Use of InSAR for Monitoring of Mining Deformations

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ABSTRACT

The reports of current research, on the use of InSAR technology for monitoring seismic events such as earthquakes and ice motion, validate the application of InSAR for the determination of mining induced surface deformation. Most investigations confirm high reliability of results from satellite interferometry. The climate conditions of Western Australia (dry, cloudless weather, minimal rainfalls) are conducive to provide very reliable InSAR interferograms. It is hoped that this technology can be applied for monitoring of surface deformations, especially in a vicinity of open pit mines, indicating their slope stability. This paper presents the initial results of the research project carried by WASM Mine Surveying Program and supported by the WA mining industry and European Space Agency (ESA, Project Category 1:1123).

1 INTRODUCTION

Surface deformations and slope stability are very important issues to the open pit mining industry. Slope and batter instability can be a potential source of danger for people and equipment. It may also disrupt mine scheduling and increase the cost of mining production ([10], [6], [1]). Surface subsidence, which occurs above underground mining and in areas adjacent to open pit operations, may affect buildings and other man made structures. The effective prediction and management of mining induced deformations of ground surface should be a key concern for the mining industry.
Existing stability monitoring systems in open pit mining can be divided into two categories, namely, surveying techniques and geotechnical methods ([3], [14], [1]).
Surveying techniques can be used to determine the absolute positions and positional changes of any point on the surface. When using survey techniques, survey instruments such as levels, theodolites, total stations, GPS receivers and photogrammetric cameras are usually utilised to collect data. Surface deformation monitoring systems employ a levelling line or mesh of points to establish vertical movement. Currently, highly accurate total stations and GPS systems are favoured for their ability to determine all three spatial coordinates (X, Y, Z). Post-processing techniques can determine the positions of surveyed targets, in relation to a stable references, and further, determine their movements by comparing positions from at least two different surveys.
Geotechnical monitoring methods usually employ specialised instrumentation to measure deformation or displacement over a relatively short measurement base. Common geotechnical instrumentations used in slope stability deformation surveys include ([3], [8], [9]): crack measuring pins, extensometers, inclinometers, piezometers, tilt-meters and micro-seismic geophones.
Surveying and geotechnical monitoring systems are usually established in areas where the likelihood of deformation is very high. The main advantage of the conventional monitoring techniques used for deformation control is the high accuracy of measurements. However, the major disadvantages are a complicated and costly instrumentation, high influence of field and weather conditions, discrete character of observations and high cost of frequent surveys.
In the resent years the satellite based remote sensing technologies have been utilised for deformation monitoring. Of the special interest is the method employing a space borne Synthetic Aperture Radar (SAR) system. This method combined with comparative processing of space radar scans (InSAR) is able to detect relatively small movements (of sub-centimetre magnitude) occurring on the earth's surface. So far, the method was utilized to monitor large-scale geomorphological processes, earthquakes, volcanic eruptions and deformation and glacier movements. Initial research was conducted, to utilize this method to monitor vertical deformations in coalfield areas. The Mine Surveying Program at WASM initiated a research project that investigates the applicability of the Synthetic Aperture Radar Interferometry (InSAR) to determine surface deformations induced by open pit and underground metalliferous mining operations, so called hard rock operations. Implementing differential interferometry for monitoring of mining deformations could provide better, continuous coverage. This should lead to determination of more precise deformation models of rock strata

and in effect, increase the safety margins of mining operations. Monitoring of changes in pit depths, heights of stockpiles and waste dumps, and levels of tailing dumps may provide additional important production data.

2 MINING APPLICATIONS OF INSAR

The modern open pit and underground mining operations usually have significant areas of extent. They can also influence relatively large portions of terrain adjacent to the crest of an open pit or above longwall or room-and-pillar extraction areas. The significant extent of mining operations is an important factor that suggests that InSAR based subsidence-monitoring techniques may be applicable.
Initial research efforts have focused on the application of InSAR for monitoring of mining induced subsidence over the coalfields ([13], [11]). The research suggests that the method can produce valuable and accurate results. In the report by [13] authors conclude, "… Mining subsidence can be detected using 35 day repeat SAR data and SAR interferometry techniques, and that this subsidence can be measured at the very least to an accuracy of few centimetres. However, there would appear to be a central dilemma in applying this technique. A balance needs to be found between a usable temporal separation between images (in terms of interferogram coherence) and allowing a suitable length of time to lapse for measurable amount of subsidence to occur."
Taking the above into account and very favourable weather and ground conditions of Western Australia, it seems reasonable to assume that InSAR technology may be successfully used for deformation (subsidence) monitoring inside and in the vicinity of large open pit mining operations (Fig.1). The results of InSAR processing may indicate early ground movement of pit walls and prompt more detailed monitoring (using classical surveying or geotechnical methods) or other actions preventing loss of life and equipment due to wall failure.

Figure 1: Large surface deformations next to an open pit mine.

3 SLOPE STABILITY MONITORING USING INSAR – RESEARCH PROJECT

At the start of 2002 the Mine Surveying Program of WASM (Curtin University) was able to obtain some industrial support for "pre-feasibility" study focused on application of InSAR for monitoring of subsidence in the vicinity of large open pit operations. The project also gained support from European Space Agency (ESA) and is classified as a Project Category 1 (1123), that provides discounted prices for satellite radar imaginary. Three test sites have been chosen for

initial InSAR processing. The primary focus of the research was the Leinster (WA) site with further studies at Kalgoorlie (WA) and Eastern Pilbara region (optional).
The selection of the primary test site was determined by the existence of large-scale surface deformations in the proximity of its open pit. The large surface deformations (subsidence) are caused by underground extraction (using a sub-level caving method) of an ore-body that has followed the open pit phase of mining. Also, an important factor in choosing the test site is the availability of deformation monitoring data that has been collected using classical survey and GPS methods. Existence of such data will provide a reference base for assessment of results obtained from InSAR.

4 DATA SETS

A search of an ESA On-Line Catalogue (EOLI from http://odisseo.esrin.esa.it/) for available interferometry data for the Leinster region produced the following results that could be used for this project.

TABLE 1.

No.	Frame	Orbit	Baseline	Satellite	Date
1	**4164**	**22650**	**0**	**ERS1**	**1995-11-14**
2	**4164**	**2977**	**515**	**ERS2**	**1995-11-15**
3	4164	8488	318	ERS2	1996-12-04
4	**4164**	**9991**	**-199**	**ERS2**	**1997-03-19**
5	4164	34039	?	ERS2	2001-10-24
6	4164	35041	630	ERS2	2002-01-02

The usefulness of data was determined on the bases of date (in relation to development of deformations), satellite baseline and weather conditions. However, the quality of the above data and the baselines significantly reduced the number of scenes that were utilised for DinSAR processing. Particularly, the tandem pair from November 1995 (No.1 and 2) and one 490-day repeat (No. 4) were used for processing and were bases of the preliminary results. Unfortunately, these results could not include any significant deformations as the extensive underground mining extraction started in 1997. Due to data acquisition problems researchers were not able to obtain any new scenes during 2002.

The archival data sets were extended by data from newly planned missions between December 2002 and April 2003. The planned missions are listed in Table 2. The SLC frames for these missions were provided by ACRES (Australian Centre for Remote Sensing) after consultation and ESA approval.

TABLE 2.

No.	Frame	Orbit	Baseline	Satellite	Date
7	4164	40051		ERS2	2002-12-18
8	4164	40552		ERS2	2003-01-22
9	**4164**	**41053**	**0**	**ERS2**	**2003-02-26**
10	**4164**	**41554**	**65**	**ERS2**	**2003-04-02**

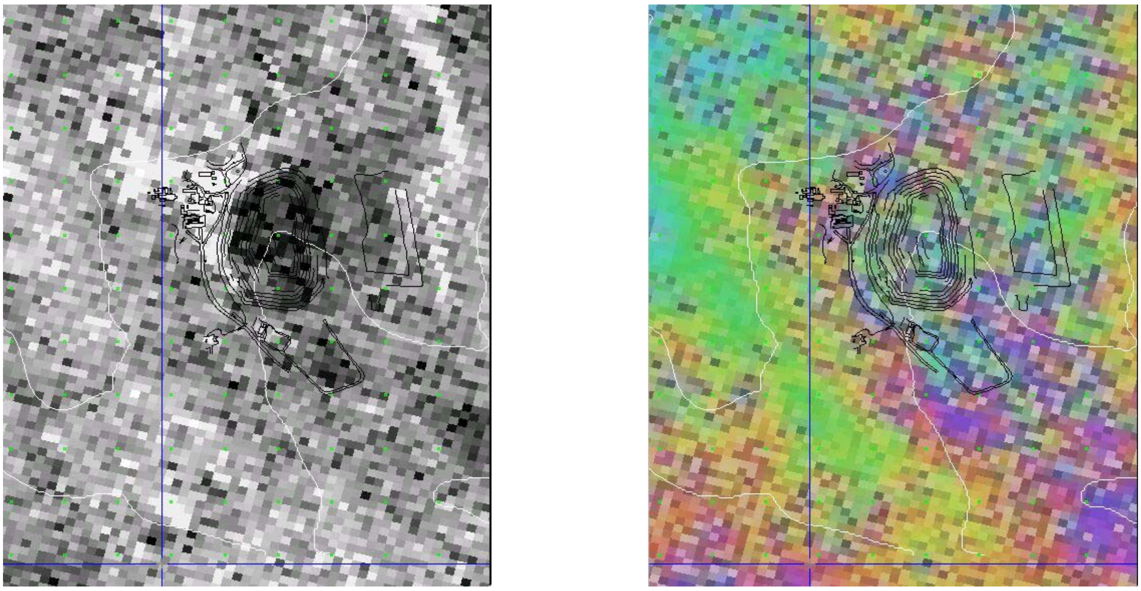
After collection of data it was realised that the baselines for different combinations of scenes from the above series were characterised by relatively large values (above 600m). Only one combination (Feb2003 – April2003) yielded successful differential interferogram representing mining related deformations.

5 PROCESSING SOFTWARE

After reviewing the available software for InSAR processing it was decided that DORIS InSAR Processor developed by the Delft Institute for Earth-Oriented Space Research (DEOS), Delft University of Technology [7] was to be used in the initial phase of this project. DORIS is free software (for non-commercial scientific purpose) that runs on UNIX/Linux platforms. It can generate interferometric products and end-products from Single Look Complex radar data provided by ESA. Scenes generated by ERS1, ERS2 and Envisat satellites can be processed.
Interferogram unwrapping was performed using the SNAPHU software developed by Curtis W. Chen [2] and integrated as module with DORIS.
GRASS free GIS software was used for data integration and visualization (http://grass.itc.it/index.html).

6 RESULTS

The tandem pair of ERS SLC satellite radar images from 14/15 November 1995 with a base of 515 m were used to generate the reference interferogram that includes topographical effects only. It is assumed that it has not included any effects of deformations as the underground mining had just started. The topography interferogram was compared with 9” DEM obtained from Geoscience Australia yielding good correlation results.
The 490 day repeat interferogram was generated using scenes from 14-November-1995 and 19-March-1997 with a baseline of -199 m. A small section of the interferogram is presented in Fig. 2. The presented area is limited to the vicinity of Leinster mining operation. The data was filtered and multi-look processed to improve phase statistics. The interferogram has horizontal resolution at the ground level of about 20 m.
The initial review of the results suggests very good coherency between both SLC images despite the very long time base (490 days). This suggests that Western Australian conditions are ideal for long-term interferometry analysis and the InSAR technology should be able to detect the long-term and slow ground movements.
The interferogram, itself, does not yield any conclusive results, as there was minimal subsidence movement during the investigated period. Underground mining was initiated at the end of 1996 and any meaningful subsidence results were detected (using classical surveying methods) in the second half of 1997.

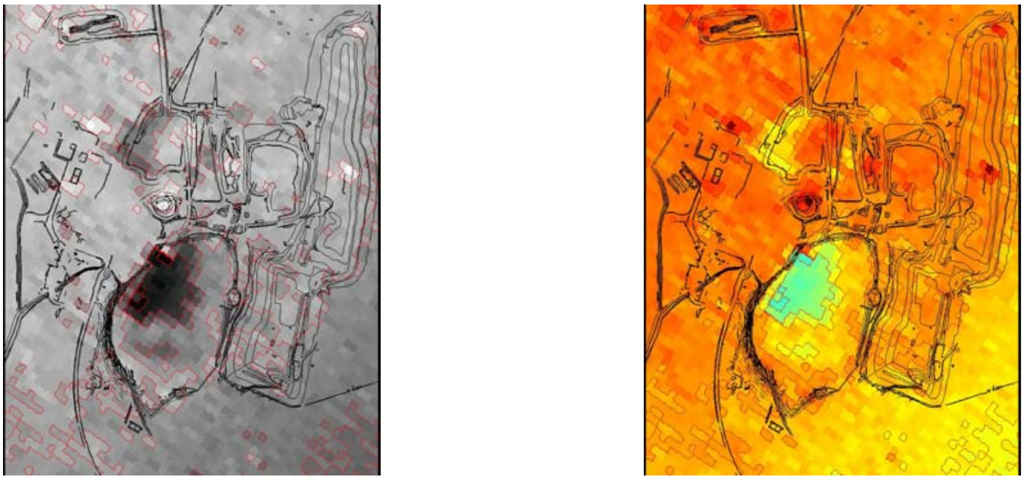


a) Coherence b) Interferogram (with topo)

Figure 2: Interferogram of Leinster area.

The further investigation based on 2002 – 2003 datasets (No. 9 and 10) is showing significant subsidences inside the active mining operation. A small section of coherence and unwrapped interferogram is shown in Fig. 3 and 4. The presented area is limited to the vicinity of Leinster mining operation. The data was filtered and multi-look processed to improve phase statistics. The interferogram has horizontal resolution at the ground level of about 20 m.

It has to be realised that no initial knowledge of baselines was available before processing of the four planned missions from 2002 – 2003. Therefore, only one pair with suitable baseline was able to co-register. This baseline had a distance of 65m, when all other combinations were larger than 600m. It will be an advantage to have knowledge about the baseline parameter on planning stage to minimize acquisition of unsuitable data.



a) Coherence b) Unwarped interferogram (deformation)

Figure 3: Coherence and Interferogram of Leinster area.

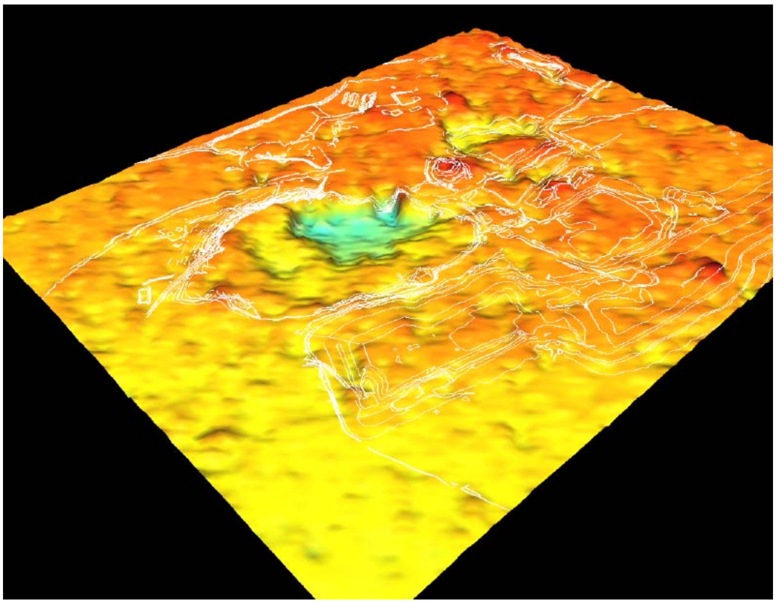


Figure 4: NVIZ (GRASS) 3D representation of mining subsidence

7 CONCLUSSIONS

InSAR can play an important role as an initial method allowing to determine the subsidence active area and further plan for other monitoring methods employing usually “classical” surveying techniques. It can be also used as complementary method providing accurate monitoring of vertical component of rock strata movements.

The real production environment requires significant improvement of consistency of InSAR raw data before they can be used for real time deformation monitoring. From the planned and obtained four data sets only one combination was utilised. Others had baselines that were too large for interferometric processing.

8 ACKNOWLEDGMENTS

The European Space Agency's (ESA) ERS-1 and ERS-2 satellite(s) have been used to collect the interferometry data. The data were obtained as a part of ESA Cat-1 Project (No.1123).
The interferometry processing in this project was performed using the freely available Doris software, developed by the Delft Institute for Earth-Oriented Space Research (DEOS), Delft University of Technology (http://www.geo.tudelft.nl/doris.html).
Data integration and georeferencing were performed using the GRASS the free GIS software (http://grass.itc.it/index.html).

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