

ON LINE GENERATION AND VERIFICATION OF DIGITAL TERRAIN MODELS

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Abstract

This paper presents a procedure for an interactive generation and verification of digital terrain models (DTM) directly during data capture from stereo models. This procedure consists of the following steps: DTM data capture, DTM construction and derivation of contours. For the data capture progressive and selective sampling is used, including the possibility of verification of these data by means of optical superimposition. The generation of the DTM is performed on-line. Different algorithms for DTM construction using quadrangles and/or triangles can be used. The derived contours are superimposed onto the stereo model. Thus, the geometric and geomorphological quality of the DTM can be checked. The paper describes this procedure in detail, with special emphasis on the algorithms and on the interactive possibilities. It is concluded by a practical example and a comment on current state and future activities.

1. Introduction and review

Today the digital terrain model (DTM) is used for quite a number of tasks in planning and mapping. Moreover, DTMs are now becoming part of land information systems. However, with this growing use of DTM it turned out, that there is a need of suitable methods for checking the quality of digital terrain models and derived products, especially for high quality DTMs which are mainly related to large scale applications.

This paper - with limitation to photogrammetrically sampled DTMs - presents a procedure for an interactive on-line DTM generation, with different possibilities to check the DTM quality directly in the stereo model during data capture.

For data acquisition the methods of progressive and selective sampling [Makarovic, 1976] are applied. In [Ebner and Reinhardt, 1984] it was shown that these methods can be employed very effectively in practice by using the PROSA program. With this program first a coarse grid is measured, which is subsequently densified according to the local shape of the terrain. The densification process is performed in patches of approximately eyepiece image size. Patchwise processing is also used for on-line DTM generation, because of the limited amount of data to be handled.

The application of systems for optical superimposition as a tool for checking captured DTM data and derived contours has been discussed in [Ebner and Reinhardt, 1987]. In the presented paper this work has been extended, with special emphasis on the on-line generation of digital terrain models. For the verification of DTM data also optical superimposition is used.

The paper starts with some general remarks on on-line DTM generation and a discussion of the requirements for such a procedure. This is followed by a description of the on-line construction of a continuous DTM from progressive and selective sampling data using a grid of variable size and/or triangles. The next part describes the software realization for on-line DTM generation and verification including interactive features for data editing and display. The paper is concluded by a presentation of a practical example which has been processed and a comment on current state and future activities.

2. Requirements for interactive on-line DTM construction

On-line DTM generation in this context is intended for the patchwise construction of a continuous DTM from photogrammetrically captured data directly after measurement to provide a capability of a rigorous check of this DTM in the stereo model. This task inheres the following requirements:

- a) A continuous surface description has to be provided to allow for the derivation of contours.
- b) Short response times have to be realized, which can be assumed to be acceptable if they are in the range of 10 - 30 seconds for one patch, for the process of DTM construction as well as for the derivation and visualization of contours.

If the check of the DTM results in a revision of the captured data:

- c) an update of the DTM (e.g. insertion and deletion of points) without a complete reconstruction should be possible.

As DTM generation in this case is mainly related to high quality DTMs in large scales :

- d) geomorphological data like break lines, skeleton lines and characteristic points should be represented by the DTM.

Furthermore interactive DTM generation becomes easier if:

- e) the measured elements are represented directly in the DTM.

For the design of a system for interactive on-line DTM generation a method for DTM construction has to be selected which fulfils the given requirements best. In [Östman, 1986] a graphical editor for DTMs was presented. For this purpose a comparison of interpolation algorithms with respect to their suitability for on-line applications was performed [Östman, 1984]. As a resume the interpolation of a dense regular grid by means of the weighted mean interpolation was chosen, but triangulation was recommended, too. With regard to the requirements given above (esp. c, d and e), we decided to construct a primary DTM from the measured data, consisting of quadrangles and/or triangles, to provide for a continuous surface.

3. Construction of a primary DTM

This chapter describes three approaches, which are used for the construction of a primary DTM consisting of progressive and selective sampling data and a discussion on their suitability for this task.

3.1 Variable grid with local triangulation

As mentioned above, progressive sampling leads to a point pattern adapted to the roughness of the terrain (fig. 1a). From these points a variable grid can be constructed, where only a few points have to be interpolated by means of linear/bilinear interpolation (fig. 1b). If there is additionally selective data available, the relevant grid meshes are subdivided by local triangulation (fig. 1c).

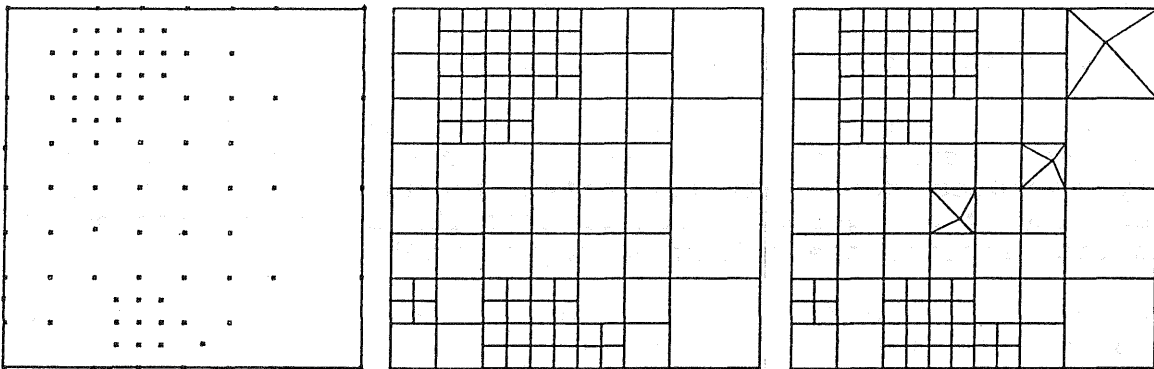


fig. 1a

fig. 1b

fig. 1c

fig. 1: Example of -progressive sampling data (1a)
-variable grid (1b)
-variable grid with local triangulation (1c)

3.2 Triangulation

If progressive and selective sampling data are available for a patch and especially when the selective data are predominant, a surface representation using only triangles can be applied, too (fig. 2).

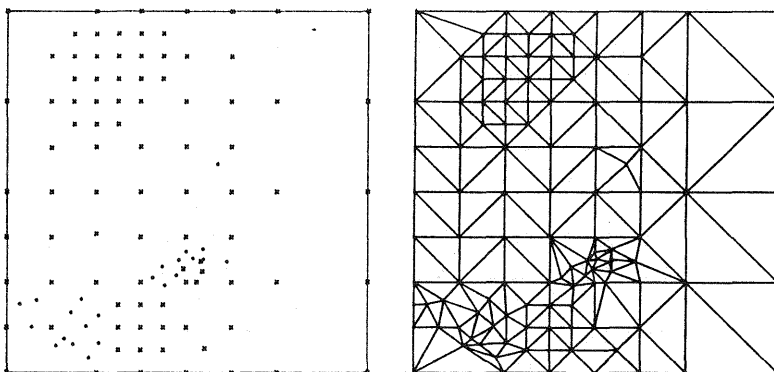


fig. 2a

fig. 2b

fig. 2:
Progressive and
selective sampl-
ing data (2a)
Triangulation of
these data (2b)

3.3 Variable grid combined with triangles

Another approach for the construction of a primary DTM from progressive and selective sampling data are the use a variable grid in combination with triangles (fig. 3). This concept can be considered as the most general, because it leads to a variable grid (3.1) if only progressive sampling data are available and to triangulation (3.2) if so much selective data has to be considered that all grid meshes are replaced by triangles.

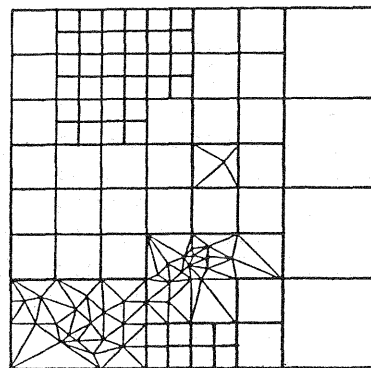


Fig. 3: Combination of variable grid and triangles.

3.4 Comparison

In principle each of the mentioned approaches will accomplish the task of constructing a primary DTM from progressive and selective sampling data. But the efficiency of the different methods, related to computing times and quality of surface description, depends on the kind of data available. The construction of a variable grid with local triangulation (3.1) is most suitable if mainly progressive sampling data are available, because of the very short computing time. In special cases, however, local triangulation does not lead to a representative surface description, when the edges of the variable grid mesh are used as fixed lines in the triangulation. Triangulation (3.2) can be used for both kinds of data, but common triangulation algorithms require a lot of computing time, which is not necessary for grid data provided by progressive sampling. The combination of a variable grid with triangles (3.3) combines the advantages of both methods and is best adapted to the planimetry of the captured data.

3.5 Triangulation algorithm

All the methods mentioned for the construction of a DTM are using triangles in a way. But the requirements for triangulation are rather special here, because often a number of fixed lines has to be treated, the DTM has to be updated when measurements are additionally taken or deleted, and furthermore the triangulation should be combined with variable grid construction in areas where only progressive sampling data are available. Relevant literature almost exclusively deals with Delaunay triangulations. Very efficient solutions are given for fast triangulations of arbitrarily distributed points in a plane [e.g. Watson, 1981; Lawson, 1977]. But in general these algorithms are not suitable for the given requirements.

For this reason a new approach has been developed which is adapted to the given task. This algorithm triangulates the fixed lines in a first step and includes all other points in a second step.

This can best be demonstrated best by an example:

At first the margin lines (hull of the area) are triangulated (fig. 4 densely rastered triangles). The margin lines are expected to be polygons and can also lie inside of the area (e.g. dead areas). After that all other fixed lines (fig. 4 solid lines) are triangulated (fig. 4 rastered triangles) and finally all remaining edges are triangulated (fig. 4 not rastered triangles).

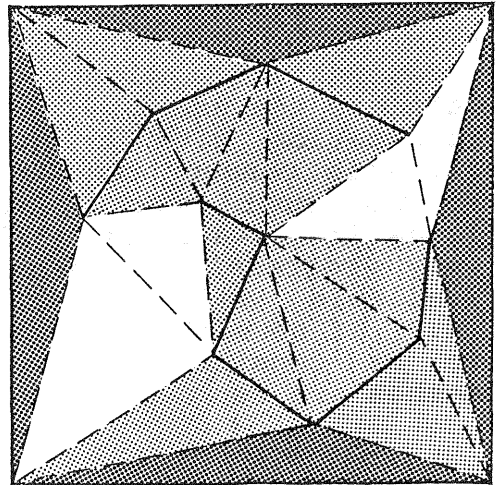


fig. 4 : Triangulation of fixed lines

For the construction of triangles Lawson's criterion [Lawson, 1977] for Delauney triangulations is used, which considers a triangle as optimal, if there is no other point located within the circumcircle of the 3 vertices of a triangle. Exceptions from this rule are made if required by the planimetry of the fixed lines.

In the second step the given points are included in the triangulation by using the swapping algorithm of Lawson [Lawson, 1977] which should be described shortly in the following:

To introduce a new point P into a triangulation, an existing triangle T has to be found, which encloses P. Triangle T is deleted and three new triangles are created (see fig. 5)

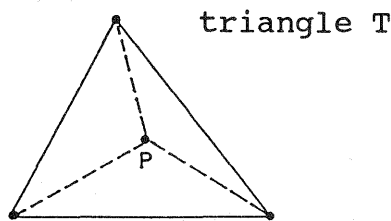


fig. 5.: Insertion of P

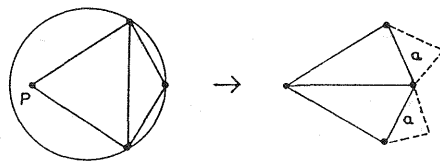


fig. 6.: Swapping algorithm

Next, each of the new triangles has to be checked together with the adjacent one according to the Delauney criterion (fig. 6, left). Each time this test results in the replacement of two old triangles by two new ones (fig 6), this procedure also has to be performed for these new triangles and their adjacents (a in fig. 6). An exception is made, if the common side of the adjacent triangles is a fixed line.

A deletion of points is also possible without complete new triangulation, by cancelling all triangles which include the

deleted point as a vertex and restarting the phase of triangulation of the remaining edges (see above).

As a result the Delauney triangulation is not destroyed after the update of triangulation.

As an extension to this algorithm, for progressive sampling data the triangulation can be combined with the construction of a variable grid. This can be done by including these points in the order of the size of the grid they belong to. This means at first the points of the grid with widest grid size are inserted to triangulation and if these grid meshes are not affected by the selective data the algorithm switches to variable grid construction for these areas.

Summarizing the benefit of the proposed algorithm, fixed lines are rigorously considered in the triangulation, a fast update of the triangulation is possible and it can be combined with variable grid construction.

4. Interactive on-line DTM generation and verification

4.1 Program realization

For the given task a program was written in FORTRAN 77, which runs on a HEWLETT PACKARD HP 1000 A mini computer in conjunction with an Analytical Plotter ZEISS PLANICOMP C 100 and the mono superimposition system ZEISS VIDEOMAP. But in general the program is not limited to this hardware.

This program supports an interactive on-line DTM generation and verification and includes 3 main parts :

Part 1 : DTM Data Editing

This part provides functions for graphical editing of DTM data in the stereo model, these are :

- Capture or deletion of points
- Capture or deletion of lines,
- Visualization of the DTM data

The function mentioned last provides for a possibility to visualize all measured data in the stereo model by means of optical superimposition to allow for a first check of completeness and correctness of the captured data.

Part 2 : DTM Construction

This part is used for the construction of a primary DTM as described in 3.1 and 3.2. An installation of the algorithm presented in 3.3 is in preparation. The following functions are available in this part :

- Triangulation of the captured data
- Update of the triangulation
- Construction of variable grid with local triangulation
- Visualization of the DTM

The update of a triangulation can be used for a fast insertion or deletion of points. The visualisation of the DTM (variable grid and/or triangles) in the stereo model allows for another check of the DTM quality.

Part 3 : Check of DTM

The following functions allow for a check of the DTM in different ways :

- Calculation of the height differences between DTM and terrain at pre-chosen locations
- Calculation of height differences at checkpoints
- Derivation and visualization of digital contours

The first function provides a possibility to check the DTM quality by calculating the height differences between the DTM and the terrain at pre-chosen locations and by moving the floating mark of the analytical plotter to the DTM height at this location.

Using the second function, the differences between given checkpoints and the DTM are calculated and some statistics concerning these differences are given.

The derivation of contours is performed with the corresponding module of the HIFI-88 program package [Ebner et al., 1988]. In the current version contour polygons are derived from the DTM and can also be visualized by means of optical superimposition to allow for a check of the DTM. Smoothing of the contour polygons by means of spline approximation [Aumann, 1988] is possible but not yet installed as an on-line task.

4.2 Operational aspects

All mentioned program modules communicate via extended memory area [HEWLETT PACKARD, 1986], which means that the transfer of data can be done very fast. The general response times of the system for the mentioned tasks are fast enough to stand the requirements of an on-line system.

The program can be used in an on-line and a 'quasi' off-line mode. In the first mode the program is linked to a program for data acquisition, like PROSA, and after data acquisition is finished for one patch, control is transferred to the program described in 4.1. Then the DTM is constructed and verified e.g. by contours. If necessary supplementary measurements can be taken, the DTM is updated and again contours are derived. This process is repeated till the result satisfies the requirements. In the second mode the program works 'stand alone' which means that all data are read from files, but can be processed as described for the on-line mode. A PROSA version with possibilities for on-line DTM generation and verification has been made available recently [Ebner et al., 1988].

5. A practical example

Example 'Togo':

Material : 1 stereo model, image scale about 1 : 30 000,
pictures taken with WILD UAG c = 150 mm,
size of the area = 3040 * 4000 m²

This material has been evaluated formerly in connection with another project using the PROSA program. A 160m grid, locally densified up to 80m and 40m respectively had been considered as sufficient. Part of these data have been checked directly in the stereo model using the program described in 4.1 in the off-line mode. For an area of 1280 * 1280 m² 11 break line points and 118 single points have been measured additionally (18 % of the previously captured data). These additionally taken measurements had been caused by the different checks included in the procedure described in 4.1, but mainly by an inspection of the visualized captured data and the verification of digital contours. It turned out that contour polygons are in general sufficient for this check, but a slight smoothing of contours would make this procedure more comfortable to the operator. The improvement of the DTM has been proven by comparing the digital contours derived from the original and the checked data set. Figure 7a shows the contour polygons for one patch of the area and the originally captured data, Figure 7b the contours and captured data referring to the checked data set. In both cases triangulation was used for DTM construction.

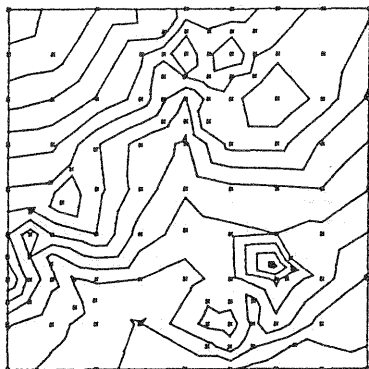


fig. 7a

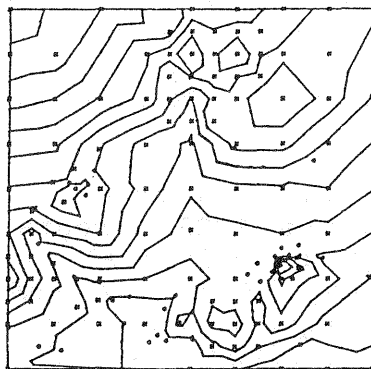


fig. 7b

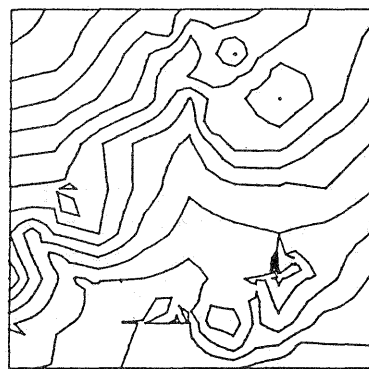


fig. 7c

fig. 7: Contour polygons and data acquisition

- from triangulated original data (7a)
- from triangulated checked data (7b)
- from variable grid with local triangulation of the checked data (7c)

Comparing these figures, it can easily be recognized that the check of the DTM led to the detection of areas where the captured data didn't represent the terrain comprehensively. Similar to this in all treated patches discrepancies could be detected mostly in rough areas.

In figure 7c contours derived from a variable grid with local triangulation of the checked data set are given. Comparing fig. 7c and 7b it can be noticed that these contours are smoother in

the upper half of the patch (no additionally measured selective data) than the ones derived from triangulation, and that the contours in the lower part were affected by local triangulation. Concerning DTM construction these data give an example of the suitability of the combination of variable grid and triangles as proposed in chapter 3. In this case the advantages of the variable grid (smoother contours in flat areas) and of triangulation (better terrain representation in rough areas) are combined and furthermore the computing time of triangulation is reduced considerably.

The computing time for triangulation, derivation, and visualization of digital contours in the example shown in figure 7b was about 22 seconds using a HP1000 A900. Using a combination of triangles and variable grid the computing time is estimated to be about half of the given value.

6. Conclusions

A procedure has been presented which allows for an interactive on-line DTM generation and provides the capability for checking the DTM in different ways. This procedure includes features for an on-line construction of a primary DTM as well as for data editing, contour derivation and DTM and contour verification. It could be shown by an example that the visualization of DTM data acquisition and digital contours by means of optical superimposition enables the operator to check the completeness and correctness of the captured data to a certain amount, which improves the geometric and geomorphological quality of the DTM and of derived contours. Additionally it can be concluded that the suggested method uses the potential of computer assisted photogrammetry in the field of DTM generation in a rather rigorous way.

Concerning the practical application of the proposed procedure, e.g. in connection with the PROSA program, it can be assumed that it is not necessary to perform all steps of the procedure in every patch. This means, in quite a number of cases (probably in smoother areas) computer assisted DTM data acquisition can be performed as usual, without switching to interactive DTM generation. But the visualization of the measured data should be used in each case to be sure to detect areas where switching is necessary.

This procedure is also very suitable for training matters because the effect of measurements on the DTM and derived contours can be demonstrated directly in the stereo model.

Of course there are some problems left which should be mentioned here, e.g.:

There is currently no filtering of the data included. Concerning large scales with very precisely taken photogrammetric measurements these problem can be neglected but smoothing of the contours may be helpful.

From our experience in capturing DTM data using stereo plotters with fixed optical enlargement e.g. of 8-times, we noticed that

operators are often tempted to represent terrain features which are not suitable to the actual scale. On the one hand an optical zoom is a proper tool to provide for a better survey of the area to be measured, and on the other hand there is a module included in the proposed procedure (see chapter 4) which allows the display of the discrepancy in height between DTM and terrain (stereo model) in a numerical way, which simplifies the decision whether distinct features should be measured or not.

Summarizing, the current state of the program installation allows for comprehensive tests in DTM production using the proposed procedure for an interactive on-line DTM generation.

7. Acknowledgement

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