INTERSECTION AND COMBINATION OF DIGITAL ELEVATION MODELS - METHODS AND APPLICATIONS

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Commission IV

ABSTRACT:

Three-dimensional surface descriptions, which exist in the form of digital elevation models, are well suited - by using any mathematical function - for a combination of different types of surface data (DEM, digital slope model, digital soil value model, etc.), as well as for the intersection of these digital surface models with polygon areas. Corresponding methods were realized in the DEM program system SCOP.

Typical application examples are the derivation of height difference models from two DEMs, a subsequent volume computation, the determination of slope statistics from a digital slope model, or the production of soil loss prediction maps by combining the influence factors for soil erosion.

KEY WORDS: DEM, volume computation, soil loss prediction, polygon overlays

INTRODUCTION

In addition to the conventional DEM applications (isolines, profiles, perspective views) arithmetic operations on the DEM data like the DEM intersection and the functional combination of DEM data represent a new challenge for DEM systems.

DEM intersection and combination methods are already used for volume computation. In addition, they open many new fields of application to a DEM system.

Up to now surface data describing the terrain (e.g. elevation, slope) have usually been intersected with polygon areas by polygon overlays. In a first step the surface data had to be classified and described by polygon areas with constant class values (e.g. slope class areas derived from a digital slope model). This classification includes a considerable loss of information which leads to erroneous results, especially in cases where the polygon data are used for a functional combination with other terrain data (e.g. for soil loss prediction).

Therefore methods had to be developed for intersection and combination which made full use of the three-dimensional surface information of a DEM.

Together with the necessity of having a SCOP module for volume computation, the above considerations were the reason for the development of the program SCOP.INTERSECT.

2. THE DEM PROGRAM SYSTEM SCOP

SCOP is a multi-purpose program system for the generation and application of digital elevation models (Kraus et al. 1982, Ackermann 1991). Its flexible high-quality interpolation methods produce DEMs of cartographic quality. SCOP includes all common DEM application modules which derive follow-up products like single heights, isolines, profiles, volumes, perspective views, digital slope models and raster graphics DEM representations.

SCOP has been used world-wide by numerous organizations for all types of DEM projects, from large-scale engineering projects up to the generation of national DEMs. SCOP is a joint development by INPHO GmbH (Prof. Ackermann) and by the Photogrammetric Institute of the Technical University Vienna (Prof. Kraus). The structure of SCOP is shown in fig. 1.

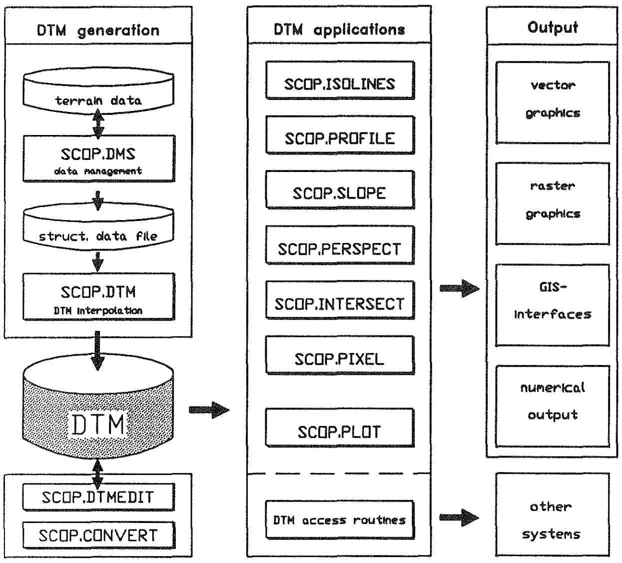


Fig.1: SCOP modules

3. DATA STRUCTURE OF THE SCOP DEM

The heart of a DEM system is the digital elevation model which is characterized by the quality of its interpolation methods and by the efficiency of its data structure.

SCOP interpolates a highly densified grid model with variable grid width (Köstli/Wild 1984) from irregularly distributed points (mass points, spot heights) and lines (break lines, form lines, border lines) of any origin. The measured lines are rigorously stored in the DEM and are therefore available for all DEM applications. A subdivision of the DEM area into small rectangular computing units enables the processing of huge DEM projects even on personal computers. The data structure is shown in fig. 2.

The DEM is stored as an index-sequential file with direct access to local parts (Köstli/Sigle 1986). Thus a very efficient processing of the DEM data is guaranteed, with access times of less than 0.1 sec. even in an extremely large DEM.

The SCOP DEM data structure is not exclusively used for the storage of terrain heights, but it is also the data basis for derived data like digital slope models or height difference models. Those digital surface descriptions are called "SCOP models" in the following.

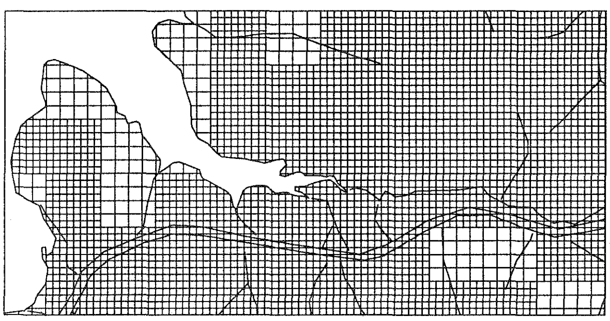


Fig.2: DEM data structure

4. VOLUME COMPUTATION - A FIRST EXAMPLE FOR DEM COMBINATION AND INTERSECTION

A volume computation from digital elevation models may be done in two steps:

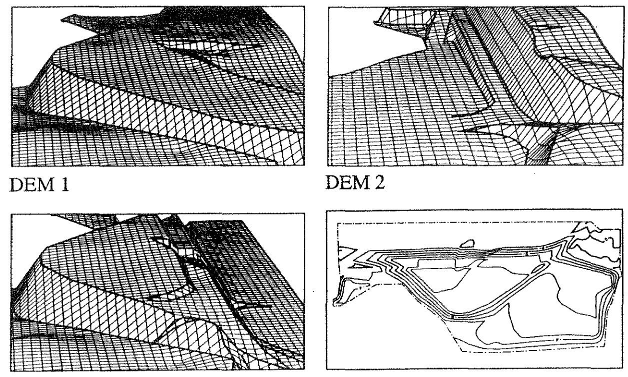
1. derivation of a height difference model
2. volume computation from the difference model for predefined areas of interest (e.g. earthwork areas).

4.1 Derivation of a Height Difference Model

Two DEMs for the same area have to be given in the SCOP DEM data structure. They may describe a former or existing terrain, but also projected terrain forms.

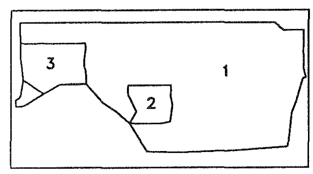
The two DEMs may have different grid intervals and different line information (break lines etc.). From the two DEMs the height differences are computed and stored in the difference model as shown in fig. 3 for an open mining area.

The difference model inherits the grid structure from one of the DEMs and the line information from both DEMs. Thanks to this, embankments and other important terrain features are fully represented in the difference model.



DEM 1 DEM 2

difference model difference isolines



areas of interest

area no.		area	volume
1	cutting:	25402.48	144809.41
	filling :	921.57	204.08
2	cutting:	1357.36	15569.44
	filling :	0.00	0.00
3	cutting:	2219.11	6358.70
	filling :	189.90	107.49

results of volume computation

Fig. 3: Example of a volume computation

4.2 Volume Computation

It is the aim of a volume computation to determine the earth volumes separated into cutting and filling for some areas of interest (e.g. earthwork areas).

Areas of interest may be any areas within the difference model defined by closed polygons. Cutting and filling are separated by the intersection line of the two DEMs, which is the isoline of height difference zero.

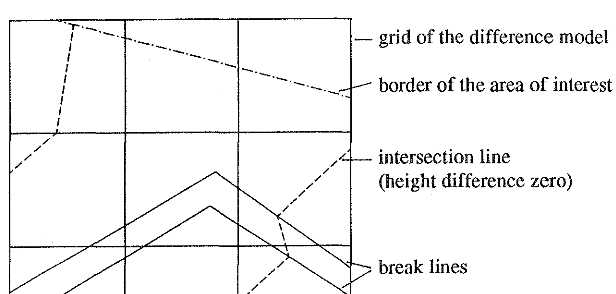


Fig.4.1: Lines for volume computation

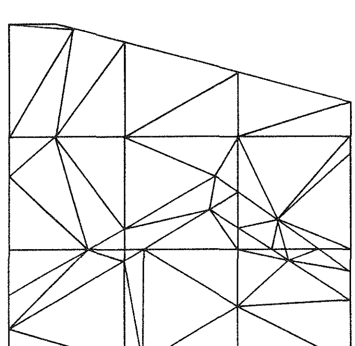


Fig.4.2: Triangular prisms

Volume computation has to start from a grid of height differences and from different line information (limit of the area of interest, intersection line, break lines, form lines, DEM border lines). Fig. 4.1 shows the initial lines for a small part of a difference model.

The lines build up irregular polygons. For each grid mesh a triangular network is derived from the irregular polygons (see fig. 4.2). Thus, the volume computation can be reduced to triangular prisms which have to be related to either cutting or filling, depending on the sign of the height differences.

5. GENERAL VIEW OF THE COMBINATION AND INTERSECTION METHODS

The methods used for volume computation shall in the following be used as an example for a more general view of the arithmetic operations on DEM data.

5.1 DEM combination

Building up a difference model from two DEMs is a functional DEM computation by using a simple subtraction as a combination function.

$$Z_{diff.} = Z_{DEM1} - Z_{DEM2}$$

SCOP.INTERSECT is now extended for the use of any mathematical function of the form

$$Z_{funct.} = f(Z_1, Z_2)$$

The function f is described by the fundamental arithmetic operations and by a discrete description of more complex functions.

The functional values $Z_{funct.}$ are stored in a SCOP model with the grid structure of either the Z_1 or the Z_2 SCOP model and the line information of both models.

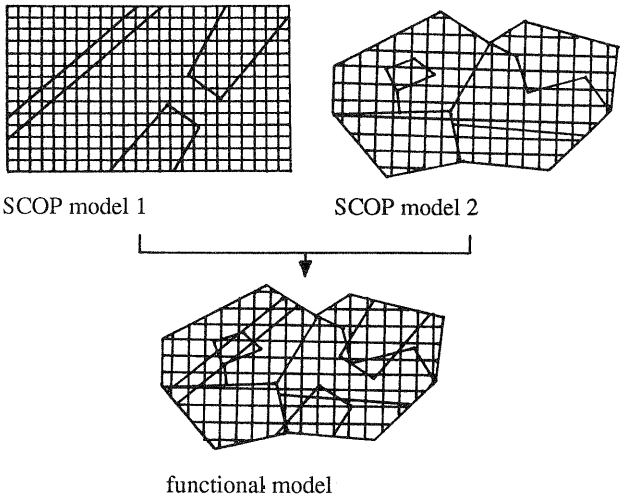


Fig. 5: Data structure of the functional model

Each point of the functional model needs its values Z_1 and Z_2 before performing the computation of the functional Z value. In most cases only one of the Z values is directly stored either in the Z_1 or in the Z_2 model. The corresponding Z value of the other model is automatically determined by an interpolation within the respective grid mesh.

5.2 DEM Intersection

Volume computation is a special case of DEM intersection for which the DEM is a difference model. It is intersected with areas of interest. Each area of interest is subdivided by the isolines of height difference zero into areas of cutting and filling. The intersection results are volumes of cutting and filling.

In general the DEM can be any *SCOP model* (DEM, slope model or any functional model). The areas of interest may be any *polygon areas*. And the height difference zero for dividing cutting and filling may be replaced by any *class limits*.

The intersection classifies the polygon area and computes the intersection results which may be classified areas, volumes or surfaces. Applications of a DEM intersection are described in chapter 7 and in table 1.

5.3 Polygon Overlays

In many cases the input data for a functional combination of surface data or for an intersection do not exist in form of a DEM, but have to be digitized from maps in form of polygon areas. Each polygon area has a corresponding value Z.

Such polygon areas may be converted with SCOP.INTERSECT into a SCOP model, and are then available for a functional combination with other surface data or for an intersection.

The conversion into a SCOP model is done by overlaying the polygon areas with a regular grid. Each grid and polygon point is stored with the Z value of the referring polygon area. The result is a surface description which consists of adjacent horizontal terraces.

After a conversion of polygon areas into a SCOP model SCOP.INTERSECT is able to solve a conventional polygon overlay by intersecting a second set of polygon areas with the SCOP model.

6. OTHER APPLICATIONS FOR A DEM COMBINATION

The two following examples show how other arithmetic or boolean operations can be used for a combination of digital elevation models.

6.1 Integration of planned structures into a DEM

A simple boolean function can be used for the integration of planned terrain surfaces (roads, railways, embankments etc.) into a DEM of the existing terrain.

Input data are two DEMs, one for the existing terrain, and the other for the planned structures surrounded by border lines. In the combined DEM the planned elevations are stored where the planning DEM exists. Outside the planned structures the Z values of the existing terrain are taken.

The combined DEM can then be represented in form of perspective views or evaluated in form of profiles.

6.2 Prediction of Soil Erosion

A more complex function is used for the combination of the influencing factors for soil erosion. In most investigations the expected annual soil loss per unit area is described by the universal soil loss equation (USLE) (Wischmeier/Smith 1978) as the product of 6 influencing factors:

$$A = R * K * L * S * C * P$$

with

A = expected annual soil loss per unit area
R = rainfall factor
K = soil erodability factor
L = slope-length factor
S = slope-steepness factor
C = cover and management factor
P = support practice factor

Amongst other applications, the USLE is being applied to terrain planning in land consolidation projects (Sigle 1991). The maximum tolerable slope length of the restructured terrain is computed by combining the slope factor S (derived from a digital slope model) and the soil erodability factor K. K is stored in a SCOP model which was built up from digitized polygon areas of a map of soil classes. All other influence factors could be kept constant for a local land consolidation area.

The combination results in a digital slope-length model which can be represented in a map of classes of tolerable slope-length.

A graphical presentation is given for a small part of the land consolidation project Sulzfeld in fig. 6. Data acquisition was done by the land consolidation authority of Baden-Württemberg. In practical use the soil loss prediction maps could be considerably improved compared to fig. 6 by using colour hatching or a z-coded raster representation for the slope-length classes.

The Sulzfeld project has an extension of 5km x 5km. The DEM data were acquired by a photogrammetric grid measurement (44 178 points including 18 461 points on break lines, form lines and border lines). The K-factors were digitized by 869 polygon areas with 16 485 polygon points.

The total project was realized under MS-DOS on a 80386 PC (33 MHz). It required a disk capacity of 40 MB and computing times of 64 minutes for DEM interpolation, 18 minutes for derivation of a digital slope model, 9 minutes for building up the K factor model, 58 minutes for the derivation of the slope-length model by combining the two SCOP models, and 3 minutes for the output of a soil loss prediction map for the total area.

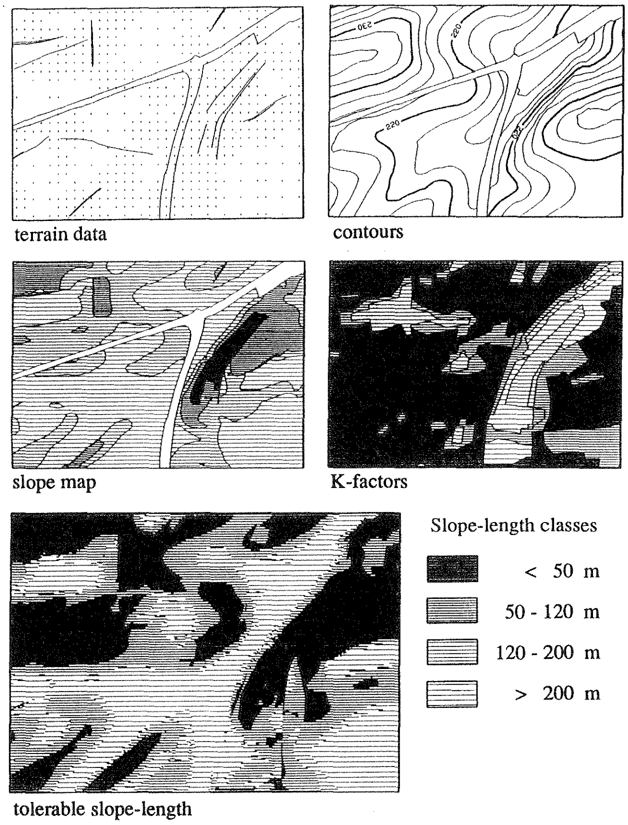


Fig. 6: Soil loss prediction for a land consolidation project

7. OTHER APPLICATIONS FOR A DEM INTERSECTION

Two applications are described in the following which are used for the estimation of agricultural land (e.g. for land consolidation projects).

7.1 Slope Statistics

SCOP includes a module for the derivation of a digital slope model from a DEM. The slope model has the same data structure as the DEM, but the terrain heights are replaced by slope values (steepness in per cent). Break line information is rigorously considered in the slope model.

For land estimation the slope model is intersected with pieces of land (polygon areas) by using several slope values as class limits. The results are the slope class areas for each piece of land.

7.2 Soil Value Statistics (Polygon Overlay)

An example for a polygon overlay is the computation of soil value areas for pieces of land.

Soil value classes usually exist in form of polygon areas in soil value maps. The polygon areas have to be digitized and to be converted into a SCOP model which is then intersected with another set of polygon areas (e.g. pieces of land). Class limits for the intersection may be any soil values in between the different soil value classes of the map.

8. SUMMARY

Flexible, accurate, fast and rigorous methods were developed on the basis of the SCOP DEM data structure in order to combine and to intersect different types of surface data. The methods were made available for a practical use by the program SCOP.INTERSECT.

In addition to the applications described in this paper there are many similar other ones possible. They cover a wide field ranging from projects which are closely connected with digital elevation models to projects which only make use of the DEM data structure as a data basis for polygon overlays.

A summary of the methods and applications is given in table 1.

This example shows that a DEM program can no longer be seen as a stand-alone system. Today's methods are carefully designed to be of general use, e.g. in geographic information systems.

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Application:	**volume computation**	**slope statistics**	**integration of planned terrain**	**soil loss prediction**	**polygon overlays**
1. DEM combination					
input model 1	DEM 1		DEM (existing)	slope model	
input model 2	DEM 2		DEM (planned)	erodability model	
function	subtraction		boolean function	USLE	
functional model	↓ difference model		↓ combined DEM	↓ slope-length model	
follow-up products	difference maps		perspective views	soil erosion maps	
2. DEM intersection					
SCOP model	difference model	slope model			soil value model
polygon areas	earthwork areas	pieces of land			pieces of land
class limits	height difference 0	slope classes			soil value classes
intersection result	↓ volumes for cutting and filling	↓ areas of slope classes			↓ areas of soil value classes

Table 1: Summary of methods and applications