REMOTE SENSING APPLIED IN MINING SECTOR

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ABSTRACT

We will discuss in this paper about how remote sensing methods are used in mining domains, doing reference at minerals, geology, soil, topography, land cover and vegetation, water and groundwater and mine contamination. There are a lot of methods used for exploration are airborne and ground based geophysical methods, such as magnetic, electromagnetic, gravity, radiometric and seismic investigations to map the subsurface geology; multispectral and hyperspectral airborne and satellite remote sensing can provide valuable information about the surface mineralogy and geology.

Detailed knowledge of the surface topography or the change in surface topography is important in several aspects of the mining sector. Mapping and monitoring of vegetation around mine sites is important in all phases of mining, from mine planning to mine closure and rehabilitation. Vegetation maps are often required. Knowledge of surface and ground water pathways is also important in and around mining areas. Ground water can to some extent be mapped with optical remote sensing techniques. A common type of contamination caused by mining is acid rock drainage.

Keywords: detailed topographical maps, remote sensing, mine contamination, rock drainage, vegetation maps

INTRODUCTION

A plus of many remote sensing methods from satellite, aircraft or ground based is that information can be acquired in 2D or 3D and can therefore help to interpolate traditional point based measurements. Optical remote sensing can be used for a wide range of requests that can be appropriate for the miningsector. Both during planning of new mine sites, during mine operation and after mine closure, remote sensing methods can be used to obtain necessary information, monitor changes and monitor effects ofconducts.

MATERIAL AND METHODS

We will discuss in this paper about how are used remote sensing methods in mining domains, doing reference at minerals, geology, soil, topography, land cover and vegetation, water and groungwater and mine contamination.

Exist a lot of methods used for exploration like: airborne and ground based geophysical methods, such as magnetic, electromagnetic, gravity, radiometric and seismic investigations to map the subsurface geology; multispectral and hyperspectral airborne and satellite remote sensing can provide valuable information about the surface mineralogy and geology.

Detailed knowledge of the surface topography or the change in surface topography is important in several aspects of the miningsector. During the planning period there may be requirements to document the original surface in order to identify and monitor changes during the operation of the mine.

Detailed surveying maps and 3D models that can be derived from these, can be used to study geomorphological and hydrological features.

Mapping and monitoring of vegetation around mine sites is important in all phases of mining, from mine planning to mine closure and rehabilitation. **Vegetation maps** are often necessary during the planning phase to assess the biodiversity in the area, assist in determining the best location of the mine structures, and to establish a base line to assess possible environmental impact.

It is a long history of using satellite and airborne optical remote sensing for local, regional and global **land cover mapping** and it is the ideal method for mapping the spatial distribution of different **vegetation** types and for detecting and mapping changes over time. **Remote sensing based vegetation mapping** is based on the difference in spectral reflectance characteristics of the different plant species and vegetation communities.

Remote sensing is used to quantify and monitor **water** quality by estimating water quality parameters, such as suspended sediment concentration, chlorophyll concentration (indication of algae and eutrophication), dissolved organic matter (DOM), salinity or water temperature. Heavy metal pollution in water cannot usually be detected by remote sensing directly, but it has been shown that it can be estimated indirectly to some extent.

Information about surface and **ground water** pathways is also important for the water management in and around mining areas. Ground water can to some extent be mapped with optical remote sensing techniques. Information on surface water pathways can be obtained through general land cover mapping. A common type of **contamination caused by mining** is acid rock drainage.

RESULTS AND DISCUSSIONS

Remote sensing in exploration is is used in the geological science as a data acquisition method correspondent to field observation because it allows mapping of geological characteristics of regions without physical contact with the areas being explored. Remote sensing is conducted via detection of electromagnetic radiation by sensors.There is a long history of using remote sensing methods for exploration. The most common methods used for exploration are airborne and ground based geophysical methods, such as magnetic, electromagnetic, gravity, radiometric and seismic investigations, to map the subsurface geology.

Multispectral and hyperspectral airborne and satellite remote sensing can provide valuable information about the surface mineralogy and geology, which can be an indicator for subsurface geology and presence of ore bodies.

The technique is based on the characteristic absorption features in the spectrum for the different minerals or mineral groups. Particularly, bands in the short wave infrared Short-wave infrared (SWIR) are useful to distinguish between mineral groups. Some of the main features that can be distinguished are related to iron bearing minerals, clay minerals, carbonates, sulfates and micas. Mineral contents can be quantified by comparing the data to known spectral features of minerals and spectral unmixing methods.

The same methods used for geological and soil mapping can be used to detect mineral contamination in soils and mine tailings. Many applications have shown that remote sensing in particular hyperspectral remote sensing in the VNIR-SWIR range (400-2500 nm) can be used to quantify various soils. As minerals or mineral groups have specific spectral features, there is a potential to use these features to map concentrations in the soil. There are reviewed remote sensing methods to estimate plumb concentrations in soil and to explain that remote sensing can be a useful tool for this purpose. Other studies have demonstrated significant correlations between spectral features and concentrations of various heavy metals. After calibration with field measurements, remote sensing can produce maps that show the spatial distribution of estimated heavy metal content. The main satellites that are commonly used for geological mapping are **ASTER, Landsat, Hyperion, Sentinel 2 and WorldView 3**. Airborne hyperspectral instruments give superior results because of the higher spatial and spectral resolution and spectral range.

An important challenge for using optical remote sensing for the mapping of surface mineralogy is the presence of lichen, particularly in Arctic regions and vegetation. When the vegetation only partially covers the soil or rock surface, the measured reflectance is a mixture of the reflectance of the vegetation and that of the soil. Through spectral mixture analysis, it may be possible to distinguish the contributions of the different land cover classes and extract information from the soil component. It can be used airborne hyperspectral data and spectral mixture analysis to quantify the degree of mine pollution: acid rock drainage, around a closed copper or zinc mine, in order to monitor the rehabilitation process. There are used airborne hyperspectral data and spectral mixture analysis to map rock types associated with nickel and copper mineralisation in country as Canada where lichen cover is abundant.

Detailed knowledge of the surface topography plus the change in surface topography is important in different aspects of the mining sector. During the planning phase there may be requirements to document the original surface in order to identify and monitor changes during the operation of the mine.

Detailed topography maps, and 3D derived models can be used to study geomorphological and hydrological features, which can help to optimize mine planning and minimize environmental impact. During the operational phase, topography maps and 3D models can be used to study geomorphological features and assess mineral resources. The volume of rock that has been removed can for example be estimated from the change in surveying between 2 measurements. Slope geometry can provide information about changes in erosion and sedimentation processes and soil properties. For example it can be analysed geomorphological features in a 3D model of an open pit mine to assess the risk of slope failure and track the change in mine extent.

Tailing dams are mine structures and failure can lead to considerable environmental damage. It is therefore important to correctly estimate the pressure or stress of the deposited sediment on the retaining dams, such that the width and height of the dams is always sufficient in order to avoid failure. The pressure on the dam depends on a number of parameters, including the volume of the sediment, surface topography, soil moisture content and grain size.

In completation to conventional methods of surveying, which are often laborious and require access to the site, two methods are most used:

1. Laser scanning or LIDAR (Light Imaging Detection And Ranging), either ground-based or terrestrial laser scanning (TLS) or airborne laser scanning (ALS);
2. Photogrammetry from manned or unmanned aircrafts (Figure 5).

It is possible to derive a digital elevation model from very high resolution stereo satellite imagery, such as WorldView or SPOT.

ALS and TLS create a detailed 3D point cloud model of the surface and are now widely used to create detailed digital elevation models, replacing photogrammetric methods.

An important plus of ALS is that it is possible to filter out vegetation such that the ground surface and structures underneath the vegetation can be precisely mapped.

A minus is that it generally requires expensive and relatively heavy equipment and a manned aircraft TLS, because some smaller instruments are now becoming available.

A low cost photogrammetric technique, named Structure from Motion has become popular for detailed topographical mapping of smaller and or remote areas. Technique uses methods from computer vision to match features in a series of overlapping photos from standard digital cameras to create a high resolution digital elevation model DEM. (Figure 5).

The technique was originally developed in the 1990's, but its use for mining applications has increased enormously in the last few years with the increasing availability of low cost unmanned aircrafts and good quality low cost digital cameras.

It can be demonstrated that the method can be used with photos taken by an unmanned aircraft to create detailed DEMs and map topographic change, by mapping the displacement in a landslide in Mintia City, Hunedoara County, Romania.

Several studies have compared the precision of the different techniques and found that DEM created by Structure from Motion are comparable within centimeters to those created by laser scanning in non vegetated areas.

However, in vegetated areas, laser scanning is able to obtain a model of both the ground surface underneath vegetation as well as the top of the vegetation surface, while Structure from Motion will give very limited information about the ground surface underneath vegetation.

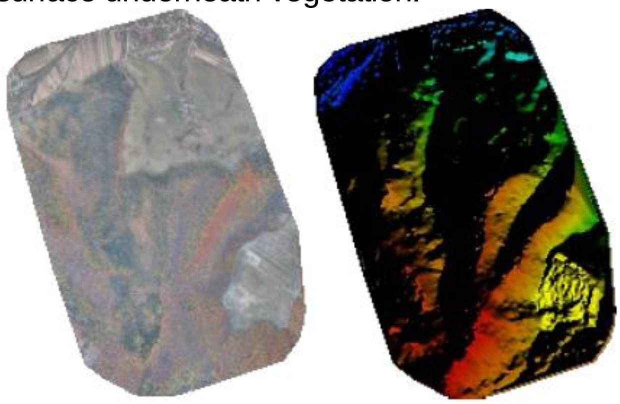

Figure 5: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before sensification derived from drone-based images using Postflight Terra 3D powered by PIX4D in Mintia area, Hunedoara county.

Mapping and monitoring of vegetation around mine sites is important in all phases of mining, from mine planning to mine closure and rehabilitation. **Vegetation maps** are often required during the planning phase to assess the biodiversity in the area, assist in determining the best location of the mine structures, and to establish a base line to assess possible environmental impact. During operation of a mine, monitoring of the vegetation can reveal contamination, like caused through leakage, dam failure or spreading of dust, and other environmental effects of mining activities. After mine closure, vegetation recovery and health can be used as an indicator to assess the results of mine rehabilitation, or to detect and monitor remaining contamination.

There is a long history of using satellite and airborne optical remote sensing for local, regional and global **land cover mapping** and it is the ideal method for mapping the spatial distribution of different **vegetation** types and for detecting and mapping changes over time. Remote sensing based vegetation mapping is based on the difference in spectral reflectance characteristics of the different plant species and vegetation communities. These spectral characteristics are determined by the leaf pigments (chlorophyll, carotene etc.), the leaf structure, the water content in the leaves, and the overall structure of the plant, tree or vegetation community (leaf size, density, etc.). Although it is usually not possible to map individual plants, it is possible to distinguish vegetation types, like different forest types (pine, spruce, larch, and birch), different heather types or grasslands.

Remote sensing of vegetation utilizes mainly electromagnetic radiation from visible and infrared bands. Due to absorption of red and blue light for photosynthesis and high reflectance of infrared light by spongy mesophyll, vegetation can be distinguished on remotely sensed image by means of mathematical operations yielding so-called Vegetation Indices, e.g. **NDVI.**

Vegetation Indices are significantly correlated with percentage vegetation cover, crop yields and plant vigor. In remote sensing of vegetation various sensor types are used: aerial photos or satellite images provide different scale of spatial and spectral detail, hence they are used in different types of studies. Remote sensing and GIS are powerful tools for vegetation mapping, environmental protection management and many other applications.

Remote sensing can be used to detect and map vegetation stress. Vegetation stress appears when an unfavourable condition or substance affects a plant's metabolism, growth or development. Stress conditions include water shortage or excess, low or high temperatures, insects and bacteria; substances that can cause stress include pesticides, air pollution, mineral deficiency, heavy metal pollution and acid rain. Vegetation stress causes changes in leaf pigments and leaf and plant structure, and can lead to stunted growth, changes in vegetation type and plant death. These changes affect the reflectance spectrum and can therefore be detected with optical remote sensing. Surveyors have developed many different vegetation indices that relate to the health of vegetation, such as the Normalised Difference Vegetation Index (Figure 6), which is based on the normalized ratio between NIR and red. Vegetation indices have been used to map vegetation stress due to heavy metal pollution near a zinc factory and a talc mine using airborne hyperspectral data.

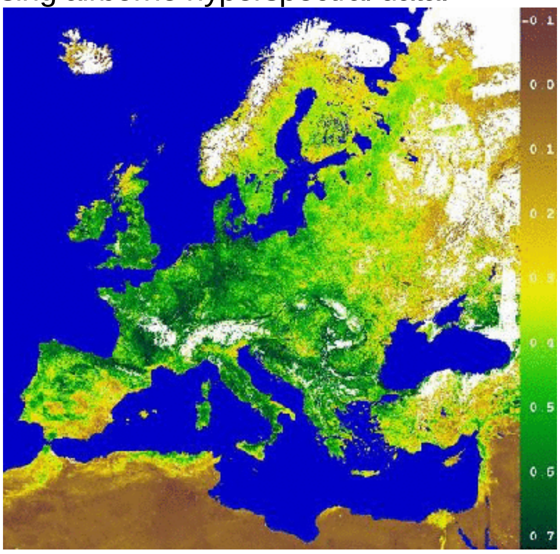

Figure 6: Example of NDVI in Europe

The presence of toxic materials, such as heavy metals, in the soil can affect the health of the vegetation. This vegetation stress can result in a change of the spectral signature of the vegetation and can therefore be detected through spectral analysis. The changes are subtle and high spectral resolution, for example hyperspectral imagery, is usually needed to detect them. One of the effects of vegetation stress is a change in the amount of chlorophyll and the chlorophyll a/b ratio in the leaves. Other effects can be a change in particular absorption or reflectance features in the spectral signature, and in some cases specific wavelengths can be used to correlate directly with, for example, metal or nitrogen concentrations in the vegetation or soil. There are results of a number of researches that have shown spectral changes in vegetation as result of exposure to or uptake of various heavy metals and metal sulphide, and show that the ability to measure stress effects from heavy metals is dependent on species, the phase of the growth cycle and the environment.

Soil contamination can have several different stress effects on the vegetation that may be able to be detected by remote sensing. 1. Taxonomic modifications: the stress can change the vegetation type and the presence or absence of plant species: depending on the type of contamination, some species will not survive, while others are able to adjust or even thrive. Some species depend on the presence of certain minerals in the soil and can even be used as an indicator of copper or selenium. Spectral differences between plant species permit the possibility of distinguishing different vegetation types and identifying changes. 2. Structural modifications: vegetation stress can alter the appearance of the plants and cause growth abnormalities. 3. Spectral contrast: a change in the spectral signature as result of exposure to contamination. Relationships have been identified between spectral features and concentrations of heavy metals or radionuclides in the soil.

Remote sensing is used to quantify and monitor **water** quality by estimating water quality parameters, such as suspended sediment concentration, chlorophyll concentration: indication of algae and eutrophication dissolved organic matter DOM, salinity or water temperature. Heavy metal pollution in water cannot usually be detected by remote sensing directly, but it has been shown that it can be estimated indirectly to some extent. The reason for this is that heavy metals in water are either absorbed by suspended sediment, bonded to DOM, or taken up by algae, and these water quality parameters can be measured by remote sensing. Therefore, combining field measurements of water quality parameters and concentrations of heavy metals associated with suspended sediments, DOM or algae with remote sensing analysis can give an estimate of the spatial distribution of the pollution and the changes over time.

Typical sensors that are used are satellite or airborne multispectral and hyperspectral sensors.

In Arctic regions, monitoring the evolution of the snow cover, such as the duration of the snow cover, snow thickness, the snow water equivalent and timing of snow melt, is important for hydrological modelling and assessment of the potential water in flow. To be able to estimate the water flow can assist mining companies with the water management in the mining area. Snow cover can be mapped using optical satellite data, such as **MODIS**, and commercial satellite based snow cover mapping services are available.

Knowledge of surface and **ground water** pathways is also important for the water management in or and around mining areas. Ground water can to some extent be mapped with optical remote sensing techniques. Information on surface water pathways can be obtained through general land cover mapping, as hydrological features are often related to certain land cover types. In Arctic alpine areas, permafrost is also an important influence in hydrological processes and changes in permafrost distribution can affect the water pathways. Difference between some of the land cover types based on optical satellite imagery analysis alone can be problematic. Land cover types of interest may be small and fragmented and may be spectrally similar to each other, which means that very high resolution multispectral satellite data (Ikonos, WorldView with 0.5-2 m resolution etc.) is likely to be necessary and additional information such as geomorphological features (slope, aspect, surface roughness) that can be derived from a detailed DEM may be useful.

While groundwater flow cannot generally be mapped using optical remote sensing, the upwelling of groundwater and the inflow of groundwater into surface water can be detected and quantified due to the temperature differences between groundwater and surface water at certain times of the year.

Temperature differences can be measured using handheld or airborne Thermal infrared cameras (Figure 7), measuring the spectrum between 8 and 14 am.

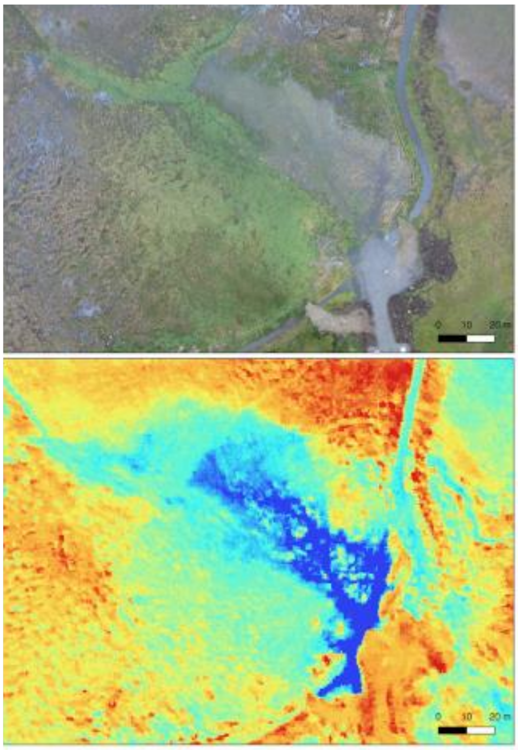

Figure 7: Drone-based normal colour photos (top) and TIR images (bottom) of wetlands Temperature differences in the TIR images show possible groundwater upwelling as indicated by colder

temperatures (blue colours). This is not visible in the normal photos

Satellite-based TIR sensors have a spatial resolution that is too low to be useful for mining applications. The same method may be able to be applied on the detection of leakage from mine tailing ponds: at certain times of the year there is likely a temperature difference between contaminated water leaked from tailing ponds and surface waters.

A common type of **contamination caused by mining** is acid rock drainage. This can cause environmental damage long after a mine is closed. When sulphide minerals are exposed to air and water, oxidation of the sulphide minerals leads to the formation of sulphuric acid.

The acid reduces the pH in the water, which increases the dissolution of heavy metals in water and therefore the leaching of heavy metals from the host rock or sediment. The result is that water draining from sites with sulphide minerals is acidic and is often contaminated with heavy metals such as arsenic, copper and lead; this is called **acid rock drainage** ARD (Figure 8).

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Sulphide minerals occur naturally and acid rock drainage is a natural process, but as most metal ore deposits and some coal deposits are rich in sulphide minerals, mining, quarrying and construction works significantly increase the exposure of sulphide minerals to air and water. The environmental impact of acid rock drainage can be considerable: the increased acidity and toxicity, because of the dissolved heavy metal content, when acid rock drainage is discharged into rivers and lakes can have negative effects on aquatic life and vegetation. Because of the negative effect on vegetation, acid rock drainage can reduce the effect of rehabilitation of mines after closure.

Figure 8: Examples of acid rock drainage: *The acidic red water is a result of rain and springwater running through the minerals exposed by the mine, Village of Geamana, Romania*

One think of preventing or controlling acid rock drainage from operational or closed mine sites is to minimise the oxidation process by reducing exposure to air, by storing waste under water or by flooding and sealing underground mines. Good understanding of the hydrology around the mine sites is important in order to control the water pathways in and out of the mine site and prevent contamination of ground water. Other prevention techniques include neutralizing the acidic water, biological or chemical treatments, and covering the sulphide-rich rock or sediment.

Geamana is one of Romania’s greatest ecological disasters, surpassed only in 2000 when a gold mine in Baia Mare in the north of the country spilled an estimated 100 tons of cyanide into a river. The latter incident was described as Europe’s worst environmental disaster since Chernobyl (figure 9).

Figure 9: Acid mine dranaige, Village of Geamana, Romania

Remote sensing techniques can be used to detect, map and monitor the extent of acid rock drainage **and** the effect on the environment in and around mine sites, and can contribute with additional information to help control acid rock drainage and monitor the efficiency of rehabilitation measures. It can be show the possibility of using airborne hyperspectral imagery combined with field spectral measurements to classify the degree of acid rock drainage pollution at a mine site using the negative effect of the pollution on vegetation, and the possibility to map Fe bearing minerals. It can be demostrated the use of very high resolution WorldView 3 satellite imagery to map mine tailings and acid rock drainage from small abandoned mines in an alpine environment (Figure10).

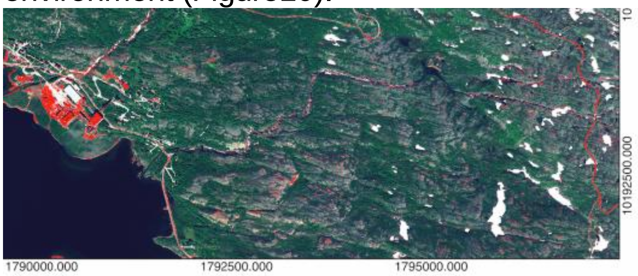

Figure 10: Mapping of mine tailings and ARD using WorldView-3 satellite imagery with spaţial resolution of 2,5 m

CONCLUSIONS

Remote sensing represent the acquisition of information about objects or areas from a distance, that is, where the sensor is not in direct contact with the object. The sensors can be based on space borne: satellite or airborne platforms: manned or unmanned aircraft system, but they can also be ground-based: handheld or mounted on a tripod. Remote sensing makes use of electromagnetic radiation and generally involves an interaction between the incident radiations: illumination by the sun and the object or area of interest. Incident radiation can be absorbed, transmitted or reflected by the object, and the amount and spectral signature of the reflected radiation that is measured by the sensor provides information about the material properties of the object: chemical composition, surface roughness and internal structure. Remote sensing is very usefull for mining domain, even there are some challenges regarding of optical remote sensing like cloud cover and atmospheric interference. As optical remote sensing measures the amount of reflected sun light, cloud cover will (partially) block sunlight reaching the earth's surface as well as reflected light reaching the satellite. Cloud cover will also affect the amount of shadow. The atmosphere is not constant (the amount of moisture in the air) and correcting for the atmospheric interference is not always straightforward. Atmospheric correction is particularly important when comparing data from different dates or when comparing satellite or airborne data to ground data.

Two short definitions of Remote Sensing might be presented as follows: “To study or measure an object without being in physical contact with it” or “feeling without touching”. The term generally implies that the sensor is placed at some considerable distance from the sensed target, in contrast to close in measurements made by "proximate sensing." Remote sensing means aerial photography too. Aerial platforms are primarily stable wing aircraft. Aircraft are often used to collect very detailed images and facilitate the collection of data over virtually any portion of the Earth's surface at any time. The scale and quality of the data collected is affected by several factors including, but not limited to, altitude of the aircraft, position of the plane, and the quality of the photographic equipment used.

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