Detection of Spectral Changes over Sokolov open-pit mine areas, Czech Republic, using multi-temporal HyMAP Data (2009-2010)

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Among the environmental hazards created by mankind, mining activities are of serious and immediate impact for its local surrounding. Formation of sinkholes, loss of biodiversity, dust, erosion, contamination of soil, groundwater and surface water by chemicals from mining processes are some of the harmful effects that are observed in these areas. Mining areas are of the most rapidly changing areas on earth. The obvious changes are caused by extraction of soil and placement in waste dumps. This causes changes in terrain altitude, top soil components, mineralogical alteration by exposing deep compressed minerals to air, water and wind. Other changes can be seen such as urban changes resulting from employment opportunities related to the mining industry. Detecting and analyzing these various changes using hyperspectral imaging, is of major importance.

Two HyMap images acquired over the same lignite open pit mining site in Sokolov, Czech Republic, during the summers of 2009 and 2010 (12 months apart), were investigated in this study. The site selected for this research is one of the three test sites (besides one in South Africa and another one in Kirgizstan) where research is being carried on within the framework of the EO-Miners FP7 Project (http://www.eo-miners.eu). The goal of EO-MINERS is to "*integrate new and existing Earth Observation tools to improve best practice in mining activities and to reduce the mining related environmental and societal footprint*". Accordingly, several change detection algorithms were applied, compared and evaluated for their ability to track changes between the two over flights. Two hyperspectral data cubes were atmospherically corrected and the reflectance images were used as an input to apply the change-detection algorithms.

Fig. 1- Images of two hyperspectral data cubes which were analyzed.

The hyperspectral data cubes were atmospheric corrected and geo-referenced, using GPS/INS data and ground control points, to obtain a complete geo-matching. A subset from each image, containing the lignite mine, was selected and analyzed.

Fig. 2- The two geo-referenced subsets with an overlapping area (outlined with dotted red line).

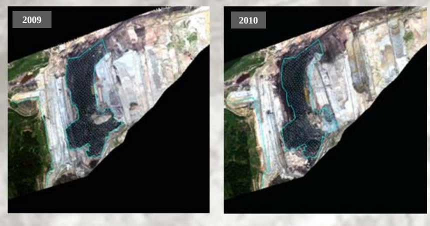


Fig. 3- The progress of mining is emphasized by bounding the exposed lignite area and marking one of the mine's margins (cyan lines).

The Spectral Angle Mapper algorithm was applied to each of the two subsets, with a Cyprus clay spectrum (measured in the field using an ASD spectrometer) as the endmember (reference) spectrum.
The resulted rule maps (Fig. 4) were analyzed. The difference in the angle value of each pixel between the two acquisition dates of the over flights represents the spectral change occurred in the pixel.
Dividing the two rule maps results with values representing the degree of the spectral change in each pixel (Fig. 5).

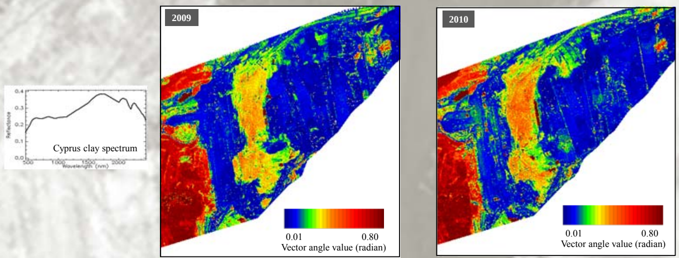


Fig. 4- Rule maps of the two subsets. The spectral similarity between each pixel's spectrum and the Cyprus clay spectrum is determined by the vector angle value of each pixel namely, smaller angle value represents higher similarity.

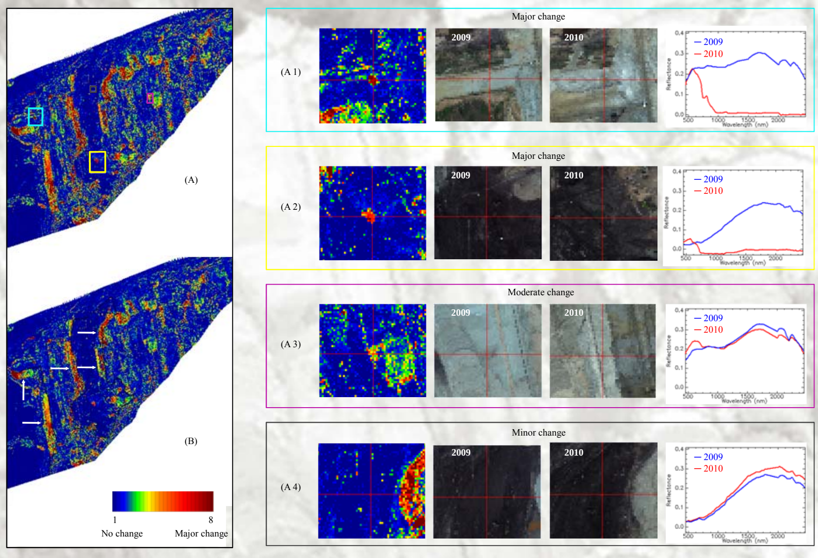
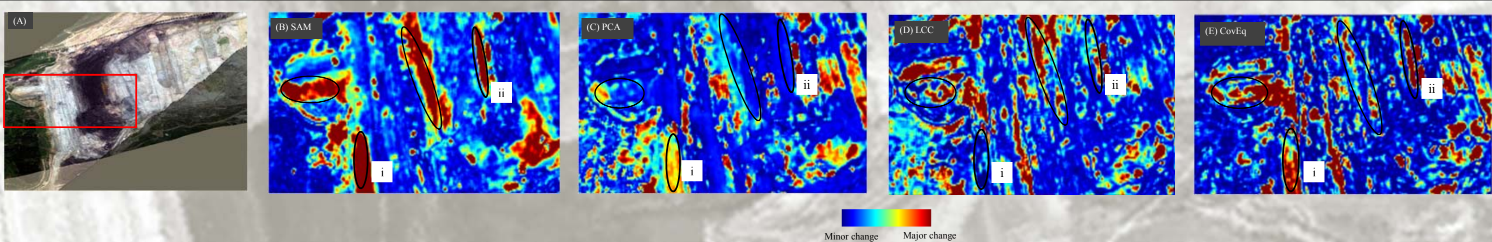


Fig. 5- Division map emphasizing the pixels in which spectral changes occurred. Examples of spectral changes are shown: (A1) from clay to water, (A2) from lignite to water, (A3) different clay condition, (A4) minor change. White arrows in (B) point to changes due the progress of mining mentioned in Fig. 3.

Several change detection algorithms were applied to a small subset, compared and evaluated for their ability to track changes between the two over flights. Some of the most common and leading change detection algorithms in the field were chosen: simple Spectral Angle Mapper (SAM) between the two images (Yuhas et al. 1992, In *Summaries of the Third Annual JPL Airborne Geoscience Workshop*, p. 92–14), PCA (Wiemker et al. 1997, In *Proceedings of the Third International Airborne Remote Sensing Conference and Exhibition.*, p. 640–647), Linear Chronochrome (LCC) (Schaum and Stocker 1997, In *Proceedings of the International Symposium on Spectral Sensing Research*), Covariance equalization (CovEq) (Schaum and Stocker 2004, In *Proceedings of SPIE*, p. 77).



SAM: The angle between two corresponding vector-pixel of the two images that relate to the same geographic location was calculated. Large angles indicate significant change and small angle values minor changes.

PCA change detection: PCA is based on the eigenvectors of the covariance matrix of the data set (in our case IS data). These eigenvectors are ordered in descending order according to the eigenvalues. The eigenvectors' matrix is used to project the data into a new coordinate system where the new axes are the eigenvectors. In the case of change detection, the PCA procedure is performed at each band over pairs of pixels from the two images. The result for each pixel is two values; one is the projection on PC1 (represents no change) and the other on PC2 (represents change if high value). After the PCA procedure is applied to all bands the angle between the resulting vector of each pixel and the mean vector of the PC2 entire image is computed.

Linear Chronochrome (LCC): This algorithm is based on a linear transformation from one image to another, where the mathematical solution is given by minimizing the transformation error in terms least squares error (LSE). This method is optimal in that sense, assuming no geo-rectificaion error. After applying the linear transformation, RX anomaly detector is applied to reveal the changes between the two images.

Covariance Equalization (CovEq): Similar to LCC this method is based on a linear transformation followed by RX anomaly detector. The attempt of the solution of the linear transformation here is to bring the covariance matrices to be as close as possible. That is, make the statistical properties as close as possible. This method is said to be resistant to geo-rectification errors.

Fig. 6- (A) The subset to which the change detection algorithms were applied, (B-E) the algorithms, The ellipses in (B-E) outline the areas changed due to the progress of mining, as mentioned in Fig. 3.

The applied change detection algorithms show different performance regarding the degree of spectral changes occurred in different areas, even with major changes, as exampled in Fig. 7 for two areas. Fig7(A) indicates the extension of the mining area to the west on the edge of the mine, these changes were detected with SAM, PCA, CovEq (area i in Fig. 6 B,C,E) with different levels of intensity but not with LCC (Fig. D). Fig7(B) indicates the same extension trend with movement of water ponds to the west, these changes were detected with SAM, LCC, CovEq (area ii in Fig. 6 B,D,E) with different levels of intensity but not with PCA (Fig. 6 C).

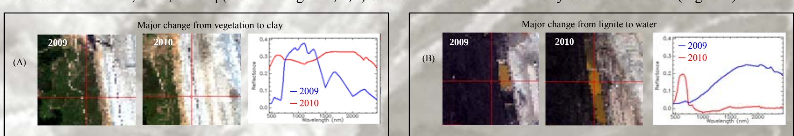


Fig. 7- Examples of spectral changes for two areas.

The change detection algorithms were successfully applied to the two Sokolov over flights data. The various change detection algorithms perform differently over the same data. We analyzed the ambiguity between the various methods by comparing the spectral signatures of the two images and showed misdetection of changes in some of the algorithms while others successfully highlighted them. Among these changes some were invisible to the naked eye.

Further research is planned to detect significant spectral changes and the capability of revealing mineral processes and soil formation. Further study in this direction is being conducted under the above mentioned initiative in order to extend this approach to other mining areas worldwide.

THE REMOTE SENSING LABORATORIES

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