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In the coastal line of Zonguldak cut-and-fill areas were determined and these areas were extracted successfully using object based image analysis on the basis of the reference image.

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COMBINATION OF AIRBORNE LASER SCANNING AND OTHER NON-DESTRUCTIVE TECHNIQUES FOR ARCHAEOLOGICAL PROSPECTION

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ABSTRACT

During years 2010–2013 the Czech Office for Surveying, Mapping and Cadastre in cooperation with Ministry of Defense and the Ministry of Agriculture of the Czech Republic had acquired a unique dataset based on airborne laser scanning (ALS). This dataset covers the whole area of the Czech Republic and can be nowadays used in archaeology to describe complex areas and to suitably complement earlier findings.
This article describes visualization and image processing methods that can be applied on digital terrain models (DTMs) to highlight objects hidden in the landscape. Besides that, other methods for verification of object found in DTM such as aerial photogrammetry, traditional surveying methods etc. are described. The use of these methods is tested in several case studies. Three sites were chosen to represent various objects which can be under archaeological interest. The first is area around the Třebel Castle – a battlefield from the Thirty Years' War, the second is a part of old route called "Devil's Furrow" near the town of Sázava and the last is a medieval mining area near the town of Jáchymov.
Thanks to the analysis of visualized DTM it is possible to understand the landscape evolution including the differentiation between natural processes and human interventions. In case study areas, various visualization methods were applied.
The article depicts possibilities, limitations and specifics of documentation of diverse archaeological areas using airborne laser scanning.

Keywords: ALS; shaded relief; digital terrain model; non-destructive techniques; archaeology

INTRODUCTION

After WWII there was a significant change in the paradigm of the archaeological community. The higher interest in ecological, ethical, demographical and other issues demanded complex understanding of large sites instead of focusing on detailed excavations. From this point of view, non-destructive approaches were suitable, since they are easily applicable to large areas and, in comparison to traditional archaeological techniques, cause minimal or no damage to the investigated archaeological source.
Aerial photography was, during most of the 20th century, an invaluable tool for archaeological prospection; however, the application of this tool is limited to deforested

areas. The increasing use of airborne laser scanning data for heritage landscape assessment [1] is connected to a rapidly growing availability of these datasets during the past decade. The greatest advantage of the ALS technique compared to aerial photography lies in its potential to discover objects hidden in forested areas via laser beams, which are able to penetrate even a dense vegetation.
The DTM (digital terrain model) based on ALS visualized in appropriate way to highlight topographic variations serves archaeologists as an invaluable source of information. The ways of DTM visualization are described in detail in following paragraphs.

DATASET

In our project, we used data acquired by the Czech Office for Surveying, Mapping and Cadastre. Between years 2010 and 2013, the entire area of the Czech Republic was mapped by ALS (full-waveform scanner RIEGL LMS 680 was used). This dataset is being used to obtain a highly accurate digital terrain model for the purposes of administration, for example in the detection of flooded areas, orthorectification of aerial images etc. Different parameters of mapping were used depending on the season – during spring an average flying height of approximately 1400 m above ground level and a flight lines distance of about 830 m, during the vegetation season an average flying height of approximately 1200 m above ground level and a flight lines distance of about 715 m. A typical product of this mapping is a DTM in form of a regular grid or a point cloud. The data for project was acquired in form of Digital Terrain Model of the Czech Republic of the 5th generation (DMR 5G), which represents the image of natural or artificial terrain in digital form as heights of discrete points in a triangulated irregular network (TIN) with total mean error of the height 0.18 m in open terrain and 0.3 m in a forested terrain [2].
The density of the point cloud representing DTM (for many areas, lower than 1 point per square metre) is not sufficient for every application. Nevertheless, it has been successfully used in archaeological projects before [3], [4].

SITES

Třebel battlefield

A pair of engravings of the battle of Třebel is part of a detailed report on the Swedish campaigns in Bohemia at the end of the Thirty Years' War in 1647. The report was published in an extensive journalistic work Theatrum Europaeum, issued since 1633 by the Frankfurt engraver and publisher Matthäus Merian (1593-1650).
The first engraving "Engraving of the state to 19th August 1647" depicts an area of approx. 11.5 to 7 km, in an oblique view from north-west to south-east. The engraving displays a polygonal cut of landscape roughly between today Planá and Černošín. The plot impresses a faithfully rendered looking at the terrain surrounding the castle Třebel along with neighbouring settlements.
An analysis of the first engraving was based on confrontation of the engraving with field archaeological survey and written and cartographic sources along with application of methods of geomatics and cartography. The DTM enabled identification of control points suitable for georeferencing of the engraving and served also for visibility analysis [5].

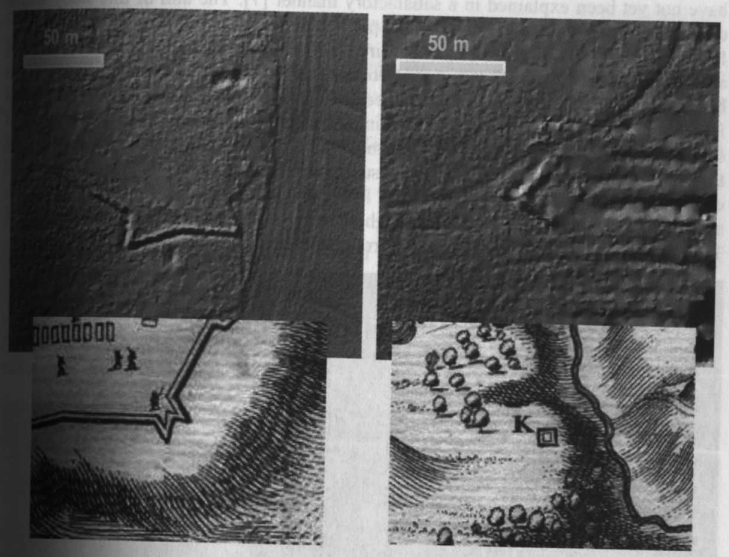

Figure 1. Comparison of identified terrain objects and their rendition in the engraving.

From the ALS data, a triangular irregular mesh has been computed which served as source for further computations. The most widely DTM visualization method – a shaded relief (also called hill-shading) – was used. The shaded relief simulates the cast shadow thrown upon the represented surface; it produces an appearance of three-dimensional space and can visualize even small height variations and terrain discontinuities typical for man-made objects. The illumination direction was chosen from the north-west according to common standards, but to prevent disappearing of objects parallel to this direction, the complementary illumination from north-east was combined to achieve a reliable view on all terrain forms and contours. The formations found using DTM were verified by a field survey.

Devil's Furrow

Northwest from the town Kouřim, in the landscape between the villages Lipany and Chotouň, there are relics of an unusual linear formation to be found. From time to time, this formation has been related to the fabulous Devil's Furrow (Čertova brázda in Czech), which has been under historical and archaeological prospection for the last few decades. According to a medieval legend described in a number of sources since 16th century, St. Prokop furrowed the formation from the village town Sázava to the village Chotouň (or oppositely – depending on the source) by the devil [6]. The formation has, during centuries, almost disappeared, but the traces of it are still visible in the landscape. In spite of many efforts towards an interpretation of the formation, its original form and purpose

have not yet been explained in a satisfactory manner [7]. The aim of this study was to distinguish between natural and artificial parts of the formation.
In this case, visualization techniques inspired by methods applied by Doneus a Briese [8] and Bofinger and Hesse [9] were used. Doneus and Briese used a simple difference map between the DTM and its low pass or median filtered derivative, contrary to Bofinger a Hesse who created the smoothed DTM in two steps to get more reliable elevations of small features over terrain. In our case, smoothed DTM was created and subtracted from the original DTM. This DTM was then visualized in the form of a grayscale height image characterised by the spatial resolution of 1 metre. Afterwards, the image histogram was stretched (the values 0/256 were set to higher/lower values than the extreme values were). This procedure highlighted even small terrain variances (Fig. 2 a), b)).

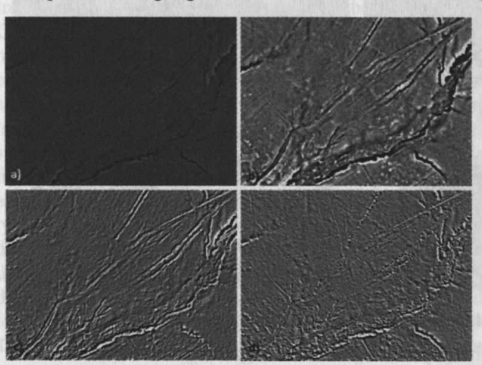

Figure 2. a) Difference DTM (original), b) Difference DTM (stretched histogram), c) Direction filter – 40° (applied on b)), d) Direction filter – 130° (applied on b))

Figure 3. Difference DTM

Finally, a low pass filter with 3×3 kernel size was applied to the difference DTM to slightly reduce the noise. Besides that, a directional filter (first-derivative edge enhancement filter) was applied to the image. The filter was tested on a group of parallel tracks – it leads in highlighting objects of known orientation, if similar orientation is used for filtering (Fig. 2 c).
Next example – Fig. 3 – displays how the difference DTM highlighted a gap in rampart (in the middle of the field).

Jáchymov

Jáchymov is one of the most frequently used ore district in the Czech part of the Ore Mountains. Mining history of this region started in 16th century by silver fever and, over the centuries, deposits of different ores were found in this region – apart from silver, also bismuth, nickel, cobalt and uranium.
From shaded relief (Fig. 4) it is clear where the mining pits surrounded by excavated material are. Some of them lie in-line and show where the lodes go.

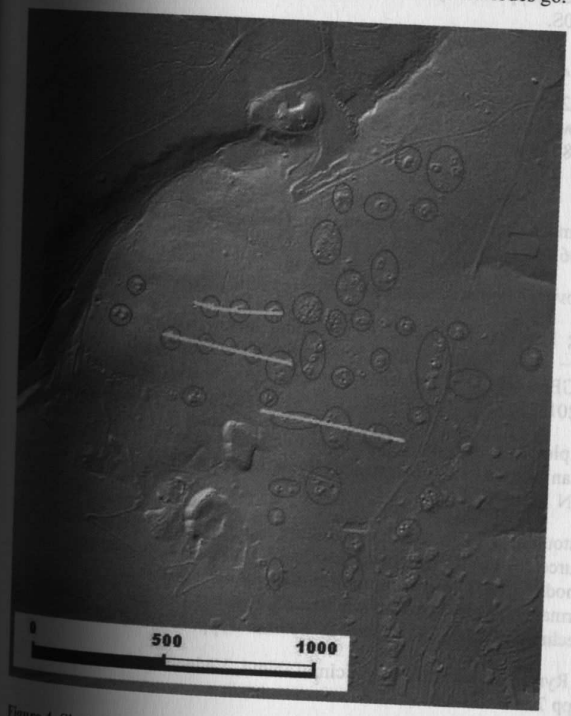

Figure 4. Shaded relief - Jáchymov

CONCLUSION

The airborne laser scanning technology found its place as invaluable tool for detailed and precise DTM production. The increasing availability of ALS datasets opened a new epoch in heritage landscape assessment which goes hand in hand with higher interest in non-destructive approaches in archaeology. It is possible to systematically study complex areas hidden under canopy without long lasting field survey.

There is a plenty of DTM visualization techniques with different strong points and limitations. Therefore, the use of a combination of visualization techniques appears to be a possible solution.

It is necessary to keep in view that the ALS outputs should not lead to an explicit interpretation of prospected object and it is necessary to confirm the findings using another method and/or data source (e.g. field survey, old maps).

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SOURCE OF DATA

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