Making Plate Digital Terrain Model

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Abstract

Digital terrain model (DTM) is important for the civil engineering, for viewing buildings influence on their environment. Therefore an effective model terrain output is needed.
There are several types of DTM: grid, polyhedry, plate model, etc.
The plate model has the most effective output. A terrain is parceled out into smaller areas. Not only plane ones. They can be anyway curved.
One of the problems to make the plate model is continuation and curvature of the terrain plates.
The quadratic area is the most used method of the terrain plates approximate.
The smooth curvature of these plates problem is difficult. Sometimes it may be insoluble.
One of the optimization way to the best smooth continue
and curvature plates are to use evolution computing methods.

The next problem is a triangulation. It is merging of input points to a triangle net. So triangle net can be constructed by many ways. Some of the way are more available for next operations that others ones. A result of the triangulation is the terrain model described by an available data structure. A member of terrain model construction can be optimization of single plates. Needless edges of triangle net are cut out during the optimization. Then the model is composed quadrangles and more compound polygons.

An effectiveness of the whole programme package for the terrain and landscape digital model is highly influenced on the triangulation algorithm. This algorithm must be enough fast and besides offer a good duality of triangulation.

The last phase of the model creation is treatment singularities. The singularity is a place, where a terrain runs by different way that it is expected from going on around of the singularity. E.g. it can be an edgy ridge or a coast of a lake.

There are different types or the singularities. Sometimes we can apply for some edges a smooth continuity of the terrain itself but no smooth continuity of the plates (derivatives continuity). E.g. ridge. Sometimes terrain itself as a function of two variables (high Z is assigned to position coordinates X and Y) do not have to be continuous. The terrain can include a break (a vertical brow what two plates do not continue smooth on), or even a cornice (a place on what two plates

overlap partly and the terrain does not make a function). Because the types of singularities (break, cornice) affect rather rarely and their programme treatment is very difficult, a lot of programmes for DTM run without a those singularities solving. The break is often realized by a steep plate what is still a graph of a function of two variables. A steep brow appears in a resultant model instead of a vertical brow.

The staffs team of the department of applied informatics at our college deals with DTM more 15 years. A lot of the indicated theoretical problems were resolved and their resolutions were tried in practice, others problems wait for complex resolutions.

Introduction

The modeling is widely used in civil engineering. Buildings are unique, large and very expensive. Therefore they are modeled before their realization. We try to achieve the best attributes of the future object. Often it is impossible to achieve the optimum by classic computing tools. If a space of possible states is too large to search, we try to approach the optimum. We want to find tools for this approach among evolution computing methods.

Terrain model - others models relationships are very important for the best attributes finding. Link terrain model to GIS is very difficult but useful. When we want analyzing geography objects in difficult terrain relief, when we want working with topology and terrain relief together, when we want working with three-dimensional map.

Digital Terrain Model

Digital Terrain Model (DTM) is programme equipment for terrain relief description as 3D model form. DTM is available to provide some operations by this model and to edit this model. There are several types of DTM: grid, polyhedry, plate model, etc.

The grid model is the easiest type of DTM. A terrain relief is described by the array of vertical coordinates of points. The points are located in a regular grid. The polyhedry model is another type of DTM. For the polyhedry model a landscape is parceled out into smaller plane areas (usually triangles or quadrangles) so as to be joined to the nines. The terrain relief is replaced by regular polyhedron with triangle or quadrangle faces. The plate model has the most effective output. A terrain is parceled out into smaller areas. Not only plane ones. They can be anyway curved.

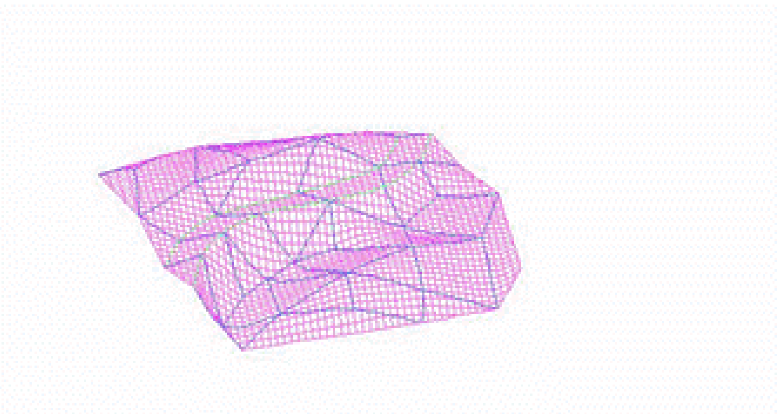

Fig.1: Digital Terrain Model

What all Include the Making of DTM

- Coordinates of points
- Triangular net of edges
- Making of plate DTM
    - Optimization of the net
    - Curvature of approached areas
    - Maintenance of the plate DTM

Making of the Triangular Net

The triangulation (constructing of the triangular net of the edges) is the basic tool to making polyhedry or plate DTM.

The set of points *P1,P2,P3,...,Pn* with their space coordinates [*x, y, z*] are the input data. The triangulation goal is to connect these points by edges and therefore to make a set of triangles adjoining one to other and not crossing one to other. The basic characteristic of the triangular algorithm is their optimization condition, it means which condition is chosen for classificating set of triangles to the terrain. The other characteristic of the algorithms is their time consumption.

One of the often used optimization criteria is the minimization of the lengths of the edges aggregate. Many programs use following algorithms for triangulation (or its analogy). The time consumption of this algorithm is n^2 (*n* is the number of the input points).

Algorithm 1.:
1. By some (random) way make somehow bad triangular net *K*.
2. Repeat steps 3 and 4 while by proceeding of them are any changes in the set *K*.
3. Repeat step 4 for all edges *AB* from the set *K*.
4. Take the edge *AB* and the two adjoining triangles *ABC* and *ADB*. If length of line *CD* is less then the length of line *AB*, put edge *AB* off the set *K* and put edge *CD* instead it to the set *K*.

The second useful condition of the triangular net optimality is called Delenuay condition. The inner of any circle circumscripted to any triangle of the triangulation does not contain any point of the input point set. By using satisfying data structures it is possible to reach linear time consumption of the triangular algorithm which can run as follows:

Algorithm 2.:
1. Take any starting point *A*.
2. Find second point *B*, the closest point to the point *A*, put edge *AB* to the set *K* and put edges *AB* and *BA* to the list of not execute edges *S*.
3. If the list *S* is empty, stop the work. In other case repeat steps from 4 to 6.
4. Take last edge from the list *S* (denote *XY*) and find point *Z* as to the angle *XZY* is maximal.
5. If the point *Z* is not the starting point of any line from the set *K*, put edges *XZ* and *YZ* to the set *K* and edges *XZ* and *ZY* to the list *S*.

6. If the point Z is contained in any line of the set K, it is necessary to determine several situations and put some lines to the set K and list S by the way such list S contains edges on the circuit of the triangulated area.

Plate DTM

One of the problems to make the plate model is curvature of the terrain plates so as to continue one by another smooth.

This problem is missed in a many commercial programmes. Because a visual image is the most important for a practical work. Sometimes approx smooth continuity of the polyhedry plates is enough. Another time smooth continuity of the plates specially polyhedry ones with various numbers of apexes is a large theoretical problem.

The quadratic area is the most used method of the terrain plates curvatures. The area can be written by equation:

$$z = ax^2 + by^2 + cxy + dx + ey + g$$

This area is running for all border points of the plate. The terrain plates continue smooth. First derivation of the terrain is continuous at a border of two plates. These rules give set equations. By that we can express several of the area parameters (*a, b, c, d, e, g*). These expressions may be substituted to the right and left derivations of the altitude along the arbitrary trajectory which goes through across the edge of these edge.

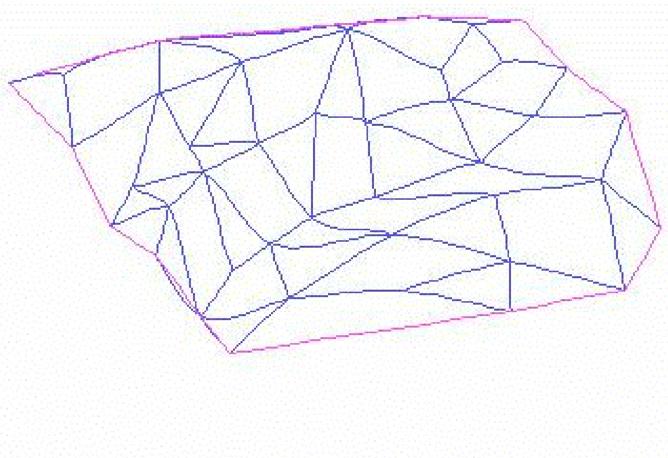

Fig.2:Plate DTM

Problem of the Terrain Plates Curvature

Generally, triangular and quadrangular plates are used. Fluent curvature of these plates problem is difficult. Some time it may be insoluble. It arises the theoretical problem to follow up on these plates at least as much fluent as possible. That means the difference of the right and left derivation of altitude along the arbitrary trajectory at the border of the plate comes to be the nearest to 0.

One of the optimization ways to the best smooth continuing plates is to use evolution computing methods. It is possible to use the Genetic Algorithms for finding the best curvature of approached areas. We can use GA for finding the optimal parameters. We want to use Genetic Algorithms for finding the best model parameters in civil engineering.

Our aims are to develop the GA which will be looking for optimal terrain plates connection.
We will adjust this GA by experiments so that it will work effectively and it will be acquisition for curvature of the terrain plates in the plate digital terrain model solving.

Genetic Algorithm

A genetic algorithm for a particular problem must have the following five components: A genetic representation for potential solutions to the problem. A way to create an initial population of potential solutions. An evaluation function plays the role of the environment, rating solutions in terms of their fitness. Genetic operators that alter the composition of children. Values for various parameters that the genetic algorithm uses (population size, probabilities of applying genetic operators, etc.)

Building of GA for Plate Making

One of the ways the DTM curvature optimization is use of GA. We can use the GA for finding the optimal parameters of the plates. We will generate a lot of the terrain models by this way. We will choose one model from them according to some criteria.

There are several problems of making GA:

To find efficient representation of the models – 3D dimensional array of binary string:

6 parameters of plates
X
number of plates
X
size of binary code for real numbers,

or 2 dimensional array of real numbers?

It is possible to use arrays of numbers with floating point. This way was found more efficient than the array of binary code by executed experiments. To invent applicable crossing operator and mutation operator, and their probabilities. Possibilities are dependent on the way of the models representation.

Set of acceptable solutions constrain. There are constraining conditions: for the continuity plates, and for the curvature DTM - these conditions depend on parameter R setting. We need to find a system to make first solving generation, system of selection and current generation projection to next generations. We need to find stop rule for this GA. Then we are finding expectations of crossing and mutation by experiments, so that next generation will be improving.

To save promising sequences of plates. This problem was solved for Traveling Salesman Problem. Many experiments were executed and many crossing operators were invented. These operators save the promising sequences. We can use and modify these invented operators.

We will choose the best set of models from generated individuals set models along some criteria. We must find this criterion –fitness. It may be minimal from the amount of all of first derivations different at a border of two plates.

We will choose the most fluent model: such plates whose first derivations different at a border of two plates values are the nearest to 0. For the plates of the chosen model it must hold: all of the first derivations different at the borders of the plates must be under parameter R. Parameter R will be determined by experiments.

The algorithm for model finding must be effective, generating DTM must run for reasonable time. It will be necessary to provide a lot of experiments for various types of terrain areas and to set GA and its parameters.

Singularities

The last phase of the model creation is a treatment singularities. Singularities are places where the real terrain is running in other way that can be determined from the surrounding. It is necessary to make some classification of the possible singularities. One of the possible classifications can be following.

All singularities we can consider to be some lines. We call these lines the forced edges and we can classify them by two aspects:

1) The shape of the edge
   1. Line
   2. Curve of the vertical plane
   3. Arbitrary curve
2) Method of connecting the adjoining plates
   1. Smooth adjoining
   2. Sharp adjoining
   3. Break of the terrain

By combination of these classifications we can determine 9 types of the singularities. In fact the type 3,1 of the singularity (arbitrary curve, smooth adjoining) makes no addition the criteria of curving the plates. So there are only 8 types of singularities which must be considered in the curveting algorithms.

Mining from DTM

The main goal of the making DTM is visualization of a terrain and construction on it. For visualization of the terrain model we can use mapping of 3D solids to the plane common algorithms. However, the plate terrain model can be easily transformed into the 3D solid by adding a socle and a bottom pedestal.

Other exploration of DTM includes some simple calculations. For example we can easily deduce the altitude of any point from its x,y coordinates. We can also compute distance between two points in a level and in a 3D space and compute a inclining of a terrain between these two points.

More complicated exploitation of a DTM involves designing of line constructions in a real terrain relief. Also determining of coverage of the signal for cellular telephones or for other sources of radio waves broadcasting can be useful. Cooperation of our department includes cooperation with Romania Telecom on a building of a net of broadcasting stations in the Locvei mountains area in the south west Romania.

Natural phenomena research and forecasting include recording and forecasting of deluges and floods and documentation of soil erosion. Snow avalanche danger forecasting in mountains is described in other section of this paper.

Link DTM to GIS

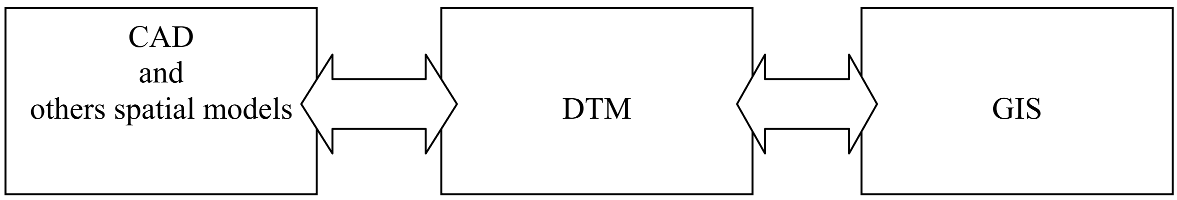

Fig.3:Links – DTM to GIS, DTM to CAD

The digital relief models have gradually become as a part of GIS what are considered as the consequence of rapid development of computer technologies during processing of large sets of various spatially localized data from individual components of geographic sphere. There are many DTM for many purposes but only a few of them comply with required criteria from viewpoint of geographic analysis.

First of this link problems is way of saving topographic objects.

We designed solution for input terrain data format which included information (complete with topology ones) about all input terrain entities (points, edges)

We designed following extension of this data file:

First raw(header):

pvb,pvh,pvp,pt

Meaning of values in the header:

pvb (integer)………number of relevant points in the file
pvh (integer)……… number of relevant edges in the file
pvp (integer)……… number of relevant areas in the file
pt (integer)……… number of relevant solids in the file

Following *pvb* raws:

i*b, x, y,n,z,p,r*

Meaning of values in these rows:

ib (integer)……. Point identifier
x (real)…….x coordinate of the point
y (real)…….y coordinate of the point
n (1 or 0)…. sign of relative z coordinate
z (real)…….z coordinate of the point
p (integer)… 0…when point is vertex of a relevant edge
else number of relevant points group
r (integer)…. only for *p*>0, exactly determines meaning of the points

Following *pvh* rows:

ih, ib1, ib2,u ,p,r

Meaning of values in these rows:

ih,p,r ….similarly as points
ib1,ib2 (integer)……start and end of edge (identifiers of points)
u (1,2,3)…………..geometry type of edges (line, vertical curve, general curve)

Following *pvp* rows:

ip, p,r,ih1,ih2,ih3,ih4

Meaning of values in these rows:
similar as edges and points. ih4 is not obligatory, it depends on shape of areas.

Following *pvt* rows:

$it,pp,ip_1,\ldots ip_{pp},s,t$

Meaning of values in these rows:

pp (integer)……number of areas which make the solution
$it,\ ip_1\ldots ip_{pp},t,s$…similarly as others entities, t and s make reference to tables of relevant solutions (because solids may be very difficult)

There is possible to solute it similarly for output data format.

We created programme for to make editing and geometry and topology operations with so data.

Transformation Terrain Model to DXF Data Format (CAD Data Format)

DXF is universal data format for models which were made in CAD. This format, developed by fa Autodesk, is in fact ASCII file. It includes information about individual graphics elements.

This format is very interesting for CAD and DMT link. This link is important for possibility building model of spatial objects to DTM, for possibility using visualizing tools by DTM, etc. Link between CAD and GIS is needed too. And the way through DTM is logical.

This transformation included following problems:

- Using of curves and surfaces which are not defined in DXF data format. (approximating by polyline => how many segments by?)
- Impossibility topology to save (topology loosing).
- DTM is saved in structure *winged edge*, => difficult reading from difficult table structure

⇨ Terrain in DXF included only list of polylines without topology.

We make programme for this transformation (DTM → DXF).

Interesting Spatial Problems Solution by DTM

Mathematical construction of DTM makes possible to make some complicated mathematical analysis. By the equation of the plates we can determine basic terrain figures and we can conclude natural condition in some areas.

One of the basic characteristic of terrain relief is contour or decline convexity or concavity of the terrain. By mathematical approach we can define these attributes as following:

Part of the terrain is contour concave if following holds for any two points of the terrain on the same contour: the line connecting these two points lies under the terrain relief (fig 4).

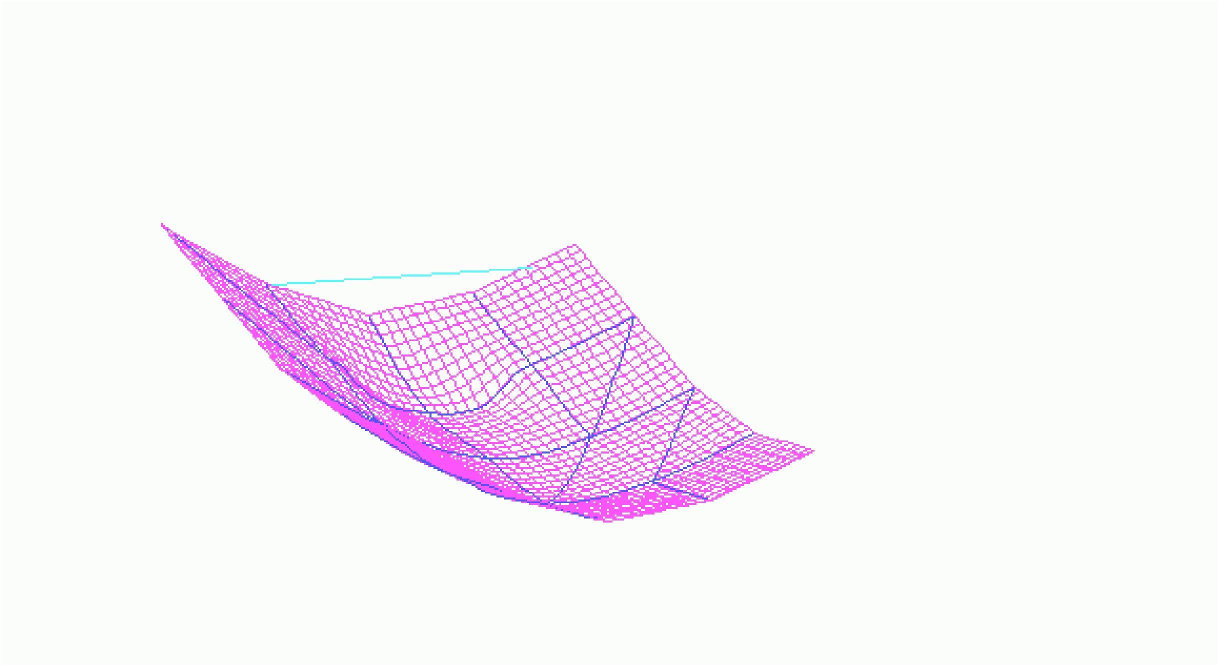

Fig.4: Contour concave terrain

Part of the terrain is contour convex if following holds for any two points of the terrain on the same contour: the line connecting these two points lies above the terrain relief (fig 5).

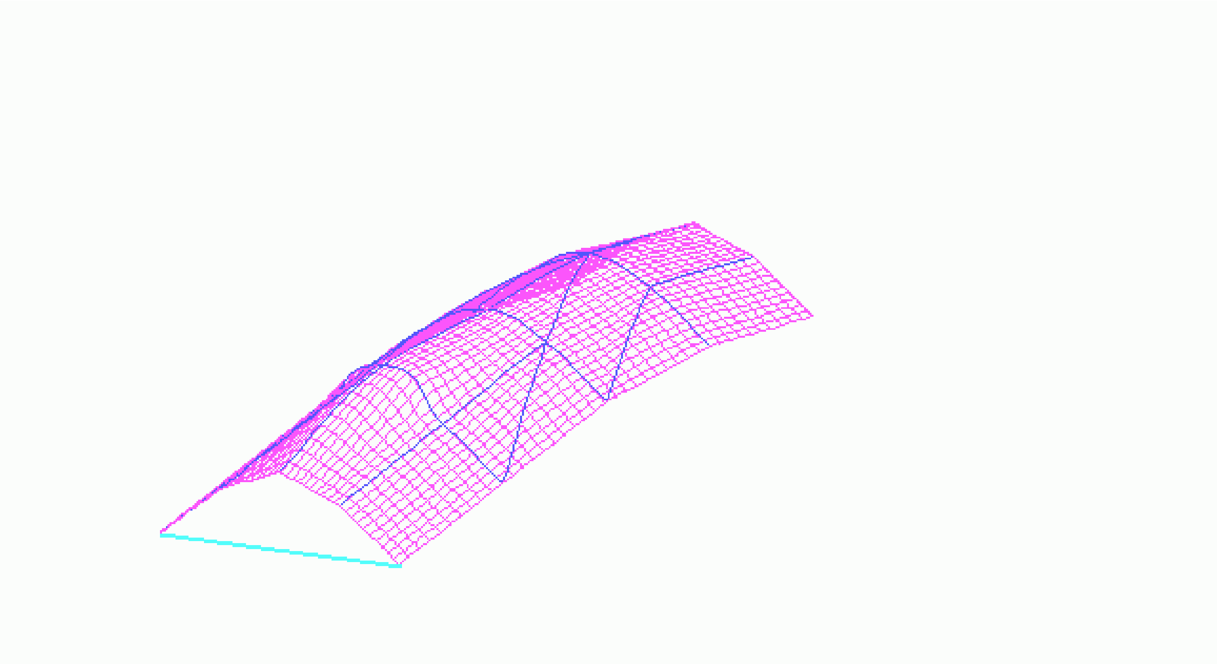

Fig.5: Contour convex terrain

Part of the terrain if decline concave if following holds for any two points of the terrain on the same contour: the line connecting these two points lies under the terrain relief (fig 6).

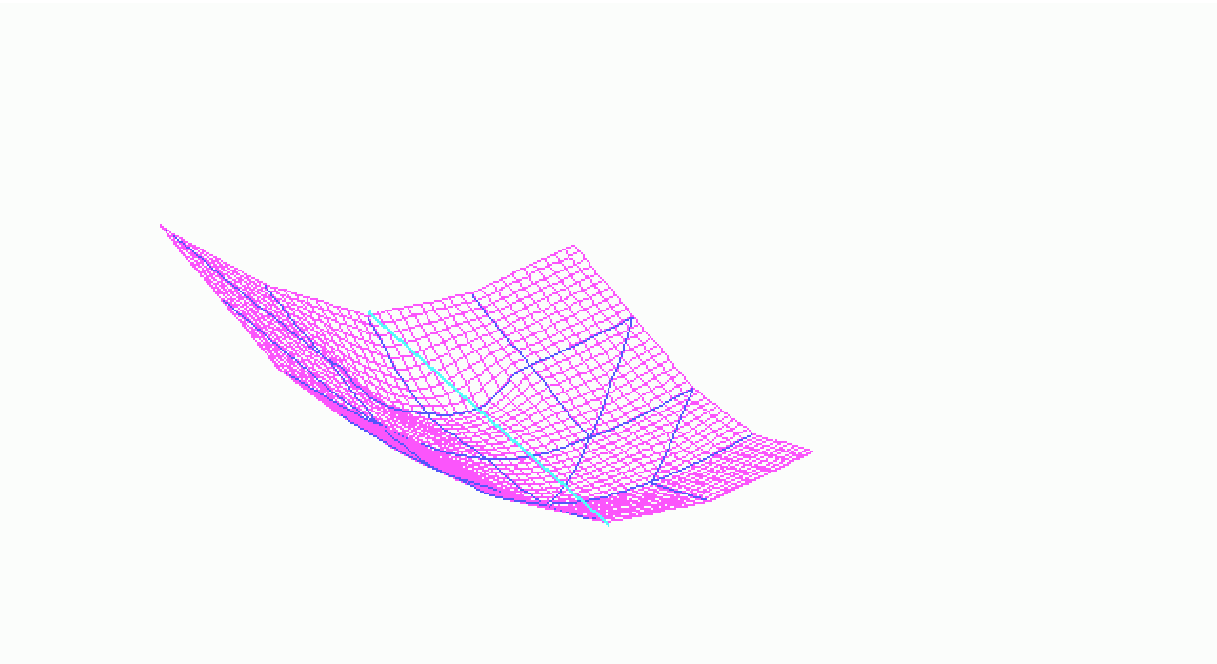

Fig.6: Decline concave terrain

Part of the terrain if decline convex if following holds for any two points of the terrain on the same contour: the line connecting these two points lies above the terrain relief (fig 7).

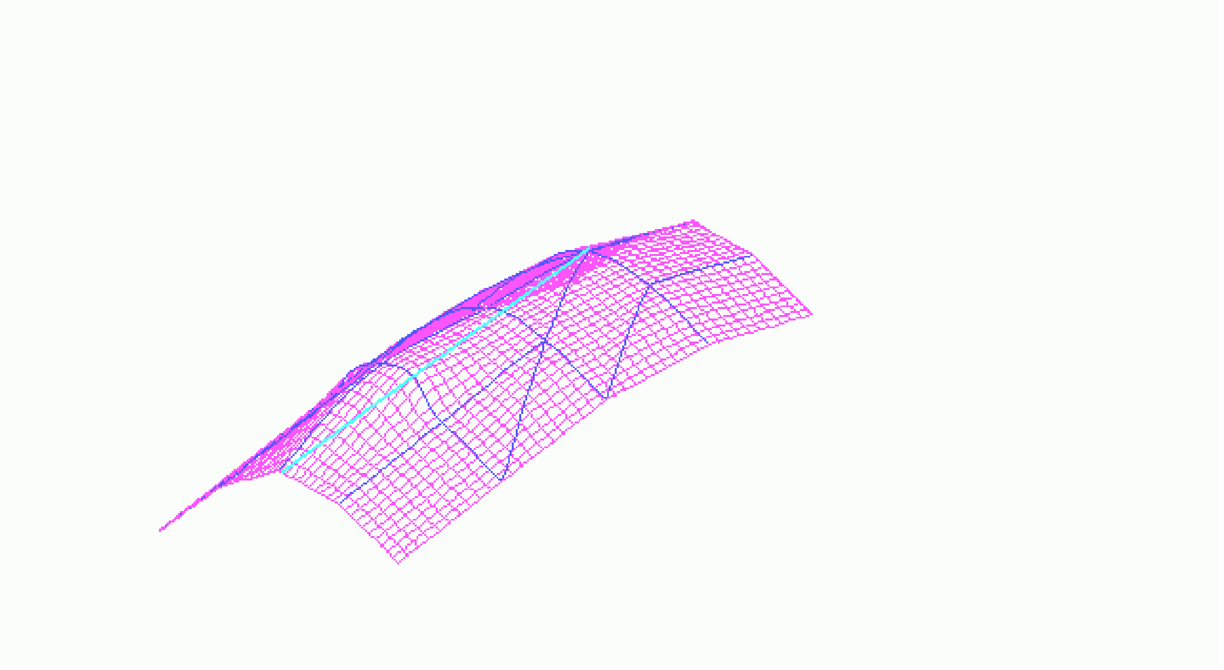

Fig.7: Decline convex terrain

By combination of these criteria we can determine four basic terrain figures: contour and decline concave (fig. 8),

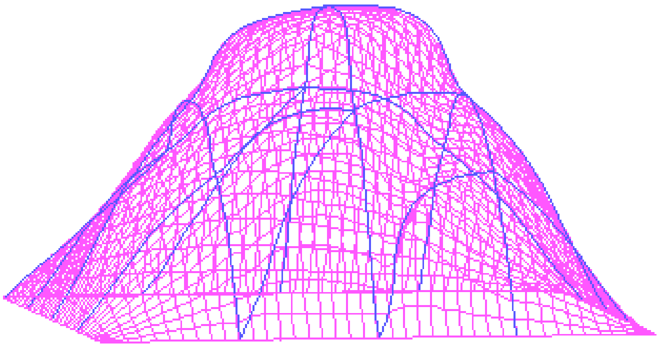

Fig.8: Contour and decline concave terrain figure

contour and decline convex (fig. 9),

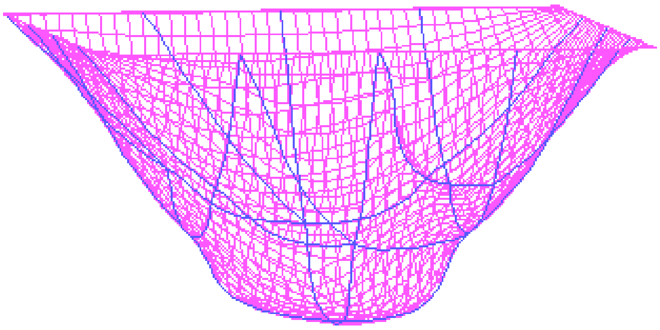

Fig.9: Contour and decline convex terrain figure

contour convex and decline concave (fig. 10),

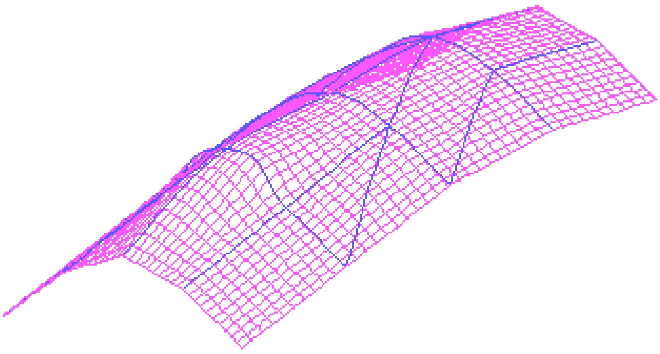

Fig.10: Contour convex and decline concave terrain figure

contour concave and decline convex (fig. 11).

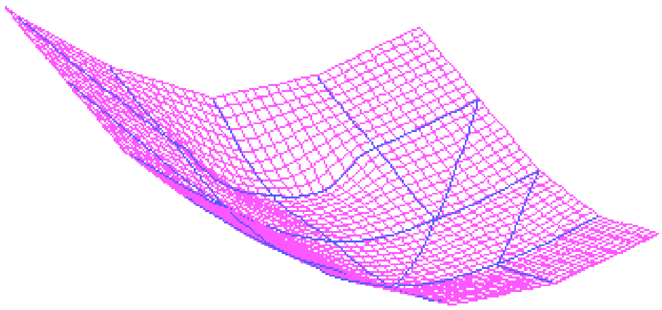

Fig.11: Contour concave and decline convex terrain figure

Avalanche Danger Forecasting

Avalanche danger in the mountains area is higher in the contour concave areas and especially in the contour concave and decline convex areas (fig. 11). We can also measure contour concavity of the terrain as the limite of the substract of z-coordinate and the coordinate of the tangent to the terrain contour in the given point. In the similar way we can define decline concavity of the terrain in the given point. The hypothesis is following: there is the correlation between these two values and the number of snow avalanche in the season.

These hypotheses we used to certify in some areas of the Krkonose mountains by collaboration with the Salvamot service of these mountains. Proof of the correlation is result which can be used for the avalanche larger forecasting in others areas.

Conclusions

DTM is very important and difficult member between spatial models and GIS.
Many of its problems are not perfectly resolving to now.
Some of them are not possible resolute by classical methods.

Our department has been soluting these particular problems many years. Many of them we soluted by some easy way which are different than usually one.

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