Applications of Geomatics in Surface Mining

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Abstract. In terms of method of extracting mineral from deposit, mining can be classified into: surface, underground, and borehole mining. Surface mining is a form of mining, in which the soil and the rock covering the mineral deposits are removed. Types of surface mining include mainly strip and open-cast methods, as well as quarrying. Tasks associated with surface mining of minerals include: resource estimation and deposit documentation, mine planning and deposit access, mine plant development, extraction of minerals from deposits, mineral and waste processing, reclamation and reclamation of former mining grounds. At each stage of mining, geodata describing changes occurring in space during the entire life cycle of surface mining project should be taken into consideration, i.e. collected, analysed, processed, examined, distributed. These data result from direct (e.g. geodetic) and indirect (i.e. remote or relative) measurements and observations including airborne and satellite methods, geotechnical, geological and hydrogeological data, and data from other types of sensors, e.g. located on mining equipment and infrastructure, mine plans and maps. Management of such vast sources and sets of geodata, as well as information resulting from processing, integrated analysis and examining such data can be facilitated with geomatic solutions. Geomatics is a discipline of gathering, processing, interpreting, storing and delivering spatially referenced information. Thus, geomatics integrates methods and technologies used for collecting, management, processing, visualizing and distributing spatial data. In other words, its meaning covers practically every method and tool from spatial data acquisition to distribution. In this work examples of application of geomatic solutions in surface mining on representative case studies in various stages of mine operation have been presented. These applications include: prospecting and documenting mineral deposits, assessment of land accessibility for a potential large-scale surface mining project, modelling mineral deposit (granite) management, concept of a system for management of conveyor belt network technical condition, project of a geoinformation system of former mining terrains and objects, and monitoring and control of impact of surface mining on mine surroundings with satellite radar interferometry.

1. Introduction

Mining is defined as a number of actions required in order to extract minerals, including: exploration and documentation of a deposit, deposit preparation and enabling works, mining of the deposit, mineral transportation and processing as well as post-mining area reclamation and development. Effective management and monitoring of the aforementioned stages of deposit development might be supported by geomatics. The term Geomatics has been introduced by Paradis in 1981 [1] and has been since then internationally recognized as a discipline of gathering, processing, interpreting, storing and
delivering spatially referenced information. Geomatics integrates methods and technologies used for collecting, management, processing, visualizing and distributing spatial data and information. In other words, the meaning covers practically every method and tool from spatial data acquisition to distribution. Because of this fields of geomatics applications are wide and include for example: climate change and environmental monitoring, geodynamics, urban and regional planning, natural resource management including mining. It has become a widely used platform that facilitates and supports decision making processes in mining companies, mining authorities responsible for supervision of mining operations, institutions conducting research and development activities in the field of mining, e.g. geological services, mining engineering institutes and research centres. This article presents the solutions developed within the frameworks of geomatics supporting mining illustrated with an example of deposits extracted by a surface mining method in the selected stages of their functioning.

2. GIS based study of mineral deposit accessibility

In the study of land accessibility for potential large-scale surface mining project geographic information systems weighted map overlay functions and Analytical Hierarchy Process (AHP) methodology have been employed in multicriteria analysis aimed at determining scale of conflict between potential surface mining of large lignite deposit and other land functions, i.e. environmental and spatial development. The study has been done for the documented Legnica lignite deposit located in SW Poland (lower Silesia voivodeship). The entire deposit area consists of three lignite fields: Legnica W, Legnica N and Legnica S, which are accompanied by two smaller deposits Seinanawa and Ruja. The anticipated economic geological resources in place for the Legnica deposit are 3,425,999 thousand tonnes.

The combined methodology consisted of the following main steps: (1) identification of spatial and environmental factors representing criteria of deposit area accessibility for development, (2) development of AHP model to derive weights of factors through their pairwise comparison, (3) preparation of GIS database and spatial representations (raster maps) of criteria, (4) weighted overlay of standardised maps of criteria, (5) classification, presentation and interpretation of results. Steps 1 and 2 have been done with participation of a group of experts representing various specialisations. The complete procedure has been described in [2]. AHP methodology has been explained in [3], whereas map overlay concepts and applications, e.g. in [4].

The criteria used in the multicriteria analysis and their weights obtained from the AHP model have been given in table 1.

| No  | Type of criterion                        | Weight of criterion |
|-----|-----------------------------------------|--------------------|
| 1   | build-up areas                          | 9.3%               |
| 2   | main roads (national and regional)      | 3.5%               |
| 3   | roads other (local)                     | 1.8%               |
| 4   | railways                                | 3.3%               |
| 5   | electrical power network                | 2.5%               |
| 6   | gas network                             | 2.3%               |
| 7   | surface waters (flowing, still)         | 8.7%               |
| 8   | protected underground waters            | 9.5%               |
| 9   | good-quality arable land                | 4.9%               |
| 10  | arable land (other)                     | 1.5%               |
| 11  | forest                                  | 4.7%               |
| 12  | nature protection areas                 | 19.3%              |
| 13  | areas of valuable nature                | 7.6%               |
| 14  | ecological corridors                    | 6.7%               |
| 15  | national heritage sites and monuments   | 14.2%              |
The following have been found to be the most conflicting with surface mining project: nature protection areas (19.3% of total score), cultural and historical monuments (14.2%), built-up areas (9.3%), underground water reservoirs (9.5%) and surface waters (8.7%). The least prohibiting from the point of view of a group of experts are poor quality arable lands (1.5% of total score) and secondary roads (2.5%).

Each criterion has been represented by a raster map with pixel resolution of 50 m and size of 663 columns by 863 records. The maps have been standardized to a 0 to 1 scale where 1 represented a given factor in space. In the process of GIS weighted overlay the maps have been multiplied by given weights and their products added up. The obtained maximum pixel value for the area of Legnica deposit has been 0.55 for a theoretically possible score of 1 (all criteria present in a given location). The mean value of output raster has been 0.10. The results have been classified into three classes, using natural breaks (Jenks) optimization method, and representing least accessible parts of deposit area (score above 0.24), relatively accessible (score of 0.12 to 0.24) and most accessible (score below 0.12) parts. The map has been shown in figure 1. For the total area of 161.26 sq km, 2.1% (3.41 sq km) have been classified as most restricted, 52.1% (84.08 sq km) as relatively restricted and 45.8% (73.77 sq km) as least restricted for potential development. The Legnica W field has been found as most accessible (71.2% of area least inaccessible) and the Legnica N field as least accessible (20.7% of area least inaccessible).

![Figure 1. Results of the multicriteria GIS analysis of lignite deposit area accessibility [2]](image)

3. **Modelling of the state of deposit development**

Designing the deposit model with the use of GIS systems enables one to support the management of deposit mining at every stage of its life cycle. The works of [5-6] show the examples of applications of tools available in GIS systems used to build a spatial model of Borów I granite deposit, quarry 49a, and Rogoźnica granite deposit, including their later use for analyses showing the progress of mining.
works and for planning reclamation and development of an excavation pit. On the basis of data obtained from geological documentation of deposits (geological maps, borehole sheets), excavation maps, land register maps as well as land survey and height maps, there was a database developed including files/vector data representing landform, thill and floor boundaries, ledges as well as boundaries of an excavation pit, mining terrain and area. This database is the foundation for building spatial models of a mining terrain.

3.1. Borów I. granite deposit, quarry 49a

Three models presenting the subsequent stages of the mine’s life cycle (Figure 2) for Borów I granite deposit, quarry 49a: state of the deposit from 1992 in the first year of operation of the company mining the deposit; state of the deposit from 2011 showing the level of exploitation of the deposit (the year of the study [5]) and the state of target exploitation of the deposit at the documented level of thill at the datum +170 m a.s.l. The models of the deposit were used to conduct further analyses showing the progress of mining works concerning the deposit. For instance, volumetric analyses were carried out to calculate the state of recoverable geological resources for 1992 and 2011 and for the moment of final exploitation of the deposit to the level of +170 a.s.l. (Figure 2a). What is more, the direction of reclamation and target development of the excavation pit was offered together with calculating a volume of water needed to fill in the excavation pit for two variants of sidewall inclination to the terrain’s datum +235 m a.s.l. (Figure 2c) as well as there was a visibility analysis to evaluate the visibility of the excavation from three vantage points, after its final development (Figure 2b). The analyses conducted within the frameworks of this research study with the use of the tools available in GIS systems and the executed models of deposits may turn out to be useful when preparing documentation concerning the method of development of a deposit and managing a deposit during its exploitation.

Figure 2. Visualisations of the results of analyses conducted within the frameworks of this research study [5]: volumetric analysis (a), visibility analysis (b) and proposal of development of the deposit (c)
3.2. Rogoźnica granite deposit

A database for boreholes was developed for Rogoźnica granite deposit, which included information on specific lithological surfaces differing in physical and functional properties of the deposit. Subsequently, there were a spatial model of the terrain and a spatial model of the deposit executed (Figure 3). Figure 3a shows a model of terrain surface together with the deposit from the western side with the boundary of the documented deposit marked; figure 3b shows the model of the terrain surface from the western side with the marked granite roof of the deposit before the exploitation; figure 3c shows the model of granite deposit with a marked layer of weathered granite from the north-eastern side, and figure 3c shows the model of the granite deposit with a marked layer of weathered granite and tertiary and quaternary formations from the north-eastern side. What is more, recoverable resources of the deposit were calculated for the boundary of deposit roof defined at the level of +170 m a.s.l. taking deposit exploitation into consideration.

![Figure 3. Spatial models of Rogoźnica granite deposits executed within the frameworks of the research study [6]](image)

4. Study of land movements in vicinity of surface mine with satellite radar interferometry

The subject of another study based on geomatics has been an analysis of satellite radar interferometry and data from Sentinel 1A mission of the European Space Agency application to detect land movements within borders of surface lignite mine. The Turów mine located in SW Poland on the border with Germany and Czech Republic has been selected for this case study. Surface mining of lignite causes large scale changes of landscape, most of all development of open pit and waste dump. This kind of mining system is also responsible for transformation of local hydrographic network and hydrogeological conditions in result of mine drainage of open pit and its foreground. Removal of overburden and extraction of lignite deposit causes changes of stress distribution in the surrounding rock mass what results in continuous and discontinuous deformations.

One of the methods employed in this study has been DInSAR (Differential Satellite Synthetic-Aperture Radar Interferometry) that is used to determine land movements in the line of sight of satellite (LOS) in time between two subsequent SAR image acquisitions. In this method registered phase difference is used to calculate distance between sensor and earth surface. To remove topographic effect component of the phase digital elevation model (DEM) is used. For the Sentinel 1A satellite the accuracy of land movement determination, which is dependent on the wavelength (ca. 5.6 cm in this case), is estimated at several millimetres. The theory of DInSAR method can be found in...
[7]. In the tests two SAR images from 22-11-2015 and 04-12-2015 have been used. The map of displacements has been shown in figure 4. The maximum displacements calculated for a 2-week period range from -53 mm (subsidence marked in blue) to +44 mm (elevation marked in red). Subsidence has been detected in the area of waste dump in the open pit and on eastern slope of open pit (up to -18 mm). Subsidence has also been recorded in the area of revitalized waste pit located east of the mine (up to -8 mm). Elevation occurred in the region of mineral exploitation in the southern part of mine area. The obtained coherence coefficient values of above 0.45 (Figure 5) indicate good quality of results and dense set of points with registered displacements.

![Figure 4](image-url)

**Figure 4.** Land movements in Line of Sight for a pair of SAR images in the 22.11.2015 – 4.12.2015 period determined with DInSAR method

![Figure 5](image-url)

**Figure 5.** Map of coherence for a pair of SAR images in the 22.11.2015 – 4.12.2015 period, dark areas indicate low coherence, light ones indicate high coherence
The complete results of this study have been published in [8]. High acquisition frequency of SAR images for a pair of Sentinel 1A and 1B satellites (7 days) suggests that the proposed method can augment terrestrial measurements realized by surveying services of surface mines. Application of a combination of traditional and SAR methods gives access to reliable data describing geometrical movements of surface for the entire area of mine surroundings with high temporal and spatial resolution. In addition, it can serve as a source of information about phenomena that result in continuous and discontinuous deformations.

5. Management of the technical state of conveyors in a brown coal mine
A transport system plays a significant part in every mine. One of the most common is belt transportation. The most developed belt transportation system can be found in brown coal open-pit mines. Conveyor belts create there very extended systems of dozens of kilometres. Together with the progressing exploitation of useful mineral deposits, conveyor systems have to develop through increasing the number and length of transport paths. As the transport systems are getting developed, a number of used conveyor subsystems is increasing which may amount to several thousand components. Effective information management concerning such a great number of components involves great labour intensity, especially when it is done with a traditional circulation of documents. This also rules out the possibility of quick data analysis with regard to the components of the system. It is difficult to control the course of their operation and, in particular, the automatic prompting of the need to intervene when they reach the working time limit. Therefore, [9-10] has developed the concept of a system for monitoring and forecasting the technical condition of conveyors for Turów brown coal mines in GIS technology. The spatial layout of the system gives the operator the opportunity to analyse the wear and tear of components in connection with mine operations, locating breakdowns and abnormalities in conveyor operations. Planning activities at the mine site and the appropriate selection of conveyors with their matching to the existing transport system also takes place in space and facilitates the management of proper placement of components. Thanks to the spatial perspective, it is also possible to detect other objects nearby and assess the risk for other devices, machines and people nearby. The system enables analysis of the collected data to evaluate the correct arrangement of conveyors, conduct statistics, report development and results for mine workers. It is also important to be able to rationalize the mining process, which can reduce operating costs [11]. Figure 6 shows screenshots of the dashboard system proposed showing the activity status of conveyor belts operating in the mine site (Figure 6a), an interactive map showing the location of the conveyor being analysed against the background of each section (Figure 6b) with close-ups (Figure 6c), as well as an exemplary analysis of data concerning the search for modernized conveyor belts exceeding 500 m in length together with the report (Figure 6d).

6. Geoinformation system of post-mining structures and areas
Data and spatial information may be also used at the last stage of the life cycle of the deposit, i.e. at the time of its development and reclamation. The geoprocessing tools are used, for example, to support decision making related to the use of the excavation after mining [12], and spatial visualization can be used to present reclamation plans and to highlight the landscape values of developed post-mining areas [13].

An example of the use of geomatics as a solution for a sustainable management of the deposit and mining structures is the geoinformation system for the post-mining terrains and areas [14]. Such a system can function as an independent web portal or as an integral part of already existing geportals, constituting a component of the systems subject to the authorities at various levels: national, provincial or poviat. Geodatabase system designed structure contains: reference data, among others, roads, rivers and protected areas as well as thematic data including: DEPOSITS, MINES and the DIRECTION OF RECLAMATION.
The first two layers are point representation of the locations of deposits and mining plants with attributed qualities. In the case of the DEPOSIT layer the attributes are: identifier, deposit name, development status, mineral type, resource size, and MINES layer specifies data about: user of the deposit, operating system, mining volume. Layer of DIRECTION OF RECLAMATION shows the geometry of the reclaimed area together with the defined direction of reclamation. Data supplementation includes 3D visualizations, photographs and sketches of post-mining areas. The designed pilot version of the system was limited with regard to the territory and raw material, taking into account only areas after the exploitation of rock raw materials located within the borders of the Lower Silesian Voivodeship. System functionality includes basic tools for measuring distance and surface, scaling, printing, displaying attribute data and data searching, as well as editing and caching. The basic version of the portal does not exclude its extension.

It is envisaged that the portal would be useful for recording reclaimed structures. The main users of the geoinformation system would be local government units, which, thanks to the information obtained, will be able to streamline the decision-making and planning processes related to the reclamation of mines in their area. The system would be a source of information for authors of local tourist guidebooks. The additional users can be: research and development units, education system, business and private individuals.

7. Conclusions
The article presents examples of application of geomatics in opencast mining at various stages of the development of the deposit. The solutions concern: analysis of the availability of lignite deposits prior to the beginning of mining operations, monitoring of lignite mining operations using radar interferometry, modelling of the state of development of granite deposits from the beginning of exploitation to its completion with the proposal of post-mining area development, the concept of managing the technical state of conveyors in the brown coal mine and the project of the geoinformation system of the post-mining structures and areas after the exploitation of rock resources.
The presented examples of solutions are aimed at enhancing the efficiency of mining operations, and applied methods and tools as well as their applications demonstrate the usefulness and functionality of geomatics solutions, allowing for data collection, their effective processing and presentation. Further information on implementation of geomatics solutions in mining can be found in other publications of the authors.

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