TERRAIN MORPHOLOGY MODELLING

Massoud Sharif
Alfred Zinck

International Institute for Aerospace Survey and Earth Sciences (ITC)
P.O. Box 6, 7500 AA Enschede, The Netherlands
Tel. +31-53-4874345, Fax. +31-53-4874335
E-mail:SHARIF@ITC.NL

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ABSTRACT

Terrain morphology can be described in terms of morphographic and morphometric attributes. Morphographic attributes refer essentially to the geometry of the geoforms, including shape and profile of the topography, aspect, configuration and contour design of the forms, and drainage pattern. Morphometric attributes refer to the dimensions of the geoforms, including relative elevation, valley density and slope steepness. Both morphographic and morphometric attributes of geoforms can be derived from a topographic map by visual interpretation or from a DTM by either visual or automated procedures. The first issue concerns the acquisition of terrain morphologic features either by photogrammetric selective modelling or by means of an automated process. Selective procedure is a highly subjective one which calls for an objective automated method using digital terrain modelling (DTM). The second issue concerns the quality assessment models. Different approaches allow to assess the accuracy of modelling. They deal mostly with the terrain morphologic representation in terms of statistical consideration, namely, the standard deviation of the discrepancies. However in some applications, it may be more relevant to assess the fidelity of the terrain representation in relation to the real terrain morphologic features. In this context, the mathematical background of an analytical approach is discussed, and a model to assess the quality of the representation is presented. The third issue refers to the determination of an optimum model for grid densification. Idealized simulated terrain primitives were used for that purpose as well as for extracting selective modelling rules. Morphologic modelling was carried out using the primitives and applying different grid densities to determine an optimum model for grid densification. The performance of the optimum digital morphologic model was verified using not only geometric primitives but also real terrain morphology. The effects of the skeleton information on terrain morphologic features were analyzed, and the rules drawn from idealized geometric primitives were tested on a real terrain using a moderately rough terrain model. The analysis of the test results provides a feedback for optimizing the procedure to generate an optimum terrain morphologic model.

INTRODUCTION

Terrain morphology modelling is the process of extracting and representing the spatial location of morphologic points, lines or features on the terrain surface. This requiresthe fulfilement of three basic objectives: (a) the acquisition of terrain morphologic features either by photogrammetric selective modelling or by an automated process; (b) the assessement of the modelling quality in terms of statistical accuracy but also as tothe fidelity of the terrain representation in relation to the real terrain morphologic features; and (c) the determination of an optimal model for grid densification using terrain geometric primitives and expert rules. These three issues are discussed in the present paper.

1. TERRAIN MORPHOLOGY REPRESENTATION

The representatin of morphologic terrain features can be performed either by manually controlled selective representation of those features, referred to as the skeleton information (Σ), or by means of semi-automated representation of more homogeneous morphologic features, called filling information (Π).

Optimum representation combines selective with semiautomated representation. The aim is to portray terrain morphology faithfully, without excessive redundancy of the presented information. For that purpose, an expert system for optimum representation of morphologic terrain features, integratedin a GIS was developed. It is practically impossible to represent either the global terrain surface in an exact mathematical expression (approximateld by a reference ellipsoid) or the macro-reliefs (via different polynomials or via superimposition of sinusoids with variable amplitudes and frequencies, etc ...). Therefore we have decided to simulate the terrain morphology by computer generation of ideal geometric primitives, and the combination of those primitives. These are the geometric primitives for which, on one hand, a mathematical definition is possible and, on the other hand, the assimilation to terrain morphologic features is probable. These are: semi-spheroidal surface, semi- ellipsoidal surface, conical surface, gaussian surface , parabolohyperboloidal surface, fault , ridge, and any combination of those.

The simulation of terrain morphology via geometric primitives allows us to know the input signal to the processing and evaluate the error of terrain morphology representation. The probability of simulating perfectly terrain morphologic features by the geometric primitives is very low, but combining those primitives will increase the probability. In any case, the verification of the concept by real terrain morphologic features is necessary.

Basically, terrain morphologic modelling can be performed in the following manners:

- Selective representation of terrain morphologic features.
- Semi-automated representation of terrain morphologic features.
- Combination thereof (optimum representation).

1.1 Selective representation

This method is carried out manually to portray the terrain morphology. It is applied to abrupt changes in terrain slope. Basically, it is a subjective method of portraying the skeleton of terrain morphology.

The main stages of optimum representation are shown in figure 1.

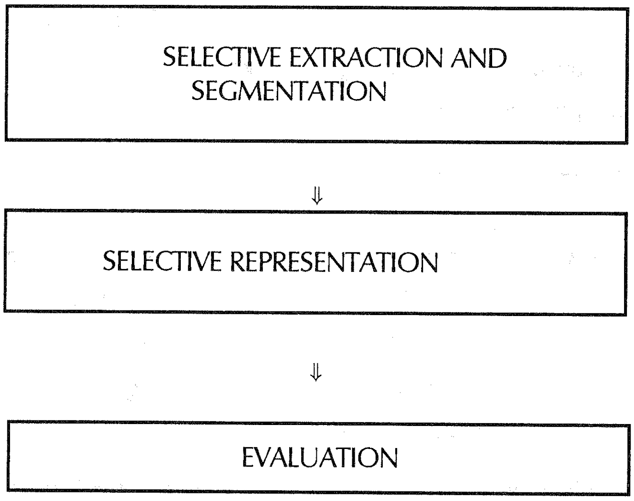


Fig. 1 Main stages of selective representation

The general procedure for data preparation and feature extraction for selective representation of distinct morphometric features (Σ information) is treated by Makarovic (1976).

Because the procedur is subjective, it needs to be systematised. To attain a balance between selective and semi automated representation via a smooth operation, some rules have been formulated. These represent the RULE BASE for terrain morphologic representation.

The general procedure for segmentation, extraction and selective representation of the terrain morphologic features are explained by Charif (1991). From the results of the experimental tests applied to ideal geometric generated primitives, their composite surfaces and to real terrain surfaces, some rules have been extracted for selective representation of the terrain morphologic features (Charif and Makarovic, 1992).

1.2 Semi-automatic representation.

This is a method for representing terrain regions, which are mainly homogeneous, though irregular, thus providing the filling information (Π information). The density of the grid is locally adapted to terrain morphology.

The main stages of semi-automated representation are shown in figure 2.

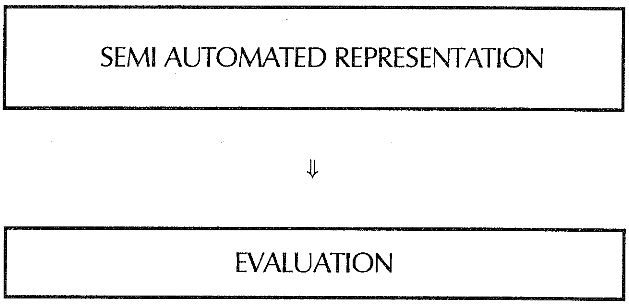


Fig. 2 Main stages of semiautomated representation

In Makarovic (1973), a on-dimensional (1D) Laplacian operator was used separately in the X and Y directions. Tests using some representative, geometrically ideal primitive surfaces show that "1D-Laplacian in four directions" proves to be a potential alternative criterion for the self-adaptive densification in semi-automated representation Charif (1992)

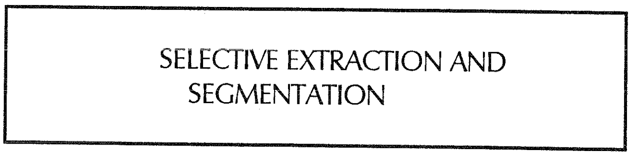
For the study, the following densification criteria were used: 1D-Laplacian algorithm separately in X and Y, 2D-Laplacian algorithm, extended 2D-Laplacian algorithm, and 1D-Laplacian algorithm separately in four directions.

The following potential alternative criteria: median height, fitted plane, and second difference for a quadruple of points, separately in the X and Y directions, should be investigated, to define the optimum densification criterion in semi-automatic representation of terrain morphologic features.

1.3 Optimum terrain morphology representation.

This method concerns selective representation of distinct morphologic features, followed by semi-automated representation of more homogeneous morphologic terrain features.

The four main stages of optimum representation are shown in figure 3.



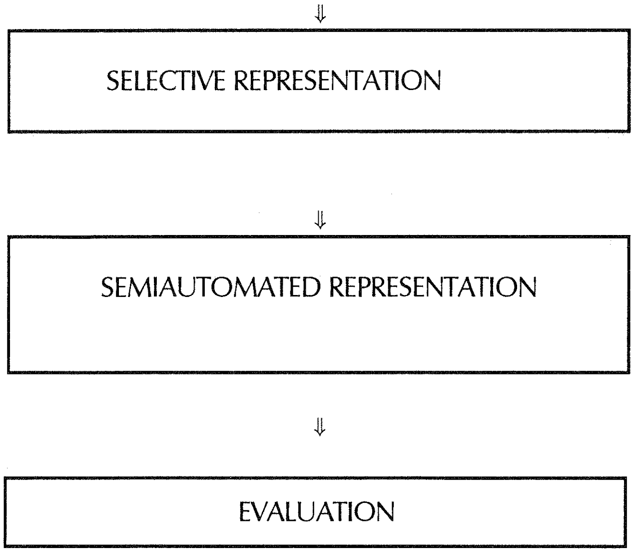


Fig. 3 Main stages of optimum representation

2. TERRAIN MORPHOLOGY CLASSIFICATION

In the context of optimum representation for terrain morphology modelling, the purpose of classification is to provide some initial information on the terrain morphology for specifying the presentation process. Thus, formulation of a suitable model for a quantitative terrain morphology classification is necessary. The terrain morphologic information is differentiated according to the skeleton and filling sub-sets (Charif, 1991).

The skeleton information (Σ) is represented by distinct morphologic features. They represent, mathematically, lines where the spatial derivatives are discontinuous. It is possible to extract the morphologic features from a photogrammetric stereo model, if they are distinct enough. The problem is to define an objective criterion for detecting those morphologic features. In this context, however, a method based on the concept of profile analysis by applying the second difference criterion, is used.

The second difference in height of a triplet of points (Δ_h^2) is compared with a certain preselected threshold value. In the case (Δ_h^2) is greater than the threshold, the point belongs to the skeleton (Σ), otherwise, to the filling (Π) information.

Hence, the total terrain morphologic information (T) is composed of the skeleton (Σ) and the filling (Π), such as:

$$T = \Sigma + \Pi \qquad (1)$$

3. QUALITY MEASURES

The quality assessment of terrain morphologic representation is differentiated according to the performance (accuracy, fidelity), reliability, and efficiency (Charif, 1991).

3.1 Performance

The performance is one of the main criteria influencing the estimation of the quality of terrain morphologic representation products. Performance was differentiated further according to completeness of Σ information, accuracy of Σ and Π information, and fidelity of Σ and Π information.

In optimum representation, the terrain morphology is represented by the Σ and Π sub-sets. Consequently, the accuracy estimation should be differentiated according to the standard error.

The standard error σ_Σ of modelling by the Σ set depends on: image quality and scale, precision of instrument, operator skill and care, and sampling mode(stationary, dynamically)

The standard error σ_Π of modelling by the Π set depends on: apriori Σ set and σ_Σ, grid interval, pointing error, and interpolation algorithm.

3.2 Sources of errors

The accuracy of terrain morphology modelling is influenced by two main sources of errors: error of sampling and interpolation σ_s, and the measuring errors σ_m Assuming f(x) is the terrain profile, and $f_i(x)$ is the correct height of a point and $g_i(x)$ is the modelled height, then

$$g_i(x) = f_i(x) + m_i(x) \qquad (2)$$

In photogrammetric measurement, m_i(x) is considered partly systematic and partly random, thus the latter part of m_i(x) can be defined as a sequence of uncorrelated values, which are normally distributed, with the mean equal to zero and the variance σ_m^2. Assuming that $f_i(x)$ and $m_i(x)$ are mutually independent and thus uncorrelated, the variance of the error of the modelling is:

$$\sigma_T^2 = \sigma_s^2 + \sigma_r^2 \qquad (3)$$

3.3 Accuracy of morphologic modelling

Accuracy of terrain morphologic modelling can be estimated by analytical, semi analytical, or experimental approaches.

Quality of the modelling of the ideal geometric primitives can be assessed using the following criteria:

- The mean error σ_Σ of selective representation is determined for all the grid points on the morphologic modelled surface.

$$\sigma_\Sigma = \sqrt{(v_\Sigma^2/N_\Sigma)} \qquad (4)$$

Where v_Σ^2 represent s the discrepancy between true and modelled heights, and N_Σ is the total number of points on the morphologic feature.

- The mean error σ_Π of semi automatic representation is determined for all the grid points on the modelled surface.

$$\sigma_\Pi = \sqrt{v_\Pi/N_\Pi} \qquad (5)$$

Where v_Π^2 represents the discrepancy between true and modelled heights, and N_Π is the total number of points.

- The mean error $\sigma_\Pi opt$ of optimum representation is determined for all the grid points on the modelled surface.

$$\sigma_{opt} = \sqrt{(v_{opt}^2/N_T)} \qquad (6)$$

Where v_{opt}^2 represents the discrepancy between true and modelled heights, and N_T is the total number of points.

For comparison with other tests, the mean error is normalised with the maximum height in the represented surface H_{max}.

$$\bar{\sigma} = \sigma \,/\, H_{max} \qquad (7)$$

- In each experiment , the maximum discrepancy between the ideal and the interpolated DTM surface was normalised by Hïmaxî, i.e., to have a measure that is independent of the height of the primitive:

MĀXER = maximum discrepancy / H_{max} (8)

- The sampling efficiency is defined by the number of sampled points per unit area:

$\bar{E}$ = [Numb. of modelled pts] / [total Numb. of pts] (9)

4. MORPHOLOGIC MODELLING APPLIED TO IDEAL GEOMETRIC PRIMITIVES

Terrain morphology modelling was applied to some artificial ideal geometric primitives. The following rule base was set up as a result of these experiments.

4.1. Semi-spherical features. Terrain morphology modelled as semi-spherical surfaces can only be modelled via selective modelling when Δz/z ≤ 2%, where Δz is the height of the feature and z is the flying height. Applying the optimum modelling the accuracy was improved by 0.4% to 1.5%, and the efficiency by 34% to 77%.

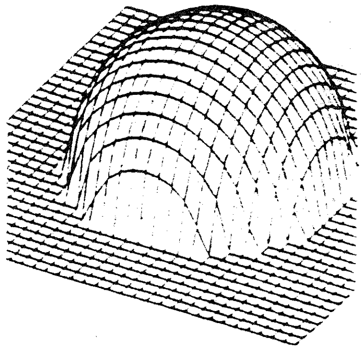


Figure 4.1. Semi-spherical feature

4.2. Semi-ellipsoidal features. Terrain morphology modelled as semi ellipsoidal surfaces can only be modelled via selective modelling when Δz/z ≥ 1.5%. Applying the optimum modelling the accuracy was improved by 1.7% to 3.1%, and the efficiency by 3% to 75%.

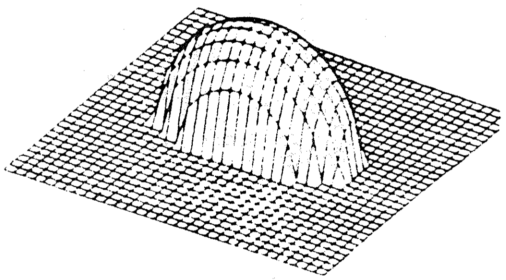


Figure 4.2. Semi-ellipsoid feature

4.3. Conical features. Terrain morphology modelled as conical surfaces can only be modelled via selective modelling when Δz/z ≥ 2.5%. Applying the optimum modelling the accuracy was improved by 0.26% to 1.4%, and the efficiency by 11% to 57%.

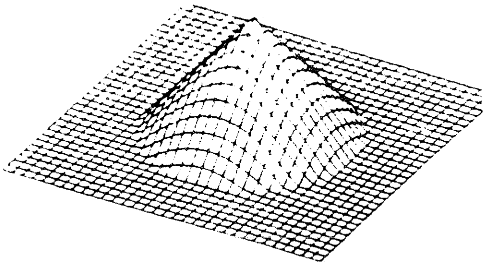


Figure 4.3. Conical feature

4.4. Gaussian features. Terrain morphology modelled as gaussian surfaces can only be modelled via selective modelling when Δz/z ≥ 2.0%. Applying the optimum modelling, the accuracy was improved by 0.8% to 1.17%, and the efficiency reduced by 5% to 10%.

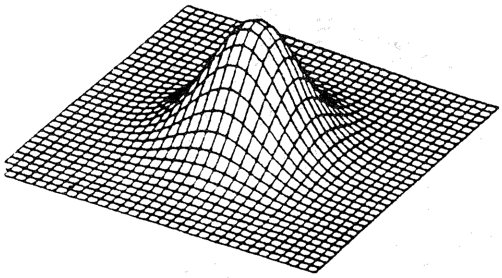
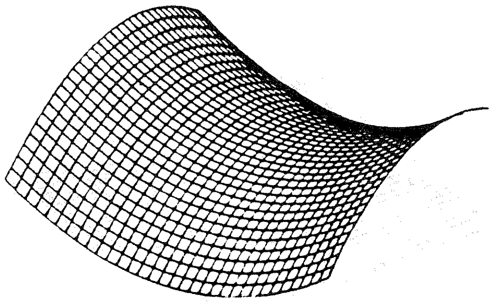


Figure 4.4. Gaussian feature

4.5. Hyperboloparaboloidal features. Terrain morphology modelled as hyperboloparaboloidal surfaces can only be modelled via selective modelling when $\Delta z/z \geq 6.0\%$. Applying the optimum modelling, the accuracy was improved by 0.13% to 1.33%, and the efficiency by 6% to 19%.



4.5. **Hyperboloparaboloidal** feature

4.6. Ridge line features. Terrain morphology modelled as ridge line can only be modelled via selective modelling when $\Delta z/z \geq 2.0\%$. Applying the optimum modelling the accuracy was improved by 1.6% to 3.6%, and the efficiency by 10% to 27%.

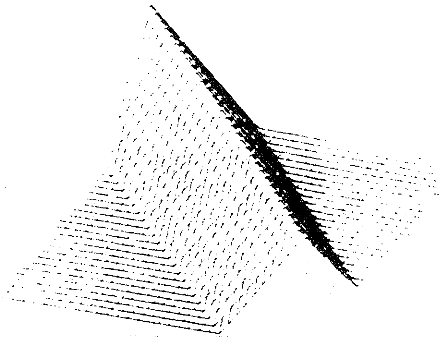


Figure 4.6. Ridge line feature

4.7. Fault features. Terrain morphology modelled as fault surfaces can only be modelled via selective modelling when $\Delta z/z \geq 2.0\%$. Applying the optimum modelling, the accuracy was improved up to 9.4%, and the efficiency up to 25%.

4.8. Combposite features. Terrain morphology modelled as a combination of those surfaces can only be modelled via selective modelling, when $\Delta z/z \geq 5.0\%$. Applying the optimum modelling the accuracy was improved by 0.1% to 0.28%, and the efficiency by 4% to 13%.

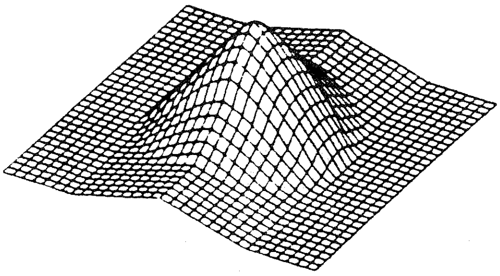


Figure 4.8. Composite feature

5. OPTIMUM SAMPLING APPLIED TO REAL TERRAIN RELIEF

To verify and consolidate the conclusions drawn from the experiments using artificial ideal geometric primitives and their composites some experiments using real terrain morphology were conducted in the Bonnieux region (south of France).

This region is partly covered by flat and partly by accidental terrain. This justifies the use of optimum morphologic modelling. The Easting of the area was between 840 200 and 841 800, the Northing between 174 000 and 176 880, the altitude of terrain between 482.000 m and 243.000 m. The terrain relief was represented by 16384 points. Two areas with some abrupt changes have been delimited from a more homogeneous terrain, and Σ information was collected selectively using the MAPS 200 system. This information contained 382 points in vector form.

variant	σ	MAXER	Pts
Π	6% of z	2.78	0.65
opt	8% of z	5.87	0.71

Table 1 performance estimates for optimum versus semi automatic modelling

Test	R_σ	R_{max}	R_E
opt/Π	1.33	2.11	1.1

Table 2: Performance estimation of different variants of opt with respect to Π

In conclusion the following can be stateed: the fidelity of the representation is improved by inclusion of Σ information. Apart from a great improvement in the accuracy of the skeleton information, the overall accuracy and overall efficiency are also improved significantly, compared to semi -automated modelling (R σ= 33% and R E = 10%). Finally, for this region, we observe that by including the Σ information which fulfils the specifications of the rule base we can get, not only a better modelling, but also higher accuracy, with less effort.

6. CONCLUSIONS

By including the Σ information in the modelling process, the accuracy increases substantially. At the same time, the inclusion of Σ information results in a considerable gain in efficiency. From the results of the modelling experiments applied to ideal geometric primitives, a simulated composite surface and real terrain morphology, additional rule bases were set up. Rule base to systemize selective modelling and rules for the procedure of the subsequent phase of semi- automated modelling, in order to achieve a balance between Σ and Π information, allow for optimum sampling.

The above method allows promissing applications in descriptive geomorphology. Both morphographic and morphometric attributes of geoforms can be derived from a topographic map by visual interpretation or from a DTM by either visual or automated procedures. Morphometric attributes refer essentially to the geometry of the geoforms, including shape and profile of yhe topography, aspect, configuration and contour design of the forms, and drainage pattern. Morphometric attributes refer to the dimensions of the geoforms, including relative elevation, vally density and slope steepness. On-going research explores specifically the possibility of using the ideal geometric primitive surfaces for computer-assisted recognition of elementary landforms, as a basis for environment.

REFERENCES

Ayeni, O.,1976. Objective terrain description and classification. I.S.P.R.S. 23(III/1), pp 1-8.

Charif, M.,1991, Echantillonnage optimal pour modele numerique de terrain, partie integrante d'un systeme d'information geographique. Ph.D.Thesis, Paris 7 University, France, 135 pp.

Charif, M., Makarovic, B., 1988. Optimizing progressive and composite sampling for Digital Terrain Model, I.S.P.R.S., 27 (B10):III-264-280, Kyoto

Fredrikson, Poul., Jacobi, Ole., Kubik, K. 1983. Optimal sample spacing in Digital Terrain Models I.S.P.R.S. Proceedings, commission 3.

Fredrikson, Poul., Jacobi, Ole., Kubik, K. 1984. Accuracy prediction in Digital Elevation Models, I.S.P.R.S. Rio de Janeiro, 26 (3/1), pp. 246-255.

Fredrikson, Poul., Jacobi, Ole., Kubik, K. 1984. Modelling and classifying terrain, I.S.P.R.S. Rio de Janeiro, pp. 256-265.

Mandelbort, B.B., 1982. The fractal geometry of nature. W.H. Freeman and co. San Francisco, 480 pp.

Kubik, K., Roy, B., 1986. Digital terrain model workshop proceedings. Columbus, Ohio, 150 pp.

Laan, R.C., 1973. Information transfer in reconstruction of data from sampled points of a sinewave I.T.C. Journal 1973, 3, pp 379-396

Makarovic, B., 1973. Progressive Sampling for DTM's, I.T.C. Journal 1973-3 pp 397-416

Makarovic, B. 1977. Composite Sampling for Digital Terrain Model I.T.C. Journal 1977-3, pp 406-431

Tempfli, K., 1980. Spectral analysis of terrain relief for the accuracy estimation of DTM, I.T.C. Journal 1980-3, pp 478-510