MONITORING TERRAIN CHANGES DUE TO ORE EXPLOITATION USING DRONES

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Abstract: *The paper considers the option of visual display of the situation in an open-pit mine over time. In addition to visual monitoring of the condition, the use of aerial photogrammetry method enables efficient and fast calculation of excavated masses. Monitoring of changes in the terrain and calculated quantities of masses is used in all phases of design and management of an open-pit mine and enables easier decision-making. For these purposes, geodesy, geodetic survey, and drones are used. With the development of technology and the advent of unmanned aerial vehicles, data collection has become much easier.*
Keywords: *geodetic survey, aerial photogrammetry, triangles of irregular network, drone, surface mine, environmental.*

Introduction

Engineers of various professions often have problems on the site when determining the location of works, precise calculation of the amount of mineral raw materials, the volume of landfills, etc. With the development of technology, we have the application of unmanned aerial vehicles (UAV – drones), where we can obtain a larger amount of data in a shorter period of time. The aerial photogrammetric method is increasingly being applied, because a realistic tree dimensional (3D) model of the actual situation can be obtained. Pearson, Fricks, and Penna (2023) provide a comprehensive overview of geodetic surveying using the Global Navigation Satellite System method (GNSS) with a special focus on survey methods, errors as well as the coordinate reference system and quality assurance and control. UAV photogrammetry presents a fast, accurate method for mapping large areas. In yours study, authors Hastaoğlu et al. (2019), a new methodology for monitoring 3D areal displacements with UAV photogrammetry and software suitable for this methodology were developed.

Geodetic surveying at a specific location open pit mine ‘Crveno brdo’ is carried out with the aim of producing monthly reports on the quantities of overburden removed from a given open pit during a period of one month. The surveying is carried out continuously on a monthly basis, whereby two digital terrain models are analyzed and compared: a model of the previous state, which was created based on the geodetic survey from the end of the previous month, and a model of the new state, recorded at the end of the current month. Based on the difference between these two models, the volumes of material removed during the analyzed period are precisely determined. The visual display also enables the presentation of the impact of mining operations on the surrounding terrain.

Material and Methods

In-situ data

The open pit mine 'Crveno Brdo' is part of the exploitation field of the surface mine 'Šikulje'. The second and first roof coal seams are exploited within the contours of the limited open pit mine. The thickness of the second roof coal seam ranges from 2.9 m to 13 m, and the thickness of the first roof coal seam is on average about 6 m. The process of coal exploitation at the surface mine 'Šikulje' began in 1985. The mine was designed for 3 million tons of coal per year. The limited exploitation quantities of coal in the mine contour according to the Main Mining Project are about 102 million tons of coal, for which it is necessary to excavate about 522.0 million tons of overburden. The limited area (exploitation field) of the surface mine 'Šikulje' with the position of the external and internal dumps is given in Figure 1.

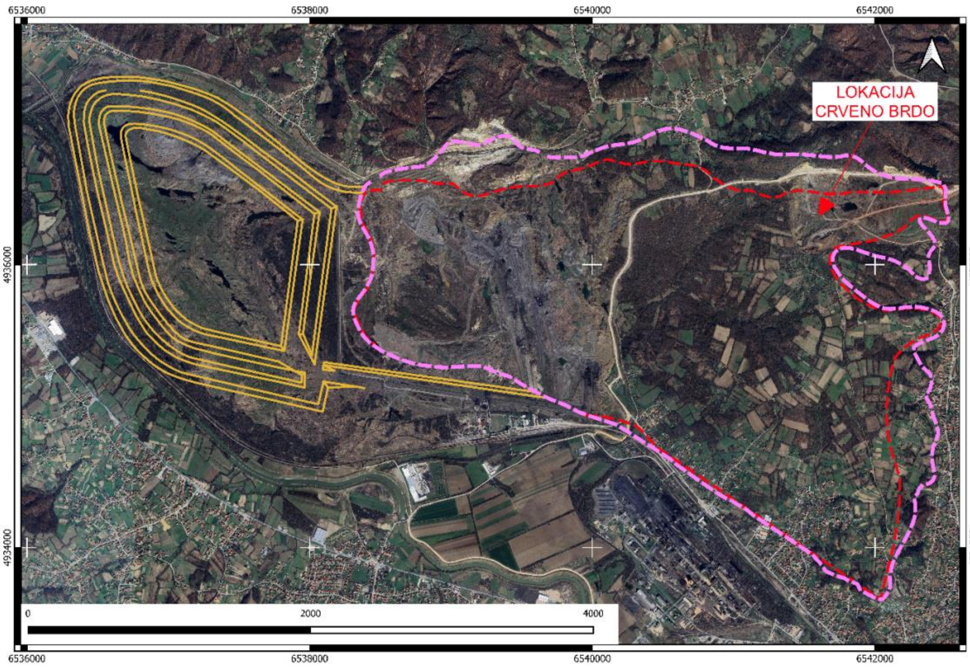

Figure 1. Location of the surface mine 'Šikulje' (source: Amela Kešetović)

In order to be able to monitor the works in the field in real time as effectively as possible, it is necessary to use all available techniques, equipment, methodologies and materials.

Used equipment

Trimble R8 GNSS system, Phantom 3 Professional drone was used for the purposes of geodetic measurement. Compact Measurement Record (CMRx) protocol provides maximum compression of corrections to optimize communications bandwidth and fully utilize all of the satellites and signals in view. The Trimble R8 GNSS (Figure 2) supports a wide range of satellite signals, including Global Positioning System (GPS) L2C and L5 and GLONASS L1/L2 signals (Trimble, 2024).

Figure 2. Trimble R8

Device features:
- Trimble R-Track Technology;
- Advanced Trimble Maxwell™ Custom Survey GNSS Chip;
- High-precision multiple correlate for GNSS pseudo-range measurements;
- Unfiltered, unsmoothed pseudo-range measurements for low noise, low multipath errors, short time correlation, and high dynamic response;
- Phase measurements with <1mm accuracy in 1 Hz bandwidth of very low noise;
- Signal-to-Noise Ratio in dB-Hz;
- Proven Trimble low elevation tracking technology;
- 72 Channels;
- GPS L1 C/A Code, L2C, L1/L2/L51 Full Cycle Carrier;
- GLONASS L1 C/A Code, L1 P Code, L2 P Code, L1/L2 Full Cycle Carrier;
- 4 additional channels for SBAS WAAS/EGNOS support.

Drone Phantom 3 Professional as shown in Figure 3, represents a new generation of quad-copters. It can record 4K videos. The built-in camera has an integrated gimbal to make the aircraft as stable as possible considering its size and weight.

Even when the GPS signal is not available, the aircraft uses the Vision Positioning System to land the aircraft at the set point (DJI, 2024).

Figure 3. Drone DJI Phantom 3 Professional

Table 1. DJI Phantom 3 Professional drone specifications

Aircraft	**Gimbal**	**Smart battery specifications**	**Camera**
Weight 1280 g	Stabilization Three-axis (pitch, roll, yaw)	Capacity 4480 mAh	Sensor ½.3” CMOS
Maximum speed 16 m/s	Maximum controllable angular speed 90°/s	Voltage 15.2 V	Lens FOV 94° 20 mm (35 mm format equivalent) f/2.8 focus at ∞
Maximum tilt angle 35°	Angle control accuracy ±0.02°	Battery type LiPo 4S	Image size 4000×3000
Maximum flight time 23 min		Energy 68 Wh	Photo formats JPEG, DNG (RAW)
GPS data recording GPS/GLONASS		Net weight 365 g	Video formats MP4, MOV (MPEG-4 AVC/H.264)
Flight accuracy range Vertical/Horizontal ±0.1 m/±0,3 m (with Vision positioning) ±0.5 m/±1.5 m (with GPS positioning)		Maximum charging power 100 W	Supported SD cards Micro SD
			Maximum capacity 64 GB

The geodetic network is represented by all permanently stabilized geodetic points, with known coordinates, which are needed for a defined task. Terrestrial grids can be: trigonometric, polygonal, linear and leveling. Geodetic measurements and the parameters calculated from them are related to various mathematical models (Raeva et al., 2016). The most popular equalization method in geodesy is the parametric model. It is appropriate in all cases where each measurement can be expressed as a function of some unknown and independent parameters (Nurić et al., 2024).

Recording methods

Geodetic surveying is carried out using the aerial photogrammetric method, which collects spatial data for the creation of a three-dimensional terrain model. For the purpose of geo-referencing and increasing the accuracy of the model itself, it is necessary to mark control points on the ground. To cover an area measuring 300 m x 600 m, approximately 15 control points are placed, due to constant height changes in space. These points are precisely determined using a GNSS (GPS) device, whereby their coordinates are obtained in the National Coordinate System. The obtained coordinates are then entered into the software during the creation of the aerial photogrammetric model, which allows the model to be displayed in the appropriate coordinate system, with high accuracy and spatial credibility (Štroner et al., 2021); (Dream Civil, 2024); (Nurić et al., 2024).
Since the GPS device uses an internet connection to receive correction signals (Real Time Kinematic - RTK method), in some parts of the work site signal reception is difficult due to poor network coverage. Therefore, it is necessary to carefully plan the positions of the control points, in order to ensure that each point can be reliably measured and precise coordinates are obtained. This approach allows for smooth data processing and the creation of a high-quality model in accordance with the requirements of accuracy and credibility (Department of Municipal Affairs and Transport, 2016); (Hastaoğlu et al., 2019). Also, during rainy periods, due to the characteristics of the soil at the construction site, movement on the terrain becomes difficult. Wet and soggy material creates unfavorable walking conditions, often leading to sinking into the mud, which further complicates the process of marking and measuring control points on the ground.

Results

Agisoft Metashape software was used for data processing. After importing the photos, the photos are merged based on the overlap. The geo-referencing of the model is approached, by marking control points on the photos. Those points are marked on the ground, and their position is determined by a GPS device using the RTK method. In this step, it is necessary to define the coordinate system, official state coordinate system of Bosnia and Herzegovina MGI Balkans zone 6, EPSG: 31276 (Nurić et al., 2024). According to obtained data during the period of time from November 2024 until April 2025, TIN models are presented in Figure 4 to 8.

Figure 4 Drone footage of the 'Crveno brdo' open-pit mine location on November 8. 2024 (Source: Amela Kešetović)

Figure 5 Drone footage of the 'Crveno brdo' open-pit mine location on December 3. 2024 (Source: Amela Kešetović)

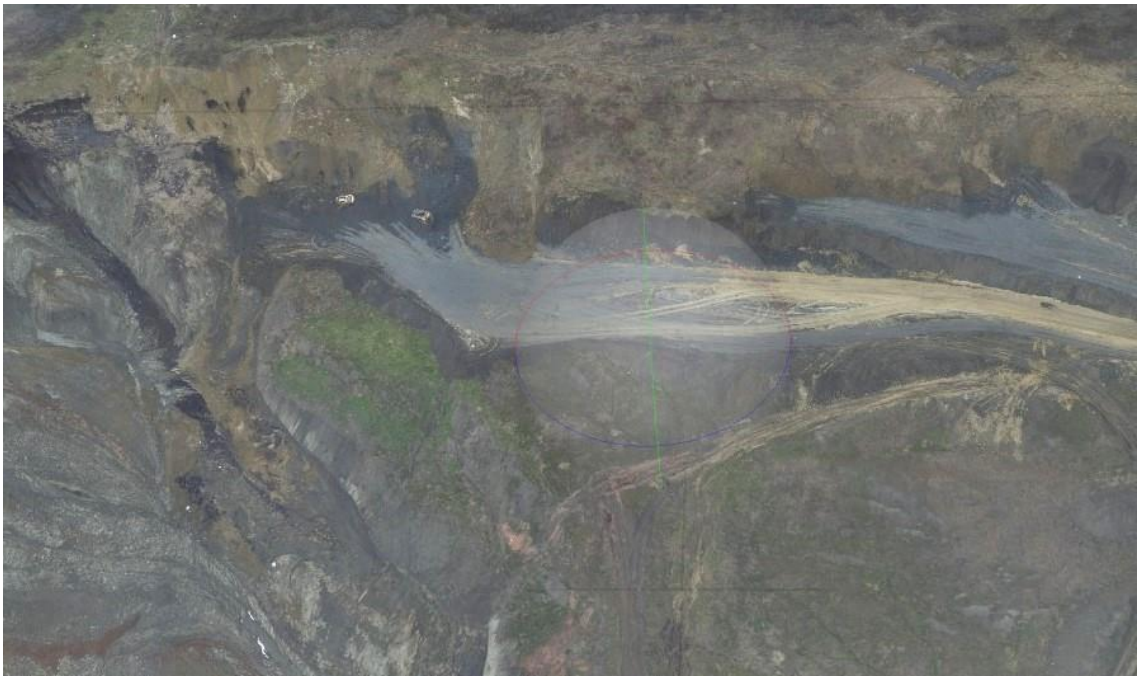

Figure 6 Drone footage of the 'Crveno brdo' open-pit mine location on February 3. 2025
(Source: Amela Kešetović)

Figure 7 Drone footage of the 'Crveno brdo' open-pit mine location on April 2. 2025
(Source: Amela Kešetović)

Figure 8 Drone footage of the 'Crveno brdo' open-pit mine location on April 30. 2025 (Source: Amela Kešetović)

Discussion

Regular recording and monitoring of changes in the field using a drone greatly facilitates decision-making on future activities related to surface coal mining at the open pit mine 'Šikulje' – part 'Crveno brdo'. Taking into account the fact that all mining processes are extremely expensive, it is important to have timely and valid information on the basis of which we can effectively manage these processes. This paper presents an overview of the usefulness of using modern technologies in mining. In addition to facilitating monitoring the development of mining operations, it also facilitates recording possible instability on slopes, positioning of mining equipment or possible endangerment of the surrounding terrain, as well as environmental safety requirements. As can be seen from the attached images, the significant influence of mining works on the surrounding terrain is obvious in terms of the appearance of instability of the surrounding masses during the formation of the benches, but also the development of dust during the performance of mining works, excavation, blasting and transport. However, due to the location of the surface mine, it can be concluded that all observed changes will not significantly affect the safety of people and buildings (there are no buildings on the given location), and that a certain impact on the flora and fauna in the immediate vicinity can be expected.

Conclusion

This paper presents the aerial photogrammetric method of recording of the pit mine with the DJI Phantom 3 Pro drone. The data collected by the aerial photogrammetric method were processed in the Agisoft software, and a model represented by a network of irregular triangles was presented. In addition to a larger amount of data that is collected in a shorter time interval, using this method we have a reduction in costs (Nurić et al., 2024). The recorded and processed data have multiple uses: displaying the current state of the open pit, calculating the areas and volumes of excavated masses, plotting transverse and longitudinal profiles, monitoring the operation of mining machinery, monitoring slope stability, the impact of the changed topology of the open pit due to excavated masses on the surrounding terrain, the impact of mining processes on the environment, etc.

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