ALGORITHMS FOR AUTOMATED BORDER DELIMITATION OF ELEMENTARY FORMS OF GEORELIEF AS A PART OF GEOMORPHOLOGIC INFORMATION SYSTEM

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Abstrakt. Elementární formy georeliéfu tvoří jádro Geomorfologického informačního systému (GmIS). Elementární forma georeliéfu je geometricky spojitá plocha, která má stejnou genezi a předpoklad pro stejný průběh geomorfologických procesů. Elementární forma je ohraničena liniemi nespojitosti, na kterých je tato geometrická, dynamická a genetická spojitost narušena. Klíčová úloha elementárních forem georeliéfu spočívá v tom, že se z vymezených a určených elementárních forem georeliéfu odvozují další typy dat, využívané pro analýzy v GmIS. Vymezování elementárních forem georeliéfu nyní probíhá pomocí tzv. expertního systému, kdy geomorfolog vymezuje hranice jednotlivých elementárních forem a určuje jejich typ podle vrstevnicového podkladu na základě svých zkušeností.

První krok při automatizovaném vymezování elementárních forem georeliéfu spočívá ve kvalitní přípravě vstupních dat. Zde musíme brát v úvahu charakter zpracovávané oblasti stejně tak jako vstupních dat. To ovlivní i volbu interpolačního algoritmu a jeho vlastností.

Dalším důležitým krokem je vymezení jejich hranic. Pro vymezování hranic elementárních forem bylo použito několik algoritmů z oblasti zpracování digitálního obrazu (vyhlazovací operátory, hranové operátory). Tyto algoritmy jsou nyní testovány pro dosažení co nejlepších výsledků.

Další kroky vymezování elementárních forem georeliéfu se budou odvíjet od úspěšnosti vymezování hranic elementárních forem georeliéfu.

Účelem příspěvku je přiblížení problematiky elementarizace georeliéfu a prezentace doposud získaných výsledků z navrhnutých algoritmů pro vymezování hranic elementárních forem georeliéfu. Výsledky dosud aplikovaných algoritmů nejsou plně ideální. Získání lepších výsledků bude záviset na úpravách testovaných algoritmů a kvalitní přípravě vstupních dat.

Klíčová slova: elementární forma georeliéfu, vymezování, hranice elementární formy georeliéfu, GmIS, GIS, interpolace RST.

Abstract. Algorithms for automated border delimitation of elementary forms of georelief as a part of Geomorphologic information system. Elementary forms of georelief are in fact the heart of Geomorphologic information system (GmIS). The elementary form of georelief is a continuous surface, which has the same genesis and the premise for identical process of geomorphologic processes. An elementary form is delimitated by lines of discontinuity, where is the geometrical, dynamical and genesis continuity broken. The main aim of elementary forms of georelief is that from delimitated and determined elementary forms are derived other data types used for analysis in GmIS. Delimitation of elementary forms is nowadays made by so-called expert system, when the geomorphologist delimitates borders of elementary units and determines their type along the contour map, based on his experiences.

The first step of automated delimitation of elementary forms of georelief is based on quality input data preprocessing. Here we have to take into account the character of the processed georelief as well the input data. This influences the right choice of the interpolation algorithm and its attributes.

The next important step is delimitation of the elementary forms borders. For delimitation of those borders were used algorithms from the field of digital image processing (smoothing filters, edge operators). Those algorithms are now being tested to obtain the best results.

The following steps of delimitation of elementary forms of georelief are unwind on the preciseness of delimitated borders of the elementary units of georelief.

The main aim of this article is to show the problematic of georelief elementarization and to show acquired results from tested algorithms for delimitation of borders of elementary forms of georelief. The results of tested algorithms are not ideal. Getting better results will depend on modifications of tested algorithms and on high quality data preprocessing.

Keywords: elementary form of georelief, delimitation, border of elementary form, GmIS, GIS, RST interpolation.

1 Preface

This article deals with possibilities of automated border delimitation of elementary forms of georelief, what should be the first step in automated delimitation of elementary forms of georelief. The whole process of elementarization should make easier the nowadays used methods of geomorphologic mapping.

2 GmIS

Geomorphologic information system (GmIS) is a specific type of information system concerned about collecting, managing and analyzing geomorphologic information. GmIS is an excellent tool for applying geomorphologic analysis. [8]
In our conditions is GmIS being developed in cooperation of Department of mathematics – geomatics section at Faculty of applied sciences and Department of geography, Pedagogical faculty at the University of West Bohemia in Pilsen and Department of physical geography and geoecology, Faculty of natural history at Comenius University in Bratislava, Slovakia.
The concept, database model and possibilities of geomorphologic analysis are described in [8] and [9]. The following text is concerned about one of the most important parts of GmIS – border delimitation of elementary forms of georelief.

Elementary forms of georelief are “the heart” of the whole GmIS. The main aim of delimitated elementary forms of georelief is that from delimitated and assigned forms of georelief are derived other layers used for analysis in GmIS. Delimitation of elementary forms of georelief is nowadays being done by the help of so-called expert system, when a geomorfologist delimitates borders of each elementary form and is selecting type of each form from contour lines, based on his experience and knowledge. The main aim of this work is to make this process partially automatically.

3 Input data

Delimitation of borders of elementary forms of georelief should precede duality data preprocessing. This preprocessing covers selection of quality elevation data, digital elevation model computed from those data and computation of derived surfaces.

3.1 Digital elevation model

As input data is used ZABED, map lists 21-44-03, 21-44-04, 21-42-23, 21-42-24, 21-44-08, 21-44-09 (scale 1:10 000). ZABAGED was chosen because for computing a high quality DEM are needle high quality elevation data. For computation of DEM were chosen 5 meter contour lines. Area covered by map lists listed above is the area of Černé and Čertovo jezero in Šumava. With the help of experts was in this area chosen smaller testing area, which contains characteristics suitable for the georelief elementarization.
For delimitation of elementary forms of georelief was chosen the GRID approach. That means that from the elevation data must be interpolated GRID based elevation model. With GRID approach deals for example [4] and is contained in the most GIS literature.
For GRID interpolation exists many types of interpolation algorithms, for example IDW, krigging, natural neighbor, spline and many more. Testing of preciseness of those interpolation algorithms is concerned for example [3], where is based on statistical test compared the suitability of different interpolation algorithms for different structure and density of input data.
For interpolation was chosen a non-commercial GIS GRASS v.6.1. which offers (including others interpolation algorithms) RST interpolation (RST = Regularized Spline with Tension). Testing of different interpolation algorithms is GIS GRASS is concerned for example [13]. The result of [13] is that RST interpolation is the most suitable for this area.
The theory for RST computation is described for example in [2] and [12]. Theory for computation of digital elevation model is for example in [1] and [13].
The *tension* parameter sets the toughness of interpolated surface for thin steel plate to a rubber membrane. For noisy data is possible to use the *smooth* parameter. With *smooth* set to zero is the interpolated surface passing exactly through the input data.
The parameters for interpolation were chosen as is for this area described in [13]. *Smooth* parameter was set to 0.8 and *tension* to 15.
The application of algorithms for delimitation of borders of elementary forms of georelief has shown, that the density of input data is to high. This high density of input data is caused by the fact, that the GRASS RST interpolation module *v.surf.rst* uses every breakpoint on the contour line. This led to data preprocessing when should be kept the maximal data position preciseness while containing less input points.
This is called the “trend method”, when during the interpolation are removed little geomorphologic formations, but global trend of surface is kept. [13]
For creation of such *trend surface* was used the following method:

- DEM was created using *v.surf.rst* with parameters *tension* = 40 and *smooth* = 0. Such DEM would pass exactly through input data, but it contains interpolation artifacts.
- Along with [1] was from this DEM chosen 3% of random points. The amount of points used for interpolation could be set by RST parameter *dmin*, but this leads to use only the points laying on contour lines. Selecting random points from the whole DEM will ensure, that the *trend surface* will be created from points randomly distributed over the whole DEM. The new DEM was interpolated with interpolation parameters *tension* = 20 and *smooth* = 0.8. While we have chosen the *smooth* parameter larger then 0, the interpolated surface won't pass through input points. This is called the *smoothed DEM*. Random points were generated in *Matlab*[2].

Usage of smoothed DEM for computation of morphometrical characteristics of higher orders does not have to lead to less accurate predictions of morphometrical characteristics. In other words – there is no straight proof that vertical more accurate surfaces generates more precise morphometrical characteristics of higher orders. On the other hand, there is a hypothesis that morphometrical characteristics derived from "smooth" surfaces can represent the actual situation in better way than parameters derived from vertical precise, but "bumpy" surfaces. [1]

3.2 Derived surfaces

We will delimitate borders of elementary forms in layers derived from DEM. Those derived layers are morphometrical characteristics of the first order (gradient of the scalar field of heights, slope of the topographical surface γ_N, orientation A_N), morphometrical characteristics of the second order (normal curvature $(K_N)_n$, tangential curvature K_r, curvature of flow lines in projection plane - *rotor*, normal change of gradient a_g) and derived surfaces of higher orders. Description of attributes and induction of morphometrical characteristics is described in [5], [1] and [14].

Those derived morphometrical characteristic surfaces are the fundamental layers of GmIS.

In paper [14] was shown derivation of equations for computing morphometrical characteristic of different orders with the help of symbolic computations and as well computation of derived morphometrical characteristic surfaces by using numerical computations of different computational complexity (see [11]) and with the help of pre-programmed modules in GIS GRASS.

In accordance to numerical preciseness of derived surfaces of the third and higher order are nowadays unusable. Little mistakes during interpolation of input DEM causes little (still handlebar) inaccuracies in curvature surfaces (derived surfaces of second order). These inaccuracies cause during the computation of derived surfaces of higher orders that the inaccuracy of derived surface is of much higher order. This makes such surface unusable for automatic delimitation of elementary forms of georelief.

For testing the algorithms for border delimitation may be used surfaces generated by algorithms implemented in GIS GRASS, because they describe the character of the terrain in a better way. This is caused by the fact, that the computation of derived surfaces of the first and the second order is being made together with the RST interpolation and partial derivatives needed for the computation of derived surfaces are computed directly from the spline functions. This is the difference from numerical computation, where are values of partial derivatives computed from relatively small neighborhood of discrete surface.

[2] Matlab was used, because module r.random did not produced random points as desired.

4 Elementary forms of georelief and their borders

Elementary form of georelief is on the set scale geometrically homogenous surface, which has the same genesis and assumption for the same course of geomorphologic processes, which is delimitated by lines where is this geometrical, genetical and dynamical homogeneity broken. It is than on the set scale naturally delimitated basic segment of georelief. [9]
In accordance to [10] we can define three axioms, which build the theoretical background for georelief elementarization:

- Form of georelief may be considered to be geometrically continuous surface – geometrical field of heights.
- In the set scale, it is possible to find discontinuities on the Earth surface – these may be considered to be the natural borders of geomorphologic objects.
- These discontinuities and further characteristics of the Earth surface are the result of geomorphologic processes, which depend on or are influenced by gravitation.

Specific structural elements of the field secure the natural basement for its segmentation. Those elements may be called *singular lines* and *points*. Into set of such elements belong for example *extreme points* (peaks, depress points, ridges), *inflex points* and *discontinuities* of the field of heights and other derived fields. [6]
Minár and Evans in [10] have defined the elementary set of ideal elementary forms of georelief (geometrical forms), where each of the forms is described by *fitted function* (see [15]).
Such geometrical forms have ideal inner geometrical continuity.
But we actually won't find such ideal elementary forms on the Earth surface. By recognition of types of elementary forms is being statistically tested the affinity of delimitated elementary forms to the basic set of geometrical forms.

5 Delimitation of elementary forms borders

As mentioned above, elementary forms of georelief are the main part of GmIS. To make possible the determination of single elementary forms, the forms has to be somehow delimitated. There are two ways how to delimitate them:

1. Delimitate borders of elementary forms by finding the lines of discontinuity and then determining the type of the elementary form.
2. Find a point that belongs to the elementary form and then delimitate the form by the method of growing area.

The ideal way to delimitate elementary forms of georelief is to combine both of the above described approaches. In the first step we detect lines of discontinuity – by this we get fragments of borders of elementary forms. On these fragments we can apply the second approach – where would be defined the middle point of the elementary form. Then could be applied the method of growing area to define missing parts of borders of elementary forms.
The following text is dedicated to the first part of georelief elementarization. So it would be necessary to find lines of discontinuity in surfaces derived from DEM.
The correctness of delimitated borders is needle to be made by visual control. Despite of the fact, that the control of delimitated borders in $(K_N)_n$ surface is very difficult and requires huge experience, it was decided, after consultation with expert-geomorfologist, to test algorithms only on surface of heights (DEM) and only in one case on surface of $(K_N)_n$.
Borders delimitated on DEM would then be ridge and valley lines. Despite of this was on testing area chosen even smaller area, where were the borders delimitated by expert-geomorfologist in such a way the algorithm should in an ideal case.

During searching for lines of discontinuity we in fact search for local extremes (minimum and maximum).
The algorithms were applied in *Matlab*. The resulting data were further processed in GRASS v.6.1 and ArcGIS 9.2.

5.1 Searching for local maximum from close neighborhood

First and the most simple method how to find local maxims is to compare the values in some *n*-neighborhood. We consider the output grid as a matrix of dimension $[m,n]$. The algorithm goes through the matrix in the rows and the actual cell $a_{i,j}$ will determine to be a local maximum, if $a_{i,j} > a_{i,j} \wedge a_{i,j} > a_{i,j}+1$. The same algorithm is than applied to columns with the condition $a_{i,j} > a_{i-1,j} \wedge a_{i,j} > a_{i+1,j}$.
The above described algorithm searches in the input data only for ridges. The valley lines[3] would be delimitated identically, only with the use of opposite sings in the above described conditions.
On figure 1 are visible ridge and valley lines delimited by this algorithm. By visual control we can note, that the algorithm found the ridge and valley lines similar to the ones delimitated by an expert-geomorfologist. It would be needle to implement an algorithm to compute the affinity of delimitated lines to those expertly-delimited.

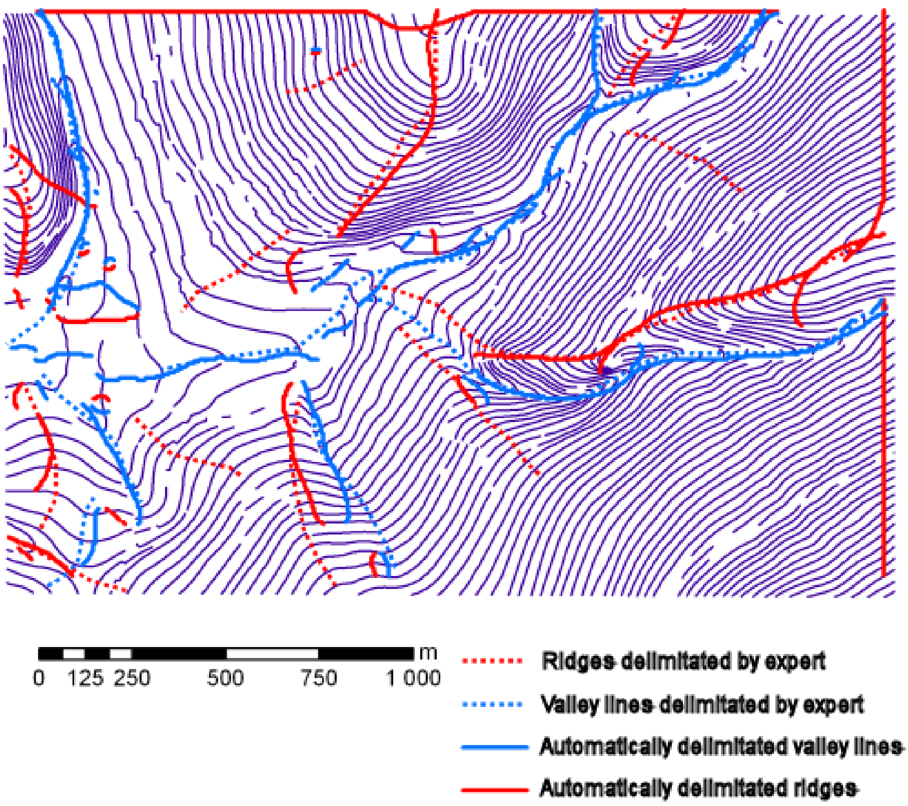

Figure 1 Lines delimitated by searching for local maximum from close neighborhood

5.2 Searching for local maximum by floating mask

The next applied algorithm is searching for local maximum with the help of floating mask.

[3] In the curvature surfaces local maxima and minima.

To make the description of the algorithm easier, is the whole process shown at figure 2.
The process is following:

1. The algorithm goes through input data in rows (despite of the size of the mask, it starts on the second row of the matrix) and it searches for the local maxima with the use of the same principle as in the previous algorithm. See part 1 of figure 2.
2. After it founds local maximum in the row (value 6 on figure 2), is on the 5-cell neighborhood applied the mask and local maximum from this 5-cell mask is searched (value 5 – part 2 of figure 2).
3. The same process goes all over until the algorithm reaches the stop-conditions described in the source code.
4. Then the algorithm goes back to the cell were in the point 1 found the first local maximum and goes on again.

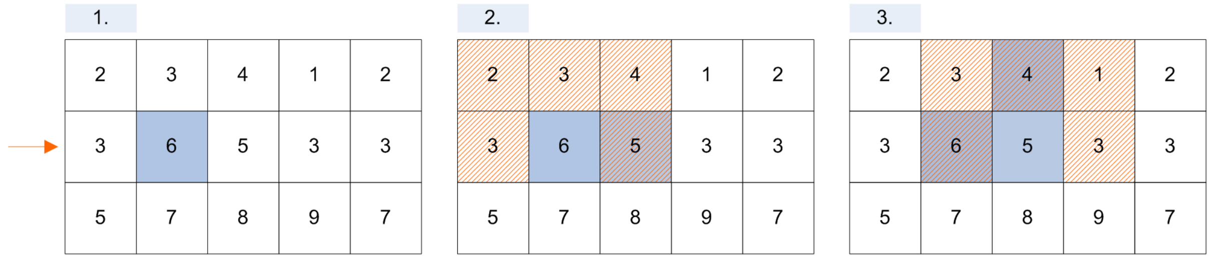

Figure 2 The process of floating mask algorithm

Despite of the character of input data was this algorithm tested only on curvature surface $(K_N)_n$. The result are areas, in which would be needle to further search for maxims (borders) – see figure 3.
To search for local maxims only with higher importance, was set the threshold to $(K_N)_n = 0.01$. This value is equal to a circle with the radius of normal curvature $(R_N)_t = 100$ m. The algorithm searches for negative maxims as well.

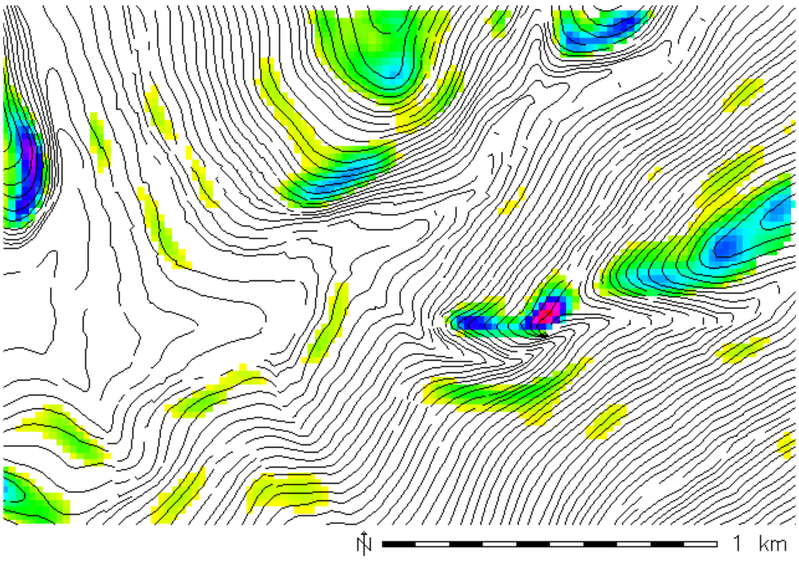

Figure 3 Areas delimitated by floating mask algorithm

5.3 Searching for local maximum with edge detectors

Very promising way for delimitating borders of elementary forms of georelief is the usage of edge detectors[4].
In the first step is on the input data applied Canny edge detector. This detector searches for edges corresponding to inflex points in the input data.
In the next step are in-between these infelx points searched local maxims and minims. During this computation, it is easy to compute the importance of the edge[5].

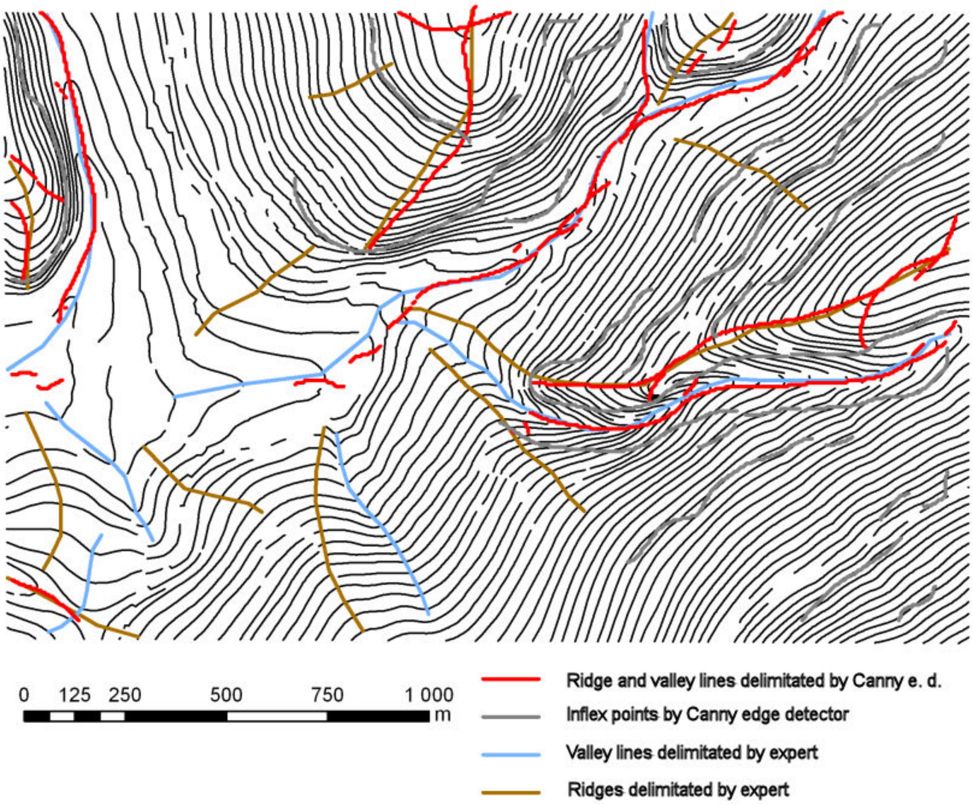

Figure 4 Lines delimitated by Canny edge detector

On figure 4 is the result of above described algorithm. Inflex points are marked with grey color (delimitated by the Canny edge detector) and with red and blue color ridge and valley lines delimitated along with [14].
After visual control we may say, that automatically delimitated ridge and valley lines correspond with expert-delimitated lines only in few areas.
This may be caused by creations of the trend surface, where the Canny edge detector was unable to detect inflex points on too smooth surface. Next problem may be to strictly set thresholds for the Canny edge detector algorithm.
This approach promises good results, but further testing is required.

[4] The edge detector searches for such cells in the image where is a sudden change in the brightness (in our case change of elevation or curvature). Such cells match the searched border.
[5] See more in [10], [14].

6 Conclusion

By the DEM creation would be necessary to test, which is the suitable amount of randomly generated points as input data for interpolation in the selected locality. Closely connected to this problem is testing the proper values of parameters for the RST interpolation.
An other possibility is to use input data from satellite laser-scanning LIDAR. Such type of data are much more precise then data from ZABAGED.
From the results of this work it is clearly visible, that there should be found a method, how to compute the curvature surfaces with accordant quality. This means to use better computation process for computation of directional partial derivatives.
The results of each algorithm are visually compared with expert-delimitated borders. It should be helpful to develop statistical evaluation of delimitated borders.
With the delimitation algorithms should be done the following: test different threshold values while searching for local extremes, apply different sizes of floating masks and at the Canny edge detector test different threshold values for edge detection.
At the delimitated borders make a selection based on the edge robustness (more in [10] and [14]).

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