Computer Vision Research at the University of Utah

Thomas C. Henderson
Department of Computer Science
University of Utah

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Abstract

Computer vision research at the University of Utah involves several areas, including: terrain micro-feature analysis for cartographic database enhancement, ridge and ravine detection in gray level images, and image database shape-based querying. An overview of this work is given.

1 Terrain Micro-Feature Analysis

The construction of large-scale geospatial databases remains an expensive and time consuming task. We are trying to automatically extract certain types of linear features with a horizontal extent significantly less than the resolution of the base-level terrain data covering the area in which these structures occur [7]. The first phase of this effort considers two classes of such features: ravines and road cuts and fills. Accurate detection and localization of these features is difficult in even high-resolution elevation data. While they are often apparent in aerial imagery, they are easily missed or confused with other features, making reliable detection based on imagery alone problematic. The key to solving this problem is to utilize techniques which combine photogrammetric analysis of the terrain with focused image understanding methods applied to individual images.

Sensor technology, limitations of photogrammetry, storage constraints, and requirements for real-time rendering and analysis all limit the fidelity with which terrain can effectively be represented in a geospatial database. For certain applications, it is critical that these databases include specific *micro-terrain* features with a lateral extent less than the resolution of base-level terrain description. In current generation terrain modeling systems, topographic micro-terrain is seldom present. Man-made micro-terrain, particularly that associated with road cuts, is sometimes included but often does not correctly correspond to the actual terrain.

This project demonstrates how feature extraction methods which combine image understanding with a terrain analysis based on other sources of information can be used to reliably locate micro-terrain features in a way that improves the utility of terrain models used for simulation and synthetic environment applications. Our initial focus is on two types of embankment features:

- Extraction of natural ravines.
- Extraction of road cuts and fills.

Great difficulty is associated with accurately extracting embankments from source data. Embankments are long, narrow features with a width typically much smaller that the spatial resolution of the terrain data used to construct geospatial databases. While they are often apparent in high resolution aerial imagery, reliable detection is difficult and the visual signature of an embankment is easily confused with other commonly occurring terrain and cultural features. As a result, enhancing the realism of such features in terrain databases currently requires substantial manual processing.

We are addressing these problems with an approach aimed at achieving the following objectives:

- Ability to accommodate a variety of terrain types and covers.
- Tolerance of source data of variable quality and uncertain pedigree.
- Ability to exploit existing tools.
- Easy insertion of results into existing tools.

Ravines are erosional features generated by large-scale processes, even if the final effect is visible mostly on a fine-scale. As a result, hydrological analysis can be used to predict where such erosion is most likely to occur. Effective algorithms exist for performing this analysis even on low-resolution, error-full representations of the terrain skin.

Except for unmaintained tracks, road construction involves local terrain modifications. When a road crosses a slope transversely, the side-to-side cross-section of the road must be maintained at or near the horizontal. For roads going up or down a steep slope, switchbacks and/or road cuts and fills are often introduced to improve trafficability. 2-D information about road position, obtained from available sources, can be combined with a 3-D analysis of the local terrain to produce predictions about where cuts and fills would have been utilized in the road building process.

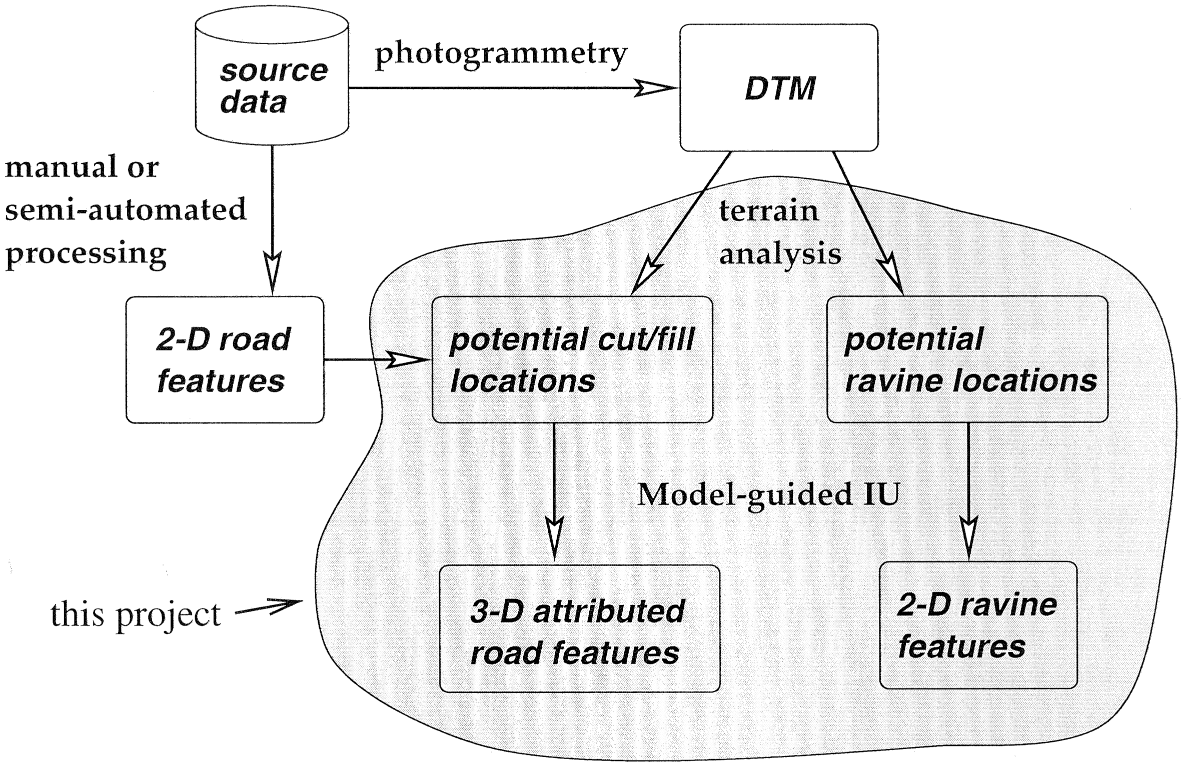

Figure 1: Combining terrain analysis and image understanding for micro-terrain feature extraction.

As shown in Figure 1, our approach uses predictions about the possible existence and approximate locations of ravine and road cut features to drive a top-down, model-guided image understanding process. The image understanding component confirms the hypothesized presence of terrain features and refines positional estimates, rather than perform a bottom-up extraction of the features themselves. The restricted nature of this task allows the use of simple and reliable image analysis methods that are tolerant of wide variability in input data.

While the initial scope of this project is limited to a set of feature-specific methods, the features themselves are often critical to the utility of the entire geospatial database, particularly when used in support of Synthetic Environment (SE) applications. Existing tools are not able to extract these features without major human effort. The solutions outlined here depend on the use of "context" to direct image understanding methods and to integrate the results of that analysis into a consistent terrain database. Our hope is that the approach will generalize to additional classes of features for which the ways in which the features interact with the surrounding terrain provide enough information to guide targeted IU analyses.

2 Ridge and Ravine Detection

Ridges and ravines are important features in some image analysis tasks and represent a basic topographic type in digital terrain data. Several methods have been proposed to recover these features, but they have major shortcomings including (1) their sensitivity, and (2) their computational cost (usually as a result of fitting a polynomial). We describe here an approach based on the Laplacian operator that has a firm theoretical foundation and which is relatively inexpensive to compute.

Haralick[2] describes how the facet model approach can be used to recover ridges and ravines. A bicubic polynominal is fit to a patch in the image; ridges are then characterized by a negative second derivative across the ridge line and a zero first derivative in the same direction. The only difference for a ravine is that the second derivative across the ravine is positive. (Haralick's book reviews several earlier techniques for ridge and ravine detection; note that Rosenfeld and Kak maintain that the Laplacian can be used to detect lines.) The computational cost is high due to the ten coefficients that are computed at each pixel.

A more recent technique related to our approach is that proposed by Gauch and Pizer[1]. In their approach, they find places where the "intensity falls off sharply in two opposite directions." They determine curvature extrema of the level curves of the image in order to achieve this. Unfortunately, their calculation requires the evaluation of a large polynominal in the first-, second- and third-order partial derivatives of the image, where cubic splines are used to calculate the partial derivatives.

Our method is based on the following sequence of observations concerning the behavior of the gradient in the neighborhood of a ridge or ravine. The gradient produces vectors on the side of a ridge which point toward the ridge and which point away from a ravine. Although the gradient can be analyzed directly to determine the location of ridges and ravines, it is computationally more convenient to do the following:

- Rotate (locally) each gradient vector -90 degrees about the out of image axis.
- Calculate the curl at each point to determine the opposed flow that exists at ridge lines.
- Calculate the extremum of this function across the ridge.

A more formal development is now given. Let the image function be $f(x, y)$. Then the gradient is:

$$\nabla f = f_x(x, y) \cdot \bar{i} + f_y(x, y) \cdot \bar{j} + 0 \cdot \bar{k}$$

The rotation is:

$$rot(\nabla f) = f_y(x, y) \cdot \bar{i} - f_x(x, y) \cdot \bar{j} + 0 \cdot \bar{k}$$

The curl of this is:

$$curl(rot(\bigtriangledown f)) = \begin{vmatrix} \bar{i} & \bar{j} & \bar{k} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ f_y & -f_x & 0 \end{vmatrix}$$

$$= 0 \cdot \bar{i} + 0 \cdot \bar{j} + (-f_{xx} - f_{yy}) \cdot \bar{k}$$

which is just the negative of the Laplacian.

Finally, a principal direction of curvature for a ridge pixel is:

$$\alpha = \frac{atan2(f_{xy}, f_{yy} - f_{xx})}{2}$$

as well as $\alpha + \frac{\pi}{2}$. We search in these directions to determine that the pixel is a local maximum across the ridge.

This ridge/ravine detector shows great promise for accuracy and robustness.

3 Image Database Shape Queries

Image databases have been the focus of much recent work in the computer vision and multimedia fields. Methods have been proposed for image compression, storage and query. Most query methods are based on the use of color, or intensity statistics (usually some form of histogram), as well as various texture parameters, and some limited kinds of shape analysis. We propose to base shape queries on the topographic features of the image, and in particular on the ridge and ravine features described here [3]. For other approaches, see [5, 6].

Image segmentation is achieved by thresholding the ridge image. The resulting image is then labeled (connected components are grouped together into segments). Properties are then computed on the resulting segments. We have shown that geometric relations between topographic features of an intensity image can be exploited as a shape representation and query method. We are exploring two major issues:

- Can property matrixes, such as the angle between segments, be compressed using standard compression techniques, ands still be recovered accurately enough to be useful?

- Can large graphs ($>$ 100 nodes) represented as Boolean adjacency matrixes be compressed and matched in their compressed representation so as to avoid the subgraph isomorphism algorithm?

Preliminary results are encouraging[4].

References

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