LANDSLIDE MONITORING IN THREE GORGES AREA BY JOINT USE OF PHASE BASED AND AMPLITUDE BASED METHODS

Xuguo Shi [1], Lu Zhang [1], [2], Mingsheng Liao [1], [2], Timo Balz [1], [2]

[1] *State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University, Wuhan, China*
[2] *Collaborative Innovation Center for Geospatial Technology, Wuhan, China*

ABSTRACT

Landslides are serious geohazards in Three Gorges area, China especially after the impoundment of Three Gorges Reservoir. It is very urgent to monitoring the landslides for early warning or disaster prevention purpose. In this paper, phase based methods such as traditional differential InSAR and small baseline subset method were used to investigate slow moving landslides. Point-like targets offset tracking (PTOT) was used to investigate fast moving landslides. Furthermore, in order to describe the displacement on landslide, two TerraSAR-X datasets obtained from different descending orbits were combined to obtain the three dimensional displacements on Shuping landslides with the PTOT measurements in the azimuth and range direction.

1. INTRODUCTION

Landslide is widely distributed in the mountainous regions of western China and accounted for more than 60% of geological disasters in China [1, 2]. Therefore, it is essential to find effective methods to monitor the displacements of landslides for early warning and disaster prevention purpose.

The Three Gorges Project played important roles in power generation and flood control etc. The Three Gorges Dam has become fully operated since the water level rose to 175 m for the first time in 2009. The reservoir water level fluctuates between 145 m and 175 m now resulting to the increase of unstable slopes. Survey showed that the number of active landslide bodies since the water level reached 135 m in 2003 was almost twice that identified in 2001. The most famous case was Qianjingping landslide, occurred a few days after the initial impoundment in 2003[3]. Many other landslides, such as Shuping landslide and Fanjiaping landslide etc., were also found to be active since the impoundment [4, 5]. More importantly, most active landslides in the Three Gorges area were found to be located near local human settlements such as villages, towns and cities threatening people’s properties and lives. Therefore, continuous monitoring of displacement at these unstable slopes must be carried out.

Differential Interferometric Synthetic Aperture Radar (D-InSAR) is an effective tool for detecting surface displacement. However, it is primarily limited by temporal and spatial decorrelation as well as the atmospheric phase screen (APS). Persistent scatters InSAR method and Small BAseline Subsets (SBAS) method were proposed almost at the same time to overcome the limitations of decorrelation. By using a large amount of SAR images, PS-InSAR and SBAS can estimate and correct the APS [6, 7]. Very high accuracy can be achieved with these methods when the movement of landslide is very slow.

However, when it comes to fast movement, phase based method is not suitable anymore. Particularly, fast displacements occurred in densely vegetated areas will be underestimated due to phase unwrapping errors. At the same time, high-resolution DEM data is needed to estimate the topographic phase when generate differential interferograms with high resolution SAR images, which might be unavailable in most cases.

Pixel offset tracking (POT) making full use of the amplitude information has been recognized as an effective method that can robustly measure large displacements caused by earthquakes, landslides, glacier motion, etc. Two-dimensional displacements (range and azimuth displacements) can be obtained by the POT while InSAR can only measure deformations in the line-of-sight (LOS) direction. Moreover, high-resolution DEM and phase unwrapping are not needed in the offset tracking procedure. Point-like target (PT) offset tracking method mainly makes use of bright targets in the natural terrain, thus the reliability of measurement will be improved [8]. The point-like offset tracking method was used in this paper to obtain the displacements on Shuping landslide.

Since the movements of landslides are very complex process, the best way to describe the processes of landslides is to retrieve the three dimensional movements in the easting, northing and vertical direction. Usually three dimensional displacements can be obtained by combing the measurement from descending and ascending orbits. In our study, only two descending TerraSAR-X data acquired from different geometry were available and used to obtain the three dimensional movements aiming to further understand the movements of landslides.

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2. DISPLACEMENT RETRIEVAL METHODS

DInSAR were applied in our process to identify the active landslides in the Three Gorges area. SBAS method was used on Fanjiangping landslide to retrieve the displacement history. Since readers might be very familiar with the traditional differential InSAR and SBAS method, the principles were not given in this paper. Readers might refer [6, 9] for details. Basic process workflow of point-like targets offset tracking was briefly described. Three dimensional displacements retrieving method from two descending orbit data was also given.

2.1. Point-like targets offset-tracking method

Point-like targets (PTs) that will not decorrelate with the increase of normal baseline over time are ideal features that can be used for matching and shift determination between SAR images [10].

The mean amplitude image with strong speckle suppression was used for PT candidate selection to avoid the influence of inherent speckle noise in single SAR images. The backscattered signal from an ideal point-like target behaves like a 2D sinc function. Cross-correlation was calculated between a sinc function template and the mean amplitude image with a moving window. Pixels with normalized correlation coefficients lower than 0.2 are excluded directly in our study. A pixel is then selected as a PT candidate if the product of the correlation coefficient and the amplitude is above an adaptive threshold determined by the mean and the standard deviation (STD) of amplitude within the moving window. The detected PT candidates will be used as the initial input for offset tracking.

After PT candidates are selected using the mean amplitude, pairwise offset tracking is performed by amplitude cross-correlation at these PTs between patches of the master image and each original slave image. Those pixels with peak correlation lower than 0.4 is discarded to ensure reliability of deformation mapping in the final step. The stereoscopic effects in the range direction were removed by applying an elevation-dependent correction assisted by SRTM DEM data of 3 arc second resolution.

A culling procedure is then performed upon the remaining PTs for each offset pair to obtain the reference PTs to estimate quadratic polynomial coefficients used for orbital ramp removal. Thus, different offset pairs may yield different remaining PTs since PTs with signal to noise ratio (SNR) lower than 7 were removed. As PTs are generally considered to be stable in all images, only PTs presented in all the offset pairs are kept as the final PTs for time series analysis. Finally, the component of orbital ramp is estimated and removed, and then the time series deformation trends are obtained at the final PT's.

2.2 Retrieval of three dimensional displacements

Accurate retrieval of three-dimensional displacement field is a vital condition for understanding earth surface deformation mechanisms. The measured azimuth and range displacements are projections of the 3D displacement vector, which can be mathematically expressed as below:

$$\begin{cases} D_N \sin\alpha \sin\theta - D_E \cos\alpha \sin\theta = d_{rg} + \delta_{rg} \\ D_N \cos\alpha - D_E \sin\alpha = d_{az} + \delta_{az} \end{cases} \quad (1)$$

Where symbols D_N, D_E, D_V represent displacements in the northing, easting and vertical directions respectively. α and θ stand for heading angle and nominal incidence angle at the target point. d_{rg} and d_{az} are displacements measured in range and azimuth dimensions separately, while δ_{rg} and δ_{az} are corresponding observation errors to be minimized.
By combining measurements from both HS and SM datasets at each point, we can establish four equations in which there are three unknown variables D_N, D_E, D_V to be solved by least square.

3. DATA AND TEST AREA

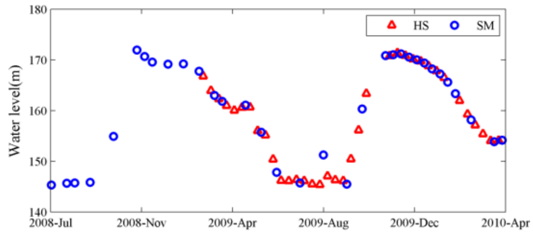

Figure 1. Temporal distribution of TerraSAR-X stripmap (SM) and high resolution spotlight data (HS).

34 TerraSAR-X strip map images and 36 TerraSAR-X high resolution spotlight images were acquired in descending orbit with different look angles. Larger look angle of 39 degrees was applied by the HS data while only a look angle of 24 degrees was used by the SM data. The water level fluctuations were huge in Three Gorges area during our observation period (Fig. 1).

The Fanjiaping landslide and Shuping landslide in Zigui area were chose as case studies as slow moving and fast moving landslide. Corner reflectors have been installed on Shuping landslide to assist InSAR measurments. The Shuping landslide covered by the HS data and SM data were used to retrieve the three dimensional displacements on corner reflectors. Locations of Fanjiangpign landslide and Shuping landslide were shown in Fig. 2.

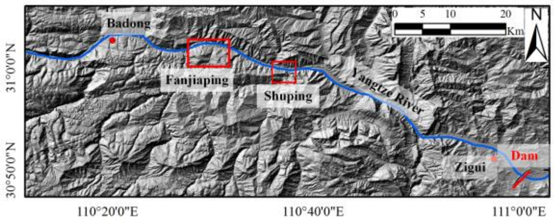

Figure 2. Location of Fanjiaping landslide and Shuping landslide.

4. RESULTS

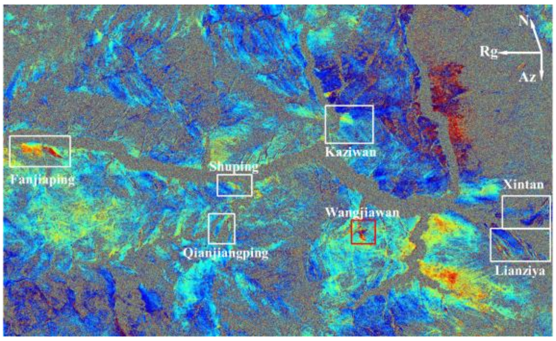

Figure 3. Differential interferogram formed by the TerraSAR-X strip map images acquired in 28th November, 2009 and 20th December, 2009.

High quality differential interferograms are very useful in locating active landslides by finding phase distortions. From Fig. 3, we can identify obvious phase distortions on Fanjiangping landslide, Shuping landslide, Kaziwan landslide and Wangjiawan landslide. The phase on Qianjiangping, Xintan and Lianziya landslide is not very clear which we cannot tell whether it is displacements or residual topographic phase.

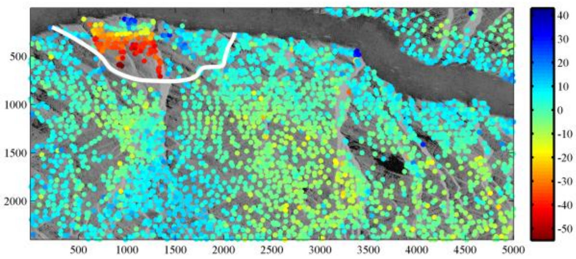

Figure 4. Displacement rate of Fanjiaping landslide retrieved from the TerraSAR-X stripmap dataset from July 2009 to May 2010.

The Fanjiaping landslide located on the southern bank of Yangtze River. It was only covered by the TerrSAR-X strip map datasets. According to [2], the displacement of Fanjiangping landslide was very small. SBAS method was applied in our process to obtain the displacement rate. The most serious displacement occurs on the head of Fanjiaping landslide. The displacement rate can reach nearly more than 50 mm/y.

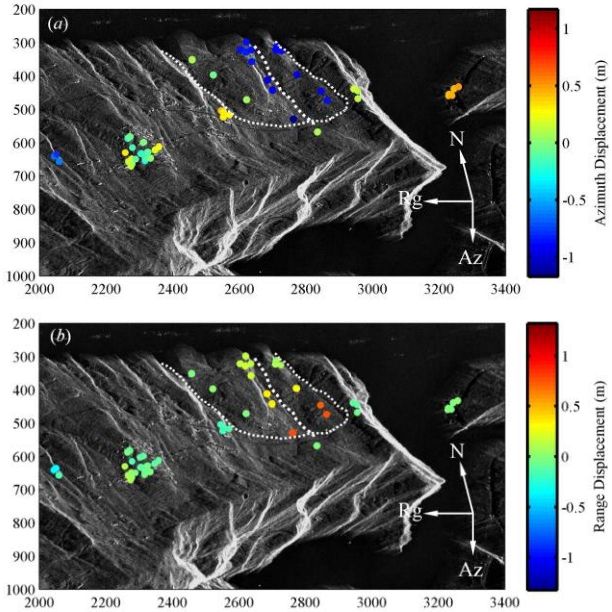

Figure 5. Cumulative displacements in the (a) azimuth and (b) range directions derived by the PTOT method on Shuping landslide from July 2009 to May 2010.

Large displacement have been detected on Shuping landslide by the GPS observations. According to the GPS observations, it is diffcult to avoid the phase unwrapping errors espcially for X band terraSAR-X data. PTOT method was applied to obtain the cummalive dicplacements of Shuping landslide. The displacements on Shuping landslide reached more than 1 meter in the azimuth direction and 0.8 meters in the range direection sliding to the north direction (Fig. 5). The east side of Shuping landslide was very active while the west side is relatively stable.

As we can see from Fig. 1, the HS and SM datasets covers a common temporal observation period from Janurary 2009 to April 2010. We selected one HS data pair acquired on 21 February, 2009 and 15 April, 2010, as well as one SM data pair acquired on 15 February, 2009 and 20 April, 2010 with almost a asynchronously temporal period. With short intervals being 6 and 5 days for start and end acquisition dates respectively between HS and SM data, we can reasonably assume that displacements occurred over the two intervals were very small and couldd be neglected so that displacements during the period from February 2009 to April 2010 measured by the two data pairs can be comparable to each other.
The 3D displacements at corner reflectors were given in Figure 5(a), (b) and (c) respectively. Visual analyses of the displacement field on Shuping landslide were carried out. Firstly, CRs outside Shuping landslide is very stable. Second, eastern part of Shuping landslide show active deformation while western part of Shuping landslide is relatively stable with small displacements.

Thirdly, displacements in north-south and vertical directions are more significant than those in east-west direction, which implies that the dominant motion of this landslide is along the slope gradient towards Yangtze River.

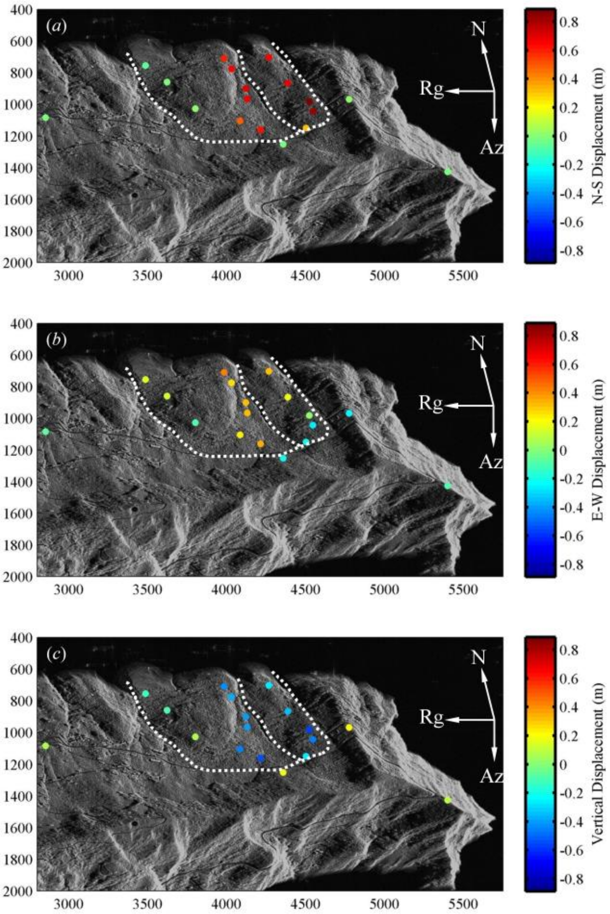

Figure 6. Inverted three dimensional displacements from the HS and SM PTOT measurements on Corner reflectors from January 2009 to April 2010. (a)Northing direction, (b) easting direction and (c) vertical direction.

5. CONCLUSIONS

SAR images usually are the only geodetic data in inaccessible mountainous areas. It is therefore very necessary to find effective method to accurately measure the displacement. D-InSAR is very effective in locating the displacement area by finding distortions if high quality of interferograms is maintained. Phase based advanced InSAR method such as SBAS are effective in measuring slow moving landslides. PTOT method making use of the bright point targets in SAR images can accurately extract the surface displacements at fast moving landslides.

Three dimensional displacements on Shuping landslide were successfully extracted by combining the PTOT measurements from two descending HS datasets and SM datasets. Although both the two datasets were acquired from descending orbits, we can still retrieve the three dimensional displacement taking advantages of different incidence angles of the two datasets.

6. ACKNOWLEDGEMENT

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