Landslide Displacement Monitoring Using Multi-aperture InSAR and D-InSAR

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Abstract— Landslides caused by open-pit mining are one of the most dangerous geological hazards in China. Displacement of landslides are different from the deformation of ground subsidence due to existing horizontal deformation and vertical deformation at the same time. In this paper, we extend the multi-aperture InSAR method to monitor large-scale horizontal deformation of landslides. And then, we integrate the multiple-aperture InSAR and traditional differential SAR interferometry (D-InSAR) to reveal deformation field distribution of landslides caused by open-pit mining. The results demonstrated that the proposed procedure is effective to monitor large-scale horizontal deformation and vertical deformation of landslides, especially for the north-south direction landslides.

1. INTRODUCTION

With the rapid exploitation and over utilization of mineral resources, the open-pit mines around the world have becoming bigger and deeper ever before. The largest open-pit mine in Asia is Fushun west open-pit mine, which located in Fushun city, Liaoning province, Northeast of China. At present, Fushun west open-pit mine has been the formation of 6,600 meters from east to west, 2,200 meters from north to south, with an average depth of about 420–520 meters, covering an area of about 10,870,000 square meters of open-pit mining. It has a long history of more than one hundred years and made important contributions to China's economic development. However, serious geological disasters, especially large-scale landslides, has become a direct threat to the residents and factories in Fushun city due to excessive and long-term coal mining. The direct economic loss has reached as much as 1.5 billion Yuan. Therefore, it is important to investigate the geological disaster situation, determine the location and size of landslides. Compared to traditional methods, for example leveling measurements and global positioning system (GPS) measurements, interferometric synthetic aperture radar (InSAR) has many advantages such as lager coverage and lower cost, and it can work in all-weather conditions to monitor surface deformation [1].

A special feature of landslides at Fushun west open-pit mine is that the main deformation occurred along the north-south direction. However, the conventional differential SAR interferometry (D-InSAR) technique can only measure one-dimensional (1-D) deformation along the line-of-sight (LOS) direction. It means that any component of motion orthogonal to the LOS cannot be detected. In the nearly north-south flight pattern of current commercial SAR satellites, the D-InSAR method are only sensitive to the deformation along the up-down and east-west direction [2]. Therefore, it is almost unable to measure the displacements occurring in the north-south direction at Fushun west open-pit mine with conventional interferometry.

To cope with the problem of deformation monitoring along the north-south direction, Michel et al. proposed a novel method utilizing radar amplitude information to measure azimuthal offsets [3]. However, this method involve sub-pixel correlation of the radar images, and are computationally expensive. Furthermore, the accuracy of the offset-tracking method, depending on the spatial resolution of the SAR data and the precision of the coregistration, is generally very low. In 2006, a significant improvement in measuring along-track deformation was made by Bechor and Zebker with a new approach: multiple-aperture InSAR (MAI) [4]. The MAI method is more accurate than the offset-tracking approach with less computation time, and it is easy to implement using conventional InSAR software. In 2009, Jung et al. further improved the accuracy of MAI method by introducing a step of baseline error correction [5].

In this paper, we aim to extend the MAI method to the large-scale landslides monitoring at Fushun west open-pit mine due to its main displacements along the north-south direction. By integrating multiple-aperture InSAR and traditional D-InSAR, we explore to reveal the 3-D deformation distribution of landslides caused by coal mining.

2. DATA AND METHODOLOGY

SAR data used in this study were acquired from the Phased Array type L-band Synthetic Aperture Radar (PALSAR) sensor onboard Advanced Land Observing Satellite (ALOS). The PALSAR sensor operated in L-band frequency (1.27 GHz), with a ground surface resolution about 7 m in both range and azimuth directions, and a swath width of 70 km. Table 1 lists the detailed information of the used SAR data. The two scenes from the ascending orbit are in fine beam single polarization (FBS, HH-polarization). The perpendicular baseline of the interferometric pair is 76 m and the temporal baseline is 1012 days.

Table 1: Summary of the used ALOS-PALSAR data.

No.	Acquisition Date	Track	Orbit Direction	Beam Mode	Polarization	Temporal baseline (day)	$B_\perp$ (m)
1	13 Apr. 2008	433	Ascending	FBS	HH	1012	76
2	20 Jan. 2011						

The MAI technique firstly divided a pair of full-aperture single-look complex (SLC) images into four sub-aperture SLC images via common band filtering method in the azimuthal direction. The azimuth common band filtering was conducted following Wegmüller et al. [6] in this study. Based on the two new forward-looking and backward-looking SLC pairs, we can produce one forward-looking interferogram and one backward-looking interferogram with the conventional D-InSAR method. And then, a complex-conjugate multiplication of the forward-looking interferogram Φ_f and backward-looking interferogram Φ_b produces the MAI interferogram Φ_{MAI}:

$$\Phi_{MAI} = \Phi_f - \Phi_b \tag{1}$$

The azimuthal displacement can be calculated from the MAI interferometric phase [4]:

$$x_{az} = \frac{l}{4\pi n}\Phi_{MAI} \tag{2}$$

where x_{az} is the surface deformation in the azimuthal direction, l represents the effective antenna length, n represents the fraction of the full-aperture width.

According to the principle of MAI, the forward-looking and backward-looking interferometric phases are differenced, this process reduces some common errors from topographic and tropospheric sources [4]. But residual topographic and flat-earth errors caused by the small difference between the perpendicular baselines of the forward-looking and backward-looking SAR pairs, should be removed before producing azimuth deformation. In this study, the polynomial models were used to simulate and eliminate both phase residuals following the method described by Jung et al. [5].

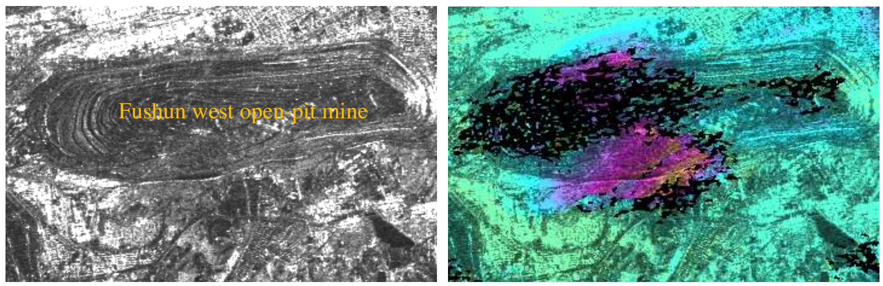
3. RESULTS

3.1. LOS Deformation from D-InSAR

The two-pass D-InSAR method was utilized to obtain the LOS displacements firstly. As part of the D-InSAR processing, an external digital elevation model (DEM) data from Shuttle Radar Topography Mission-3 (SRTM-3) was used to remove topographic component of interferometric phase. Before unwrapping the phase, it is necessary to reduce phase noise and improve fringe visibility of interferometric phase. For this purpose, an adaptive interferogram filtering algorithm [7] was applied by setting a large rectangular patch sizes and high values of exponential power spectrum filter parameter. In this study, we found that the patch size of 256×256 and the filter parameter of 1.0 improved fringe visibility significantly. Furthermore, to suppress the speckle noise, the interferogram was looked down in range and azimuth by 4 and 6, respectively. After that, the interferogram was unwrapped using the minimum cost flow (MCF) algorithm [8]. The geocoded LOS displacement in WGS84 coordinate system is shown in Figure 1. It can be seen that landslides occurred at the edge of the huge open-pit with large area in the north and south of Fushun west open-pit mine. The largest vertical displacement is estimated by Figure 1 up to 1.10 m.

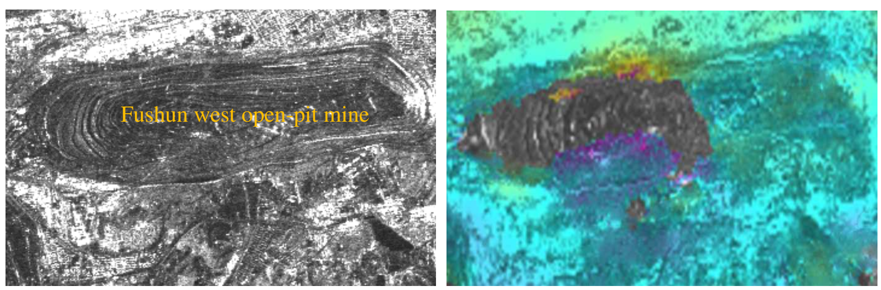
3.2. Azimuthal Deformation from MAI

The MAI data processing was applied to obtain the azimuthal deformation in this section. Firstly, the forward-looking and backward-looking SLC scenes were produced using common band filtering method. The same processing as D-InSAR described in Section 3.1 are then used to generate the forward-looking and backward-looking interferograms, however, the unwrapping step can be ignored. Then, conjugate multiplication between the forward-looking and backward-looking interferograms was conducted to obtain the final MAI interferogram. Finally, the polynomial model was used to eliminate the flat-earth and topographic phase residuals. Because the effective antenna length of ALOS-PALSAR is 8.9 m, therefore, a single phase fringe in the MAI interferogram represents 8.9 m surface displacement in the along-track direction. Figure 2 shows that the azimuthal displacement of Fushun west open-pit mine in WGS84 coordinate system. Compared with Figure 1, we can know that the region of horizontal deformation is similar to the area of vertical displacement, and the motion is direct to the bottom of the open-pit mine along the slope direction. The largest horizontal displacement is estimated by Figure 2 up to 1.45 m.



(a) (b)

Figure 1: LOS displacement obtained by D-InSAR. (a) SAR intensity image of Fushun west open-pit mine; (b) LOS deformation in the north and south of Fushun west open-pit mine.



(a) (b)

Figure 2: Azimuthal displacement obtained by MAI. (a) SAR intensity image of Fushun west open-pit mine; (b) Azimuthal deformation in the north and south of Fushun west open-pit mine.

By integrating Figure 1 and Figure 2, we can determine the boundaries and intensity of landslides in the north and south of Fushun west open-pit mine. What is most important, we can obtain the detailed distribution of landslides via only two SAR images.

4. CONCLUSION

A novel technique by integrating the multiple-aperture InSAR and traditional D-InSAR has been utilized to monitor lagre-scale horizontal deformation and vertical deformation of landslides caused by coal mining in Fushun west open-pit mine. The boundaries of landslides revealed by the new method occurred in the north and south of Fushun west open-pit mine are consistent with the results of field investigation. In the future, we plan to extend this method to time-series analysis on the basis of the small baseline subset (SBAS) algorithm to extract long time horizontal displacement and vertical displacement from the overall perspective via multi-temporal SAR data.

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