IU at the University of Utah: Extraction of Micro-Terrain Features

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Abstract

The construction of large-scale geospatial databases remains an expensive and time consuming task. We describe an approach for automatically extracting 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. 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.

1 Overview

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 demonstrats 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 which are of particular relevance to DOD:

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

Embankments are terrain features that critically affect the realism of ground warfare simulations. They provide concealment while also constituting potential barriers to traversibility. 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.

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- Tolerance of source data of variable quality and uncertain pedigree.
- Ability to exploit existing tools.
- Easy insertion of results into existing tools.

Our interest lies in cartographic features that are too small to be extracted using stereo photogrammetry and too indistinct to be found reliably using standard image understanding methods alone. Our approach combines existing methods for extracting terrain data and features with standard image processing algorithms in order to extract information not available from either source alone. While micro-features are absent from terrain models produced using conventional photogrammetric means, the presence of such features can often be inferred from even low resolution elevation maps.

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.

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 intial scope of this project is limited to a set of feature-specific methods, the features them-

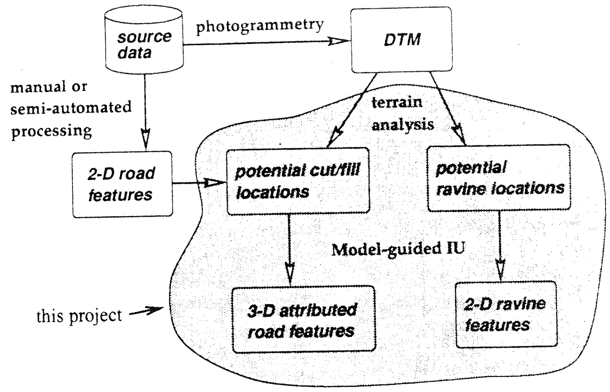

Figure 1: Combining terrain analysis and image understanding for micro-terrain feature extraction.

selves 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 Micro-Features in the Context of Modeling and Simulation (M&S) Applications.

Real-time modeling and simulation applications are increasingly emphasizing realism in both appearance and behavior (Figure 2). The current state-of-the-art in terms of fielded systems is typified by the Army's Close Combat Tactical Trainer (CCTT) [Pope *et al.*, 1995]. While based on real source data, CCTT is a *geotypical* simulation, appropriate for generic training but not for gaining experience with a specific geographic area. As image generators and other computational engines involved in implementing a simulation become more powerful, it becomes increasingly important to be able to produce richer and more accurate models of the relevant 3-D terrain structure and to update these models as changes occur in the world they are representing. Thus, extraction and representation of veridical features is

geotypical	⇒	geospecific
static databases	⇒	changeable databases
texture mapped	⇒	image mapped
training	⇒	mission rehearsal
realistic	⇒	*real*

Figure 2: Trends in real-time simulation.

increasingly essential.

One of the ways that next generation image generators such as the Evans & Sutherland Harmony system achieve improved visual realism is by draping actual aerial imagery over the terrain skin, rather than using geotypical texture mapping. Imagery is becoming part of the primary source data, rather than serving solely as a secondary data source on which photogrammetry and feature extraction is performed. While the visual impact can be dramatic, it is critical that features in the world model such as buildings, roads, and critical topography be represented and localized in a manner consistent with the draped imagery used for rendering. Image Understanding methods are thus likely to play a much more central role in future terrain database creation activities.

It is important that new approaches to the construction of geospatial databases provide improvements in economy – measured in cost and time – as well as in the quality of the resulting model. High-resolution IFSAR and high-resolution, highly calibrated photogrammetric stereo is expensive to collect and process and is not likely to be available prior to need for many geographic areas of potential interest to the M&S community. In time-critical situations, the use of terrain feature extraction methods which depend on such data may force significant delays in the model-building process as the needed data is acquired. As a result, it is important to understand the minimum necessary source data quality required to determine relevant information and to build data extraction tools able to compensate for deficiencies in existing source data.

Figure 3: Shallow wash located within Range 400.

3 Ravine Extraction

While ravines and dry washes are usually at least partially visible on aerial photographs, accurate detection and localization is difficult. In addition, ravines are easily confused with roads, tracks, and other structures commonly appearing in non-urban environments. Photogrammetry fails to extract many ravine features because of their restricted depth and small width relative to the resolution with which terrain elevation is extracted. In addition, the photogrammetric overlaps usually used for non-urban terrain preclude the ability to see into many ravine bottoms or measure the slopes of their sides.

The dry wash shown in Figure 3 is located in the live fire range (Range 400) of the USMC Air Ground Combat Center, located at Twentynine Palms, CA. The wash is 1m-2m deep and 2m-3m across. Though *very* small compared to the resolution at which terrain features are usually modeled, such ravines are of critical tactical significance to dismounted infantry, and therefore all units in a combat force.

The nominal resolution of elevation data on which terrain models are based is commonly on the order of 30m or greater. Due to the smoothing inherent in the manner in which the elevation data is obtained, the effective resolution, measured in terms of the size of distinct features apparent in the data, is much coarser. Thus, even with DEM data finer than a 30m grid, terrain structure such as shown in Figure 3 is likely to go unrepresented. Nevertheless, coarse resolution DEMs can be used to predict likely locations where smaller terrain deformations are to be expected.

Hydrological analysis based on digital elevation models is now a standard function in many geographic information systems (GIS). When combined with appropriate resampling and interpolation methods, such operations can be used to effectively

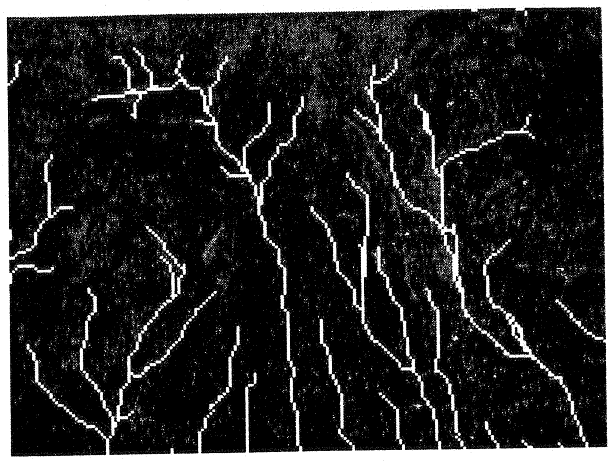

Figure 4: Hydrologic flow analysis based on 30m DEM of Range 400, Overlayed on Orthoimage.

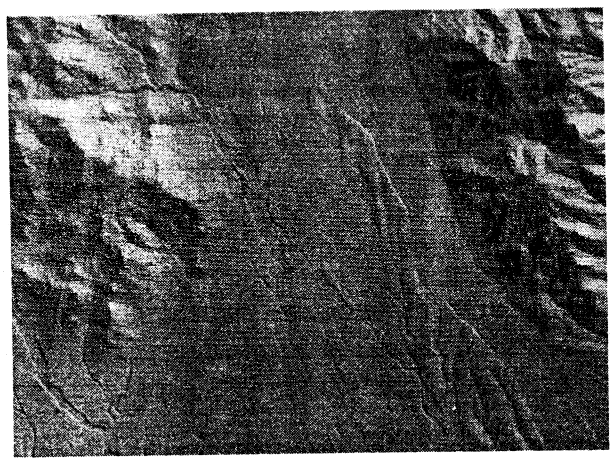

Figure 5: Shaded relief of Range 400 based on high-resolution DEM.

estimate the existence and location of ravine features using DEM data with a post spacing significantly greater than the width of the features of interest. Figure 4 shows the results of applying such a hydrological analysis to a 30m DEM of a portion of Range 400, with the results overlayed on top of a higher-resolution aerial image of the same area.

One of the advantages of using Range 400 as a demonstration area is that high quality DEM data is available with a post spacing of 1m and a nominal precision of 0.1m. For example, Figure 4 can be compared with Figure 5, which shows a shaded relief rendering of the same area, based on the higher resolution DEM. This provides the

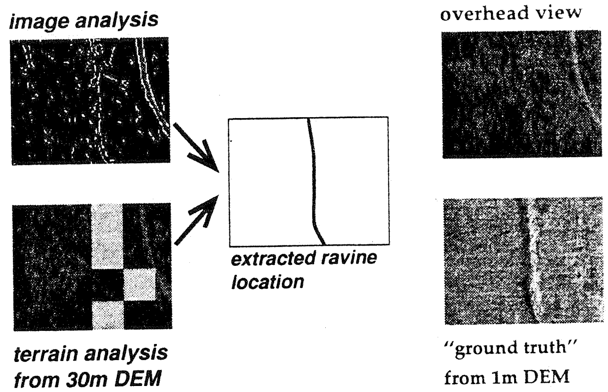

Figure 6: Combining terrain analysis and IU for ravine extraction.

ability to compare the results of augmenting standard resolution terrain data with image understanding techniques with results based on high precision (and expensive) photogrammetry (e.g., [Richbourg *et al.*, 1995, Richbourg and Olson, 1996, Henderson *et al.*, 1997]).

Figure 6 illustrates our approach. On the upper right of the figure is a section of the Range 400 orthoimage corresponding to a 120m by 150m area on the ground. In the upper left is the output of a Canny edge detector applied to this image. The lower right shows the same area, displayed as a shaded relief rendering of the high resolution DEM data. Essentially, this indicates the "ground truth" topography. The lower left indicates the results of applying automated ravine estimation to a 30m resolution DEM covering the full Range 400 area. The center of the figure illustrates how image and terrain analysis can be combined for ravine extraction (see [Thoenen and Thompson, 1997]).

4 Road Cut and Fill Extraction

For a simulation to accurately reflect tactical reality, it is important to be able to reliably determine whether or not road cuts and fills need to be added to road segments in a geospatial database. Figure 7 shows a view generated from the U.S. Army Close Combat Tactical Trainer (CCTT) Central U.S. database (CCTT Primary One). The road cut, which appears as a long trench cut through a hillside, was generated by an automatic cut and fill insertion tool that first drapes the road onto the terrain skin and then inserts cuts and fills whenever needed to keep the road grade from exceeding a preset steepness.

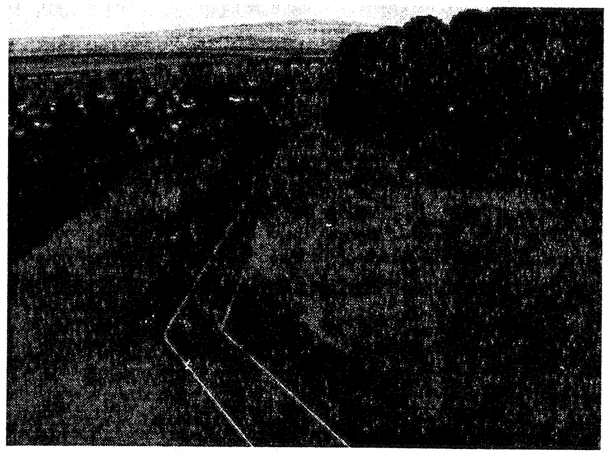

Figure 7: Incorrect road cut appearing in CCTT Primary One due to incorrect automatic insertion tools.

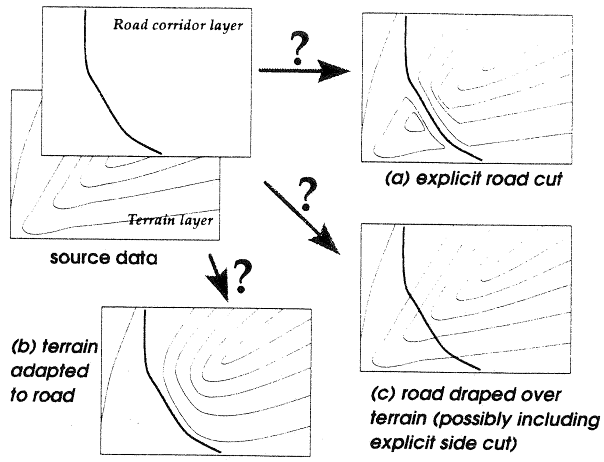

Figure 8: Road cut insertion requires merging 2-D road locations with the 3-D terrain skin by (a) introducing an explicit road cut, (b) modifying the terrain skin to accommodate the road, or (c) draping the road over the terrain.

It is one of a large number of road cuts and fills in CCTT Primary One that are obviously incorrect to anyone viewing the database. While improved cut and fill insertion techniques might reduce the incidence of implausible configurations such as shown here, there is no way to accurately represent what is actually on the ground without revisiting the source data.

In most geospatial database construction systems, information about the terrain skin and the location of roads is independently determined and then represented in separate layers in a GIS. A merging operation must then be performed to create a terrain model that is realistic and behaves in a manner consistent with the desired semantics of the simulation. Road networks are almost always initially extracted as 2-D features, with no information explicitly available about superelevation or grade. Three general approaches are possible for adding this information to produce a full 3-D representation of the road surface (Figure 8): The road can be "draped" over the terrain, adapting to the terrain surface; the terrain can be locally deformed so as to make the road surface plausible and to blend the road and terrain in a natural manner; or explicit cuts and fills can be introduced to deal with discrepancies between the desired geometry of the road surface and the shape of the underlying terrain.

As simulations move from geotypical to geospecific databases, it becomes increasingly important to determine not just where road cuts and fill are plausible, but where they actually occur. Our proposed method for detecting road cuts and fills will proceed as follows:

- Search in the imagery for roads present in the road corridor layer of the source data GIS. This step is similar to the image analysis operations used for ravine extraction.
- Use civil engineering principles applied to road corridor data draped over the base-level terrain skin to predict where cuts and fills are likely to occur.
- Search along the sides of roads in located in the imagery, looking for textural variations that correspond to the pattern of predicted cuts and fills. The key is to search for patterns of variability, since the actual visual appearance of cuts and fills is impossible to predict.

5 Integration With Existing Tools

To be cost effective, methods developed as part of this project must be easily integrated with other aspects of the geospatial database creation process. Micro-feature extraction methods should be able to utilize the full range of existing geospatial database tools. The results of these micro-feature extraction methods should be easily used by the full range of existing geospatial database tools.

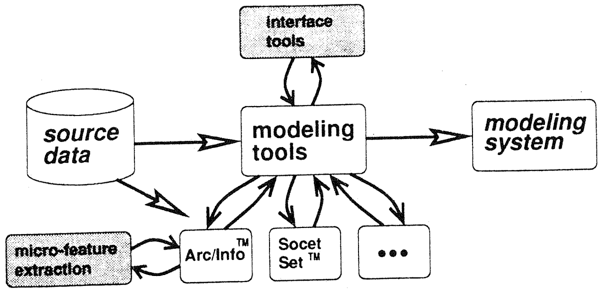

Figure 9: Integrating micro-feature extraction into established procedures for building terrain models.

Geospatial database tools use a much broader range of data formats than do most "pure" image understanding systems. Imagery, elevation data and other specifications of terrain skin, linear features, and 3-D structures must all be represented in geospecific coordinate systems. In the initial phase of this project, all code we develop will be interfaced to the Arc/Info™ GIS software. While Arc/Info is a proprietary system, it is likely to be used by anyone building production-grade geospatial databases.

Figure 9 shows how programs we develop fit into the larger context of geospatial database production. Modeling tools in common usage take in source data; organize, analyze, and process it with the help of tools such as Arc/Info™ and GDE's Socet Set™; and create models using a language appropriate to the simulation or mission planning systems required by the end user. By coupling our system to Arc/Info, we facilitate compatibility with any model generation system that uses Arc/Info as a support tool.

6 Evaluation

Too often, image understanding methods are evaluated in isolation instead of in the context of the larger systems that they are typically embedded within. The IU methods described in this paper should be viewed as adding value to existing geospatial database construction processes. For evaluation purposes, we will start with state-of-the-art simulation databases, which often have been constructed at substantial expense. These databases will have known deficiencies which affect critical aspects of the realism of simulations. The end result of the methods we have described above will be to improve these existing terrain databases. Thus, the appropriate evaluation process involves comparing the databases before and after the processing we propose. This allows for an operational assessment by letting end users interact with simulations involving the original and improved terrain databases.

Given believable ground truth data, quantitative measures can also be developed. In the case of Range 400, the availability of 1m DEM data will aid this process. Quantitative evaluation will be based on how well IU methods combined with lower-resolution DEMs can approximate the ravine features apparent in the higher-resolution DEMs. Richbourg's work in developing computational techniques for analyzing concealment features in the Range 400 data provides a valuable starting point [Richbourg *et al.*, 1995, Richbourg and Olson, 1996]. The NIST-TEC-LADS project investigating landform extraction from the Range 400 data is also relevant.

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