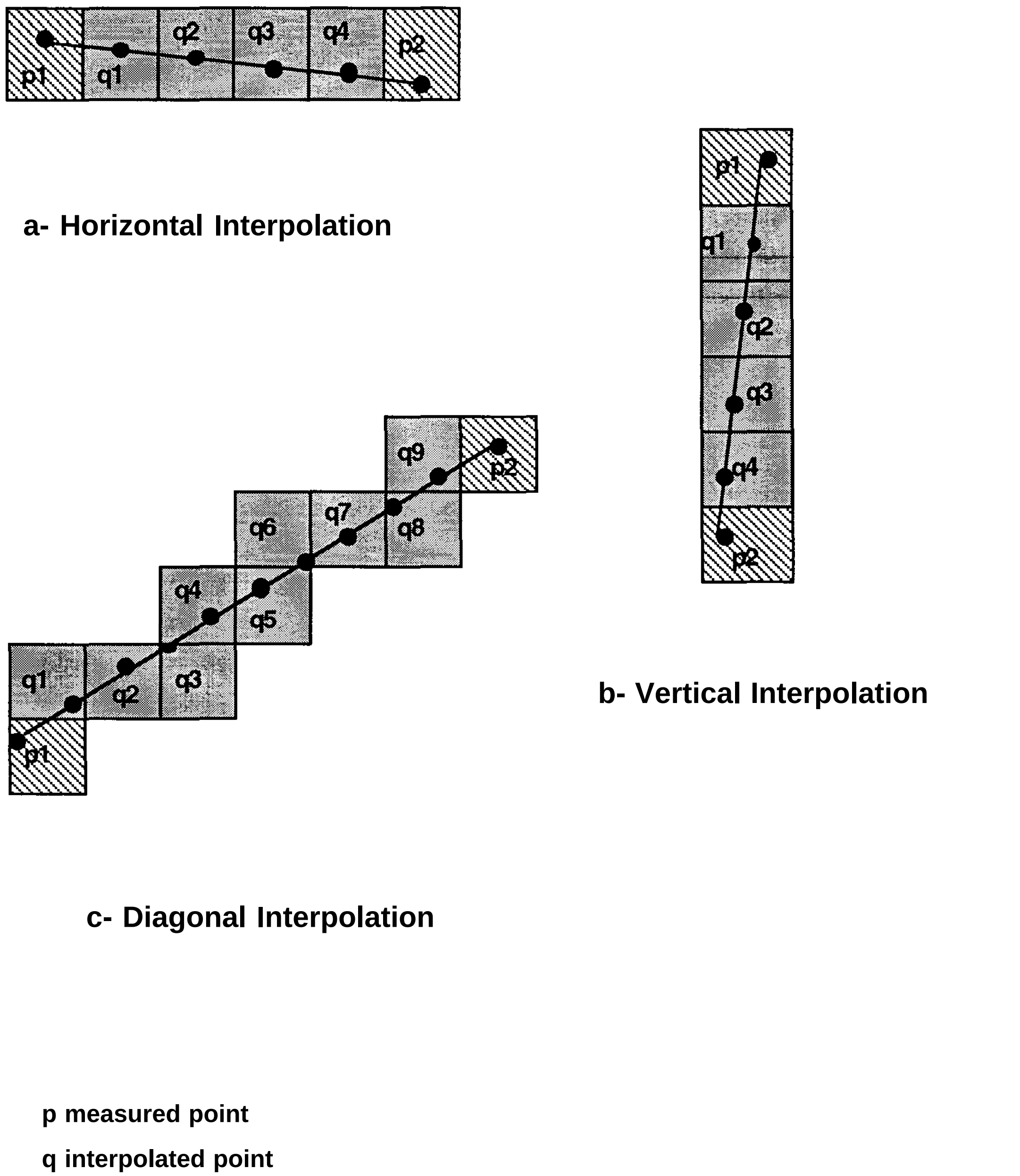


Figure 3. Interpolation of linear features.

chosen to be the intermediate point. If an intermediate point is shared by more than one region a code is set to identify that quadrant is a shared quadrant.

The generation of a triangle list differs if a quadrant contains a feature point or not. If two chosen points in two face adjacent neighboring quadrants lie on the same feature boundary, the adjacent face will not be connected. Instead, the two points are connected producing two triangles that each belong to a different quadrant.

The same number of triangles per quadrant (four) is maintained constant (Figure 1). If not, the chosen point is connected to the quadrant comers. Triangles are numbered as O, 1, 2, or 3, starting from the upper edge of each quadrant in a clockwise direction (Figure 1).

The triangle lists generated in the FPT method accurately represent both area and linear features' boundary'.

Conclusions

The Feature Point Triangulation (FPT) method accurately represents surface features as it is aligned with the boundary of the features. While other methods for surface representation, such as the Area Design and Planning Tool "ADAPT" method and the Triangulated Irregular Network "TIN" method, accurately represent surfaces, they lack a global relation between all the triangles. In addition, moving across the terrain and among the different levels of detail are not addressed. The Earth Modeler, on the other hand, gives a precise and accurate representation of the terrain and the associated contour. Furthermore, it gives a global relation that can define and relate the different neighboring regions in multiple levels of detail.

When using the FPT method to generate a feature boundary, interpolation is carried out between consecutive points if they do not lie in adjacent quadrants. Different schemes are followed for area and linear features. The scheme for areas ensures vertex adjacency and minimizes the number of points on boundary. The scheme for linear feature ensures both vertex and edge adjacency and ensures straight edges. Interpolation scheme used by the FPT point are presented.

Triangle lists generated by the FPT method accurately represent a feature boundary.

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