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INTERACTIVE GENERATION OF DIGITAL TERRAIN MODELS

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1. Introduction and review

Today the digital terrain model (DTM) has become almost a standard product in planning and mapping. Consequently quite a number of applications can be satisfied using the DTM and rather attractive graphs are supplied using vector as well as raster techniques. In contrast to this progress in DTM application and display the methods used in practice for DTM data collection almost didn't change in the last decade. In particular no capabilities are provided to check the measured data in this stage, although there is a clear necessity for it, especially when high fidelity DTM's have to be generated, which are mainly related to large scale applications.

This paper, related to photogrammetrically sampled DTMs, presents a procedure for an interactive on-line DTM generation, with different possibilities to check the DTM fidelity directly in the stereo model during data collection. Special emphasis is given to a review of the whole procedure, to its performance and to results from practical tests.

In the first chapter of the paper some preliminary remarks on DTM -accuracy, -data collection and -modelling are given. The next chapter discusses the possibilities for DTM verification and presents some results of practical investigations. This is followed by a description of the procedure for an interactive DTM generation directly in the stereo model and some aspects of its practical realization. After this the new capabilities of the PROSA program for DTM data capture using ZEISS analytical plotters with the PHOCUS system are reviewed and some concluding remarks are given.

2. Preliminary remarks

2.1 DTM - accuracy

During the period of 1980-1984 ISPRS WG III/3 has performed a DTM-test and the results were presented in [Torlegard et. al., 1984]. Due to the particular importance of the test for this topic some of the main results of the test should be summarized here: It was found that the average DTM accuracy could be predicted by participants quite well, but only by 'experienced organisations' (mostly university institutes). Furthermore, an important result was that the number of gross errors ('blunders') in the DTM's generated by the participants was very high.

As a consequence of these results, two main requirements follow for generating high fidelity DTM's: The first is that the sampling parameters (mainly the point distance) have to be choosen properly to achieve a certain DTM accuracy. The second one is that procedures have to be established to minimize the number of blunders in a DTM.

In principle the first requirement can already be met in practice as the DTM test results show, but the second one can be satisfied only when the DTM is checked during data collection in the stereo model. This paper is intented to present a procedure for this task.

2.2 Photogrammetric DTM - data collection

Concerning the measurement of mass points it is well known from various investigations that static photogrammetric measurements are superior to dynamic ones. For that reason grid measurement became very popular. But to establish a high fidelity DTM the grid measurement has to be supplemented by selectively taken measurements (selective sampling). These mesurements can be lines (e.g. breaklines) as well as points (e.g. characteristic single points) [Makarovic, 1977, Ruedenauer, 1980].

In [Ebner and Reinhardt, 1984] it has been shown that the use of the progressive sampling method [Makarovic, 1973] instead of a regular grid can lead to a clear improvement in economy without significant loss of accuracy.

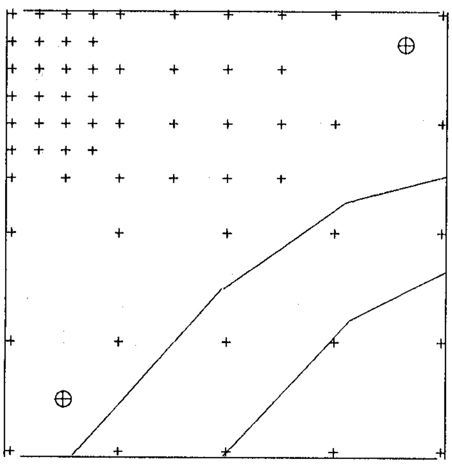

Fig.1: Example of DTM data

For progressive sampling first a coarse basic grid is measured. Then second height differences are computed at the grid points to approximate the terrain roughness, taking into account break lines if available. If the second height difference at a grid point exceeds a pre-choosen threshold the basic grid is locally densified to half the original mesh size. This procedure in general is repeated till a pre-determined minimum sampling distance is reached. In this way the measured grid automatically is matched to the roughness of the terrain. The procedure presented here for interactive DTM generation is best suited to progressive and selective sampling data, but is not limited to this methods.

2.3 DTM - modelling

DTM modelling denotes the construction of a continuous surface from the captured data. With respect to the requirements of working interactively a specific solution for this task has been presented in [Reinhardt, 1988]. This procedure includes two steps. The first one is related to a structuring of the measured data. As these data are captured by progressive (PS) and selective sampling (SS), during this step a network is generated which consists of triangles and quadrangles. Consequently it is called 'Triangle-Qudrangle-Network' (TQN) (see fig.2). This network includes all measured points and the lines are constraint to be edges of the network. The TQN leads to a variable grid structure if no SS data are available and to a 'Triangulated Irregular Network' (TIN) if only SS data are available. More details on the construction of the TQN are given in the paper quoted above. During the second step a continuous surface for this network is generated. In the most simple case planes or billinear surfaces respectively are computed for all the triangles and quadrangles.

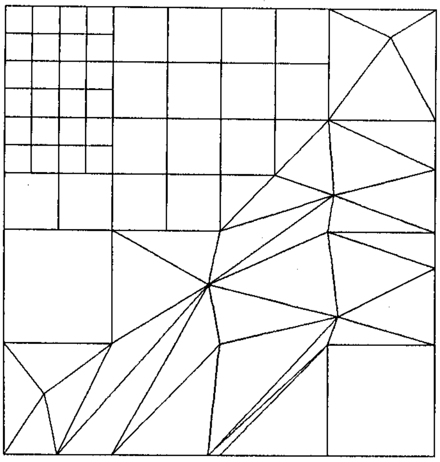

Fig.2: Example of a Triangle-Quadrangle-Network

The main advantages of this DTM are, that the original points are directly included into the DTM and therefore its structure is best adapted to the measured data. Besides, the construction requires only little computing time and the resultant DTM can locally be updated very fast if the data have been manipulated. Due to these features the suggested DTM seems to be very suitable for interactive DTM generation.

3. DTM verification

DTM Verification in this context means to check whether the DTM represents the terrain adequately. The success of interactive DTM generation substantially depends on the usefulness of the methods applied for DTM verifaction. For these reasons the methods are shortly described here and the results of investigations concerning there usefulness are given.

3.1 By means of optical superimposition

Optical superimposition in general offers different possibilities for checking the DTM by comparing DTM data and the stereo model. These possibilities have been discussed in detail in [Ebner and Reinhardt, 1987] and are briefly repeated here. The check of the DTM can be carried out by using the measured data as well as contours derived from these data (see fig. 3a). To discuss DTM verification in detail it is advisable to distinguish whether the data are superimposed onto one image (mono superimposition) or to two images (stereo superimposition) of the stereo model. If a stereo system is used the correctness and the completeness of the measured data can be checked. If a mono system is used the correctness of points of course can't be checked, but the completeness of the data can be inspected because the planimetry of the data are sufficient for this job. Concerning the check of contours both systems can be used, also because mainly the planimetry of the contours is compared to the terrain forms, but a stereo system makes this job more convenient.

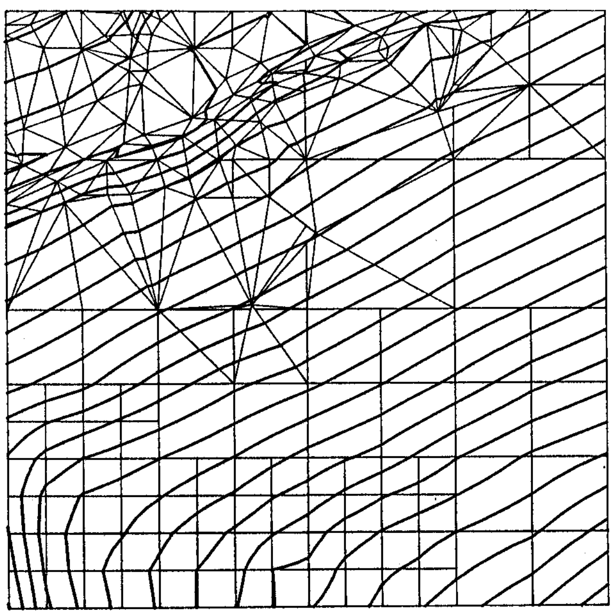

Fig.3a: Example of Contour polygons and corresponding TQN

3.2 By means of spot heights

If a continuous DTM is provided during the process of data collection it is possible to compute a DTM height at every location. Thus, for every measured spot height the difference between this terrain height and the DTM can be computed and this numerical value can help to decide whether additional measurements are necessary. For economical reasons this will be used only in critical cases when other methods don't allow for a clear decision. Of course height differences can also be computed if checkpoints from other sources are available.

3.3 Results from practical investigations

DTM verification directly in the stereo model was investigated, concerning the benefit of the method in practice, with 3 operators using different data sets.

The first and also most interesting test was performed using the test area 'Söhnstetten' (image scale 1:10 000, wide angle) which is well known to readers of photogrammetric literature and which also was subject of the already mentioned DTM test. The intension of our test was to investigate whether and to what extent on-line DTM verification could improve DTM data collection. For this purpose the test area mentioned is very suitable because about 1900 independently measured checkpoints were made available to us from the organizers of the DTM test. Thus we could numerically check the effect of DTM verification. For this purpose the DTM data measured some years before were superimposed onto the stereo model and the operator supplemented the data wherever he thought it necessary. To avoid any influence from interpolation, a continuous surface consisting of planar triangles was constructed from the original data set as well as from the supplemented data set and the differences at the checkpoints were calculated in both cases. The results confirmed the expectations that no significant improvement in the RMS value can be achieved, but the number of large differences (blunders) is significantly smaller (see table 1).

data set	*RMS [m]*	*Max [m]*	*No. of differences >1.0 m*	*> 1.5 m*
1285 PROSA pts. 1300 break line pts. (original data)	*0.47*	*4.4*	*80*	*17*
1285 PROSA pts. 1398 break line pts. 21 single pts. (supplem. data)	*0.43*	*2.8*	*57*	*11*

table 1: results of the 'Söhnstetten test'

Additionally it could be noticed that the contour quality was clearly improved.

For reasons of brevity the results of the other tests are ommitted and only the résumé is stated here:

The experienced operators fully accept the necessity to check the captured data directly in the stereo model as well as the methods suggested for checking. The additional time needed for chekking of course depends on the terrain roughness which makes it difficult to give figures, but the time for checking can be estimated to be in the order of 10% of the time for data capture. An important result is that in general it is sufficient to use the measured data for DTM verification, supplemented by taking some spot heights to derive height differences in critical cases. If contours are used for DTM verification, operators confirm that using stereo superimposition makes the procedure more convenient (faster), but it is also possible with mono systems. In this case the problem arises that line graphics of the contours shouldn't be to dense to avoid negative effects for the stereoscopic viewing. On the other side the contours should be dense enough to allow for DTM verification. In spite of it, it can be recommended to use contours for DTM verification, especially if they are a main result of the DTM project. This section shouldn't be finished without emphasizing that the quality of contour polygons derived from the DTM without smoothing is regarded to be suitable by the operators (see fig. 3a and 3b).

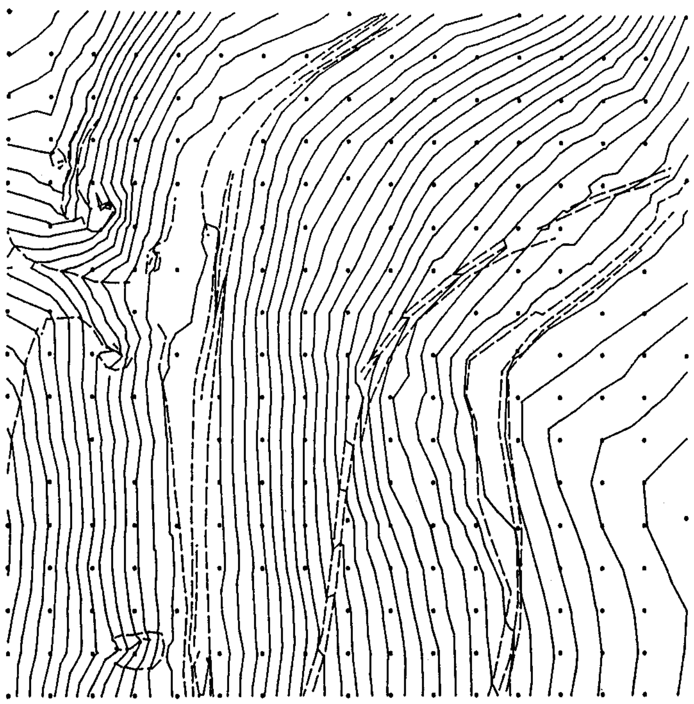

Fig.3b: Project Söhnstetten, contour polygons (solid lines), measured break lines (dashed lines) and points

4. Interactive DTM generation

4.1 Review

Conventionally DTM generation consists of the two steps, data collection and DTM modelling. These two steps are performed subsequently which means DTM modelling starts after data collection has been finished. If any inconsistency within the captured data comes up after the data collection has been finished, for example when contours are derived from the DTM, one has to go back and remeasure in the stereo model. This is absolutely unacceptable in a productional environment or sometimes almost impossible, when a new project has been started in the meantime. Interactive DTM generation in most cases prevents such problems, because the DTM and also contours can be computed and checked directly in the stereo model. Consequently the measured data are corrected or supplemented and the DTM is updated, if necessary. This procedure of DTM verification, data correction and DTM update can be repeated till the result satisfies the requirements. Figure 4 shows a schematic flowchart of the individual steps of interactive DTM generation.

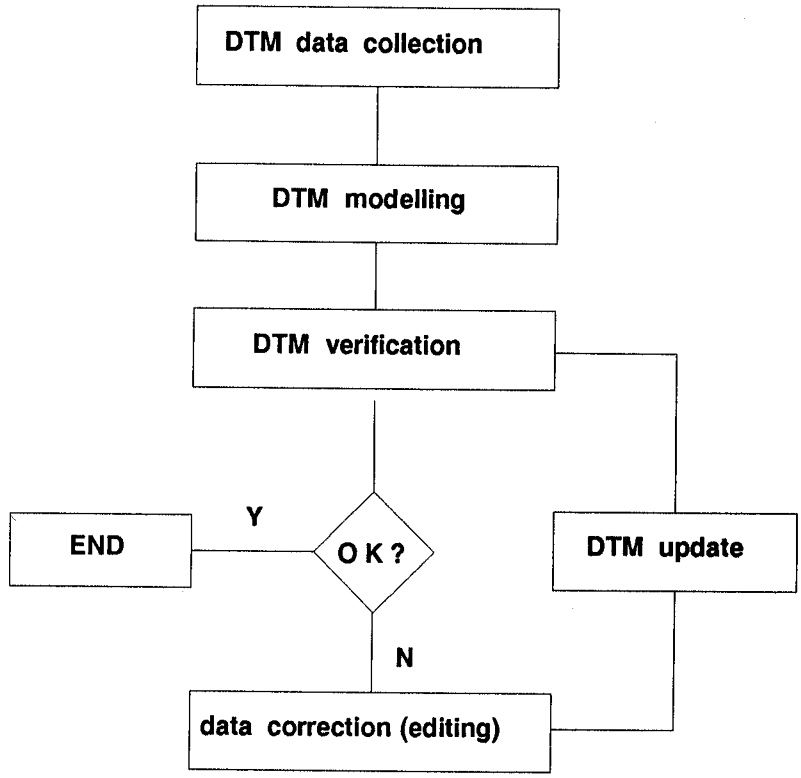

fig. 4: schematic flowchart of interactive DTM generation directly in the stereo model

4.2 Hard- and software components

Interactive DTM generation as presented requires components for:

- stereo compilation
- superimposition
- system control and computations

For stereo compilation in general any analogue, analytical or even digital plotter is suitable, but from a practical view the analytical plotter in the moment certainly is the proper choise. In connection with analogue or analytical plotters a specific optical superimposition system is required, with digital systems the image display system, in general a high resolution graphics screen, can be used for this task. For control purposes and computations computer can be used, but a mini computer or a PC is absolutely sufficient.

Software components are required mainly for the following tasks:

- graphical data editing
- DTM modelling and update
- DTM verification

Working interactively requires a possibility to edit the measured data, in case corrections are necessary. For reasons of convenience graphical editing has to be performed directly in the stereo model using the superimposed graphics of the measured data.There is also software necessary for the DTM modelling directly in the stereo model and for updating the DTM locally if manipulations of the measured data have been carried out.The methods for DTM verification have been described above (see 3.). Also for this methods specific software components are necessary, mainly modules for the derivation of contour polygons from the DTM and for the calculation of differences between terrain and DTM.

4.3 Practical realizations

First experience with an experimental system for interactive DTM generation based on the procedure described above have been given in [Reinhardt, 1988]. This system runs in conjunction with an analytical plotter ZEISS PLANICOMP and a VIDEOMAP system for optical superimposition.

Summarized this system includes components for :

- graphical editing of DTM data performed directly in the stereo model (insertion and deletion of points and lines)
- DTM modelling as described in 2.3
- fast DTM update without complete recomputation (insertion and deletion of points and lines)
- DTM verification using DTM data, contours and / or spot heights

For DTM generation directly in the stereo model the overall area is processed in patches of approximately eyepiece image size which on one side makes the procedure of checking the DTM or contours easier and on the other side prevents delays caused by necessary data processing. Nevertheless special emphasis was given to the development of fast algorithms for DTM modelling and update to stand the on-line requirements. As a result we could notice that this aim has been achieved.

Other systems for interactive DTM generation have been presented by [Östman, 1986] and [Steidler et. al., 1987].

5. PROSA - a Program for interactive DTM generation

The PROSA program was first presented in 1983 at the photogrammetric week [Reinhardt,1984] as a program for progressive sampling in conjunction with the ZEISS PLANICOMP. The program has been further developed through the years. As a first important improvement the connection of PROSA with the superimposition system VIDEOMAP can be mentioned. Thus, a first step towards interactive DTM generation was taken, because this extension provided a possibility for the operator to see what he has measured and how the terrain is represented by the measured data [Ebner and Reinhardt, 1987]. Another 'highlight' for PROSA was the integration into the PHOCUS software system of the P-Series PLANICOMP [Menke, 1988] which was performed in

1988. Caused by this integration various additional capabilities are offered to the PROSA user. The most import ones are:

- Command menus for different devices (soft keys, digitizing tablett, cursor keys, graphics terminal, PHOCUS command panel)
- Graphical output to different devices (high resolution graphics terminal, VIDEOMAP, STEREOVIDEOMAP)
- off-line graphical editing

Thus, PROSA can be controlled like any other program of the PHOCUS system using different input devices and the graphical output can be displayed on various devices defined by the user.

Coincidentally the possibilities for an on-line check of the measured DTM have been extended fundamentally by including HIFI-88 components into PROSA. HIFI-88 is the completely new and substantially extended version of the well known HIFI DTM program package [Düsedau et. al., 1987; Ebner et. al., 1988]. Within PROSA the HIFI-88 components provide the capability to construct a continuous DTM from the measured data of a PROSA patch and to derive contours from the DTM. These contours, superimposed onto the stereo model, can be used for checking the DTM directly in the stage of data collection (see 3.).

Furthermore the commands available within PROSA have been extended. For example there is now a possibility to delete the last measured point, to mention just one of the extensions. Besides that the HELP functions have been adapted to the PHOCUS standard and also a tutorial is available.

Summarized the 'new' PROSA program is clearly more than a program for data collection, it is a kind of on-line DTM program which allows for:

- data collection using progressive sampling
- additional selective sampling
- construction of a simple continuous DTM
- derivation of digital contours
- checking of the measured DTM using visualized DTM data and contours

6. Conclusion

A procedure has been presented which allows for an interactive DTM generation including capabilities for checking the DTM in different ways directly in the stereo model. This procedure has been realized in an experimental system to perform practical investigations. Furthermore it has been shown that the PROSA program has been extended substantially on the one side by an integration into the PHOCUS system and on the other side by providing on-line DTM components adopted from the HIFI-88 DTM package.

Finally it should be mentioned that the integration of DTM into Land information systems (LIS), brings up new questions which are related to the topic presented here. Until now general strategies for the integration have been developed, and also practical problems concerning the storage of both data as well as the supply of DTM data and products for LIS applications have been discussed [e.g. Fritsch, 1989; Hößler and Würländer, 1989; Sandgaard, 1988]. Also within the data collection there are some points which should be discussed. For example it could bring some benefit to coordinate data collection for LIS and DTM. This topic will certainly be investigated more detailed in the near future.

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ABSTRACT

This paper describes a procedure for an interactive generation of digital terrain models (DTM) directly during data collection from photogrammetric stereo models. The procedure starts with data collection and DTM modelling followed by a DTM verification, mainly performed by means of optical superimposition. Depending on the result of the verification procedure the collected DTM data can be corrected and the DTM updated or not. The process of DTM verification, data editing and DTM update can be repeated iteratively till the results satisfy the requirements. In the paper experience with an experimental system for interactive DTM generation is given and a first realization of this method within the PROSA program for DTM data collection at analytical plotters ZEISS PLANICOMP is described.

INTERAKTIVE ERSTELLUNG DIGITALER GELÄNDEMODELLE

ZUSAMMENFASSUNG

Es wird ein Verfahren zur interaktiven Erstellung digitaler Geländemodelle (DGM) direkt während der Messung im Stereomodell vorgestellt. Dieses Verfahren beginnt mit der Datenerfassung, worauf sich die Berechnung des DGM anschließt. Im nächsten Schritt wird Messung bzw. DGM überprüft. Dies erfolgt im wesentlichen durch optische Überlagerung von DGM - Daten mit dem Stereomodell. Falls erforderlich können die Daten, und entsprechend das DGM, dann korrigiert bzw. ergänzt werden. Der Prozess der Überprüfung und Korrektur kann so lange wiederholt werden, bis das Ergebnis zufriedenstellend ausfällt. Des weiteren werden Ergebnisse praktischer

Untersuchungen mit einem experimentellen System zur interaktiven DGM Erstellung präsentiert, und es wird über eine erste Realisierung dieser Methode in Verbindung mit dem DGM - Meßprogramm PROSA und analytischen Auswertegeräten ZEISS PLANICOMP berichtet.

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