OBJECT-BASED LANDFORM MAPPING AT MULTIPLE SCALES FROM DIGITAL ELEVATION MODELS (DEMS) AND AERIAL PHOTOGRAPHS

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ABSTRACT:

The interest in and need for digital landform mapping is permanently growing, but still lacks fully developed transferable object-based classification approaches. In this study a shared object-based mapping workflow is applied to two different input data sets: aerial photographs and DEMs. We aim to end up with promoting insights leading to a data-independent, so to say transferable, multi-resolution segmentation followed by an object-based classification approach of landforms on different scales. In order to identify a well-suited scale level for data segmentation the Estimation of Scale Parameter (ESP) tool was used. In the next step we developed knowledge-based classification approaches using (border/edge) contrast information for classifying gullies from aerial photographs as well as contextual and terrain layer information as derived from DEMs for mapping drumlins. We found that spectral data (e.g. aerial photographs) as well as terrain data (e.g. DEMs) may be successfully processed. The workflow is furthermore transferable onto reference data sets. Existing differences in contrast/shadowing which occur within aerial photographs from different points in time constitute disadvantages in successful landform mapping which are insignificant when terrain data is used. Knowledge-based identification of landform diagnostic object features improves landform mapping with respect to the input data type and transferability of the classification system. Data integration may enrich the object-based analysis of landforms and will finally advance our understanding of formative processes.

1. INTRODUCTION

The interest in and the need for digital landform mapping at multiple scales has been constantly increasing within the last years. Landforms represent support units for many applications, since they may be directly linked with processes occurring in natural environments and vice versa. A common denominator of many studies which cannot all be referenced herein (for a detailed review see MacMillan and Shary, 2009) is that researchers aim for generic, i.e. not process-specific, landform classifications. Another group routed in geomorphology is progressively developing a sub-discipline of geomorphometry (Pike et al., 2009) and uses geomorphometrical analysis of Digital Elevation Models (DEMs), which can be used for automated object-based classification of geomorphological features (Anders et al., 2011, Drăguţ, and Blaschke, 2006). We may amply refer to a landform as a relatively homogeneous assemblage of cells in a scene that exhibits similar morphometric/spectral characteristics. This assumption makes OBIA a highly attractive approach to landform modelling, overcoming problems of cell-based classifications such as the highly scattered nature of output maps due to the non-consideration of space (Drăguţ and Eisank 2011).

Although more and more data sets such as DEMs, as well as aerial photographs and satellite data at ever higher resolutions are readily available, the main challenge in object-based landform mapping remains yet unsolved: transferring and optimizing the object-like perception of human recognition into segmentation algorithms and subsequently into classification rules. It was also pointed out by Blaschke (2010) that we would have to include the epistemological and ontological aspects of objects. Overall these points mentioned above may be regarded as the key for achieving a higher interoperability in digital landform mapping.

In this study we present our recent experiences and achievements in the integration of knowledge in the object-based modelling of landforms, namely gullies from aerial photographs and drumlins from DEMs. Using two different types of input data, the proposed workflow can be comparatively tested. We concentrate on relatively narrow applications of GEOBIA methods and landform delineation. It will be shown that as soon as more than one scale is involved all kinds of geometric and semantic problems arise. We especially elaborate on the usability of the two input data types, i.e. DEMs and aerial photographs, for the segmentation and classification of specific landforms in OBIA.

2. METHODOLOGY

2.1 Optimizing multi-resolution segmentation

Multi-resolution segmentation (MRS) is used for decomposing the input scenes (e.g. terrain layers, aerial photographs) into areas (partially) containing targeted landforms. Due to variation in size, not all landforms of interest, i.e. drumlins, as well as gullies, are delineated as single objects when relying on only one segmentation scale. Therefore, multiple segmentations are produced for a specific scene. With the support of the ESP-tool (Estimation of Scale Parameter, Drăguţ et al., 2010) the statistically significant segmentation levels are detected. Those identified optimal scales are visually checked and compared with landform boundaries obtained from field mapping.

2.2 Multi-scale classification of landforms

The chosen workflow was developed for a comparison of two different types of input data for landform classification. Therefore the process structure needs to be similar for processing both of the chosen input data types. In Fig. 1 the entire workflow is illustrated and comprehensible. A detailed description of the processing of each landform type is given in the following paragraphs.

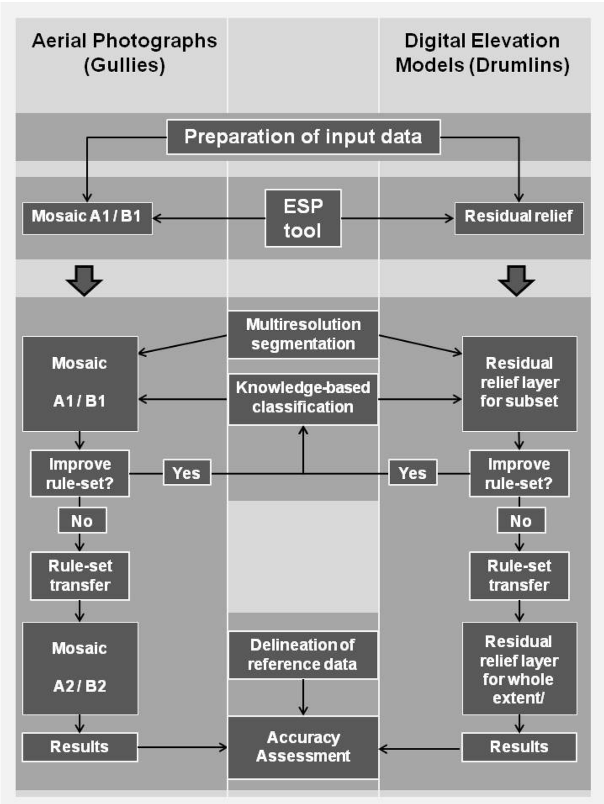

Fig. 1: Overall workflow of data processing

2.2.1 Drumlins

A subset of the 'Eberfinger Drumlinfield' was selected as the study area for the object-based mapping of drumlins based on a DEM. The site is located in the German province of Bavaria and covers an area of about 60 km² with a mean elevation of 640 m.a.s.l. The field consists of 360 drumlins that have been formed during the last glaciation by an interaction of glacial erosion and accumulation processes (Petermüller-Strobl and Heuberger, 1985). The individual drumlins significantly deviate in form and shape and some drumlins merge or overlap with others, which poses challenges for their automated extraction from DEMs.

As found by Smith et al. (2006) DEMs are the most promising data source for the mapping of drumlins. The ideal spatial resolution was reported to be 10 m or higher (Napieralski and Nalepa, 2010). For our study we used a 5 m DEM derived from laser point clouds.

A range of terrain layers such as slope and curvatures were calculated from the original DEM. Based on a literature study the optimal terrain layers for segmentation were identified. We performed segmentation on a normalized relative elevation layer that was produced by a method known as 'residual relief separation' (Hillier and Smith, 2008). This layer was created by applying multiple filter operations in order to increase the local contrast in elevation, which is especially important for emphasizing drumlin topography (for details see Hillier and Smith, 2008). The values range from 0 to 1 whereby high values indicate regions of high relative differences, which may be associated with drumlins. The ESP indicated four optimal scale parameters for the multi-resolution segmentation of the relative relief layer.

Qualitative statements as used in definitions of the term 'drumlin' (e.g. Menzies, 2004) were translated into classification rules. For example, drumlins were described as multi-convex features with an elliptic and elongated 2D shape. In OBIA these properties can be expressed by positive curvatures of objects respectively high object values of elliptic fit and elongation. The class rules were applied to each of the generated scale levels resulting in four classifications. The final output map was compiled by merging those individual classifications.

2.2.2 Gullies

The delineation of gullies is challenging due to the heterogeneous appearing morphologic characteristics of gullies (Poesen et al., 2003). The chosen gully spots represent ephemeral gullies (mosaic A1, A2), as well as a bank gully (mosaic B1, B2). The image data was acquired during field campaigns in the Souss Basin, Morocco in autumn 2010 and 2011. A description of the study area is given by d'Oleire-Oltmanns et al. (2011). Aerotriangulation using bundle block adjustment of these annually acquired very high resolution aerial photographs delivers image block bonds which are used for precise DEM extraction, as well as for creating image mosaics (Marzolff et al., 2009). The development of the classification rule-set took place on two image mosaics A1, B1 and was transferred to two more image mosaics A2, B2. The mosaics A2, B2 were set as reference data.

In a first step the two image mosaics (A1, B1) from 2010 were trimmed to a rectangular extent and analysed using the ESP tool in order to help find a well-suited scale parameter for the multi-resolution segmentation within the eCognition Developer© software from Trimble (see 2.1). In this approach the largest scale parameter used aims at following the principles of a top-down approach. For the multi-resolution segmentation a scale factor of 140 was chosen, shape was set to 0.1 and compactness to 0.5. Setting the value of shape to 0.1 weights the influence of colour lowest possible.

For the knowledge-based classification a rule-set was developed using features which are unlinked from the location of the input data since the rule-set shall remain transferable. The main features used in the first classification step were *border contrast* and *edge contrast of neighbour pixels*. A customized ratio was built from these two pixel-based features in order to isolate the values of gully rill borders from the surrounding areas. The squared *edge contrast of neighbour pixels* value was added to the square root value of *border contrast*.

$$\sqrt{border\ contrast} + (edge\ contrast\ of\ neighbour\ pixels)^2$$

This increased pixel values for gully rills while simultaneously reducing the pixel values for the surrounding areas with less contrast. In subsequent steps aspects of polygon shape and geometry were used. In addition, aspects of neighbouring polygons which were already classified in the first step and/or fulfilled specific conditions (e.g. edge contrast values, compactness) were incorporated.

2.3 Accuracy assessment

For the presented landform mapping projects an accuracy assessment was performed at this stage using qualitative methods. The delineation of gullies is still an open issue since the borders are not precisely definable at a given point in time and additionally dynamics due to ongoing erosive processes occur. The classification of gullies was compared with a manually digitized poly-line network. This allows the comparison of the overall structure of polygons resulting from the classification process with the abstract composition of the existing gully rill network.
As yet, the extracted drumlins were only visually assessed by overlaying them on optimized DEM visualisations such as analytical hillshade and slope maps.

3. RESULTS

The two landform mapping efforts are still ongoing. Application of the ESP-tool is helpful in detecting meaningful segmentation scales of a specific scene. However, the ideal case where landforms correspond to single segments is sometimes hard to achieve, especially in cases where landform boundaries are not really present in the data.

3.1 Drumlins

Fig. 2 illustrates the selected subset of the 5 m DEM and the therefrom computed residual relief layer. The layer clearly emphasizes local drumlin relief, as can be seen by the prevailing linear texture. The normalisation ensures that differences in the relative relief of the observed drumlins are equalized. Drumlin covered areas may be associated with brighter tones indicating high local differences in elevation, while drumlin limits are likely to be located at transitions from bright to dark colour.
Multi-resolution segmentation of residual relief generates objects that are homogeneous in normalized relative relief. By segmenting the layer at the four optimal scale parameters, as identified by the ESP-tool, we were able to delineate similar-sized elevated features, which might represent drumlins, as individual objects. The delimitation of drumlins as one object is a prerequisite for applying classification rules that relate to the reported shape of drumlins. Based on qualitative knowledge terms we decided to incorporate the two shape features elliptic fit and length/width in our classification system. In addition, a contextual feature ensuring that the drumlin object is higher than its neighbours, as well as a positive curvature constraint were specified.
These classification rules were applied to each of the four object levels without modifications. At each scale different drumlins - depending on their size - were extracted. The final output as illustrated in Fig. 3 shows all of the identified drumlins.

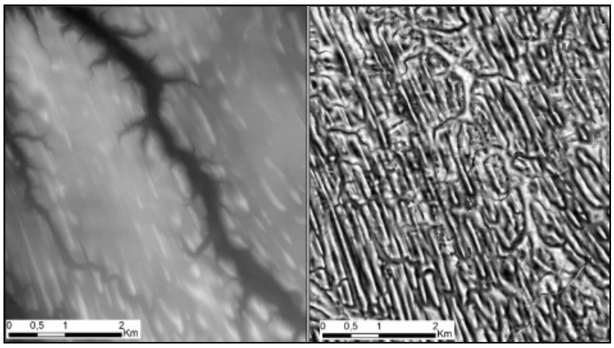

Fig. 2: DEM 5 m (left) and the normalized relative elevation layer (right) derived from the application of the 'residual relief separation' (Hillier and Smith, 2008) operation (right)

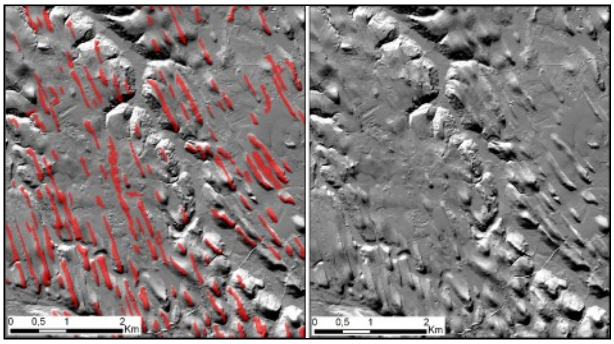

Fig. 3: Classification of drumlins for the subset (left) and the analytical hillshade model for visual comparison (right)

3.2 Gullies

Identifying gully characteristics using annually acquired aerial photographs supports the analysis of independent morphologic characteristics since differences in contrast and shadowing may already be taken into account.
In Fig. 4 the values derived from the customized ratio (see section 2.2.2) are illustrated. The left image shows values for the year 2010, the right image for the year 2011.

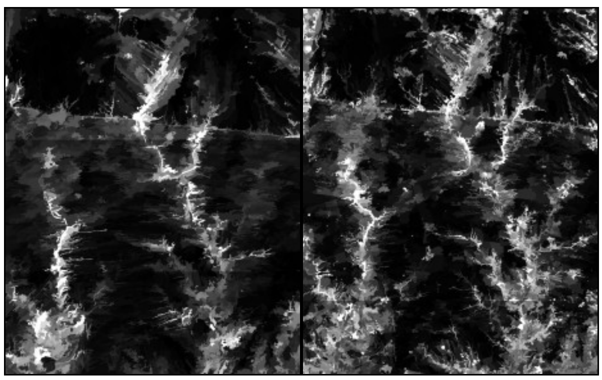
Fig. 4: Ratio values for 2010 (left) and 2011 (right)

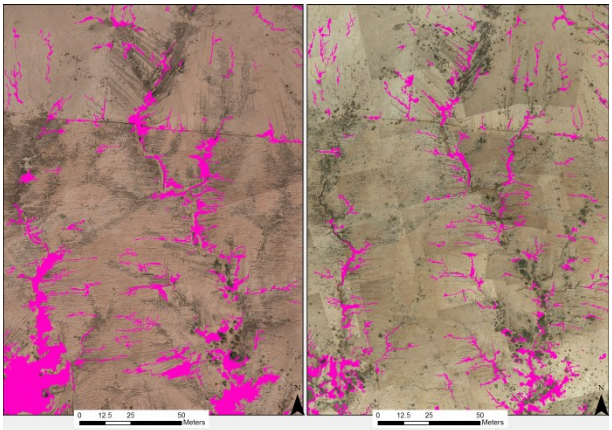

Fig. 5: Classification results for gullies in 2010 (left) and 2011 (right)

Results of the gully classification for image mosaic A1/A2 (see Fig. 1) are illustrated in Fig. 5. The left image contains results for the year 2010, the right image for the year 2011.

The focus is set on two aspects which have a major influence on the segmentation and therefore on classification results: Contrast/shadowing on the one hand and landform borders on the other. On the image mosaic from 2010 sun was a bit off-nadir position during data acquisition. Therefore clear shadowing appears in the image mosaic and differences in contrast may be well used for classification: as illustrated in Fig. 4 (left) there is a clear gully structure identifiable. On the image mosaic from 2011 there is no direct lighting due to closed cloud cover during data acquisition. As opposed to the image mosaic from 2010 neither clear shadowing nor large differences in contrast exist, delivering a much more fuzzy result for ratio values as illustrated in Fig. 5 (right). Subsequently this led to a less accurate classification result. A detailed explanation is given in the following discussion.

4. DISCUSSION

As stated earlier, a main goal in landform classification using OBIA is to transfer and optimize the object-like perception of human recognition into segmentation algorithms and subsequently into classification rules. In a particular manner this would mean to assign single segments to landform borders in the closest possible way within the segmentation process. Using optical data incorporates features, which have varying values in different images, such as lighting situation and subject to larger or smaller differences in contrasts. In a relatively homogeneous environment, as it was the case with many of the gullies, this may lead to a relatively low heterogeneity concerning image contrast values.

For a similar spatial resolution the overall contrast in DEMs and terrain layers is generally lower than the local differences in optical images, which makes OBIA on DEMs more challenging. For instance, despite the knowledge-based selection of an optimal segmentation layer, i.e. the residual relief, the results of the drumlin delimitation demonstrate the difficulty in detecting the exact limits of drumlins. Visual interpretation of slope and hillshade maps suggests that the classified drumlin objects are only partially consistent with the real extent of drumlins. In general, the detected drumlins were smaller than the observed drumlins. Especially, lower lying parts of drumlins belong to more than one object, and additional rules have to be created in order to address these problems in the classification process.

The major advantage of using DEMs, however, is that the problem with contrast/shadowing can be avoided when DEMs and DEM-derived products are used. Since the acquisition of DEMs is unaffected by external factors such as the sun angle, daytime and weather conditions, they present more comparable, thus standardized data sets (at least for similar spatial resolutions). Consequently, if a classification system has been successfully tested on terrain layers at a specific resolution, it may be applied to areas, where terrain data with similar resolution is available. Thus, time-consuming modifications of the rule set, as it may be required when optical images are used, are avoided.

Analysing object properties on different scale levels allows the area-wide identification of landforms including different extents, shapes and geomorphologic characteristics. Identifying gully characteristics using annually acquired aerial photographs supports the analysis of independent morphologic characteristics since differences in contrast and shadowing may already be taken into account.

The aspect of landscape dynamics is not yet much taken into account. Due to permanently occurring erosive processes the development of a gully - in terms of a particular landform - is constantly transforming the landform's morphology. Hence, segmentation and classification features would ideally be independent and therefore static concerning the delineation of gullies towards other objects, and simultaneously be adaptable and therefore 'dynamic' regarding a possible adaption on erosion-based landform transformation. In contrast to gullies, drumlins are a more stable type of landforms. They are mainly subject to long-lasting erosion processes, and thus the diagnostic characteristics for their automated mapping do not change over short time periods.

Automated delimitation of specific landforms remains challenging. Still, the target scales – following the nomenclature of Burnett and Blaschke (2003) – are relatively clear: Within the OBIA segmentation and classification the objects of interest are given. Although the landscape can be regarded as being complex the geomorphological feature types of interest – the gullies and drumlins - may be addressed by a particular set of segmentation parameters, at least for the same data type. Object-based analysis of DEMs potentially allows for the production of results that are invariant, and accurate in resembling the geomorphologists' views of landforms. Clear operational definitions that mainly include absolute statements are required in order to increase the quality of landform delineation and classification, as claimed by Evans (2012). A definition of semantic models has been proposed in order to make landform knowledge explicit, thus supporting the selection of landform diagnostic object features in OBIA (Eisank et al., 2011). Adopting such an approach is still a matter of our ongoing research. However, the vagueness of some landform terms is problematic and hinders their exact specification. To cope with the spatial uncertainty of landform limits, the conflation of a series of fuzzy classifications has recently been proposed (Evans, 2012). Thus, it would be possible to define a central and a peripheral area of each landform.

5. CONCLUSION

We evaluated object-based landform mapping of gullies and drumlins by integrating a statistical approach for landform delineation at multiple scales with knowledge-based classification. We showed that this approach can be applied with moderate success on both DEMs and aerial photographs. The presented work clearly illustrates the need for further improvement and development of classification approaches for object-based mapping of landforms at multiple scales. The presented results are well-suited examples of landform mapping and its potential of linking landforms with processes. Researchers increasingly aim to automate processing steps and workflows for the analysis of large datasets and some of them additionally aim to limit the expert input which is required in such a process. Explicit formalization of geomorphological knowledge prior to classification is a prerequisite for effective and transparent landform mapping (Mark and Smith, 2004). With respect to the optimization of MRS segmentation, we could demonstrate that a purely statistical approach is supportive, but has its limits. Only recently, a knowledge-based segmentation optimization strategy has been proposed as an alternative (Anders et al., 2011).

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