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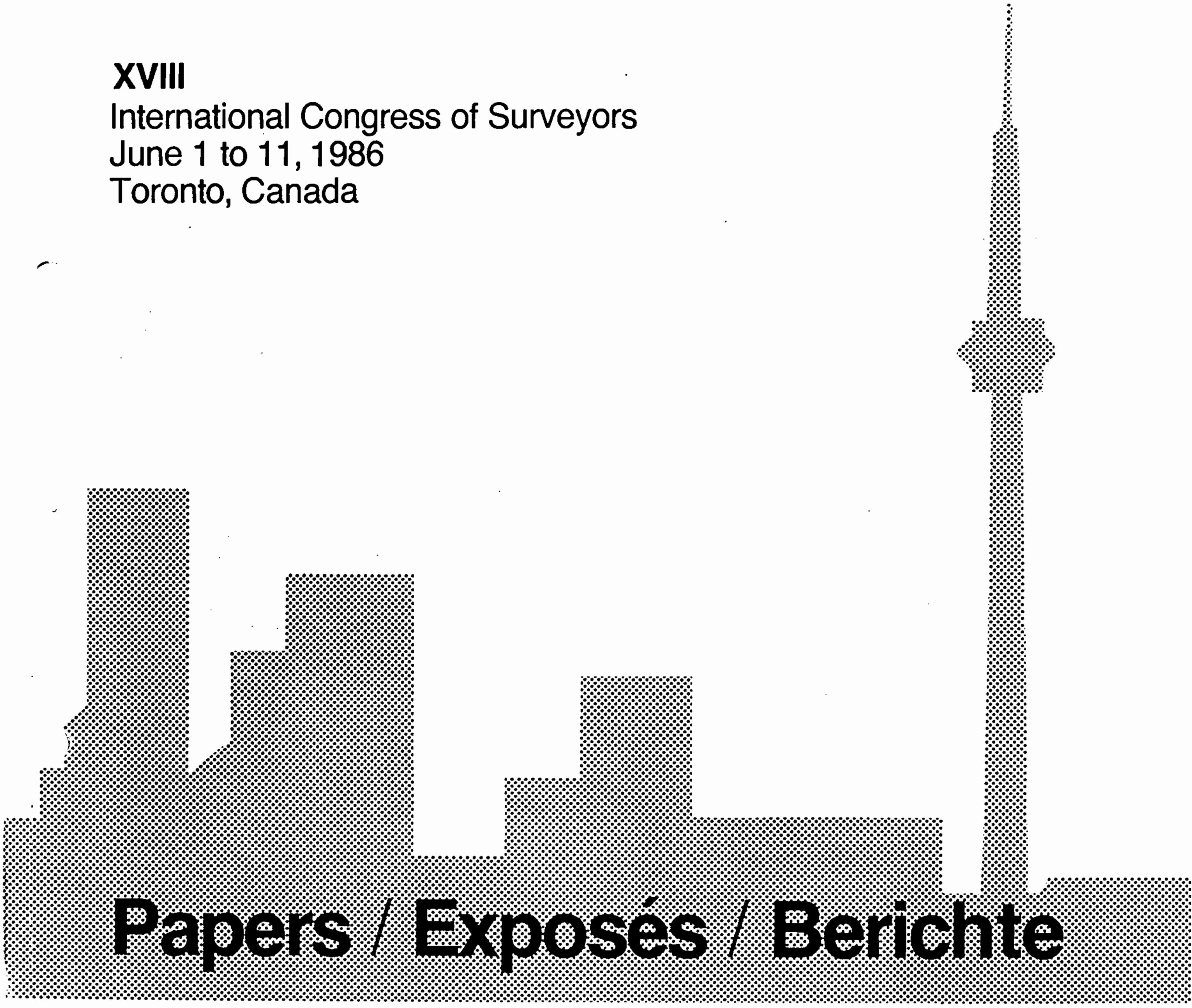

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Survey Instruments and Methods

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Survey Instruments and Methods
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High Fidelity Digital Elevation Models - Elements of Land Information Systems

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HIGH FIDELITY DIGITAL ELEVATION MODELS - ELEMENTS OF LAND INFORMATION SYSTEMS

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Summary

During the last three decades digital elevation models have been used more and more for planning and mapping purposes. Although at the beginning the interests were directed to the applications of the digital elevation model (DEM) with less demands on its quality so lead nowadays the inclusion of DEM's into land information systems to general purpose elevation data bases of high fidelity. For that reason the paper reviews the methods employed for the derivation of DEM's under consideration of modern demands for general purpose applications. Also future developments in computer aided mapping and planning by means of DEM's will be exhibited.

DIGITALE HÖHENMODELLE HOHER QUALITÄT - ELEMENTE VON LANDINFORMATIONSSYSTEMEN

Zusammenfassung

Digitale Höhenmodelle bilden heutzutage immer häufiger die Grundlagen für Planungen und kartographische Anwendungen. Mit der Vielfalt ihrer Einsatzmöglichkeiten sind die Anforderungen an ihre Qualität gleichermaßen gewachsen. Die anstehende Integration von digitalen Höhenmodellen (DHM) in Landinformationssysteme stellt hohe Qualitätsansprüche an die Geländehöhendatenbanken, um einer generellen Verwendbarkeit Rechnung zu tragen. Unter dieser Prämisse werden im vorliegenden Beitrag existierende Methoden zur Generierung von digitalen Höhenmodellen überprüft. Ebenso sind zukünftige Entwicklungen zur rechnergestützten Kartenerstellung und Planung aufgezeigt.

LES MODELES NUMERIQUES D'ELEVATION DE QUALITE EXTREME - ELEMENTS DES SYSTEMES D'INFORMATION DU TERRITOIRE

Résumé

Les modèles numériques d'élévation forment aujourd'hui de plus en plus les bases pour les planifications d'ingénieur et pour les applications cartographiques. Avec les possibilités de leur pratiques l'exigences à leur qualité a augmentié. L'integration actuelle des modèles numériques d'élévation dans les systèmes d'information du territoire exige une qualité extrême des données d'élévation en vue d'une utilisation générale. Sous cette condition l'article présent vérifié les methodes existentes de création des modèles numériques d'élévation e il montre des développments à venir.

1. Introduction

The history of digital elevation models began three decades ago in the mid'fifties, when at the Massachusetts Institute of Technology the first ideas arosen on a digital representation of terrain. With the research work of the M.I.T. Photogrammetric Laboratory the era of computer aided planning and mapping has been opened up, because the work was concentrated on "new approaches to highway engineering through the application of photogrammetry, automation instrumentation and electronic computers". It was the famous contribution of C.L. Miller / R.A. Laflamme (1958), which gave the guidance for the generation and application of digital elevation models valid all the years after till the present date. Since this introduction of the digital elevation model a really flood of contributions has been published in dealing with sampling considerations, elevation modelling strategies and practical applications.

A second highlight in this context was the introduction of land information systems (FIG Com.5, 1974) at the FIG-Congress in Washington D.C., because therewith the main frame for general purpose applications of digital elevation models has been provided. Thus it was obvious considering digital elevation models as components of land information systems (B. Makarovic, 1977b, R. Adler, 1978) since for this item some concepts of data structures and digital elevation data bases were available already (A.A. Noma, 1974, J. Jancaitis, 1976, A.A. Elassal, 1978, D.M. Mark, 1978, A.A. Noma / N.S. Spencer, 1978). Following this way the door has been opened to the topographic information system with its heart being the topographic data base (K. Kraus, 1983, W. Staufenbiel, 1983), what represents also a main topic for research work in near future.

2. Topographic Information Systems

With the introduction of land information systems (LIS) based on electronic computers the question of handling leads inevitably to an appropriate partitioning of the whole system into subinformation systems (SIS) as also commented on by R. Conzett (1980). Looking at the inverted tree structure (Fig.1) the organization may be the following one: the LIS has been partitioned into the SIS cadastre, the SIS topography, the SIS ordnance survey and so forth, what again can be subdivided. Let us take for example the SIS cadastre consisting of the groups: parcel cadastre, cable cadastre, tree cadastre and emission cadastre; every

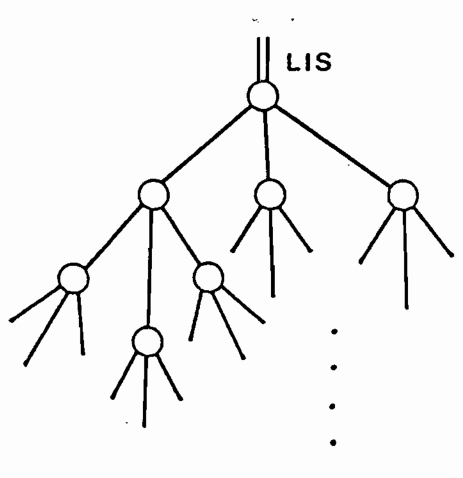


Fig.1: Tree structure of LIS

group constitutes its own information system. For that reason the LIS of different users might differ from each other depending on their sovereignty duties and special applications (G. Eichhorn, 1978, 1980).

The integration of digital elevation models into land information systems has led to the SIS topography, nowadays more and more important for planning and assessment of extensive engineering projects as well as environment studies. Its data base consists primarily of a digital elevation model, what may be supplemented by situation data such as street drawings and waters, building structures as well as coverings to obtain a comprehensive knowledge of the anthropogenious living space (see Fig.2). For reasons of topicality the situation data may be obtained by the methods of remote sensing (G. Konecny, 1979, W. Göpfert, 1982, 1985) or photogrammetrically using e.g. analytical plotters and modern orthophoto techniques (K. Kraus, 1979) respectively in connection with digital filtering algorithms (D. Fritsch, 1984). All data have to be centered on one common reference frame, what might be the UTM-system, the system of Gauß-Krueger coordinates (GK-system) or the system of geographical coordinates. Considering an easier communication with the data base it is appropriate to use carthesian reference frames, though they overlap each other at the main meridians contrary to the latter one.

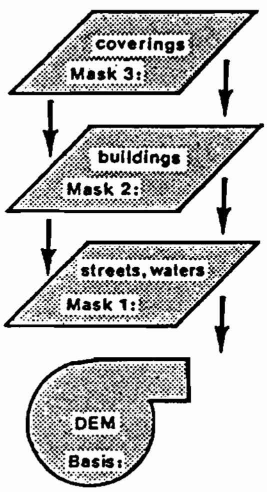


Fig.2: Data stocks of the topographic data base

The structure of the data base for concatenation of all the data can be based on a chain file system (J. Niedereichholz, 1983), whereby the data model for the files should be a relational one because of its simple pattern (flat files). For data manipulation within the topographic data base two different concepts are used in practice today

(i) a data manipulation language (DML) integrated into the host language concept, that means the use of subprograms for batch processing or combined menue-masking techniques for an interactive processing mode

(ii) a query language (QL) as independent tool for data manipulation.

Experience in this field for set-up and up-dating a topographic data base is given by the staff of the Institute of Photogrammetry, Technical University of Vienna (H. Haitzmann et al, 1980, H. Kager, 1980, E. Aßmus et al, 1982, K. Kraus, 1983, L. Molnar / A. Köstli, 1984), which have developed its own data base software named TOPIAS (Topographic Information and Evaluation System) especially suited to the management of elevation data. But the more situation data are entering the data base the more complex will be the data administration. Hence the other way around using standard data base software adapted to the manipulation of heterogeneous topographic data has also to be investigated. First experience is given here by W. Staufenbiel (1983) for the set-up of a topographic system (TOPSY) of the land Lower Saxony, FRG.

3. High Fidelity Digital Elevation Models

Creating a topographic information system on the basis of elevation data involves a number of essential considerations on data sampling, data editing and elevation modelling strategies. Elevation data can be captured by different methods depending on accuracies and costs such as direct measurement of topography, photogrammetry and remote sensing techniques or by digitizing maps. The data have also to include informations on terrain features such as break lines, skeleton lines, characteristic points and by-pass areas.

3.1 Sampling Considerations

Before data capturing begins one should be aware of the measurement error and the sampling error resulting from the sampling theorem (A. Papoulis, 1966). These values may be used determining an optimum sampling interval (K. Tempfli, 1982, P. Frederiksen et al, 1983, 1984, D. Fritsch, 1985) if terrain profiles are available. But further investigations are needed for assessment of the different approaches.

The most frequently used method for sampling the terrain surface is digitizing contour lines from available maps or photogrammetrically. Within photogrammetry however there are also other methods for efficient data capturing. After profiling and static grid measurements within the stereo model the trend is moving to automated techniques. Data capturing software based on the techniques of progressive sampling (B. Makarovic, 1973, 1977a, H. Ebner / W. Reinhardt, 1984) drives meanwhile analytical plotters in a semi-automatic mode. The terrain will be sampled by a grid varying in size according to the roughness (see Fig.3); moreover also terrain features have to be sampled in supplementing the gridded data. Developments based on correlation techniques aim at a fully automated mode:

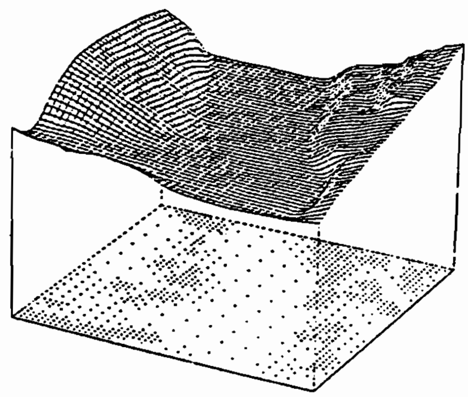


Fig.3: Progressive sampling of terrain

while the first analog device known as Gestalt Photo Mapper is still operating successfully (R. Kelly et al, 1977) there are recent efforts in the application of digital image correlation for very precise elevation data capturing (G.L. Hobrough, 1978, D. Pape, 1984, F. Ackermann, 1984, W. Förstner, 1986).

3.2 Data Editing

Speaking furthermore in terms of 'high fidelity' leads to data editing of the sampled data set for removing gross errors as well as having a quality control on data recording. Also here photogrammetry offers advanced techniques in off-line mode (S. Masry / R. McLaren, 1979) by superposition of graphical products of the terrain data with the stereo model or most recently in on-line mode (W. Reinhardt, 1986). The data check for direct measurement of topography or by digitizing maps should be done likewise as before by comparison of graphical products with available map information.

After data sampling and editing a first digital description of the terrain surface by means of original elevation data is given. This data set has to be archived because it contains all the genuine informations of the input data. Furthermore also data continuation as result of recent changes should be done within these data. For that reason the data have to refer to a common reference frame in which they will be sectioned into squared units for easier administration. Seperate files with additional informations on data origin, numbering scheme, storage media etc. will supplement the data set. More detailed experience on the storage of these data is given by K. Kraus (1983) in connection with the TOPIAS software.

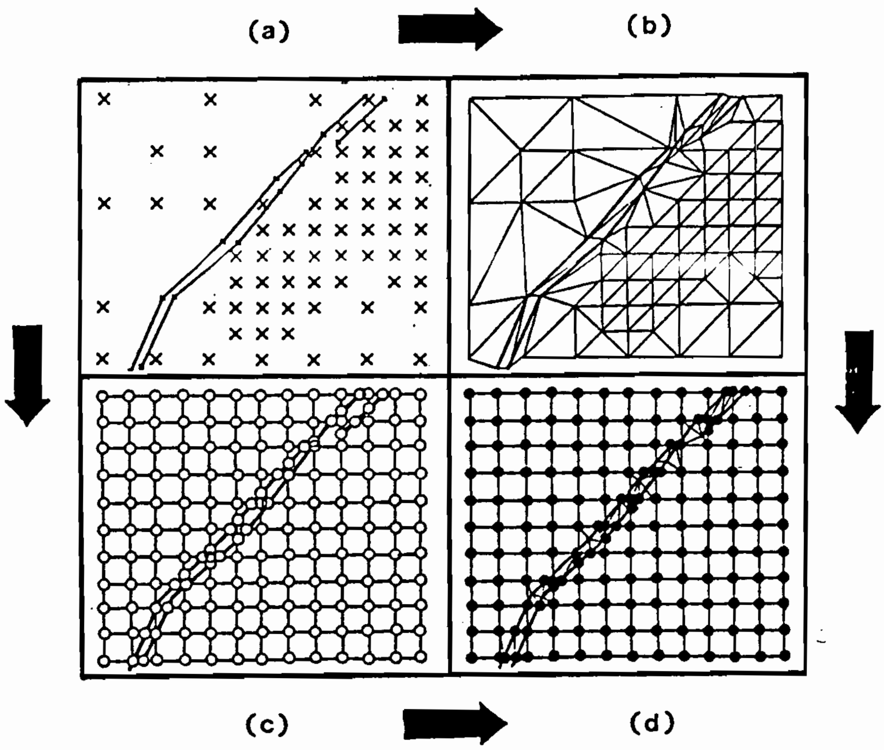
3.3 Elevation modelling

The original elevation data are not yet particularly suited as permanent data base guaranteeing fast access and efficient description of the terrain surface. Therefore they have to run through some processing stages to arrive at the final digital elevation model used as general purpose data base within the topographic information system. Two main strategies for processing the original elevation data can be found in practice today:

(i) the concept of irregular data structure, as the original samples are incorporated into plane or curved triangulation

(ii) regular data structure consisting of a squared grid supplemented by terrain features.

Both concepts differ completely from each other but they are equivalent in terms of 'high fidelity' and can even be combined (see Fig.4).



(a) original elevation data

(b) processed by triangulation

(c) processed by grid interpolation

(d) processed by combined grid and triangle interpolation

Fig.4: Processing stages in digital elevation modelling

For certain applications such as mining exploration, extreme hill areas or highway engineering the method of triangulation may be more effective than the grid model, being supposed that too much non-gridded informations on terrain features have to be considered. Experience with triangulation reaches back to the beginning of the seventies, when a general purpose program package on digital height modelling by Messerschmitt-Bölkow-Blohm (MBB), Munich, has been developed (F. Bauhuber et al, 1975). Since then several contributions on triangulation were published by P. Yoeli (1977), R.J. Heil / S.M. Brych (1978), H. Akima (1978), J. Gleue (1981), W. Kropatsch (1983) to name only few.

Further developments with triangulation in digital height modelling are given by the staff of Wild Heerbrugg (P. Hügli et al, 1984, F. Steidler, 1986) where the program package CIP (Contour Interpolation Program) is available, and by A. Preusser (1984), who interpolates over triangles by higher order polynomials. Recent applications with triangulation in brown coal mining can be found in K.R. Koch (1985); also I. Kruse (1985) used triangulation for derivation of contour lines from water lines as input in hydrographic applications.

Contrary to the irregular data structure the current trend in topographic information systems is aiming at a highly processed regular data structure with all its advantages of modesty in storage and access. A further reason speaking for gridded data as final data structure is given by gridded data capturing if photogrammetry serves as data source. The transformation of the more or less irregular distributed sampling points into gridded data expects a great deal from the interpolation methods. On the one hand original data have to be filtered because of measurement errors, on the other hand there should be not any important loss of geomorphological quality caused by interpolation.

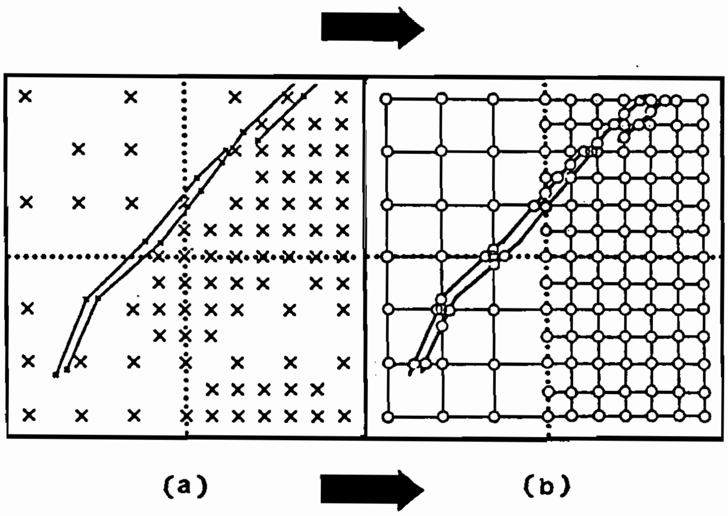
Going back to the earlier sixties, when a first IBM software package "Evaluation Digital Terrain Models" was available (L. Rapior / D. Bopp, 1975) the interpolation based on higher order least squares polynomials as mathematical model describing the terrain surface. But it took about one decade till the polynomial description was bounded on gliding surfaces of lower degree, as it is today standard of many program packages on digital elevation modelling (K.R. Koch, 1973a, L. Rapior/ D. Bopp, 1975, I. Kruse, 1979, E. Assmus et al, 1982). With the spreading of least squares prediction the next step in model fidelity has been caused, as the gliding surfaces were supplemented by random parts taking care for better local approximations (S. Lauer, 1972, K. Kraus, 1972, 1973, K.R. Koch, 1973b, R.L. Hardy, 1977, F. Ammanati et al, 1983).

A quite different approach in digital elevation modelling has been proposed by K. Kubik (1971), G. de Masson d'Autume (1976, 1979), H. Ebner/P. Reiß (1978), H. Ebner (1979) and G. Mélykuti (1982), what can be classified into the method of finite elements. They use an elastic grid consisting of bilinear and bicubic meshes and determine elasticity by weighted curvature measures. A least squares solution with band structured normal equations provides for efficient computation of the unknown grid heights. The method is also ideally suited for modelling of inhomogeneities and anisotropy of terrain because the elasticity of every grid element can be influenced. First experience in this way is given by H. Ebner (1983).

Although at the beginning in digital elevation modelling there was not attached great importance on characteristic terrain features, so lead today just the exact modelling of these features in connection with inhomogeneity and anisotropy considerations to the 'high fidelity' digital elevation model. In the meantime most of the methods employed are considering the challenges above as far it is possible within their mathematical approaches. Very sophisticated program packages on this basis have been developed to name the SCOP (Stuttgart Contour Program, K. Kraus, 1973, F. Ackermann, 1978, E. Assmuß et al, 1982), the HIFI (Height Interpolation with Finite Elements, H. Ebner et al, 1980, H. Ebner / P. Reiß, 1984) supported by Zeiss, Oberkochen, the TASH (Topographic Surveying and Evaluation System Hannover, J. Kruse, 1979), the DTEDS (Digital Terrain Data Base System, A.A. Noma / N.S. Spencer, 1978) of the Defense Mapping Agency and TOPAS (Topographic Anaysis System, T.W. Gossard, 1978) of the US Forest Service.

Other developments in software creating gridded elevation models are grouped around the GPM-system (Gestalt Photo Mapper, R. Kelly et al, 1977). Although most applications aim at medium and small scale photographs especially in the United States (US Geological Service, A.A. Elassal, 1978) and Canada (Topographical Survey Division, M.M. Allam, 1978) there is also first experience on the use of GPM for large scale photographs delivering DEM's of higher quality (R. Swann et al, 1978). As soon as data capturing is fully automated by correlation techniques additional informations of low cost such as slopes and curvatures can provide for better geomorphological fidelity (W. Förstner, 1983).

The output today of most of the program packages above is a highly processed gridded digital elevation model with dynamic grid size (see Fig.5) adapted to the roughness of terrain.



(a) original elevation data

(b) processed by grid interpolation

Fig.5: Modern gridded digital elevation models

The total area is subdivided into squared patches of gridded data, which may be supplemented by some triangles for high fidelity representation. These data will be accompanied by informations on grid size, triangle arrangements if any, numbering scheme of patches etc. forming now the final elevation data base for topographic information systems.

4. Conclusions

The development and use of high level software packages creating digital elevation models leads directly to topographic information systems for general purpose applications. These software packages provide besides the digital elevation model for other succession products such as contour lines, profiles for orthophoto production, volumina etc., so that they represent their own 'elevation information systems'. Several investigations on the fidelity especially of contour lines (F. Ackermann, 1978) give evidence of the high standard meanwhile reached. But improvements on data sampling, editing and modelling goes on coming as close as possible on the high fidelity reproduction of the 'real world'.

There are also future developments on the improvement of the interface between the elevation information system and the general topographic information system in such a way that data structures with regard to data bases become more significant (E. Assmus et al, 1982).

The use of gridded elevation data enables furthermore the application of digital signal processing algorithms aiming at a high level computer aided planning and mapping (E.U. Fischer, 1982, D. Fritsch, 1984).

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