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Preliminary Results of Displacements Monitoring from Radar Interferometry in the Area of "Kazimierz-Juliusz" Coal Mine

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SUMMARY

In this paper the analysis of satellite radar interferometry data (PSInSAR data) was presented. These data concern mining area of Kazimierz-Juliusz coal mine and they supply information about small, long-period surface displacements, which occur there. PSInSAR data have been compared with conventional leveling, GPS and InSAR data. They were also compared with locations of the exploitation fields. Paper provides basic information connected with technique of the radar scenes processing (PSInSAR) and presents description of the available PSInSAR data as well as characteristic of Kazimierz-Juliusz mining area.
Introduction

Subsidence is a kind of deformation of the surface which can involve both small and long-period movements and large displacements over short period of time. Subsidence occurs over the whole world and it can be caused by many different factors. One of these factors is mining activity. Underground exploitation has great impact on surface stability. In order to enlarge safety the permanent monitoring of the mining areas has to be performed. Measurements of the deformations can be done using many different methods. The choice of the method depends on the scale and periods of subsidence and also how hazardous the environment is.

In this paper the deformations of the surface in the area of “Kazimierz-Juliusz” coal mine have been presented. The measurements, which have been obtained using classical methods (leveling surveys, GPS, satellite interferometry InSAR) have been complemented by PSInSAR (Permanent Scatters Interferometry Synthetic Aperture Radar) data which derive information about small, long-period ground deformations. As it has been presented in this work (on “Kazimierz-Juliusz” coal mine example) PSInSAR data in substantial manner enrich conventional methods of displacements measurement. Connection results obtained with different methods help us to better explain the mechanism of subsidence phenomenon.

Coal mine subsidence

Ground deformations due to coal exploitation have known to be a major problem in mining areas, especially in densely urbanized and heavily industrialized areas. Subsidence has great impact not only on natural and man-made features on surface but also on sub-surface infrastructure. The nature, magnitude and limits of ground displacements depend on many factors from which the most important are: method of the liquidation of excavations, geological structure, hydrogeological conditions, surface topography, water pumping and distance between the mine workings and the ground surface. If we know well these conditions the mining induced subsidence is relatively predictable. The surface displacements in the mined areas are very precisely measured using classical leveling surveys. Their values can attain even several meters. Subsidence occurs also after finishing exploitation. In this case the displacements are not so large but they can not be omitted because in future they can also be menace to infrastructure and building on surface. This post-mining subsidence very often occurs in large parts of mining areas. Because conventional leveling and GPS surveying are not efficient and quick ways to obtain large data sets to monitoring small deformations of the surface we can use satellite radar interferometry - PSInSAR technique.

Radar interferometry

The development of satellite radar interferometry is giant step forward better control of unstable regions. It provides rapid and economic methods for monitoring large areas. These method use radar images recorded by SAR (Synthetic Aperture Radar) antennas at different locations and/or at different time to generate interferograms, which show the values of deformations. Classic InSAR (Interferometry Synthetic Aperture Radar) method, which uses two radar images, has found application in monitoring mining subsidence (Perski, 1998). InSAR derive information about values of deformations which occurred between times when the SAR images were performed. The limitations of this method are due to temporal and geometrical decorrelation of the radar signal and due to atmospheric inhomogeneities.

Permanent Scatterer Synthetic Aperture Radar Interferometry (PSInSAR) technique was evolved in the nineties of XX century by the scientist from the Politecnico di Milano (POLIMI). It overcomes some limitation of InSAR method by exploiting long series of SAR data. PSInSAR technique uses set of several dozens of radar images (minimum 30). In these images the permanent scatterers points (PS points) are identified. These points are distinguished by amplitude and phase of the radar signal stable in time, which is backscattered.
to SAR antenna (Ferrett et al. 2001). They correspond very well with the targets on the Earth surface, especially man-made features like buildings, bridges, lanterns, viaducts etc, which are very good reflectors for microwave radiation. Only for PS points the values of subsidence can be determined. The accuracy of PSInSAR method is unprecedented even of the order of 0.1 mm/yr. The important factor that affects the capability of the method is the density of the PSInSAR in the analyzed areas. This technique can be used to monitoring subsidence in the urban areas, where a lot of PS points can be identified. For rural area the number of stable reflectors is sometimes not sufficient. Usefulness of PSInSAR technique in study deformations of surface was repeatedly confirmed by many authors (Declercq et al. 2005, Leśniak et al. 2007, Kemeling et al. 2004).

Available PSInSAR data

PSInSAR data, which have been presented in this paper, describe displacements which occurred in the mining area of “Kazimierz-Juliusz” coal mine. This mine is located in the north-eastern part of Upper Silesian Coal Basin (south Poland) and it covers area approximately 23 km². In this region near 1000 PS points were identified. They correspond very well with the land development. It has to be underlined that the housing estates are smaller part of the analyzed region (they cover 26% of it). The 22% of the mining area is covered by forests and woodland without stable radar reflectors. In the area of “Kazimierz-Juliusz” mine the intensive coal exploitation has been carried out since 1823.

In the geological structure of this region the faults with NS direction are characteristic. The throws of these faults are between 150 and 300 m. These faults are crossed by smaller WE faults with throws between 12-35 m. Such geological structure makes coal exploitation more difficult and fosters the occurrence of ground movements.

In the Figure 1 the PSInSAR data for “Kazimierz-Juliusz” mining area is presented. Data describes average annual rate of displacements, which occurred between years 1992 and 2003 and were obtained as a result of radar scenes processing from ESA satellites: ERS-1, ERS-2 and ENVISAT. The maximum value of the PS point average annual motion rate in this region is equal to 39.63 mm/yr. As can be seen in the Figure 1 location of the PS points is strongly irregular. Most of the PS points are located in the north-west part of “Kazimierz-Juliusz” mining area. There are no PS points in central part of the area. PS points with the smallest values of average annual motion rate are situated in the north part of studied region.
Closer to central part of region, where some exploitation field is located, the average annual motion rates are larger.

**Interpretation**

In order to better understand the subsidence phenomenon, which occurs in the mining area of “Kazimierz-Juliusz” coal mine, the PSInSAR have been compared with InSAR data and with results of leveling surveys (Figure 2). Because the values of subsidence strongly coincide with coal exploitation the PSInSAR data were analyzed also relate to locations of the (active and out of operations) exploitation fields (Figure 2). As can be seen in the Figure 2, the PSInSAR data supply information about ground deformations for different regions than ground-based measurements.

![Figure 2. Values of subsidence in the mining area of „Kazimierz-juliusz” coal mine with localization of the exploitation parcels.](image)

Conventional leveling is performed on and near exploitation parcels. Measured values of subsidence in these regions are larger then values, which can be revealed with PSInSAR technique (that is why there are no PS points). Leveling surveys are performed at the average three times a year (in the Figure 3 the values of subsidence for three bench-marks have been shown).

For land subsidence detection, in the Upper Silesian Coal Basin, the InSAR technique was used (Perski 1998). Results confirmed the usability of this method to study mining subsidence. In the mining area of “Kazimierz-Juliusz” coal mine, between 04.10.92 and 08.11.92, the ground displacements bigger then 1 cm revealed by InSAR technique were located in central and south part of region. These results correspond very well with location of exploitation fields. The rest part of mining area of “Kazmierz-Juliusz” mine was in that time stable.
Conclusions

Investigation of the subsidence in the mining area of “Kazimierz-Juliusz” coal mine using PSInSAR technique allows to reveal the small, long-period deformations in the region where the conventional leveling was not performed. The origin of these small deformations has not been explained yet. Taking into consideration data, was presented in this work, probably two factors affected n subsidence phenomenon, which occurred there. First one is a contemporary tectonic activity of this area e.g. isostatic subsidence. The second one, with less influence, is the intensive underground exploitation performed for the long time.

Despite the fact that PSInSAR technique does not register the large values of motions (that is these which are caused by active coal exploitation) it can be used to monitor small, long-term displacements which can occur even several years after exploitation. This technique is helpful for study the ground stability of post mining areas. Also regions where neotectonic movements take place can be monitored by this method. PSInSAR technique cannot be independent and basic tool in terrain deformation monitoring but it complements considerably the conventional leveling and GPS surveying and helps in better understanding the mechanism of ground displacements considerably.

Reference

Declercq P.Y., Devleeschouwer X., Pouriel F. 2005. Subsidence revealed by PSInSAR technique in the Ottignies-Wavre area (Belgium) related to water pumping in urban areas. Proc.of FRINGE 2005 Workshop, 28 November-2 December, Frascati (Italy)


Figure 3. Values of subsidence measured using leveling survey for tree bench-marks (IV, V, VI).