Fringe 96

Monitoring of Small Motions in Mining Areas by SAR Interferometry

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Abstract

In the former WISMUT uranium ore mining and processing area (Thuringia, Germany) controlling of small surface movements with "cm"-accuracy is required. A promising tool is the D-INSAR technology, which could reduce man power spending, compared with other geodetic techniques (GPS, precise levelling). The GeoForschungsZentrum Potsdam (GFZ), the DASA Jena-Optronik company (DJO) and the WISMUT company participate in a joint project (sponsored by the German Space Agency DARA) to apply INSAR in the WISMUT area, using a stable corner reflector (CR) reference net and measuring CRs. The phase difference between the CRs are investigated with the objective to monitor CR movements. The network has been initially positioned by GPS and is also controlled by terrestrial geodetic measurements. Experiments are presently being carried out by shifting CRs out of position. The project status and first results are presented in this paper.

Keywords: corner reflectors, mining area, small motions

Introduction

Under the supervision of GeoForschungsZentrum Potsdam (GFZ), a SAR interferometry (INSAR) application project for monitoring surface deformations in the WISMUT mining area started in September 1995.

Over more than 40 years the former Soviet-German corporation WISMUT was intensively occupied with exploitation and processing of uranium ore in Thuringia (Eastern Germany). In 1990, the uranium ore production stopped and the WISMUT Ltd. was established to control or perform the redevelopment measures in the 37 km^2 large area.

Seeking for cost-effective geodetic measurement methods to monitor anticipated surface movements, the spaceborne SAR interferometry is obviously a promissing tool. The capability of differential INSAR (D-INSAR) was already shown in the "Bonn-Experiment", performed by ESA-ESRIN, INS-University of Stuttgart and Politecnico de Milano (Prati et al. 1993). Several drawbacks for SAR applications are inherent in the WISMUT area: vegetation, limited space between mining facilities, abrupt terrain height changes in the precincts of slagheaps and of sludge settlement basins. To overcome some of the terrain deficiencies and to achieve the best possible accuracy, corner reflectors (CRs) are employed. A CR represents a defined geometrical reference point in the radar image and shows favourable reflection characteristics with respect to intensity and stability. The detection of surface movements with "cm-accuracy" is required.

In a joint project the GFZ, the DASA Jena-Optronik company (DJO) and the WISMUT company are developing procedures to derive point movements from a CR network analysis. This includes the elaboration of scientific background as well as practical testing. The methodology is evolved on the principle of the division of labour by GFZ and DJO. In addition, GFZ is mainly focusing on the project assessment where as the partner from industry, DJO will put the technique into practice. The WISMUT defines the user demands, and assesses the project continually from its point of view.

Project MODIFI

Within the project MODIFI (<u>Mo</u>nitoring of <u>Di</u>splacement <u>Fi</u>elds by Radar Interferometry) the field work has reached a level of full availability of a corner reflector network (10 CRs) for experiments. The array is deployed over an area of 15x6 km^2.

All CRs, with an edge length of 1.50 m, were installed on concrete platforms of 2.5x2.5x0.8 m^3 dimension, see Fig. 1. They were centered above GPS groundmarkers with an accuracy of 1 mm, which means that the CR apex and the groundmarker is in one vertical line. The CRs can be rotated allowing an orientation on descending or ascending orbits of ERS-1/2. The axis of rotation coincides with the vertical line defined by apex and groundmarker. The CR base is fixed to the concrete foundation in a way that no CR displacement by wind is possible. The CR funnels may be removed to perform GPS measurements in a specific height above the ground marker using a centering rod with a top for a GPS antenna. The CR points are tied to stations of the International GPS Service for Geodynamics (IGS), Potsdam and Wettzell, to ensure an absolute accuracy of better than 1 m. This is comparable to the accuracy of the ESA precise orbits for ERS-1/2, generated at GFZ/D-PAF, Oberpfaffenhofen. The coordinate differences between CRs are controlled within 5 mm. All INSAR calculations are performed within the ITRF, the International Terrestrial Reference Frame.

Fig. 1: GFZ corner reflector installed in the former WISMUT mining area (Thuringia/Germany)

The WISMUT mine surveyors integrated the CR/GPS points in their terrestrial geodetic nets. This ensures an additional control of platform stability. Because the center markers are continuously occupied by CRs, eccenters were placed in 3 corners of each platform. Small movements like vertical shifts or tilt effects are detectable by precise levelling. The height differences between center and eccenters are determined once by levelling, the Gauß-Krüger coordinate differences have been derived by simple distance measurements.

2 CRs are equipped with translation devices to perform defined shifts out of position of the funnel in any direction. The radar echo of such a "measuring" CR has to be applied to the signals of the 8 reference CRs. Experiments are presently being carried out. 2 flexible "mobile" CRs are under preparation to test different network configurations (optimization). Real surface deformations are anticipated after flooding the underground mines in a few years. If MODIFI ends successfully, a new application project with a densified CR network is scheduled afterwards.

Data evaluation strategy and first results

DJO as well as GFZ develop a methodology which allows the detection of small point movements within a CR network using SAR interferometry. The diagram in Fig. 2 describes the GFZ concept. A "flat earth" corrected interferogram is derived from a SAR SLC image pair and the corresponding precise orbit data. For conversion of interferogram phases into height values, the knowledge of accurate imaging geometry is required. This is obtained from the orbit data and the GPS heights of the CRs depicted in the radar image. An optimization is performed to adjust the interferogram to the heights of the reference CRs. In the following step the phase values of the measuring CRs are investigated. They should be in agreement with phase values calculated from GPS heights. The difference is a measure for a CR motion.

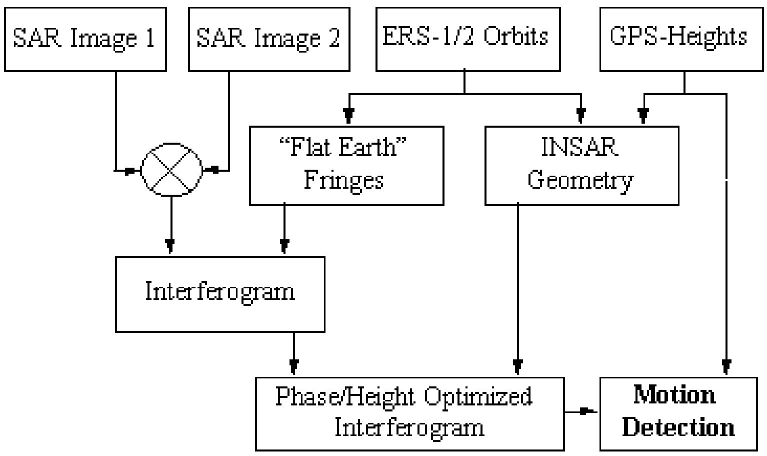

Fig. 2: Data evaluation strategy to detect relative point movements between corner reflectors (project MODIFI)

In a first experiment, an ERS-1/2 tandem data pair, acquired at 8.2. and 9.2.1996 with base line length of 142 m, was evaluated. At that time 5 CRs were available. The objective was the determination of the heights of 4 CRs relative to a CR with fixed height. Tab. 1 compares the results, obtained at GFZ and at DJO, with the "true" GPS results. DJO attained a very good agreement within 3 m. The GFZ result shows one larger discrepancy of 10 m for point CR9. An accuracy of 10 m corresponds to an error of 50° in phase or 4 mm in wave lenght. Considering that a vertical CR shift out of position of only 4 mm causes a misinterpretation of 10 m, the overall result is satisfying.

Tab.1: Comparison of corner reflector results, obtained at GFZ and at DJO, with "true" GPS results.

Station	GPS-Height	DJO INSAR-Height	Difference (DJO-GPS)	GFZ INSAR-Height	Difference (GFZ-GPS)
CR1	306.33 m	306.33 m	/	306.33 m	/
CR2	296.09 m	294.48 m	1.61 m	296.41 m	+0.32 m
CR3	335.79 m	334.99 m	0.80 m	334.36 m	1.43 m
CR4	328.36 m	331.20 m	+2.84 m	325.87 m	2.49 m
CR9	379.72 m	381.12 m	+1.40 m	370.31 m	9.41 m

Encouraged by this first result a SLC image from 4.1.1996 was included in the radar data analysis. After the acquisition of that ERS-1 image, the CR2 position was moved by 2 cm in range direction. Now the objective was the detection of that motion. The corresponding interferogram (4.1./8.2.96, baseline 272 m) was disarranged in most of its parts, the low coherence made it impossible to derive any result for the terrain and also for the CR points. The reason may be found in the different environmental conditions at the two epochs. During the acquisition time on 4.1.1996 (10:00 p.m.) the weather was misty with an overcast sky, 95% relative humidity and -7°C, the earth surface was dry without any snow coverage. On 8.2.1996 (similar at 9.2.1996) the weather was clear with no clouds, 90% rel. humidity and -14°C, the surface was covered by snow (no grass visible). In this special case, the employment of CRs for point motion detection may be restricted due to: 1) perturbations in the radar propagation delay through the troposphere, and/or 2) changing properties of the surrounding terrain surface (radar penetration into the frozen soil and the crusted snow coverage, influence of vegetation).

Conclusions

The first result demonstrates the accuracy potential of D-INSAR technique. A subcentimeter accuracy may be possible. But the described result is obtained under favourable environmental conditions. The evaluation of the SLC image pair, acquired in the ERS-1 35 day repeat cycle, gave no result. This is understandable considering that the radar measurements of the CRs are not independent from the environment. In additional experiments, using images with negligible atmospheric perturbations, it has to be assessed how strong the surrounding terrain with its changing surface conditions may affect the CR observations. The CR reflectivity may not be as dominant as expected, which would require a wider area surrounding the CRs, with a cleared plain surface.

Acknowledgements

The authors thank the German Space Agency DARA GmbH for sponsoring the project MODIFI through the research grant 50 EE 9429, and ESA for providing the SAR SLC images (project code AO2.D133).

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