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# SPACE TECHNOLOGIES OF EARTH REMOTE SENSING IN APPLIED PROBLEMS AND THEORETICAL STUDIES IN MINING

*This paper reviews scientific publications which enable outlining main research areas for practitioners and experts to handle large-scale applied problems in the global mining industry using different-time resources of satellite surveying. The main challenges for the theoreticians and practitioners to deal with in this respect are the factors of ecology, technology and geodynamics of mineral mining. The research embraces all biosphere and mineral envelopes of the Earth on all continents. Almost all problems have two stages of solution, namely, the processing/interpretation of images and imagery data and the analysis of the initial information with justification of specific recommendations to enhance efficiency of business entities in the mining industry.*

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## Introduction

The size of the open pit mineral mining output intensively grows recently on all continents of our planet. By the authors' estimates, the global surface mining operations handle not less than 90 billion tons of rocks. One of the development trends in the space technologies of the earth remote sensing is satellite observations and their usage in solution of numerous and different-scale applied problems in mineral mining. At the modern stage, the theoretical and applied research in this field needs systematization of the new knowledge acquired from solving of the applied problems in the mining industry using the satellite observations. The authors aim their analytical survey to specify ranges and factors of the efficient and reliable problem solving in open pit mining using space data. The reference sources are selected so that to represent the results obtained with the help of the latest achievements in the earth remote sensing.

## Remote sensing in applied problem solving in mineral mining

The pits, dumps and tailings ponds in open pit mining of solid minerals exist in continuous dynamics: their geometrical dimensions change, their slopes experience deformations, the ecological indicators of the mining areas and adjacent landscapes vary, etc. As practice shows, an effective tool of monitoring behavior of mining industry facilities is the remote sensing technologies.

In semiarid regions of open pit coal mining in China, the satellite survey-based monitoring of vegetation ecosystem had been carried out for 15 years. The ecological indicators were found to be decreased [1]. Between 2011 and 2018, in Inner Mongolia in China, the vegetation ecosystem monitoring was performed using satellite images. From the imagery interpretation evidence, it was concluded on the admissible rates of vegetation development on the slopes of dumps at open pit coal mines [2]. The remote sensing in 13 regions of Amazonia in Brazil found that the land area disturbed by open pit mining enlarged, which caused ecological concerns of the local population [3]. Based on the satellite survey data on mines in Eastern Amazonia, the forecast of the impact exerted by the extreme climatic phenomena on the logistics and performance of the mines, starting from mineral extraction and up to mineral shipment to a sea port was made up to 2050 [4].

In Russia, in the territory of the Irkutsk Region, the satellite images taken from 1985 to 2020 displayed the dynamics and the amount of work connected with forest regeneration on the surface of overburden dumps at open pit mines [5]. In the mining areas in the Russian Far East, the remote sensing data allowed determining the condition of vegetation in the mining-adjacent areas and on the surface of overburden dumps. It was suggested to estimate vegetation development using the index of phytomass volume [6]. In the Krasnoyarsk Krai in Russia, the satellite survey data served in the estimate of the vegetation ecosystem development in the area of overburden dumps of open pit iron-ore mining. The high-rate growth of trees and bushes was revealed on the East Sayan Mountains [7]. In the region of the Mufu Mountains range in China, the surface mining dynamics was assessed using the satellite data acquired between 1967 and 2019. The revealed trends in the vegetation development were suggested to be used in the open pit mine design and planning [8]. In the outskirts of Beijing, the 2000–2019 remote sensing data helped study recovering vegetation in the numerous open pit fields and on the surface of waste dumps. Apparently, the implementation of the environmental codes pushed mining companies toward ecological restoration activities [9].

Monitoring of pollution of ground surface (rivers, natural water bodies) due to open pit mining and because of mine water pouring out became possible thanks to the group of satellites Sentinel-1 and Sentinel-2 equipped with multispectral imaging radiometers [10]. In the Perm Krai, the area of closed coal mines is faced with a problem of pouring out of acid mine water in the water bodies on ground surface. Satellite monitoring informs on movement of different-quality water streams on ground surface [11]. Russian experts suggest to arrange continuous

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remote monitoring of changes induced in water bodies by mining and by other anthropogenic activities [12]. In Brazil, satellite surveys revealed silting of the large river Tapajós as a result of artisanal gold digging for 40 years. Moreover, intensification of gold mining increased concentrations of rock fines [13].

The detailed mapping of different minerals in hydrothermal alterations uses numerous sources of spectral data in the visible and near-infrared (VNIR) and short-wave infrared (SWIR) regions. Delineation of mineralization areas and solid mineral deposits involves information from satellites Landsat-8 and Sentinel-1, 2. Equipment is the advanced spaceborne thermal emission and reflection radiometer (ASTER) and space remote sensing systems WorldView-3 (WV-3). Remotes sensing data are processed using the band ratio technique and the principal component analysis. On different continents, including the Arctic region, remote sensing helps detect promising areas bearing ore containing zinc, lead, gold, copper, tin, tungsten, etc. [14–23].

In Greece, satellite images provided information about storages of bauxite processing waste. The information from the images was compared with the reflection power of samples with the pre-known concentrations of aluminum [24]. In the area of modern Oman, the satellite imagery showed the sites of mining operations in the last 50 years, as well as the ancient mining and metallurgy sites. The areas of old slag dumps are identified and mapped [25].

In Spanish areas of the mature mining industry, the radio interferometry and satellite tracking in combination with 2D modeling discovered deformation-hazardous sites on the slopes of pitwall and tailings dams. The developed approach proved its high efficiency [26]. Estimation of ground surface subsidence caused by underground mining of potash in the Perm Kari in Russia used the data from synthetic-aperture radars RADARSAT-2 and Sentinel-1. The studies were carried out within a flooded mine under the residential area of Berezniki town [27]. For the mine closure phase, in line with the current measurement standards, the relevance of the radio interferometry and satellite tracking within the integrated monitoring of undermined area deformation was validated [28].

During coal mining, oxidation of coal in contact with air often results in uncontrolled combustion. Fires occur in coal mines and in open pits, and in coal storage yards. Remote monitoring highly accurately determines an increasing temperature at such facilities. Fire forecasting uses long-term time series of high time-resolution satellite images from such devices as an advanced medium resolution spectrum radiometer and a set of radiometers for visible and infrared visualization. These remote sensing devices allow revealing coal fires [29–32].

The recent years have laid foundation for R&D in the sphere of the remote sensing techniques in the evaluation of the production potential of mines (open pit mines). Also, researchers perform feasibility studies of the environmental aspects in open pit mining of solid minerals [33–35].

It is suggested to use satellite survey data in classification of areas adjacent to open pit coal mines by the criterion of coal dust spread [36]. Drilling and blasting, and excavation and haulage of coal and overburden inevitably results in formation of an abundance of very fine particles spread with atmospheric air motion. Pollution of the adjacent natural landscape is revealed using the satellite imagery. For example, such analysis of vegetation cover pollution was undertaken in the area of open pit iron-ore mining in China with a view to making appropriate environmental decisions [37].

**Critical application areas of remote sensing data toward applied problem solving in global mining industry**

| Application area in mining | Reference sources |
|---|---|
| Mineral production ecology. Long-term monitoring of vegetation ecosystem formation and mining-induced water pollution | [1–13] |
| Exploration of mineral-bearing sites and occurrences. Assessment of useful contents in processed ore in storage. Searching of ancient underground mines | [14–25] |
| Prediction and estimation of deformations of slopes and walls in surface and underground mines, at overburden dumps and at tailings dams | [26–28] |
| Detection of surface and underground fires in mines | [29–32], |
| Evaluation of performance efficiency of mines, environmental and economic analytics | [33–35] |
| Estimation of dusting and dust spread in open pit mining | [36, 37] |
| Spotting gas emission in mines and at mining facilities, methane air emission control | [38–40] |
| Legislation in mining. Detection and sizing of illegal mineral mining | [41–43] |
| Setting and solving of integrated problems in different business areas of mining industry | [44–48] |

Methane as a greenhouse gas contributes to global temperature increase. In this respect, it is necessary to spot places of methane emission in the mining industry. Using high resolution imagery Google Earth and a thermal imaging camera (FLIR GF320) allowed detecting methane leakages in shale gas production and processing [38]. Another research came to a conclusion on the expediency of using Sentinel-2 imagery with 13 spectral bands in methane release search during open pit coal mining [39]. Methane emission control with remote sensing in six coal mines in Queensland in Australia disclosed some facts of garbling of details fed to supervisory authorities on actual methane emission size (understated estimates) [40].

In the recent years, the remote sensing techniques enjoy more often application in detecting illegal mining sites. Such sites of artisanal digging of minerals were found in great numbers in the Philippines. And the problem the experts were faced with arose when the size of a site coincided with the pixel size in the images. Eventually, they calculated surface areas corrected to a fixed error. As a result, the total area of illegal surface mining was determined [41]. For the countries of the Asia–Pacific Region, a method was proposed to find the illegal digging sites of minerals, sand and topsoil using the remote sensing data sources. The method used hybrid spatial pyramid pooling (HSPP) to get multiscale structural complications in the images [42]. The feasibility of the approach to tracking boundaries of common mineral mining lies upon the techniques of an object perimeter tracking and coding in a black-and-white image. This technique with the description of presuppositions calling for triangular and hexagonal lattices to be used in the space imagery processes builds on heuristics [43].

In the southwest of Ghana, the satellite surveys revealed natural landscape degradation because of numerous and illegal gold mining sites (open pits). The satellite data enabled closing the unlicensed businesses [44]. For the area of the Kola Peninsula in Russia, the satellite observations helped classify the changes in vegetation cover of natural landscapes under the impact of dust spread during gabbro–dolerite quarrying for broken stone production. The spectra of snow cover in winter and plant formation in summer were analyzed [45]. In the Panjshir Valley in Afghanistan, the satellite information assisted in the analysis of changes in ground surface topography for mapping emerald-bearing areas, recommending on emerald extraction improvement by uniting small mining sites into highly mechanized production facilities, as well as for detecting and controlling small artisanal digging sites [46].

Ecuador performed underground mining of gold since the pre-colonial period, including operations inside the limits of urban settlements. At the present time, ground surface above underground mines subsides, and houses ruin as a result in the city of Zaruma. It is proposed to monitor initiation and progression of ground deformation by combining Sentinel-1 imaging and interferometry synthetic aperture radar (InSAR). The detected initiation of ground surface subsidence by the remote sensing points at unlicensed underground gold mining as well [47]. The present-day remote sensing solutions laid the foundation for the applied research of vegetation formation on mining-disturbed land and for the greenhouse gas emission assessment during operation of mining and haulage machines in open pits [48].

The review of the selected reference sources and the analysis of the applied problems dealt with by the mining industry with the help of the remote sensing technologies and satellite survey data identifies 9 critical areas of professional activities in this sphere (Table). These areas are promising in terms of improvement and advancement of the remote sensing equipment and applied problem solving procedures in the mineral mining industry. The present paper's authors think the listed research areas should co-develop and represent an integral system including creation and enhancement of optical instruments, thermal imaging cameras and other equipment, as well as team-working of expert practitioners in cosmic machine engineering and in mineral mining.

### Conclusions

The review of scientific publications has outlined the main activity areas for experts engaged in handling large-scale applied problem in the global mining industry using the advanced satellite surveying resources. The challenging problems are anticipated to arise in the nearest future in the sphere of ecology, technology and geodynamics of mineral mining. Furthermore, the review shows that the remote sensing-based research embraces all biosphere and mineral envelopes of the Earth. Almost all problems have two stages of solution, namely, the processing/interpretation of images and imagery data and the analysis of the initial information with justification of specific recommendations to enhance efficiency of business entities in the mining industry.

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