MOUNTAINS' PEAKS DETERMINATION SUPPORTED WITH SHAPES ANALYSIS

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ABSTRACT:
Peaks determination is commonly applied subjectively and manually by mountaineers. The key issue of the paper is to develop the automated methods for points of regional peaks detection applying spatial analysis on digital terrain model (DTM). Detection of the peaks bases on measurements of relative heights and distances between the peaks with support of potential surfaces fulfilling topographic and morphologic criteria. The quality of the results has been proved in the following ways: visually, with the reference lists of peaks, and triangulated spot heights on the topographic maps. The advantage of the proposed automated approaches is higher comparability, objectivity and reliability of the results. A consistent result may be attained using a DTM of high geomorphological quality and robust methods. The proposed methods can be used for more reliable and graphically better cartographic presentations. The study was applied for the Kamnik Alps, Slovenia.

Keywords: *peaks/summits, DTM, morphometry, morphology.*

1. INTRODUCTION

The aim of this study is to discuss the detection of the points of peaks and their shapes. The results are intended to generate automatically by spatial analysis on a relatively high quality digital terrain model (DTM) and by utilising reference data sets for a quality control. The paper is intending to show strength, reliability and robustness of the automated methods in relation to selected standardised definitions of peaks that have been used in analogue way until now.

Researchers and mountaineers have been trying to standardize the mountain peaks descriptively at least for last fifty years. Determination and definition of the peaks base exclusively on tradition, experience and visual appreciations – on a subjective perception of peaks' natural appearances. Mapping of the peaks and mountains is generally performed manually through the fieldwork and visual interpretation of topographic maps, aerial photographs and satellite images. Professional alpinists have perhaps the best knowledge about the peaks and other characteristics of the mountains from different regions all around the world. They consider some topographic, morphologic and so called mountaineering criteria. While the mountaineering criteria are the most subjective, the topographic and morphologic criteria have a certain potential for processing by automated algorithms.

Three types of peaks are defined and introduced *(Podobnikar, 2009)*: local, regional and global. Regional and partly global peaks determination and analysis is focus of this study. Their determination is linked with a term mountain that is described furthermore. The local peak definition is basically related to algorithms for local extremes detection that

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are included in commercial geographical information systems (GIS). This is the most elementary numerical (computer-based) approach for detection of the peaks from DTM as local relief features. The local peaks comprise every raising ground and are related with roughness of the relief depending on the DTM resolution, which may be assessed in a fractal sense. Regional peaks are more complex objects involved in common definitions of peaks that are found in basic dictionaries, described by International Mountaineering and Climbing Federation, or defined by people who live at the mountains. This term comprises and is defined by a broader range of topographical, morphological and other (mountaineering) properties in a regional scale. An example for numerical implementation is the algorithm for extracting of different number peaks based on morphological smoothing method *(Sathyamoorthy 2007).* Global peaks or summits are just a few most prominent peaks in a certain mountain area, e.g. in entire Kamnik Alps. Such locations were a high interest of man several hundreds or thousands years ago. A number of studies have been trying to find these prominent locations using numerical algorithms. Their typical aim is to study specific cultural responses that influence to human behaviour, including beliefs, taboos, rituals, etc. The prominent locations (peaks) are explored by analysing their properties according to wider surroundings with exposure index, cumulative viewsheds, defining locations' hierarchy, etc. *(Llobera 2001; Christopherson 2003; Podobnikar and Oštir 2008).* Some characteristics of the local, regional and global peaks are basically depended on a scale/resolution of the DTMs.

As the algorithms for global peaks detection use considerably larger surrounding than the regional, their definition is related to the definition of the mountains. Extraction techniques of the mountains had been considerably evaluated – from manual in the past, through computer assisted, to various automated methods during the last decades. Most of the developed automated techniques are concentrated to detection or classification of the whole mountains or ranges. The examples are the studies of *Graff and Usery (1993)* (feature matching), *Miliaresis and Argialas (2002)* (component-labelling algorithm applied on the mountain terrain class), *Székely (2003)* (local histograms analysis), or *Sathyamoorthy (2006)* (mathematical morphological based algorithm).

2. PEAKS DEFINITION

2.1. Definition the terms "peak" and "mountain"

We are going to discuss the definitions of the term peak (in connotation with regional one) and introduce its relation to the whole mountain. The conception of "peak" (summit) as a topographical and morphological extreme in geographical space has several other meanings in a semantic sense. Just the most significant peaks can be seen from long distances, while in the immediate neighbourhood the peaks on the smaller rising ground are visible as well. Namely, the peaks look differently if seen from various distances, directions, and in different time or season. Furthermore, the peaks need to be defined on different way all around the world. For instance the characteristics of Alps, Carpathians, Himalaya or Pannonian Plain are immediately distinctive. These facts are depended on the physical and environmental properties like elevations above sea level, geological properties, shapes of peaks, illuminations, weather conditions, vegetation, and also on a particular perception of individual person. These findings may lead to various perceptions and consequently to different identifications, conceptions and classifications by the observer. In order to provide a proper description of the peaks, the certain surrounding with their properties has to be taken into consideration.

With common conception, the peak is defined as any point of the surface that is elevated by a certain difference in height with respect to the surroundings. The peak must be autonomous in sense of possessing individuality, interest and other characteristics. As the peaks might be considered as well the features that satisfy the less objective criterion “well defined morphology”. The main criteria are therefore already referred topographic, morphologic and mountaineering *(UIAA 1994, 2008).*

Definitions of the peaks refer to topographically related hills or mountains as their parts. Thus the conception of the mountain is introduced to support this term. The main parts of the mountains are the summits/peaks (the highest point or the highest ridge) and the mountainside (the part of a mountain between the peak and the foot) *(Sathyamoorthy 2006)*. This conception is more complicated and subjective than for the peak and involves aesthetical, ecological, chronological, and other factors. The mountain as an object comprises the following parameters: size, perimeter length, maximum elevation, mean slope, local relief, relative massiveness (according to erosion stage) shape, roughness, etc. *(Miliaresis and Argialas, 2002).*

3. APPLICABILITY OF THE UIAA DIRECTIVE

The frame for technical description of the regional peak conception as the core of this study is the directive of the International Mountaineering and Climbing Federation *(UIAA 1994, 2008)*. The rules are formulated for the peaks higher than 4000 m in the Alps according to the following three groups of criteria: topographic, morphologic, mountaineering (alpinistic).

Topographic criterion defines the level of height difference between each peak and the highest adjacent pass or notch should be at least 30 m (calculated as an average of the peaks at the limit of acceptability). An additional criterion can be the horizontal distance between a peak and the base of another adjacent peak *(UIAA, 1994).* Suggested application of this rule is by geometric analysis on DTM: the main criterion is defining by relative height (dH) of the potential peak that should be split by the adjacent peaks with a certain gap (it should be basically for 30 m lower than the peak). An additional criterion is defined as minimum horizontal distance (dL) between the peaks. These values can define the dominance of the potential peak. The bigger the mentioned measures are, more extensive and significant the peak is.

The morphologic criterion takes into account the overall morphology and aspect of the peak applied especially for shoulders, secondary peaks, rock outcrops, etc. *(UIAA, 1994).* Suggested application focuses to various techniques of spatial analysis on different sizes of the immediate neighbourhood (determination of mountain area) of the peaks. The shape of the upper part of the mountain is therefore considered, which is much depended on geological characteristics. It is not space in this paper to describe this part of the study. Anyhow, the results of automatic procedure outline sharp, blunt, oblong, circular and conical shapes of the peaks.

The following mountaineering criterion takes into account the importance of the peak from the point of view of the mountaineers: qualities of the routes reaching the peak, historical significance, frequency of climbed, etc. *(UIAA, 1994)*. This criterion is the weakest and difficult for standardisation and numerical application. It considers inspection of terrain as subjective perception of humans. That may be changed during the evolution of alpinism. The mountaineering criteria are not intending to apply; they are used just for interpretation of the results.

3.1. Peaks determination by topographic criteria

The methods for detecting the points of (regional) peaks and analysing surroundings to determine their shapes are developed. The proposed solution procedure applies the basic criteria in this field according to *UIAA (1994).* Topographic and some morphologic criteria are implemented to numerical algorithm, while some mountaineering criteria are used for their interpretation. The morphologic criteria are extended to peaks' shape analysis. All analysis uses a DTM in the Kamnik Alps study area.

3.2. Method and results

The following four-step procedure for fulfilling of basic topographic and morphologic criterion for determination of the regional peaks is proposed *(Podobnikar 2009):* (1) calculation of local peaks as a local maximum in elevation, (2) selection of peaks that are morphologically not on flat areas (peaks on plains are denoted as Gp), (3) further selection considering a minimum horizontal distance (dL) between peaks, and (4) further selection considering a relative height (dH) of peaks.

In each step of the procedure only the peaks are proceeded which satisfied all conditions in previous steps. The eventual result is graphically presented in **Fig. 1**. The four steps are in a higher detail described below.

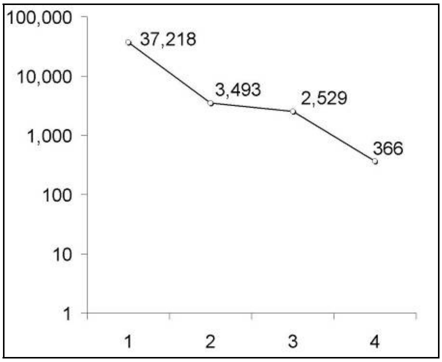

Fig. 1 Number of points of peaks for a study area of Kamnik Alps: from step 1 to step 4

(1) Through the first step, the local peaks are calculated applying 3 × 3 local moving window (kernel), dedicated to raster-based spatial data analysis *(e.g. Takahashi et al. 1995).* This step bases on topographic criteria.

(2) All of the local peaks on the flat areas (Gp) are eliminated setting criteria NOT Gp. The removed local peaks are part of insignificantly convex areas. The classification to Gp is part of regionalisation process to plains, low hills, hills, and mountains. This process applied a combination of slope, curvature and elevation of terrain *(Podobnikar 2005).* With an additional threshold the peaks lower than at a certain absolute elevation (e.g. < 600 m) can be eliminated. This step bases on morphologic criteria in order to significantly optimise the procedure.

(3) The minimum horizontal distance dL is applied. Only those peaks are kept which are the highest within the circle of radius dL. The adjacent peaks are therefore arbitrary removed with dL > [150 m, 200 m]. This step bases on the topographic criteria.

(4) The analysis of the relative height of the peaks (dH) serves as basic topographic criterion. The algorithm determinates the areas around individual peaks that are by up to the

dH lower than the corresponding peaks. Then the entire area is examined and the other peaks are counted, which were found in the third step. If there is no peak found, the examined peak was adopted. Starting with the highest peak, the procedure is being repeated until the lowest peak has been processed. The peaks eliminated in the previous iterations of this procedure were not examined anymore. The removal condition is set to dH > [25 m, 30 m].

The four-step procedure runs twice by applying two slightly different parameters in steps 3 and 4. In the first run the parameters are set to dL = 200 m and dH = 30 m, and in the second to dL = 150 m and dH = 25 m. These two calculations yield slightly different but complementary results. Acquiring of the regional peaks within the four-step procedure is presented in the **Fig. 2**.

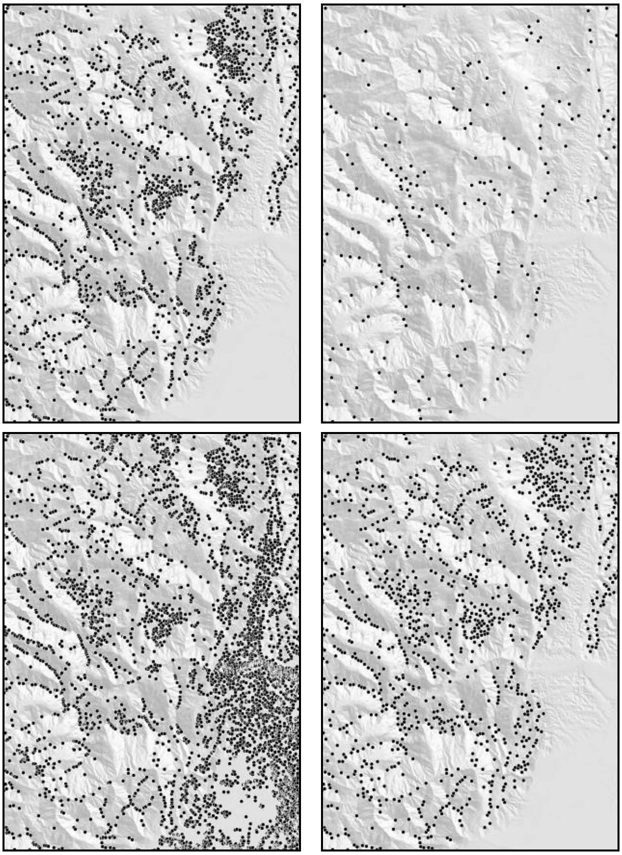

Fig. 2 Identification of the regional peaks (black dots) according to four-step procedure considering topographic and morphologic criteria in the area of Kamnik Alps (30 km × 20 km)

3.3. Discussion

The interpretation of quality of the numerically determined peaks takes into account the reference lists of the peaks. The peaks above 2000 m are documented in the Slovenian Alps, in the whole Alps the peaks above 4000 m, and in the Himalaya the peaks higher then

8000 m. Number of peaks in Slovenia above 2000 m ranges between 179 and 349 according to different lists *(SD 2001; Kern and Cuderman 2001).* There are 128 peaks higher than 4000 m in the whole Alps, but only 82 when considered stricter criterions *(UIAA 1994, 2008).* The number of peaks in Himalaya above 8000 m ranges between 14 and 21 *(Peakware 2002–2010)*. Manual process to define peaks was applied for all of the described data sets since the solutions with numerical methods were generally problematic.

The results of the proposed automated four-step procedure (**Fig. 1** and **2***)* are determined peaks, starting with local (37,218), via immediate (3493, 2529), to regional (366). 42 (of 346) regional peaks higher than 2000 m were automatically selected (List 0). Two lists (List 1, List 2) of peaks above 2000 m were compared with our results (List 0) for the Kamnik Alps case study area. The List 1 includes 41 *(SD 2001)* and the List 2 comprises 48 peaks *(Kern and Cuderman, 2001).* The comparison ascertains that 11 peaks (approx. 1/4) of List 1 do not exist in the List 0. Similarly, 12 peaks from List 1 are not presented in List 2. Considering the variability between the lists is possible to assess comparable accuracies of the automated approach (List 0) and the manual achievements (Lists 1 and 2). In the **Fig. 3** is presented the List 1 and the differences to List 0 are assigned.

Grintovec	2558	Storžič	2132
Jezerska Kočna	2540	Debeli špic	2128
Skuta	2532	Velika Baba	2127
Na Križu (Kokrska Kočna)	***2484***	***Veliki kup***	***2126***
Kokrska Kočna	2475	Velika Zelenica	2114
Dolgi hrbet	2473	Veliki vrh	2110
Štruca	2457	Ledinski vrh	2108
Kranjska Rinka	2453	Kogel	2100
Mali Grintovec	***2447***	Mrzli vrh	2094
Koroška Rinka (Križ)	2433	Krofička	2083
Planjava	2394	Velika Raduha	2062
Planjava – vzhodni vrh	2392	***Krnička gora***	***2061***
Ojstrica	2350	***Velika Kalška gora***	***2058***
Štajerska Rinka	***2289***	Ute	2029
Mala Rinka	***2289***	Mala Raduha	2029
Brana	2252	Poljske device	2028
Turska gora	2251	Lučki Dedec	2023
Lučka Brana (Baba)	2244	***Mala Kalška gora***	***2019***
Kalški Greben	2224	***Mala Baba***	***2018***
Mrzla gora	2203	***Mala Ojstrica***	***2017***
Kljuka	***2137***		

Fig. 3 List 1 of 41 peaks above 2000 m form Kamnik Alps (SD 2001). Peaks (described with names and heights [m]) written with bold italic letters were not automatically detected within the four-step procedure (they are not in List 0).

Vectorised topographic map in scale 1:25,000 *(DTK 25)* was used for another quality control the results of automatic peak detection *(Podobnikar 2005; GURS 2005).* Triangulated spot heights of DTK 25 are commonly on the highest peaks and are the highest precision. Most heights of DTM 12.5 are usually a few meters lower than the spot heights (both in the same positions). The reason lies in generalisation of the DTM where the values of the grid are just partially biased to the summits. Quite different heights concerning DTM and spot heights were ob-served just at few peaks.

Quality of the determined peaks' positions is limited with the resolution of DTM 12.5 in the most cases. However, several peaks are dislocated by up to few 100 m. A problem of the described gross errors of heights and positions of the peaks was not investigated in a detail. The errors might have sources in both, DTM 12.5 or DTK 25.

An interesting cartographical aspect is to study the peaks determination in extreme situations. An example in the **Fig. 4** presents identification of the peaks in the Alps based on *Josephine military topography* (scale 1:28,800) from the end of 18th century and modern contour lines in similar scale (1:25,000). Overlaid visualisation shows very imprecise mapping with deviations of horizontal precision of few 100 m and even totally wrong mapping in the past. Study of many alternative datasets in GIS can improve judgment in the morphologically enhanced cartography.

Fig.4 Some peaks evident on the Josephine military topography can not be identified on modern maps (shown with contour lines). One of the reasons is that at ancient times some peaks were even not climbed yet.

4. CONCLUSIONS

The study demonstrates strength of the automated numerical (quantitative) methods to solve a relatively complex task: determination of the (regional) peaks of the mountains with analysing and describing their shapes. The previous studies based on less objective manual approaches. Their applicability to numerical processing was studied. The peak detection was based on topographic, morphologic and mountaineering criteria of the *International Mountaineering and Climbing Federation (UIAA, 1994)*. The peaks' shape analysis was based on morphologic criteria that were proposed and applied in this study.

All of the methods were developed within GIS environment and tested with morphologically high quality DTM in the study area of the Kamnik Alps, Slovenia. The algorithm for peaks detection (four-step procedure) based on topographic and morphologic criteria, i.e. on measurements of relative heights and distances between the peaks with support of potential surfaces. High quality of the proposed algorithms was proved with comparison between official lists of the peaks over 2000 m (man-based, less objective) and our results. Variability amongst the official lists is similar to difference between the official lists and our result.

The results demonstrate ability for numerical application and improvement of the standards for the peaks determination. They also show capability for analysing the complex shapes and show ability for more complex terrain analysis (i.e. determination of pits or whole mountains where the peaks are just their parts). The shapes' analysis enables an improved determination of the peaks as well. Advantages of the automated approaches are the standardised parameters, and more objective comparative results yielding a higher overall quality. However, the automated methods will never 100% satisfy the requirements that come from the complexity of the nature. Some details will have to be discovered and solved by a human being. This problem is similar to generalization in automatic cartography.

Very important output of this study is better understanding of the studied geomorphology and data sources that would be used for more reliable and also better cartographical presentation of the geomorphological features. The lateral applicable outputs are numerous enhancements of: process of DTM production and quality control; cartographic presentation of the terrain; knowledge of morphology, geology, tectonics; educational process; landscape architecture studies; prominence analysis; ethnophysiographical studies, etc.

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