Using the Dynamic Terrain Model for Real-Time Calculation of Extraction Volumes

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Summary

Big volume of materials is mined and transported quite often during surface mining, especially in lignite mining. Calculating the volumes of extracted material is one of the primary jobs for mine surveyors. The present paper describes a system (GNSS MineModel) for real-time computing of extraction volumes by means surveying system for localization of bucket wheel of excavators.

Introduction

Some bucket-wheel excavators used at the quarries of Severočeské Doly, a. s., have control system devices such as GNSS, inclinometers and incremental revolution counters to identify the bucket wheel 3D position by continual calculations made over the measured data. Exact bucket-wheel position on the quarry's terrain digital model and on the geological model is an essential element in a number of applications. One recent application makes it possible to calculate the volume of extracted material.

The Theory

Used to extract coal and minerals in the Czech Republic, opencast mining entails extraction, transport, storage and stock-keeping of primary raw material, removed rock cover, dead rock, intercalation materials, secondary materials and, on occasion, some subsoil on a large scale. It is a very complex business with considerable responsibility.

Digital Model Surface Definition

The volume calculation method applied by KVASoftware's GNSS MineModel is based on the definition of surfaces as used by the quarry terrain digital model [3]. Source data (objects) used to describe the surfaces must always be vectors (including singular vectors). The software creates a general triangular web (Fig. 1) making each surveyed point an apex of the triangle.

Each triangle of the triangular web represents one planar element of the surface (Fig. 2) and is identified by three points (apexes of the triangle) X_A, Y_A, Z_A and X_B, Y_B, Z_B and X_C, Y_C, Z_C. To optimize the digital model and to run various applications like volume calculations, the program has the following basic problem to solve: Calculate the unknown coordinate Z for any Point N identified by its X, Y coordinates. Thus identify the correct triangle and project Point N onto the triangular planar element. Then calculate the missing Z-coordinate of Point N which is now attached to a known surface. Use the triangular area defined by Points A, B and C and calculate the missing Z-coordinate of Point N by means of determinants.

Volume Calculation Method

All volume calculations and secondary calculations (mass, raw material qualitative properties, etc.) are based on two known 3D surfaces described, in geometry terms, by the digital model's triangular webs. The volume is calculated as a difference between the two planes, i.e., between two digital models. The two digital models can be the MASTER model (initial quarry terrain) and the REFERENCE model (mid-way excavation quarry terrain model).

Basic calculation element is a trihedral right prism with two general planar bases. (Fig. 3) The calculation works with an integer parametric value setting the maximum allowable area of the elementary base triangle in [m²].

The calculation starts with a recursive reconfiguration of the initial triangular web to meet the maximum triangle parametric requirement.
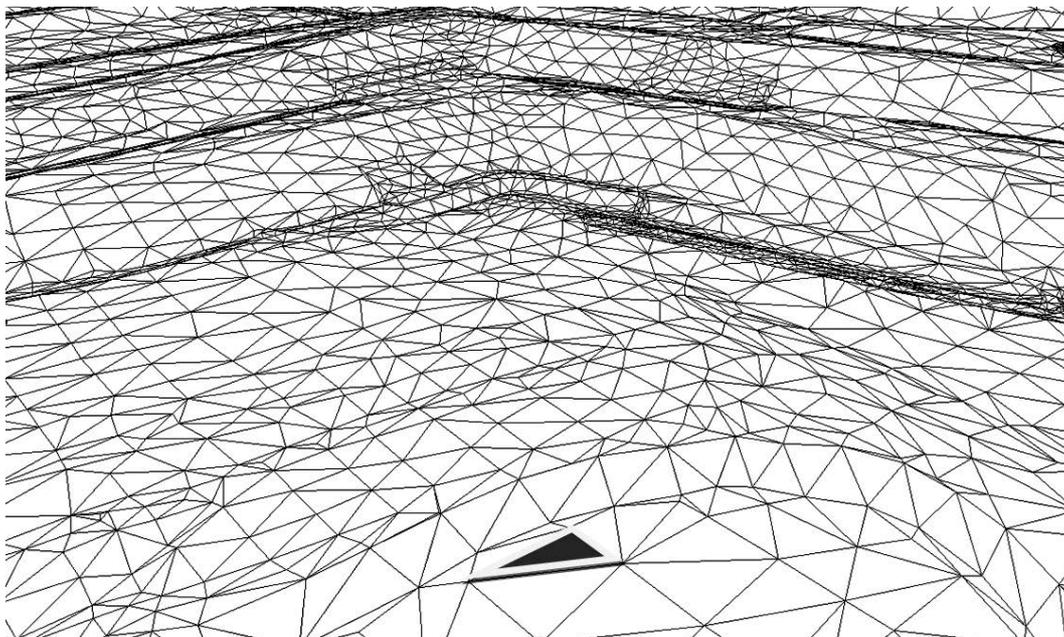
Fig. 1: Computer-generated triangular-web terrain representation in the digital model

Rys. 1. Wygenerowana komputerowo sieć w postaci trójkątów reprezentujących teren w modelu cyfrowym
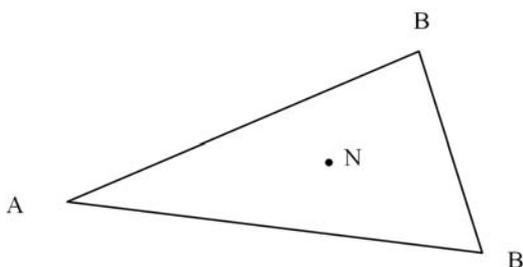
Fig. 2: A triangular element of the terrain digital model

Rys. 2. Trójkątny element cyfrowego modelu terenu
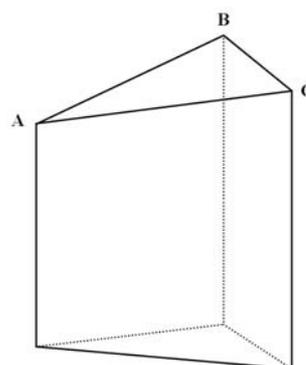
Fig. 3: Trihedral prism, a basic element in volume calculation

Rys. 3. Trójścienny pryzmat, podstawowym elementem obliczania objętości

Elementary volume:
- Positive value: MASTER model plane is located "above" the REFERENCE model plane,
- Negative value: MASTER model plane is located "below" the REFERENCE model plane.

Total volume calculated is the iterative sum of all elementary volumes accrued over all elements of the triangular web. Positive and negative volume figures are iterated separately, positive figures being interpreted as fill and negative figures as extraction volumes.

Volume Calculation as part of the Bucket Wheel 3D Position Calculation

The above volume calculation method is used by the bucket wheel position identification system to calculate extraction volumes on a running basis. The program uses what we call "the GNSS dynamic maps". A GNSS dynamic map as used in KVASoftware applications is a system of equations of partial index matrices and active element matrices designed to dynamically define and modify the matrix elements. The result is a dynamic model of the extraction area where the extraction process is represented by a parametric cylindrical model of the bucket wheel created for a GPS monitored bucket-wheel excavator.

The method of describing the GPS dynamic map surfaces pays justice to the fast indexation requirement on the planar elements, i.e. fast modification (update) of the planar elements while minimizing data volumes (file size) for over-the-network data sharing with other applications.

The calculations are carried out by separate GNSS MineModel applications (one per bucket-wheel excavator) feeding their data simultaneously into a common data space. The present quad-core processor computer (GPS server) can serve up to 4 simultaneously running GNSS MineModel applications.

Any area can be split up into an unlimited number of partial index matrices, with possibly one index matrix per bucket-wheel excavator and its progress area. Partial matrices may overlap where the extraction areas are partly shared between the bucket-wheel excavators. The application can eliminate redundant data where index matrix overlap is allowed. Index matrices are defined by graphic input over the digital model base map and can be edited freely over time (increase, reduce, delete, add). Each matrix element represents a 1 m by 1 m square. Matrix elements become inactive after initiation (i.e. hold no data).

The software simultaneously generates a parametric cylinder model of the bucket wheel, where cylinder diameter (i.e., bucket wheel diameter) and cylinder height (i.e., bucket wheel width) are the parameters used. The wheel parametric model position is defined by its axis of rotation.

Moving across the dynamic map, the cylindrical model of the bucket wheel activates map elements in its path by assigning indices to their matrix fields (files); each active element field contains 8 planar elements (triangles, i.e., area equations). (Fig. 4) The application guarantees continuity among the planar elements and with contiguous matrix elements; i.e., first derivation planar continuity. Active elements are shown in grey on the dynamic map.

Each active element has index references to 8 other planar elements to refine the model and to increase volume calculation accuracy. Each planar element (triangle) is described by a parametric equation of a planar surface where the parameters consist of the X, Y and Z system coordinates of triangle apexes. Each activated and modified matrix element gets a date and time tag of the activation/modification appended.

Calculations. Matrix Element Activation, Modification

Inactive matrix elements will activate upon being hit by the virtual bucket wheel cylinder. Matrix element activation starts with projecting all 8 planar elements on the current face of the terrain model, i.e. the planar elements now copy a 1 m by 1 m area of the terrain [4].

The next step is to calculate the intersection between the new planar elements and the bucket-wheel cylinder. Where the new Z-coordinate of an apex is less than the previous value, all affected planar elements will be modified accordingly creating elementary trihedral prisms between the new and old Z values used in volume calculations.

Figure 5 shows a 3D view of the quarry section around bucket-wheel excavator K800/103. The wire model represents the original quarry terrain as surveyed; the yellow and grey colours represent the current terrain digital model after a pass of the virtual bucket-wheel cylinder.

Each elementary trihedral prism is also used to calculate intersections with the geological model planes required for volume weight, tonnage and qualitative parameter calculations. A similar procedure is applied to matrix element **modifications**, i.e., to multiple bucket-wheel cylinder passes. Intersections between the current planar elements in the matrix and between the bucket wheel cylinder surface are calculated and smaller Z values replace the previous Z values. Date and time of modification is appended to any change of a matrix element. Each change of bucket wheel position (position sampling frequency is 5 seconds) triggers off intersection calculations over a set of planar elements whose matrix elements are affected along the bucket wheel path. Total change of volume over a time period is based on a cumulative calculation of all elementary volume changes over the sampling interval. Problems about 3D surface modelling and analysis for the purposes of computing volumes of non-extracted of andesite reserves deals [2].

1m
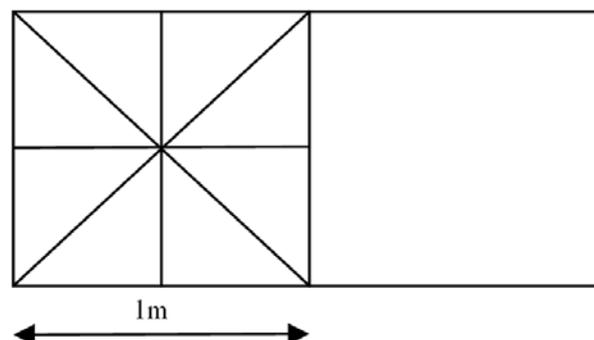
Fig. 4: Active (left) and inactive (right) 1 m by 1 m element of the dynamic map
Rys. 4: Aktywny (z lewej) i nieaktywny (z prawej) element 1×1 m na mapie dynamicznej
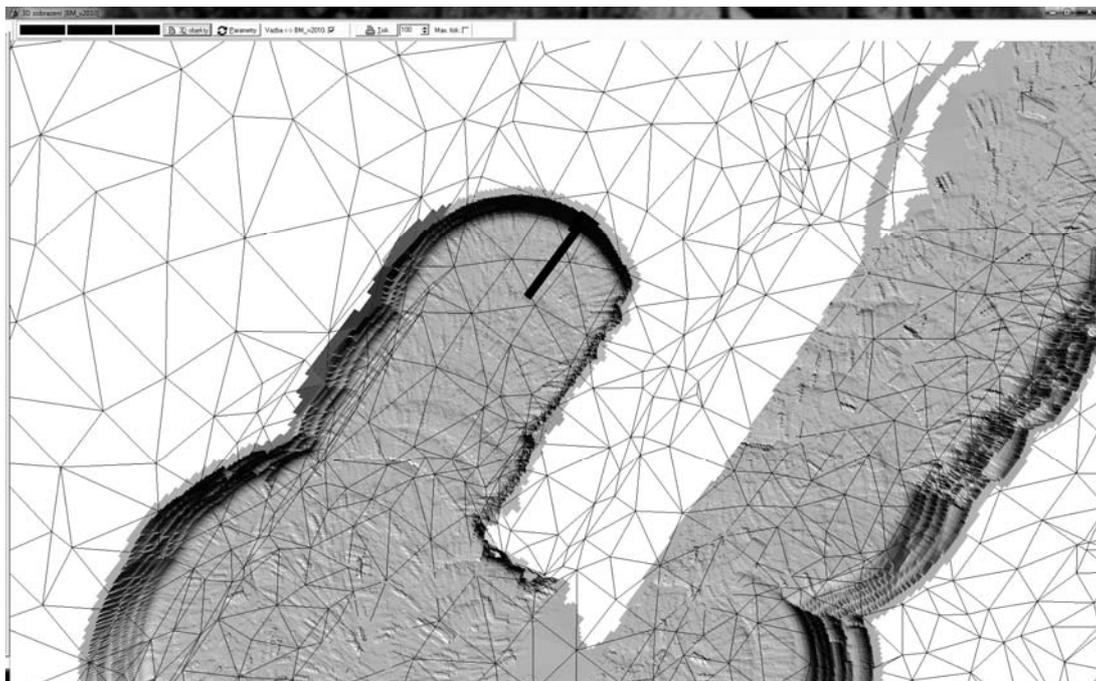
Fig. 5: A 3D view of the quarry section around bucket-wheel excavator K800/103/N1

Rys. 5: Widok 3D sekcji kamieniołomu wokół wieloczerpakowej koparki kołowej K800/103/N1

Volume Calculation Independent Cross-check

Severočeské Doly, a. s., use monthly surveying to cross-check extraction volumes. Quarry surveying is done by aerial digital photogrammetry (UltraCam X digital chamber). Digital snapshots are centred 750 m to 800 m above the quarry average altitude and photograph scale is 1:7,600.

The same method was applied to cross-check the volume results based on the real-time bucket-wheel 3D position calculation system data for bucket-wheel excavator K800/103. Material volumes extracted by the bucket-wheel excavator over the time period of interest were calculated by means of a standard surveying procedure applied to the quarry digital model and based on the trihedral prism method (Method 1). To cross-check, the extraction volume database of the GNSS MineModel was used (Method 2). The program was used to calculate the volume of extracted material over a certain period. (Fig. 6) Figure 6 shows terrain models based on the current position of the model of bucket-wheel excavator K800/103/N1 at the beginning (green) and at the end (purple) of the period. The initial terrain is represented by the wire model (grey) in the same picture. Extraction volumes

were calculated from the differences between the three surfaces by means of the GNSS MineModel software. Article [1] deals of spatial visualisation with using present geodetic methods.

Table 1 shows calculated volume comparison results.

Conclusion

A comparison between the results acquired by a conventional surveying calculation based on photogrammetric data (Method 1) and between the GNSS MineModel application under scrutiny (Method 2) has shown minimum difference. The differences are equally small if two different surveyors carry out independent calculations over the same set of photogrammetric data. Similar results were produced for two other bucket-wheel excavators equipped with the GNSS MineModel system.

Minute differences between the calculated volumes lead us to conclude that the representations of quarry cross-sections made from 3D vectorized terrain models by the GNSS MineModel software can be considered good enough to be used as input data for bucket-wheel excavator extraction progress planning.

Table 1: Volume calculation results

Tabela 1. Wyniki obliczeń objętości

Extraction volume calculation method	Volume [m^3]	Difference
Method 1: Mine photogrammetric survey	163815	
Method 2: GNSS MineModel	163179	-0,39%
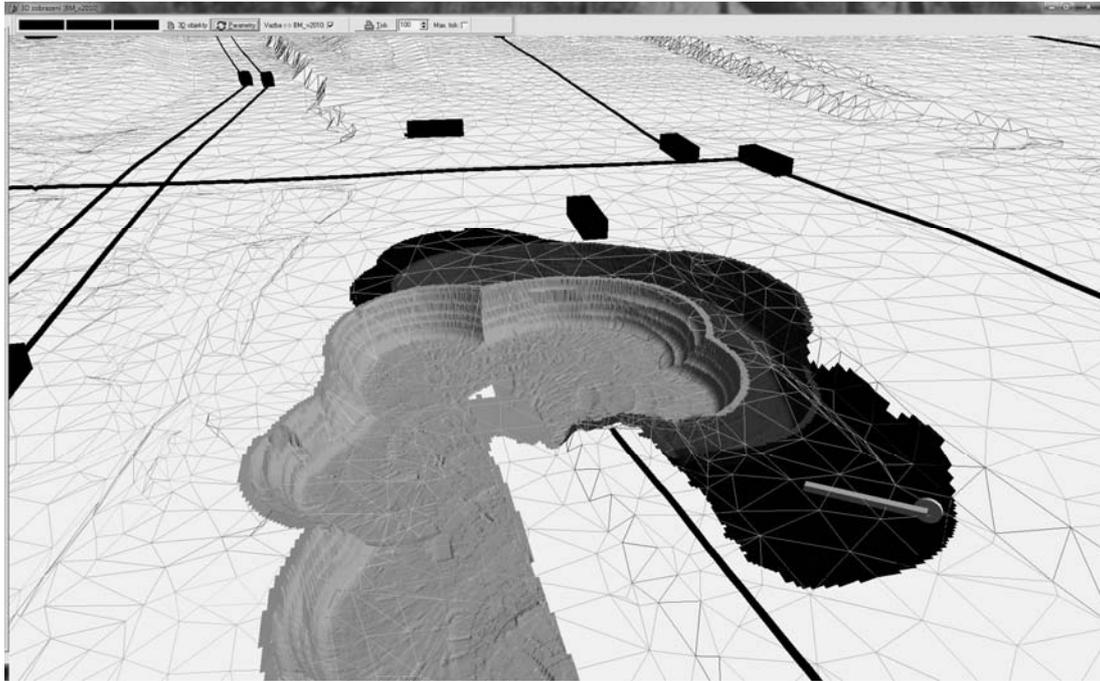
Fig. 6: Terrain models made from the bucket wheel current position model data for bucket-wheel excavator K800/103

Rys. 6: Modele terenu wykonane z aktualnej pozycji koła czerpakowego do danych modelu
dla wieloczerpakowej koparki kołowej K800/103

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Zastosowanie dynamicznego modelu terenu w celu obliczenia wydajności wydobycia w czasie rzeczywistym

Duża ilość materiałów jest wydobywana i transportowana dość często podczas górnictwa odkrywkowego, głównie w przypadku węgla brunatnego. Obliczenia dotyczące ilości wydobytego materiały jest jednym z głównych zadań inspektorów górnictwa. Niniejszy artykuł opisuje system (GNSS MineModel) obliczania w czasie rzeczywistym poziomu wydobycia dzięki użyciu systemu geodezyjnego do lokalizacji koparek kołowych.

Słowa kluczowe: koparka kołowa; cyfrowy model terenu; GNSS; GNSS MineModel; trójwymiar (3D); obliczenia objętościowe