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PHOTOGRAMMETRY AND DIGITAL ELEVATION MODELS, PRESENT STATUS OF DEVELOPMENT AND APPLICATION

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ABSTRACT

Digital Terrain Model is a tool for the description of features and properties that have a position on the earth that is relevant for solution of various problems. This paper is limited to an overview of digital elevation models measured by photogrammetry. The considered applications are automatic contour plotting, digital orthophotoproduction, and calculation of earth-work volumes. The sampling of the terrain surface can be done in a lot of ways from elevation measurement in regular grids to purely manual selection of the most relevant points to describe the shape of the terrain surface. The mathematical generation of the digital elevation model can result in gridded elevation data or a set of parameters that describe the shape of the surface. A special problem is the classification of terrain as to its geometric shape. An experimental research work is suggested so as to increase our knowledge of photogrammetric digital elevation models.

CONTENTS

WHAT IS A DIGITAL TERRAIN MODEL ?

We all have an idea of what a digital terrain model is. It is a model of the terrain and it is described in digital form. But what is meant by terrain? Is it the mountains and valleys, the fields and pastures, the streams and lakes? Is it the cultivated and wild forest areas with all the various types of trees and bushes and the cultivated land with all various crops and all the species of flora covering the ground? Is it the minerals, the soil, the types of bedrock, the landforms and its geomorphologic history? Is it the cities, towns and villages, the railroads, highways, streets and canals, the industrial, residential, commercial urban areas and the rural land used for various human activities? Is it the division of land into judicial areas given by borders between nations, provinces, counties, municipalities, neighbourhoods, estates and lots? Is it the information on the topographic map with its selection of features? Or is the terrain just a small part of what is shown on the map, e.g. the ground elevations shown as contour lines or hatching or shading or spot heights? This is after all how the digital terrain model started in the late 50's simply as a set of spot elevations defining the ground surface and used for highway design.

And what do we mean by "digital"? Do we mean the numbers describing geometric values such as elevation above and depth below sea level and position in a map projection system, or do we mean codes for land use, vegetation canopy, geology or soils? Do we mean ground-position-bound observations of emitted or reflected electromagnetic energy, or do we mean the real estate values, the productivity of land in terms of harvest in tons/acre/year, or the average travelling time from one place to another?

And how is the digital information related to the position in the terrain? Is it in raster form, in vector or polygon form, or in randomly distributed points? Is the location given in map projection co-ordinates, in postal addresses, or in real estate codes? And how is the digital information expressed? Is it written in books, on micro-film, on cards directly readable by the human eye, or in computer readable form on punched cards, magnetic tapes, flexodiscs, or whatever?

And what is our "model" of the terrain? This certainly has to do with application. For what purpose do we create our DTM? What are the essential terrain data that are needed to solve the problem? How can the data be acquired? What is the required accuracy? And how do costs and time influence the choice of method to solve the problem? Is dense data acquisition with low cost and low precision better than sparse sampling having high cost and high precision? Does the low precision and dense data acquisition give a better fidelity to the model of the terrain, or is the higher fidelity of the cheap method of greater value than the high precision of the sparse method? Parameters of this kind are important when we define what we mean by our "model" of the terrain.

PHOTOGRAMMETRIC DIGITAL ELEVATION MODELS

After these introductory unanswered questions we have got an idea of the variety of problem areas where the concept "digital terrain model" can be and has been introduced. The introduction also has shown the need of declaring what we ourselves mean by "digital terrain model". With the digital elevation model our concern is the elevation of the Earth's surface. We do not talk about terrain in general, we emphasise the elevation information. This means that we exclude almost everything that cartographers call planimetric features. The only planimetric features that we consider are those that have some relevance for the elevation, e.g.shore lines of lakes and rivers, brooks and streams, geomorphologic lines of importance for the shape of the Earth's surface, break lines, ridges, valley bottoms, boundary lines for the area of interest for our digital elevation model. We call it a digital elevation model (DEM) (German: digitales Höhenmodell) and it is a part of the more general concept digital terrain model (German: digitales Geländemodell).

For the following discussion we must focus our attention on some specific applications in order to indicate what types of conditions are considered when we talk about digital elevation models. The applications are firstly cartographic, in particular the derivation of automatically plotted contours, and the derivation of information for numerically controlled orthophotoproduction. Secondly we will consider civil engineering applications such as highway design, detailed technical planning of construction sites for industries, residential areas, harbours, airports and the like. This includes the derivation of profiles, cross sections, earthwork volumes and spot elevations from the digital elevation model.

A third limitation of our discussion is the type of data acquisition for our digital elevation model. The traditional types are land surveying, photogrammetry and digitizing of existing maps. More spectacular types can be remote sensing from satellites and space vehicles (SPOT, stereosat, SLAR, APR). We will in the following limit ourselves to photogrammetric data acquisition. This is almost selfevident when we talk about DEMs for orthophotoproduction and automatic contouring, because most of the DEMs for these applications are measured by photogrammetry.

Leaving existing maps out is done with the remark that they can be efficiently used to build up a digital elevation model for the purposes that we have mentioned. The data acquisition is fast and inexpensive when it is done manually and it seems as if the automatic approach to digitizing of contours is making good progress (Laserscan, Kartoscan and similar instruments). Manual digitizing of existing maps is today probably the most common method for primary data acquisition for digital elevation models.

But the limitation to photogrammetric data acquisition is more serious when we think of civil engineering applications. These models often cover small areas and then they are measured efficiently by automatic recording tacheometers. The calculation of earth masses is not only done in the planning stages but also during construction. Doing so one can determine volumes of separate soil types with high accuracy. Here the data acquisition is entirely done by land surveying. However, here we have already left the elevation of the Earth's surface which was the prerequisite for our own definition for a DEM.

At this point we thus have limited our subject to photogrammetrically measured digital elevation models applied to orthophotography, contour plotting and planning of earth work on construction sites.

The main interest in the DEM from the photogrammetric point of view is the sampling of the terrain. Several methods are available and various instruments are used. The sampling procedure must be such that the requirements of the final product are fulfilled. The specifications can be expressed in terms of accuracy (precision, reliability, fidelity), time, cost, etc. The sampling also depends on the type of data processing that is done to build up the elevation model and to reach a final product. Work with photogrammetric digital elevation models thus comprises

- Sampling the terrain elevation from aerial photographs
- Preprocessing: Formatting, transformation of co-ordinates, blunder detection, correction of systematic errors in instruments and photographs
- Mainprocessing: Generation of the digital elevation models by interpolation, data compression, filtering and so on, merging different data sets
- Postprocessing: Extracting the data for a certain application, formatting
- Application: Some are very familiar to photogrammetrists: Orthophoto printing, contour plotting; others are not so usual for photogrammetrists: Earthwork volumes, radar visibility, land reclaiming, simulations.

The sampling procedure leads us into the area of terrain classification. The sampling is also related to the mathematical method of generating the digital elevation model. The interaction between sampling, terrain type and mathematical generation of the model is fundamental for the prediction of the accuracy of the model. Some of these things will be touched upon in the following.

SAMPLING INSTRUMENTS

The terrain elevation is measured from aerial photographs with a photogrammetric instrument. The sampling is the process of selecting and measuring a set of points which describe the shape of the terrain surface. Depending on the photogrammetric instrument this process can be automatic, semi-automatic or manual. A few instruments are designed for production of digital elevation models, but usually the ordinary photogrammetric instruments are equipped with auxiliary devices when they are used for DEM measurements.

A stereoplotter with a co-ordinate recording device can be used directly for manual sampling. The stereo operator selects the points to be measured, sets the measuring mark on the model surface and pushes the button for recording the model co-ordinates.

Several stereoplotters can be equipped with a profiling device that moves the measuring mark systematically over the stereo model. The operator adjusts it to the elevation of the model surface in a semi-automatic mode. Such instrument systems are often primarily intended for continuous orthophotoprofiling, but some types step over the model to generate an elevation grid. The new generation of analytical stereoplotters offer new and interesting possibilities for semi-automatic sampling with computer aid, for moving the measuring mark to the next sampling point, and for checking the sampling density against mathematical conditions for the elevations. This latter type of check can also be done on on-line computers connected to the recording devices of the traditional stereoplotters, but without feed-back to the position in the instrument. This is left to the operator.

The automatic systems have as well taken over the "setting of the measuring mark" from the operator. This is done in different ways. The A8-stereomat and the Zeiss-Itek-correlators match the two stereoscopic photographs via z-movements in the mechanically reconstructed stereo model. The Gestalt Photomapper matches the two photos electronically and the movements of the photo carriages are controlled from a computer programmed for the perspective transformations. The process includes the generation of a DEM for the patch of the terrain that is used for stereoscopic matching. A third type of automatic sampling is based on purely digital techniques based on digital images stored in a computer.

SAMPLING MODES

The two extremes of the point patterns for sampling the terrain are the selective and homogeneous modes. In the selective group of modes all points are specific for the elevations. The points are single points or strings of points. They are very often coded for special use in the succeeding data processing. The sampling is purely manual. A typical point string is the breakline in the terrain. Perpendicular to this line the slope changes abruptly (first derivative of the elevation is not continuous). Along the breakline the slope varies continuously. These lines can also describe geomorphologic features but the photogrammetrist prefers to define his lines in a geometric sense. This is also natural when we are dealing with the elevation models. Another string type are lines in the gently rolling terrain.

Points in this type of string are used for the generation of the DEM to yield the required fidelity. A third type of string is the border lines for the DEM. Such border lines are not only the perimeter of the area but also define "islands" within the area where no DEM will be generated. Such DEM islands can be lakes, ponds, densely built-up urban areas. These point strings are in some DEM systems transferred from the planimetry files of a digital map. The selected single points in the sampling can be tops of hills, bottoms of pits, and points in the gently rolling terrain where they are needed to increase the fidelity of the model. Selective sampling is very often applied when the generation of the DEM is done with rather simple interpolation methods. The individual sampling points thus carry a large amount of information. They are selected with respect to the interpolation method and they are given certain codes that control the use of the points in the succeeding generation of the DEM. One example is the point sampling that builds up the DEM by plane triangles. Another is the linear interpolation perpendicular between the breaklines after linear interpolation along the lines.

The homogeneous modes of sampling are very common in photogrammetry and they are well suited for automation at various levels. As opposed to the selective mode the points are located in geometric patterns defined by mathematical rules and the location is independent of the shape of the terrain. The measuring of the elevations can be done directly in the points that constitute the DEM, which is generated at the time of measurement. The sampling is then done in the ground co-ordinate system. This is a typical semi-automatic procedure. Analytical stereoplotters and computer aided mechanical stereoplotters are appropriate instruments. The planimetric position is defined by the order of the points rather than their x-y-co-ordinates. Among these homogeneous sampling modes we first recognize the square and rectangular grid. This, however, necessitates control information in terms of starting location, number of points in each row, number of rows, spacing between points and rows, and so forth. By doing so the amount of recorded and stored data can be reduced and searching and sorting in the files can be organized according to this information. Similar advantages can be obtained with triangular grids. In manual sampling the grid, as a rule, is oriented in the model co-ordinate system. In the following data processing there will be a resampling to the DEM grid to get the proper spacing and to merge samplings from different stereo models. The resampling as such will be touched upon in the paragraph on DEM generation.

The regular grid sampling does not take any consideration of the shape of the terrain. This is, however, the case in progressive sampling, a term introduced by MAKAROVIČ. Here the sampling starts with a rather coarse grid and when certain functions of the elevations are outside their tolerances the sampling will be densified. A typical tolerance is change of slope. The densified grid will be subjected to the same tolerances and the process is repeated until the tolerances are met. This results in a regular grid with varying point density. There are more points in rugged terrain than in relatively flat areas. The analytical stereoplotter is the ideal instrument for progressive sampling. Online computation from ordinary mechanical stereoplotters can also be a solution for implementation of the method.

The DEM can also be generated from sampling in profiles. The profiles then have equal spacing but the points along the profiles are selected according to certain criteria: a) dense sampling in time or space as the operator follows the terrain profile, b) sampling where the profile passes equidistant elevations (contours) c) sparse selective sampling along the profiles. In the case of dense sampling the data processing often includes compression of data, by removal of redundant sampling points. Sampling in profiles can be done manually or semi-automatically in oriented stereo models. It can also be done automatically from profiles that have been used earlier for orthophoto production, for instance there are examples where the engraved profile plates from the Gigas Zeiss projector have been digitized automatically in the GZ 1 without diapositives and printing film, but with an encoder on the z-spindle of the projector.

Digitization of contours can of course be done directly in the stereo model. For each contour the elevation is constant and it is the x-y that is digitized as the operator scans the terrain surface. The sampling can be done using time or space increments, and it is necessary to remove redundant data to get a manageable set of points. Instead of recording x, y or Δx, Δy along the contour one can record direction and length between the points along the contour.

Sampling in profiles or contours or progressively gives an ordered set of data that is not regular in all directions as is the case for grids. Sampling along epipolar lines or other lines in the image plane also yields an ordered set of data without reference to the co-ordinate axis of the ground system used for the DEM. One sampling mode that might be of interest is random sampling; again we can talk about homogenity and isotropy of the point locations in space.

Between the two extremes selective and regular grid sampling we have all possibilities to design our own methods for data acquisition for our digital elevation models. It is also reasonable that the dominant terrain features be used for the generation of the DEM and that a homogeneous net of points fill out the areas between these features, so as to guarantee the required fidelity of our DEM. In the well developed systems for DEMs we also find what has been called composite sampling, i.e. an effective combination of selective and homogeneous sampling. It is especially interesting when the photogrammetric instrumentation provides possibilities for semi-automated sampling. The operator makes the selection and the computer helps him in the homogeneous mode of sampling. The following data processing must of course take full advantage of the different types of points in the composite sampling.

GENERATION OF THE DEM

The digital elevation model can be a set of discrete points representing the terrain surface, or a number of parameters defining the surface as a function of the planimetric position. We thus have discrete point models and continuous surface models. The grid points and the parameters are calculated from the primary points resulting from the sampling of the terrain. Sometimes the primary points or a subset of them are included in the DEM, sometimes no such points are included, sometimes the DEM contains no other points than those sampled directly from the photogrammetric stereo model.

Before the DEM is generated it might be necessary to do some preprocessing of the sampled data. A typical preprocessing is the data compression that is needed after stream digitizing of contours and profiles in semi-automatic and automatic modes. In the very dense string of points there is much redundant information. This redundancy can be reduced e.g. by elimination of all the points between two points as long as the eliminated points are within a tolerance band along the line between the two. Another method is to use the change of direction as criteria for elimination. The preprocessing also includes transformation of the digitized co-ordinates to the ground system. This is the ordinary similarity transformation as for absolute orientation of the photogrammetric model. The number, location and precision of the elevation control points are essential for the error propagation leading to the determination of the error in the final result. Earth mass volumes are for instance very sensitive for weaknesses in the ground control. But here we also may have to include correction of systematic errors, such as lens distortions, film shrinkage and instrumental errors in order to reach the specified accuracy. Computation of volumes are typical for addition of elevations over areas and in the case of systematic errors of the sampled points these errors also are additive in the final volume. The effect of random errors of the sampled points are, contrary to the systematic errors, reduced during addition. It is thus very important to eliminate and reduce the effect of the systematic errors, especially for civil engineering applications.

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The preprocessing should as well contain checks against blunders and outliers. Test plots in planimetry of selectively sampled points and contours is one way. Elevation plots of digitized profiles is another good method for graphical checks.

Calculation of test values can also be programmed and the sampled points are indicated in some way as soon as the test values exceed the tolerances.

There is always in the main data processing of the DEM an algorithm to calculate elevations for arbitrary points in the DEM area, as a function of the sampled points. This algorithm is often called interpolation, although it sometimes is something else from a mathematical point of view. The "interpolation" often is done in two steps. The first one generates a regular grid of elevations in the ground co-ordinate system. This is what we call the main processing. The second step calculates terrain elevations for new points between the grid nodes. There are a few examples of DEMs where the first step is omitted. One case is sampling directly in the DEM grid system. Another is purely selective sampling of DEMs for just one special application. The second step is always a part of the postprocessing or the application of the DEM. The interpolation methods used in the two steps can be different for the same DEM.

INTERPOLATION METHODS

Given a set of n points $\{x_i\ y_i\ z_i\}$, i = 1 ...... n, the problem is to find z for any position x, y within an area defined by a subset of $\{x_i\ y_i\ z_i\}$ describing the borders of the DEM.

$$z = F(x,\ y,\ x_i,\ y_i,\ z_i)$$

This can of course be solved in many ways and the smaller the difference between the computed z and the real terrain elevation in position x,y, the better is the method. The interpolation function F models the terrain from the given set of points $\{x_i\ y_i\ z_i\}$. The better the interpolated values z follow the real shape of the terrain, the better is the fidelity of the digital terrain model and the interpolation function.

For some methods of the interpolation the values of the sampled elevations are not changed (this is true interpolation). For other methods there is some sort of adjustment or filtering of random errors leading to residuals in the sampling points.

Another characteristic of the interpolation method is the type of shape of the interpolated surface. The types can be described by the existence of continuity in elevation, slope, and slope change, or whether the interpolation considers and maintains the breaklines and similar selectively sampled features that indicate discontinuities in the above mentioned geometric properties.

According to SHUT's review of interpolation methods for digital terrain models (SHUT 1976) the following six groups of interpolation methods can be arranged,

- Moving surface methods

  For each interpolated point a surface has to be determined. This surface can be a level plane, a tilting plane or a second degree surface. The surrounding reference points are supposed to "fit" this surface in an adjustment. Weights depending on the distance between the surface point and the interpolated point can be introduced.

- Summation of surfaces

  Linear least squares interpolation, multiquadratic interpolation.

- Simultaneous patchwise polynomials

  The region is divided into square or rectangular elements by means of a regular grid, and the heights and sometimes the gradients are computed in one adjustment. The equation system consists of observations of heights of reference points and conditions which are put on the terrain. Example Finite Elements.

- Interpolation in a rectangular grid

  Interpolation is here often made by means of polynomials

  Example: $$z = \begin{bmatrix} 1 & x & x^2 & x^3 \end{bmatrix} \begin{bmatrix} a_{00} & a_{10} & a_{20} & a_{30} \\ a_{01} & & & \cdot \\ \cdot & & & \cdot \\ a_{03} & \cdot & \cdot & a_{33} \end{bmatrix} \begin{bmatrix} 1 \\ y \\ y^2 \\ y^3 \end{bmatrix}$$

- Interpolation in a net of triangles

  This method means formation of triangles and often linear interpolation in each triangle.

- Interpolation in a string DEM

  The DEM consists of strings (lines) and interpolation can for example be made perpendicular to break lines or contour lines.

Now it seems to be of interest to find in some general sense the best of methods for interpolation. This is not a very well defined task. Firstly, the chosen method influences the structure of the sampling, secondly the interpolation function models the terrain und thus the type of terrain shape might give different answers to the question. Then we have the problem of the parameters (e.g. accuracy, times and costs for sampling, computing and application) of the value function to compare the methods. In spite of the difficulties to define the problem clearly there have been some attempts to compare different DEMs. One practical test has been done with six different DEMs to produce contour maps over five different types of terrain (Anonymous 1980). An interesting theoretical approach derived the transfer functions for three interpolation methods on a simulated terrain (TEMPFLI-MAKAROVIČ 1979). Such studies could be extended to real terrains and for more interpolation methods.

TERRAIN CLASSIFICATION

It has been emphasized already that the terrain type has a dominating influence on the sampling and the fidelity of the model. It is thus of interest to find methods to describe the terrain shape for DEM purposes. Some terrain classifiers can be recognized

- Operational classifiers (MAKAROVIČ 1979)
- Parameters of surface roughness (AYENI 1976)
- Trend surfaces and co-variance functions
- Subjective classification, often related to geomorphologic land forms.

A promising approach is the power spectrum of the terrain. Profiles are measured through the area of interest. The elevations in the profiles are subjected to spectral analysis which transforms the spatial information to the frequency domain. The undulation of the terrain is then described as a function of amplitudes and wave lengths (FREDERIKSEN 1980). The power spectra of terrains, although very complicated, can be approximated with very few parameters (straight lines). The precision of the measuring method can be identified and the optimal sampling interval for the measuring method in that particular terrain can be found. This latter possibility is of great practical importance.

Spectral analysis can, as mentioned above, be used for derivation of transfer functions of interpolation methods. Combining this with power spectrum classification of the terrain gives the fidelity of our digital elevation model. This should, however, be tested in practical experiments to give us more experience of its value under operational conditions.

COMPARATIVE TESTS

The ISPRS adopted a resolution at the 1980 Congress in Hamburg saying that Commission III should establish a working group to execute comparative tests of digital terrain models. The intention is to compare under operational conditions the relations between sampling, interpolation and accuracy. Aerial photographs from 3 - 5 different types of terrain will be distributed to the working group members. We hope that some ten organisations (not more than twenty) will participate. They will be asked to sample the terrain and to generate a DEM. Each model will be sampled for six different purposes: three contour plots in various map scales and contour intervals, and three volume calculations with varying parcel sizes and accuracy requirements. The report will include

- presentation of the sampling modes and statistics of the density and distribution of sampling points
- measuring instruments
- type of interpolation to generate the DEM
- accuracy of spot elevations in the model, and accuracy of final results (the "ground truth" will be taken from low altitude photographs)
- an attempt to separate the error components in random errors (precision) of the sampling, systematic errors from photos and instruments, and systematic errors of the interpolation (fidelity)
- time spent for sampling and calculation, preparations and amendment
- need of qualifications for personnel, relative wages for groups
- computer used, costs for calculations
- comparisons of spectral analysis of terrain measured with the photogrammetric equipment and measured on the ground with high accuracy and fidelity.

We are confident that this program will increase our knowledge, and we hope that it will stimulate theoretical and technical development in the field of photogrammetric digital elevation models for cartographic and civil engineering purposes. Those who are interested in the activities of the working group are kindly invited to contact the author who is chairman of the group.

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Stand der Entwicklung und Anwendungen digitaler Geländemodelle

Zusammenfassung

Das digitale Geländemodell ist ein Hilfsmittel zur Beschreibung von Einzelheiten und Eigenschaften, deren Lage auf der Erde für die Lösung verschiedener Probleme bedeutsam ist. Dieser Vortrag beschränkt sich darauf, einen Überblick über die photogrammetrisch gemessenen digitalen Höhenmodelle zu geben. Die in Betracht gezogenen Anwendungen sind die automatische Kartierung von Höhenlinien, die digitale Orthophotoherstellung und die Massenberechnung bei Erdarbeiten. Die Geländeoberfläche kann auf sehr verschiedene Art und Weise erfaßt werden, von der Höhenmessung in einem regelmäßigen Raster bis zur Auswahl der bedeutsamsten Punkte von Hand. Die Geländeoberfläche, d.h. das digitale Höhenmodell kann mathematisch durch Höhenangaben von Rasterpunkten oder Flächenparameter beschrieben werden. Ein besonderes Problem stellt die Klassifizierung des Geländes nach seiner geometrischen Beschaffenheit dar. Es werden experimentelle Forschungen angeregt, um die Kenntnis bezüglich photogrammetrischer Höhenmodelle zu erweitern.

Photogrammétrie et modèles numériques d'altitude; niveau actuel de perfectionnement et applications

Résumé

Au moyen des modèles numériques d'altitude on peut décrire la surface de la terre et les objets pour résoudre différents problèmes. Le présent document se limite à donner un aperçu des modèles numériques d'altitude mesurés au moyen de la photogrammétrie. Les domaines d'application sont: la réalisation automatique de courbes de niveau, la production numérique d'orthophotos et le calcul de volumes. La saisie de la surface de la terre peut être effectuée au moyen de la mesure des altitudes dans une trame régulière ou bien au moyen d'un choix manuel de points qui sont significatifs de la surface de la terre. A l'aide du modèle mathématique du modèle numérique d'altitude on peut calculer soit des informations altimétriques en forme de trame, soit des données de paramètres qui décrivent la surface de la terre. L'auteur suggère une recherche expérimentale afin d'améliorer nos connaissances des modèles numériques d'altitude.

Situación actual del desarrollo de las aplicaciones de modelos digitales

Resumen

El modelo digital del terreno sirve para describir detalles y estructuras situadas en la tierra que revisten importancia para resolver toda una serie de problemas. La presente conferencia se limita a proporcionar una sinopsis de los modelos digitales altimétricos realizados por vía fotogramétrica. Las aplicaciones consideradas son el trazado automático de curvas de nivel, la confección de ortofotos en forma digital y cubicaciones en caso de movimientos de tierra. El muestreo de la superficie del terreno podrá llevarse a cabo de la manera muy distinta, desde medición de alturas en cuadrícula regular hasta la selección manual de los puntos más destacados del terreno. El resultado de la generación matemática del modelo digital altimétrico pueden ser tanto datos altimétricos en forma de cuadrícula o bien una cantidad de parámetros que describen la configuración de la superficie. Un problema especial lo constituye la clasificación del terreno según su forma geométrica. Se propone hacer investigaciones para incrementar nuestros conocimientos acerca de los modelos digitales altimétricos obtenidos por vía fotogramétrica.

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