AUTOMATIC EXTRACTION OF TOPOGRAPHIC FEATURES USING ADAPTIVE TRIANGULAR MESHES

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ABSTRACT

A method is described for the extraction of morphological information from images approximated by triangular meshes. Topographic features such as peaks, pits, ridges, valleys, and planar regions are considered the basic descriptive surface elements and are defined in terms of the local organization of the triangles in the mesh. The approach is suitable for image analysis tasks, simplifying object recognition and scene interpretation. Several images have been used to demonstrate the performance of the proposed method.

1. INTRODUCTION

The main objective of the topographic feature recognition is to construct an accurate model based on shape descriptors in order to represent surface information in an efficient and consistent way. Several computer-based recognition tasks require high-level scene descriptions while preserving the essential surface characteristics, such as navigation of autonomous vehicles, planetary exploration, reverse engineering, and medical image analysis.

The extraction of topographic features in digital images is a primary problem encountered in any general computer vision system. Examples of some useful topographic features used in image analysis include peaks, pits, ridges, valleys, passes, and planar regions.

This paper presents a method for extracting topographic features from images approximated by triangular meshes. Initially, an incremental triangulation algorithm is applied to the original image, producing a set of points that are triangulated to produce an initial mesh. This mesh is then refined until a predefined level of accuracy is achieved. Once the final triangular mesh has been generated, characteristics points, lines, regions are defined by considering the topological and geometric relationship between the triangular elements.

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Section 2 reviews some relevant feature extraction methods. The proposed algorithm is described in Section 3. Experimental results and implementation issues are presented in Section 4. Some concluding remarks are given in Section 5.

2. RELATED WORK

Several techniques have been proposed in the literature for the identification of topographic features in digital images. In the majority of the methods, the analysis is made on the basis of cell-neighbor comparisons within a local neighborhood [1, 2] or derived from contour lines of the image[3, 4, 5, 6]. Concepts from differential geometry are often used in surface feature recognition [7], such that basic surface types can be determined by estimating directional derivatives of the intensity image.

Peucker and Johnston [8] characterize the surface shape by positive and negative differences as neighbor points are compared to the central point. Peucker and Douglas [9] describe several variations of this method for the detection of surface-specific points and lines in terrain data. The method proposed by Johnston and Rosenfeld [2] detects peaks (pits) by finding all points P such that no points in a neighborhood surrounding P have higher (lower) elevation than that of P. To find ridges (valleys), their method identifies points that are either east-west or north-south elevation maxima (minima) through an array in which each point is given the highest elevation in a 2×2 square containing it.

Paton [10] uses a six-term quadratic expansion in Legendre polynomials fitted to a small disk around each pixel. The most significant coefficients of the second-order polynomial are used to classify each pixel into a descriptive label. Grender [11] compares the grey level elevation of a central point with surrounding elevations at a given distance around the perimeter of a circular window and the radius of the window may be increased in successive passes through the image.

Hsu, Mundy, and Beaudet [12] use a quadratic surface

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approximation at every pixel on the image surface. Lines emanating from the central point in the principal axes of this approximation provide natural boundaries of patches representing the surface. The principal axes from some critical points distributed over the image are selectively chosen and interconnected into a network to produce an approximation of the image data.

Toriwaki and Fukumura [13] use two local measures of grey level pictures, connectivity number and coefficient of curvature for classification of each pixel into a descriptive label, which is then used to extract structural information from the image.

Lee and Fu [14] define a set of 3×3 templates used to convolve over the image to classify the features. Thresholds are used to determine into which class the pixel will fall. In their scheme, a pixel may satisfy the definition of zero, one, or more than one class. Ambiguity is resolved by choosing the class with the highest figure of merit.

A method for classifying topographic features based on the first and second directional derivatives of the surface estimated by bicubic polynomials, generalized splines, or the discrete cosine transformation is presented by Watson, Laffey, and Haralick [15, 16].

A technique proposed by Gauch and Pizer [17] locates regions where the intensity changes sharply in two opposite directions. The curvature calculation is based on level curves of the image, requiring the evaluation of a large polynomial in the first-, second-, and third-order partial derivatives.

A comparison of some methods for ridge and valley detection is presented by López *et al.* [18] and Mascardi [19]. The method presented by Falcidieno and Spagnuolo [20] is the most similar to the one discussed here.

3. PROPOSED METHOD

The method proposed in this paper differs from the majority of the feature detection algorithms found in literature, which are generally based on regular grid models. In our method, triangulated irregular networks represent the object surface as a mesh of adjacent triangles, whose vertices are the data points. The points need not lie in any particular pattern and the density may vary over space.

The triangular mesh is constructed by an incremental triangulation algorithm, where the vertex selection criterion is based on the maximum vertical error weighted by a curvature measure given by

$$E = \frac{h(p) - z(p)}{K(p)} \tag{1}$$

where $h(p)$ is the height value of point p, $z(p)$ is the height value of the interpolated surface at point p, and $K(p)$ is the curvature estimated in a neighborhood of the candidate point p given by

$$K(p) = \left|\frac{\partial^2 f(x,y)}{\partial x^2}\right| + \left|\frac{\partial^2 f(x,y)}{\partial y^2}\right| \tag{2}$$

The second derivatives are computed as

$$\begin{aligned} \frac{\partial^2 f(x,y)}{\partial x^2} &= f(x+1,y) - 2f(x,y) + f(x-1,y) \\ \frac{\partial^2 f(x,y)}{\partial y^2} &= f(x,y+1) - 2f(x,y) + f(x,y+1) \end{aligned} \tag{3}$$

The idea is to associate greater importance to the points in regions where the local variability of the data is high, allowing the surface to conform to the local trends in the data. A constrained Delaunay triangulation is used to maintain the topology of the data points, whose vertices lie at a subset of the input data.

The sequence of local modifications generated during the refinement step is applied to a triangulation until the desired accuracy of the approximation is achieved. The extraction of a representation of the image at a given tolerance level is obtained by using a coarse triangulation and iteratively inserting vertices into the triangulation until the desired precision is satisfied.

In our approach, the identification of topographic features is derived from the triangular models. This can be achieved by examining the structure of the triangles in the mesh.

Figure 1 illustrates some of the most common topographic features, which are classified according to the topological and geometric relationship between the triangulation elements. The angle between the normals of adjacent triangles indicates concave, convex, and planar shapes along the surface.

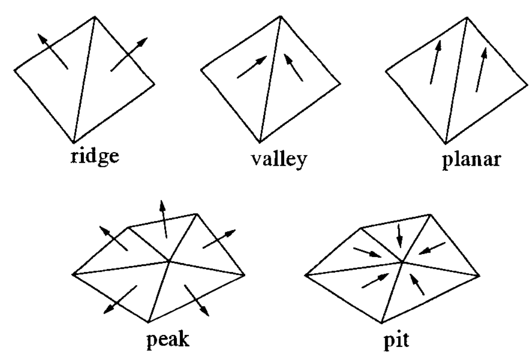

Fig. 1. Topographic features in triangular meshes.

A peak is a point such that in some neighborhood of it, there is no higher point. Similarly, in some neighborhood of a pit, there is no lower point. A ridge correspond to a long, narrow chain of higher points or crest, while a valley correspond to a chain of points with lower elevations. Such extracted feature elements can be incorporated into the triangulation as constrained vertices and edges, respectively, in a such way that subsequent operations will preserve them.

4. EXPERIMENTAL RESULTS

Our algorithms were implemented in C++ programming language on Unix/Linux platform. The triangulation algorithm is able to select 60,000 points in approximately 55 seconds on a Pentium III with a 550MHz processor and 128 Mbytes of main memory.

A number of data sets have been used to evaluate the performance of our method. Due to space limitations, only two data sets are presented here. Figure 2(a) shows the classic *pepper* image (512×512) and Figure 2(e) shows Paolina image (512×480).

For each one of these two images, the corresponding triangular meshes obtained by our triangulation method (Figures 2(b), 2(f)), the extracted peaks and pits (Figures 2(c), 2(g)), and the extracted ridges and valleys (Figures 2(d), 2(h)) are illustrated.

Although the meshes shown above have only a small percentage of the original number of points, the models still capture the main features of the images. The results have demonstrated a good balance between speed and ability to process large data sets, even though the current version of our algorithm is still unoptimized in some aspects.

5. CONCLUSIONS

We presented a method for the identification of topographic features from images approximated by triangular meshes. Characteristic points, lines, and regions are defined by examining the type of adjacency between the triangles in the mesh.

The technique provides an effective compromise between fidelity and time requirements, producing approximations with great flexibility while preserving the main surface features.

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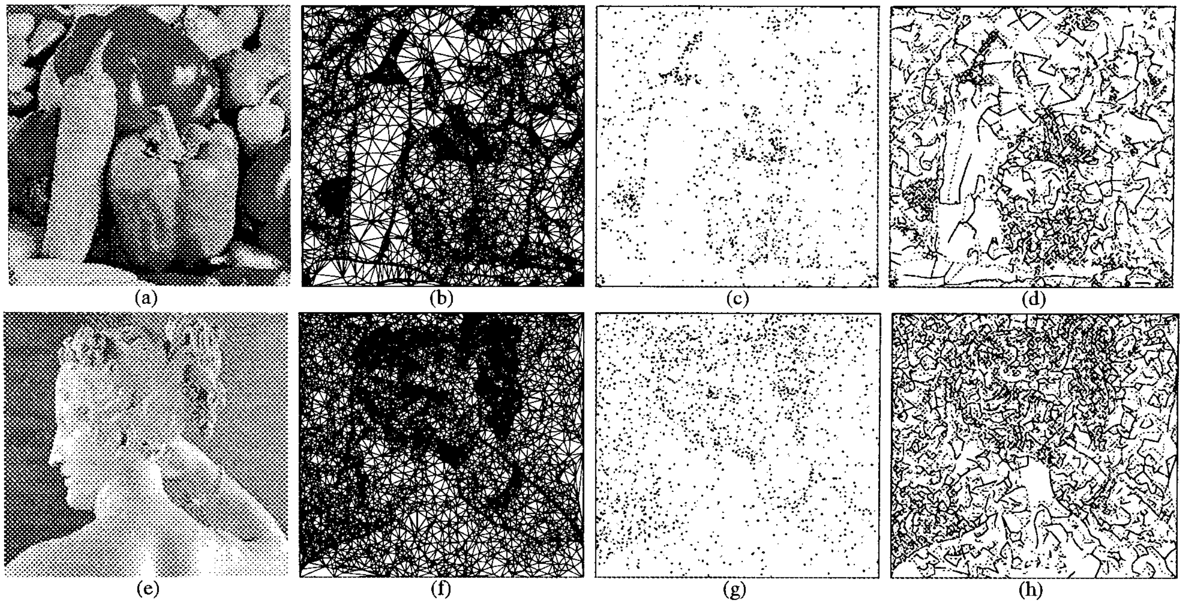

Fig. 2. Application of the proposed method to two data sets (pepper and Paolina). The images in the second column show the triangular meshes obtained by our triangulation technique. The meshes contain only 4.1% and 3.8% of the original points, respectively. The images in the third column show peaks (dark points) and pits (grey points) extracted by using the triangular meshes. The right column shows the extracted ridges (dark lines) and valleys (grey lines).

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