Landscape modelling of past, present and future state of areas affected by mining

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Summary Surface mining of brown coal changed Iron mountains basin region fundamentally. Hundreds of millions of hauled masses significantly affected the landscape appearance. Involvement of government authorities and citizens of the affected towns and villages is essential and participation is expected. For proper assessment of the projected mining intent with subsequent remediation of the consequences, processing of 3D models and interactive visualizations options shared with web technology is an important factor. Creation of dump body 3D model, including internal composition, can play important role in various tasks solving, for example in hydrology or geotechnics. High-quality processing of these materials requires use of modern surveying technology, CAD systems and various tools of computer graphics processing. © 2015 The Authors. Published by Elsevier GmbH. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Introduction

The landscape of the Podkrušnohorská area in the northwest Bohemia has already been burdened by the extraction of brown coal, which is currently realized only by means of large-scale quarrying. In places with underground mining, abandoned pits and subsidence depression often in the form of bodies of water have been left behind.

Currently, brown coal is mined in the neighbourhood of the towns of Sokolov, Chomutov, Most, and Teplice. Every year, many tens of millions of cubic metres of material are moved, resulting in irreversible changes in the landscape. In recent decades, there has been an increasing pressure on the environment issues, and for the organizations carrying out mining activities, it is often very difficult to get permission for their further operation. At present, it is already quite common that while discussing PPOE that mining companies have to prepare together with a study of the effects of mining on the environment (EIA), the state authorities also require a 3D visualization of projects contained in these

Abbreviations: PPOE, plan to prepare for opening and extraction; EIA, environmental impact assessment; CMO, Czech Mining Office; MRA, mining reverse analysis; PKAZ, Palivový kombinát (Fuel Combine) Ústí nad Labem; CAD, computer aided design; IDW, inverse distance weighting; GFU, grid file utility; VRML, virtual reality modelling language; RS, remote sensing.

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The subject of the assignment is usually processing visual studies with predefined parameters. The permission for further activities conducted by mining methods requires favourable opinion of other parties concerned (Daněk et al., 2012a, 2012b). These include municipalities whose territory adjoins the extraction area of mining organizations.

An important role in the design process as well as in addressing a number of crucial tasks is played by the spatial model solution of the affected area in the timeline.

The recapitulation of current trends in modelling mining landscape

Technological development has significantly influenced the change of approaches to the implementation of geodetic surveying and designing mining and quarrying of mineral resources. For these reasons, designing is in fact becoming spatial modelling. At the same time, we can say that the individual specializations of mining activities are becoming multidisciplinary.

Acquisition of primary data for modelling a landscape

The quality of the primary data intended for processing the 3D model of the particular area significantly affects the final product. It depends on the method of their acquisition or origin.

In principle, the origin of the input data information can be marked as follows:

- direct measurements in the field or downstream data processing, e.g. from photogrammetry, remote sensing, or laser scanning
- processing of the documents created from already processed projects, altitudinal and positional data, maps in the electronic or analogue form, historical aerial photogrammetric images, and additional documents.

In geodetic surveying of large areas, an ever-greater role is played by aviation laser scanning and the use of unmanned aircraft as carriers of non-surveying cameras in the application of aerial photogrammetry (Plakinger et al., 2013). This is confirmed by the fact that in most cases, the latest versions of the programmes used for modelling terrain and landscapes already have functions for processing laser scanning products (Brejcha, 2014).

A quality source of information for modelling historic states of landscapes are aerial photographs that the Czechoslovak Army started to take at regular intervals from 1937 with a break during WW2. Good results were achieved using software PhotoScan of Agisoft Company when a digital model of the terrain relief in the former opencast large-scale coal quarry PKAZ near Chabařovice from 1953 was created (Fig. 1).

Modelling of the past, present and future states

Modelling of the current state of a landscape affected by surface mining usually constitutes creating aboveground or underground structures with their subsequent insertion into the prepared three-dimensional model of the landscape; modelling of the future designed conditions assumes cooperation of many experts from many fields, including mining specialists, landscape architects, ecologists, dendrologists, hydrologists, and a number of other experts.
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The portfolio of software for the solution of this task has to include not only application for terrain modelling based on a powerful CAD system, but also the editor of raster data bases with functions for their rectification and vectorization, and with functions for creating buildings in the terrain, vegetation, transportation, and other line buildings. An important feature of these systems is the ability to create multiple solutions with the possibility to switch their variants in 3D interactive visualization as shown in Fig. 2.

Mining reverse analysis (MRA) of an area affected by anthropogenic activities

When solving problems in geotechnical engineering, hydrometry and mining engineering, it is necessary to obtain a wealth of information about the concerned area. To acquire the information, significant funds on, for example, exploration wells have to be spent.

A variety of operational tasks can be solved by means of the mining reverse analysis (MRA). Using appropriate data bases and modelling techniques, this method offers to create three-dimensional models of the field cover and subsurface conditions in specific time periods. A typical example of the use of MRA is the solution of hydrological conditions inside and outside the dump. When dumps are being established at large coal opencast mines, there are continuous changes in their layering, often accompanied by qualitative changes of the deposited material, and creating discontinuities in the composition of the dump body. If the spatial reconstruction of the mining and technological conditions for the given period is properly designed, it is possible to trace the spatial distribution of deposited layers in the timeline.

Methodology of modelling the distribution of materials and their quality parameters in the body of the dump

In addressing MRA, grid structures representing vertical horizons and thickness of the monitored layers together with their quality parameters are used. Besides rock composition, geomechanical properties may be included in these parameters. These data can be obtained from boreholes, wells and operational mining documentation in the graphic and text form.

To create primary grids that represent the anthropogenic activities in the monitored area, the statistical method of inverse distance interpolation (IDW) is applied. The solution is based on the assumption that the value of the interpreted parameter in the selected point depends on its values in the surrounding formulas. The function that indicates the interpolation using the appropriate weighted linear estimation can be expressed by the relation by Schejbal (2005).

\[ u^*(x_0, y_0, z_0) = \sum_{i=1}^{k} w_i \times u(x_i, y_i, z_i), \]  

(4.1)

where \( u^*(x_0, y_0, z_0) \) is an estimate and \( u(x_i, y_i, z_i) \) a known value of the quantity \( u \) at a certain point or elemental surface or spatial unit (micro block) of the body and \( w_i \) its weight. The application of the statistical method of inverse distance (ID) interpolation is based on the relations by Schejbal (2005):

\[ u^*(x_0, y_0, z_0) = \begin{cases} \sum_{i=1}^{k} (u_{0i} / d_i^p) \sum_{i=1}^{k} (1 / d_i^p) \quad d > 0 \\ u(x_0, y_0, z_0) \quad d_i = 0 \end{cases} \]

(4.2)

where the known values \( u_{0i} \) with coordinates \((x_i, y_i, z_i)\) lie within the zone of influence \( W(x_0, y_0, z_0) \) at a distance

\[ d_i = \sqrt{(x_i - x_0)^2 + (y_i - y_0)^2 + (z_i - z_0)^2} \]

(4.3)

from the estimated point, \( a \) is an exponent expressing the influence of the observation of the surrounding on the estimate. In the case of moderately variable bodies, \( a = 2 \) is recommended.

The verification of the quality of interpolation, and thus the right choice of the statistical interpolation method is implemented through the so-called boomerang testing methods (Staněk et al., 2007), where the calculation of qualitative and quantitative parameters from the surrounding points is made for each point with known parameters of the created body. Subsequently, a comparison is made of these known and calculated values according to the following relations:

\[ \frac{1}{n} \sum (u^* - u) \to 0, \quad \frac{1}{n} \sum (u^* u) / \sigma^2 \to 1 \]

(4.4)

where \( \sigma^2 \) is the scatter estimation and \( n \) is the number of points.

An important endpoint for monitoring the distribution of errors in the concerned land body is symmetrical scatter and the minimum mean square error.

Geostatistical analysis using the kriging method was also performed on the monitored dump body. This method is similar to the IDW method, except that the result of kriging also depends on the spatial arrangement of the points with known parameters. The estimate of the value of the solved quantity as a parameter for calculating the distribution of the monitored parameters in the elementary block of the solved body is

\[ u^* = \sum_{i=1}^{m} \lambda_i \times u_{pi} \]

(4.5)

under conditions that the scatter estimation \( \sigma^2 = \text{min} \) and the sum of weights \( \sum_{i=1}^{m} \lambda_i = 1 \).

The weights are determined by solving the kriging system of linear equations assembled with respect to the nature of the random field (stationary or non-stationary) based on hij distances between the block Bj and intersections bi (Fig. 3) using the semivariogram function by means of the procedure of Lagrange multipliers.

When solving of the concerned body of the Progress dump near Duchcov, the functions of the Carlson Geology programme system was used. After applying the calculations, the homogeneity of the monitored spatial fields was checked by means of interpreted semivariograms and the resulting parameters.

The created grid entities representing the addressed spatial earth elements are of two kinds that represent each layer in the form of its top and bottom; further in the text,
they are presented under the terms top and bot. Grid structures representing the thickness of the monitored layer are hereafter under the designation THK.

An important factor in the successful application of the MRA method is further effective work with the created primary grid structures. When creating inverse models of mining processes for the formation of dump bodies, the module of the Carlson Geology software system called GFU (Grid File Utilities) is used. Through a simple programming language, this software tool enables to create computational routines for dealing with relations between the layers representing the dump body resulting from the long-time anthropogenic activity.

The example below shows how to create a merge of two layers represented by grid models in the event that the gap between the layers is less than 0.5 m according Figs. 4–6. Layer merging occurs when the gap between layers is less than Min_gap_THK = 0.5.

**Interpretation of DMT documents mine-surveying documentation**

When applying MRA, the digital models of the terrain (DMT) representing the states recorded in the mining survey documents belong among the basic building blocks. At large-scale opencast coal mining plants, the so-called operational planning maps now in the electronic form are further processed, including the form of digital terrain models of the concerned areas (Figs. 7 and 8).

It is beneficial to take advantage of the possibility of processing the surface of the concerned dump bodies in the form of a triangulated irregular network (TIN) and its subsequent incorporation into a model representing the subsurface situation.

The cornerstone of the successful application of MRA is considering the parameters of heaping up and layering the dump body in the timeline. It is obvious that these parameters can be obtained mainly from mine surveying and operational mining documentation.
The starting point for reverse reconstruction of the state of dump horizons at the particular time are mine surveying documents or digital terrain models created within planning mining procedures in the production preparation department. The surface states in the individual layers of the dump body in the reverse timeline are modelled in the Carlson Surface Mining software system as shown in (Figs. 9 and 10). Based on the data from the maps of mine planning and mining parameters of backfilling, the surface states can be reconstructed.

Creating spatial models of mining landscapes from historical documents

In areas where mining activities are carried out, surveying documentation is available in most cases. It is obvious that its quality depends on the time and the method of its elaboration. It is the case of the mapping documentation elaborated in the Czech Republic in accordance with the mine surveying regulation, Section 20 of Act no. 61/1988 Coll. (on mining activities, explosives and the State Mining Authority). Older documents are often created specifically in the local coordinate system (Staňková and Černota, 2014), therefore, the key attribute of their successful utilization is a high-quality preparation. Its main steps especially include the preparation of scanning and rectification of mapping works, searching for and finding out data on identical points, vectorization, and creating 3D entities from these materials (Li et al., 2005). Moreover, the important fact is that aerial photography for the purpose of its photogrammetric processing started in the Czech Republic in 1937.

For the visual transformation of historic mine maps, similarity transformation was used after securing suitably chosen identical points:

\[ x' = m \cos \alpha x - m \sin \alpha y + Tx \]  \hspace{1cm} (4-7)
\[ y' = m \sin \alpha x + m \cos \alpha y + Ty \]  \hspace{1cm} (4-8)

where \( m \) is the scale, \( \alpha \) is the rotation angle, and \( Tx, Ty \) are the coordinate offsets.

Spatial models created in this way are important to obtain information on the morphology of the original underlay of the concerned dump body.

Conclusions

Creating spatial models is currently already common reality for each engineering discipline. Mining and quarrying of mineral resources often has a significant impact on the landscape, therefore, it is important to use all available knowledge and skills in its planning.

In connection with the materials documenting mining activities in the monitored period, spatial models of the distribution of material composition of dumps can be created. 3D models created in this way represent an important basis for solving tasks e.g. in hydrology, geotechnical, environmental, and mining engineering. Besides spatial models interpreting the past and present state of the territory affected by mining, processing their current state is relevant as well for the proper execution of decision-making procedures.

Conflict of interest

The authors declare that there is no conflict of interest.

References


