# DIGITAL TERRAIN MODELS (DTM) FROM CONTOUR LINES UPGRADED BY PHOTOGRAMMETRIC SELECTIVE SAMPLING

A.M. TULADHAR and B. MAKAROVIC
International Institute for Aerospace Survey and Earth Sciences (ITC)
350, Boulevard 1945, 7500 AA ENSCHEDE
The Netherlands
Commission IV

## 1. ABSTRACT

The paper addresses upgrading DTMs synthesised from digital contour lines and distinct terrain features sampled in the photogrammetric stereo models. Attention is given to the collection of the two data sets, then processing, and evaluation of the synthesised DTM. The emphasis in this paper is on the processing and assessment of the results by some experimental tests.

First, digital contour lines were converted into a regular DTM grid. For each grid point a circular search was applied with an increasing radius until a specified minimum number and a suitable distribution were found of the contour points and of the break-(line) points. The height was subsequently interpolated and the process was repeated at other DTM grid points.

The geometric quality was assessed of both the DTM generated from the contour lines and the upgraded DTM. To this end two types of tests were applied. In the first group of tests ideal geometric primitives were used as the input, whereas the second group concerned the experimental tests using real terrain relief as input.

## 2. INTRODUCTION

The demand for digital terrain models, especially regular or semi-regular grid DTM, is rapidly increasing and cannot be met by purely photogrammetric techniques. Hence, a considerable effort has been made to convert contour lines on existing topographic maps to a grid DTM. The quality of such a DTM, however, is seriously reduced by the limitations inherent in relief modelling by contour lines and by error sources in the materials and operations involved. To obtain a higher quality product which meets the requirements of a larger group of DTM users, digital contour lines should be supplemented and the resulting DTM upgraded by photogrammetric selective sampling. A rational approach is to sample, e.g., by means of an analytical stereoplotter, selectively all distinct (morphometric) terrain relief features. The latter represent the 'skeleton' information which is merged in the processing stage with the corresponding digital contour lines, the latter representing the 'filling' information. Such an upgrading process of an initial DTM, produced from the contour lines, can be gradual, i.e., when photographs and other resources are available.

The proposed approach also permits detection and removal of the gross errors and estimation of the quality of existing contour lines. To this end, the stereo superposition facility in analytical stereoplotter is very effective.

The same technique is also applicable to updating an existing DTM.

The procedure for collecting the two data subsets of DTM information and merging them is shown in figure 1.

```
 +-------------+                  +---------------+
 |Existing maps|                  | Photogrammetric|
 +-------------+                  | Stereo model   |
       |                          +---------------+
       v                                  |
   +-----------+                          |
  /  A/D      /                           v
 /conversion /        (option)     +----------------------+
+-----------+         +------->/    Superposition      /
       |              |       /     on image          /
       v              |      +----------------------+
 +-------------------+|               |
 |Digital contour    |-----+          |
 |lines(filling data)|                |
 +-------------------+           +--------+
       |                        /Sampling/
       |                       +--------+
       |                            |
       |                            v
       |                    +-------------------------+
       |                    |Digital distinct features|
       |                    | (skeleton data)         |
       |                    +-------------------------+
       |                            |
       |                            |
       |            +--------------+|
       +--------> / Merging  by   / <------+
                 / interpolation /
                +--------------+
                       |
                       v
                +-------------+
                |Upgraded DTM |
                +-------------+
```

Fig.1 Procedure for upgrading DTMs

This paper addresses the photogrammetric selective sampling in conjunction with the process of merging the obtained information with the digital contour lines. It includes a performance study applied to geometrically ideal primitives and to real terrain relief.

## 3. DIGITIZING CONTOUR LINES

The contour lines on existing topographic maps can be digitized manually, by automatic line following, or by raster scanning. Each of these techniques uses different hardware and software.

Manual digitizing is carried out on a digitizing table which is linked to a microprocessor or a microcomputer equipped with a recording device. The software provides for coding/indexing the contour levels and for application of different digitizing modes. The digitizing can be by selected discrete points, by continuous strings of points at a specified interval or within a specified angular or curvature range, etc. The digitizing parameters can be selected such as to prevent significant loss of information in the A/D conversion. An appropriate specification of the sampling parameters permits digitizing contour lines in a compressed form.

The main disadvantage of manual digitizing is that it is a very time-consuming and labour intensive operation. Manual tracking by a cursor is tedious and induces fatique, which reduces performance and reliability. For inspection and editing, an interactive graphic station connected with the XY digitizer is therefore highly desirable.

Automatic line following requires a manual initial setting of the cursor at the beginning of the line to be digitized. It then follows the line automatically until some ambiguity arises and the operator has to help. Although a more uniform quality data can be acquired, it has not yet been used extensively, presumably because of high cost and limited reliability. The difference in accuracy between manual and automatic line following is hardly significant.

Raster scanning, however, provides a subtantially higher speed of scanning/digitizing. It produces first a large data set in raster format, which is converted to vector format. The conversion is then followed by editing and tagging the heights to the contour lines. Interactive editing is necessary to delete and/or correct the erroneously vectorized lines.

The advantages of raster scanning over manual line digitizing are uniform data quality and high speed. The main disadvantage is considerable computer time required for vectorizing and editing the large volume of raster data.

## 4. SELECTIVE EXTRACTION AND SAMPLING OF DISTINCT TERRAIN FEATURES

The input is stereo images and a map with contour lines of the area under consideration. The quality of the images depends on the atmospheric conditions, photo scale, camera (with or without forward motion compensation), film, and the quality of photo-processing.

A mirror stereoscope can be used for selective feature extraction. For sampling, a photogrammetric stereo-plotter, preferably analytical, provided with a recording device, is suitable.

The main process stages are:
- extraction of distinct terrain relief features,
- orientations of stereo models in a plotter,
- sampling and recording the information.

Extraction and sampling can be separate or combined in a near real time process. The extraction process concerns identification of the distinct morphometric feature, their marking, coding and indexing, e.g., using a mirror stereoscope. The quality of extraction depends upon the information content in the photographs used, and on the interpretor's knowledge, experience and motivation. The distinct terrain relief features can be areas, lines, and points. According to their nature three categories of terrain features can be distinguished, namely natural, man-made, and mixed [3]. Examples of natural features are ridge lines, drainage lines, pits, peaks, saddlepoints, etc. Man-made features are cuts and fills, embankments along roads, terraces, airfields, harbours, etc. Quarries are an example of the mixed type. Clear guidelines should be provided concerning the terrain relief features to be extracted. It is important to extract all those terrain features which cannot be sufficiently modelled by the contour lines. Thus the quality of modelling terrain relief depends on the comprehensiveness of the distinct terrain features (skeleton) extracted from the stereo images, and on the contour interval of the specific map series. Figure 2 shows the interrelationships between the terrain classification, sampling procedure and the procedure for quality modelling procedure.

```
+--------------+ selection of  +------------------+
|Terrain       |--------------->|Extraction,       |
|classification|<--------------  |sampling procedure|
+--------------+ influences     +------------------+
    |    ^                            ^    |
    |    |                            |    |
    |    |selection of   selection of |    |
    |    |                            |    |
    |    |                            |    |
    |    |      +-----------------+   |    |
    |    +------|Quality modelling|---+    |
   +---------->|procedure        |<--------+
   influences +-----------------+ influences
```

Fig. 2 Interrelationships between terrain classification, sampling procedure and quality modelling procedure

The software required for digitizing terrain relief features is the same as that for 3D-modelling of other terrain features than relief (i.e., 3D-digital mapping).

Digitizing can be by either discrete points or continuous strings, depending upon the geometry of terrain features extracted .For regular (man-made) features the stationary (point by point) mode is most appropriate, whereas for irregular (natural) features the dynamic (stream) mode is usually more suitable.

## 5. MERGING OF DIGITAL CONTOUR LINES WITH DISTINCT MORPHOMETRIC FEATURES

The merging process concerns three main stages: the pre-process, the main process and the post-process. Preprocessing concerns the transformation of both data sets in a common coordinate system. The contour lines are transformed by using the first degree polynomial, which suffices to minimize the effect of regular map distortions.

The main processing concerns the merging of the contour lines with the selectively sampled terrain relief features by generating a new regular grid DTM. The procedure comprises the following operations:

i) Definition of the regular DTM grid (XY for each point),
ii) Segmentation and search for: - contour line points
  - morphometric features' points,
iii) Interpolation of the height for each grid point.

Figure 3 shows the interrelationships between the segments of the input information, the search criteria, and the interpolation procedure.

```
+--------------+                      +----------+
|Segments of   |--------------------->|Search    |
|contour lines|<---------------------|criteria  |
|and distinct  |                      +----------+
|features      |                         ^ |
+--------------+                         | |
      | ^                                | |
      | |                                | |
      | |            +--------------+    | |
      | +-----------|Interpolation|--------+ |
      +------------>|procedure     |<--------+
                     +--------------+
```

Fig. 3 Interrelationships between segments of the input data search criteria and the interpolation procedure

The layout of the regular grid is defined by the user's specifications. Commonly applied segments for interpolation are circular or square patches. From a geometric point of view, circular segments are preferable, though the search time is longer than with square segments.

The segmentation procedure is as follows:

```
Initilize the specified minimum radius = r
   Search for reference points (np) within the circle with the radius r
            If np = meets search criteria THEN
                    GO TO interpolation
                            ELSE
                            increase radius
                            and go to search procedure
```

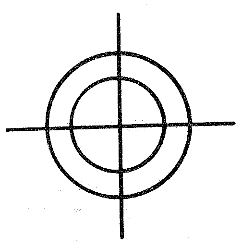

Fig. 4.a Segmentation into circular area with increasing radius

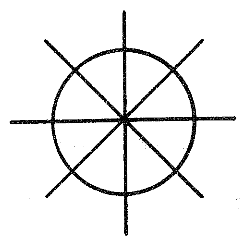

Fig. 4.b Segmentation into octants

According to figures 4a and 4b, the following two criteria can be applied in the search:

i) Minimum number of the contour points inside the circle,

ii) Distribution of these points in the octants, i.e.,
   - the number of points
   - the degree of symmetry

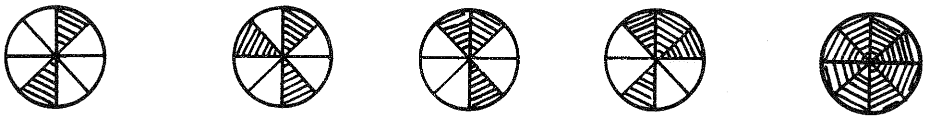

Fig. 5 Examples of acceptable patterns of points in the octants

The interpolation algorithm should, however, be capable of handling irregularly distributed points of contour lines and break lines.
The following guidelines were considered:
- use different weights for the two subsets of information (skeleton and filling),
- apply a simple, robust and time-efficient interpolation algorithm,
- exclude the points across break lines in interpolation

It is beyond the scope of this paper to identify the most suitable interpolation algorithm. For the tests, however, a simple, robust and time efficient interpolation algorithm was used, i.e., the "weighted moving average" [6, 8]:

$$f(\hat{x}) = A^T \cdot f(x)$$

where A is the vector of normalized weights for the reference points,
$f(x)$ is the vector of the reference heights within the circular search area, and
$f(\hat{x})$ is the interpolated height.

For weighting, a suitable exponential function can be used [8].

$$W = \exp\{-c(d/\Delta X)\}^2$$


Fig.6 Exponential function

The weight should not be zero for $d <$ radius r of the search area. Because r is variable, depending upon the input, the parameter c should be adapted to r.
A simple relation meeting this requirement is

$$c = a * r$$

where a is a constant.

The weights assigned to the break lines/points were double than those of the contour points. To the contour line points located across a break line were given zero weights. This is necessary to preserve distinct breaks after the interpolation (figure 7).

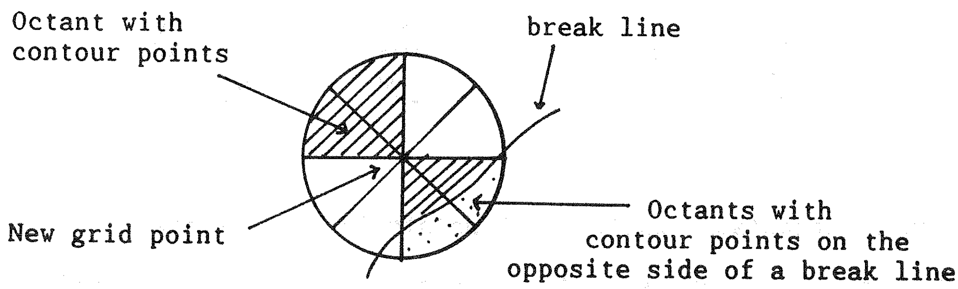


Fig.7 Weighting of points in presence of a break line

## 6. PERFORMANCE ASSESSMENT

The assessment of performance comprises two stages:
The first stage consists of assessment of the accuracy of the DTM by the standard error ($\sigma$):

$$\sigma = \sqrt{\frac{\Sigma(H' - H)^2}{N - 1}}$$

where H′ = DTM heights derived from digital contour lines or upgraded DTM heights derived from digital contour lines and break lines/points,
H = heights of check point,
N = number of check points.

This overall measure $\sigma$ is rather insensitive for the actual upgrading, especially in the vicinity of the terrain relief skeleton. A more comprehensive quality assessment model should be devised, i.e. to provide for a greater differentiation at portraying the terrain relief.

The second stage concerns assessment of the upgrading rate (UPR):

$$UPR = \frac{\sigma'}{\sigma} - 1$$

where

$\sigma'$ = standard error of the upgraded DTM derived from digital contour lines and break lines/points,
$\sigma$ = standard error of the DTM derived only from digital contour lines.

## 7. TESTS

Because of a shortage of time, the extent of the tests was rather limited. The aim was to study the effectiveness of the proposed upgrading technique. Tests were carried out in two parts, using first some geometric primitives as the input and then with real terrain relief.

### 7.1. Tests with geometric primitives

For these tests, two geometrically ideal primitives were used as the input, i.e., a pyramid and a hyperbolic-paraboloid. The height of the pyramid was assumed 10.4 m and of the hyperbolic-paraboloid 8m. Both primitives were represented by contour lines with 1m interval. Break lines were also generated for the pyramid. On the smooth hyperbolic-paraboloidal surface, auxiliary lines were generated along the maximum slope passing through the saddle point. The aim was to study the improvement in the quality of the DTM by merging the break lines and for the auxiliary lines.

The ideal pyramid used as the input is shown in figure 8. Figures 8a and b show the actual input, i.e., the contour lines and break lines, for generating a grid DTM. Figure 8c illustrates the DTM grid obtained from the contour lines only, whereas figure 8d shows the DTM upgraded by the break lines. The small irregularities emerge from the interpolation algorithm (weighted moving average). By comparing with the ideal reference surface, the standard errors without and with break lines are 0.28m and 0.24m respectively, and the corresponding maximum errors are 0.60 and 0.55m. Hence, the overall upgrading rate is 14.3%, whereby local improvement in the vicinity of the break lines is much higher. The results obtained by a similar test with the hyperboloid-paraboloid as the input show (as expected) that the effect of the auxiliary lines is insignificant.

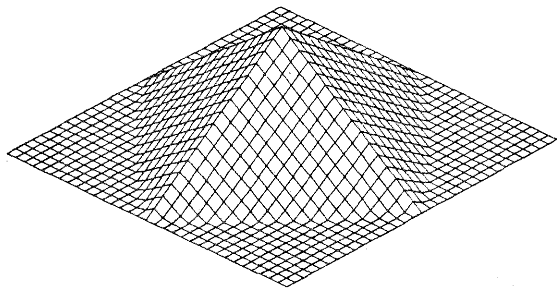

Fig.8 Ideal pyramid

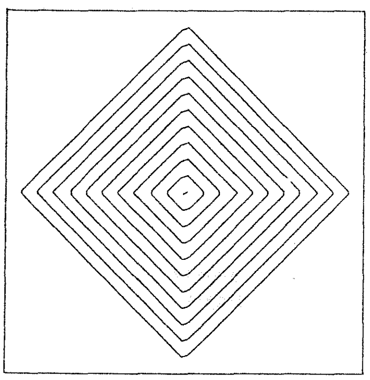

Fig.8a Input: contour lines

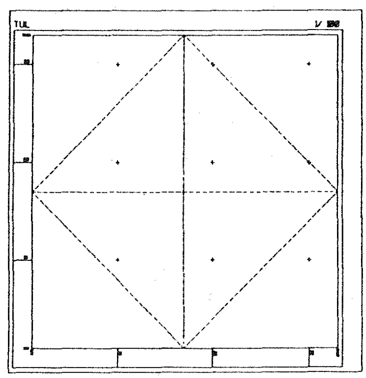

Fig.8b Input: break lines

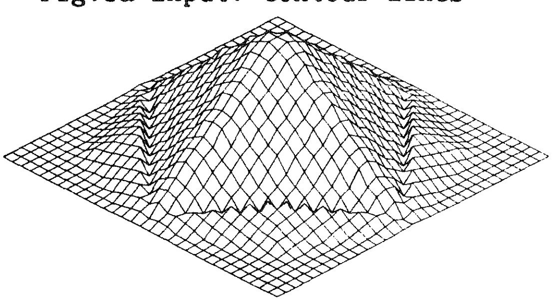

Fig.8c DTM derived from contour lines only

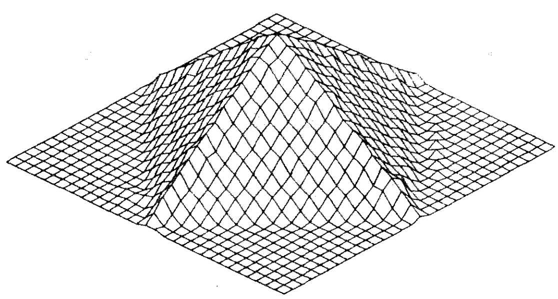

Fig.8d DTM derived from contour lines and break lines

## 7.2. Tests with real terrain relief

Contour lines with 20m interval at 1/50,000 map scale were digitized manually with the Intergraph system on-line. Digital contour lines were then transformed to the ground coordinate systems by affine transformation.

Distinct terrain features (break lines and points) were extracted from aerial photograph at 1/30,000 scale (photographs at smaller scale were not available). A Kern DSR1 with MAPS200 software was used for measuring and digitizing. A regular DTM grid at 25m spacing was sampled. This DTM grid was used as the datum for assessment of the accuracy of the DTM derived from the contour lines and the upgraded DTM.

The standard and maximum errors of the DTM derived from the contour lines (Figure 9a) are 6.62m and 17.08m respectively. For the upgraded DTM (figure 9c) the corresponding estimates are 3.08m and 14.47m respectively. Hence, the overall upgrading rate is 53%. The local improvement in the vicinity of the breaklines is assumed to be subtantially higher.

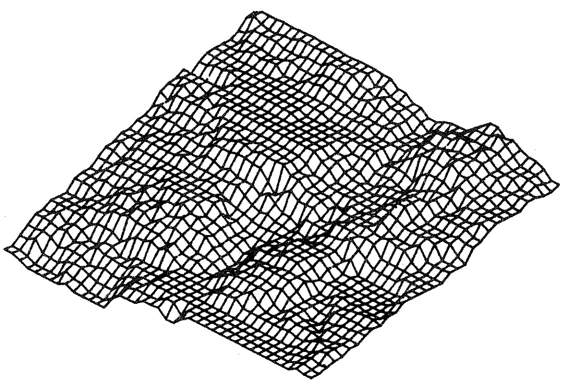

Fig.9a DTM derived from contour lines with 20m interval

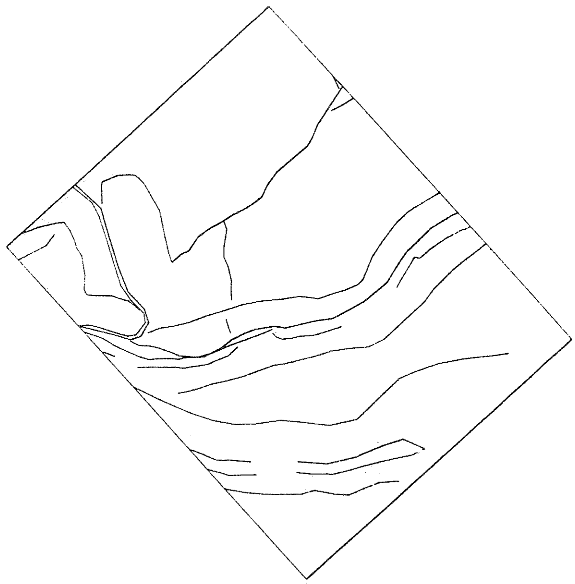

Fig.9b Breaklines sampled by the KERN DSR1

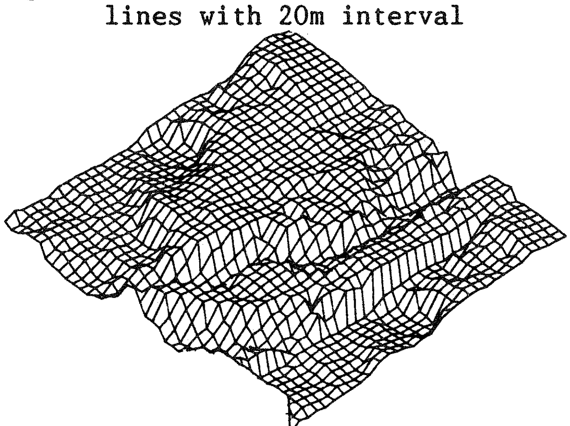

Fig.9c DTM derived from contour lines (20m interval) and from break lines

## 8. CONCLUSIONS

Because of the limited extent of the tests, conclusions in quantitative terms are not generally representative. Some conclusions in qualitative terms can be extracted.

The upgrading rate depends primarily on the number of distinct break lines in the terrain, and on the comprehensiveness and accuracy of their sampling. The interpolation algorithm and the weighting have also an impact.

In the initial experiments, the speed of search for the reference points was too low. The search program was then modified such that the search started with the radius used at the adjacent (already processed) grid point. This subtantially reduced the total number of trials in the test area, and thus speeded up the process.

The test results indicate that a subtantial overall upgrading of the quality of a DTM is attainable by the proposed technique. Moreover, the improvement is particularly enhanced in the vicinity of the break lines, and thus in faithful portrayal of the terrain relief.

## 9. ACKNOWLEDGEMENT

The authors wish to express their gratitude to Mr M. Charif for providing his software for generating a hyperbolic-paraboloid surface.

## REFERENCE PAPERS

1. Leberl, F. and Olson, D. 1982. Raster scanning for operational digitizing of graphic data. Photogrammetric Engineering and Remote sensing, 48(4): p615-627.

2. Makarovic, B. 1976. A digital terrain model system. ITC Journal 1976-1.

3. Makarovic, B. 1984. Structures for geoinformation and their application in selective sampling for DTMs. ITC Journal 1984-4.

4. Makarovic, B. 1973. Progressive sampling for digital terrain models. ITC Journal 1973-3, p397-416.

5. Makarovic, B. 1977. Composite sampling for digital terrain models. ITC Journal 1977-3, p406-431.

6. Schut, G. H. 1976. Review of the interpolation methods for DTMs. Invited paper to the XIIIth Congress of International Society for Photogrammetry, Commission III, Helsinki, 1976.

7. Tuladhar, A. M. 1986. Upgrading DTMs from the contour lines by photogrammetric selective sampling. MSc Thesis, ITC, The Netherlands

8. Tempfli, K., Makarovic, B. 1979. Transfer function of interpolation methods. Geo-processing, 1(1979), pp. 1-26.