THE TRANSMISSION CHANNEL TOWER IDENTIFICATION AND LANDSLIDE DISASTER MONITORING BASED ON INSAR

Guannan Li [1],Qulin Tan [1], Chou Xie [2,*], Xiangze Fei[3], Xiao Ma[3], Binbin Zhao[3],Wenhao Ou[3], Zhi Yang[3], Jing Wang[1], Haoran Fang[1]

[1] Civil Engineering School, Beijing Jiaotong University, Beijing - (16121174, qltan, 15121151, 16121173)@bjtu.edu.cn
[2] Institute of Remote Sensing and Digital Earth， Chinese Academy of Sciences, Beijing - xiechou@radi.ac.cn
[3] China Electric Power Research Institute, Beijing - (fxa, maxiao, zhaobinbin, ouwh, yangzhi)@epri.sgcc.com.cn

KEY WORDS: Transmission Channel, Transmission Tower Identification, InSAR, Time Series, D-InSAR, Landslide Monitoring

ABSTRACT:

The transmission distance of transmission lines is long, the line affected by the diversity of climate and topography of the corridors of transmission lines, differences in regional geological structure conditions, variability of rock and soil types, and the complexity of groundwater. Under the influence of extreme weather conditions (ice-covered, strong wind, etc.) and sudden geological disasters (such as mudslides, flash floods, earthquakes, etc.), catastrophic damage and basic deformation problems of the tower foundations are prone, and even tower collapse accidents occur in severe cases, which affect the safe operation of transmission lines. Monitoring the deformation of power transmission towers and surrounding grounds, it is critical to ensuring the normal operation of transmission lines by assessing and controlling potential risks in advance. In this paper, using ALOS-2 PALSAR radar satellite data, differential interferometry was used to monitor surface deformation near the Sichuan Jinsu line transmission channel. The analysis found that a significant landslide hazard was found near the transmission channel tower in Yibin-Zhaotong section of Jinsu, Sichuan Province, the cumulative deformation reaches 9cm. The results of this paper can provide new monitoring means for safety monitoring of transmission towers.

1. INTRODUCTION

The Jinping-Sunan ±800kV UHVDC(Ultra High Voltage Direct Current) transmission line project starts from the Xichang converter station in the west and the Sunan Wujiang Converter Station in the east, with a total length of approximately 2090.5km, via Yunnan, Sichuan, Chongqing, Hunan, Hubei, Anhui, Zhejiang ,Jiangsu and other eight provinces and cities; and highest altitude of the line through the region 3200m. The section of Xichang Yulong Converter Station-Yibin Hengjiang is belong to Sichuan Yunyun lines. The length of the line is 294.097km. The transmission distance of the transmission line is long. It is constrained by the diversity of climatic and topographic landscapes, differences in regional geological structure conditions, variability of geotechnical body types, and groundwater complexity in the Southwest Power Transmission Line corridor in China. Under the influence of various extreme weather (ice, wind, etc.) or sudden geological disasters (debris flow, flash floods, earthquakes, etc.), The tower foundation is prone to catastrophic damage and basic deformation problems. In severe cases, tower collapse accidents may even occur, affecting the safe operation of transmission lines. It is critical to ensure the normal operation of transmission lines that monitoring the deformation of power transmission towers and surrounding grounds, and assessing and controlling potential risks in advance.

The traditional methods of manual inspection, robot inspection, helicopter inspection, aeronautical digital camera inspection and installation of various sensors on the tower are the main methods for monitoring the safety status of the power grid. There are deficiencies such as small monitoring scope, limited work in harsh environments and large-scale disaster conditions. In the process of investigation and monitoring of landslide hazards, daily patrols are often used in conjunction with leveling measurements, GPS measurements, 3D laser scanning, measuring robots, close-range photogrammetry and other means. Most of the landslide hazards occur in densely-vegetated mountainous areas. The terrain is complex and the mountains are steep. At the same time, dense vegetation affects sightlines and long-distance observation, which is not conducive to the daily inspection and monitoring work,The number of landslide hazards is large and widely distributed. The huge amount of work required has caused great difficulties for the manual investigation and daily monitoring.

Synthetic aperture radar (SAR) is an active sensor that uses microwaves to sense. Compared with other sensors such as optical and infrared sensors, SAR imaging is not limited by clouds, rain, snow, and sunlight conditions. The target of interest can be monitored all-weather and all-day, and it has special advantages under conditions of natural disasters such as snow and ice disasters, earthquake disasters, and flood disasters. Differential Interferometry technology is to compares two scenes of SAR images acquired at different times in the same area and detects surface deformation information in the two image periods. The technology is capable of large-scale, high spatial resolution and high-precision deformation monitoring. In addition, thanks to its short revisit period, remote monitoring, and low cost, it can quickly monitor the displacement of landslides in a larger space. The accuracy, efficiency, and reliability of investigation and monitoring of geological hazards in complex terrain areas have been greatly improved.

* Corresponding author

In the past few decades, domestic and foreign scholars have conducted a series of studies on transmission tower recognition landslide monitoring and analysis.

At present, there is relatively little research on the target identification technology for transmission towers of SAR images. Liao et al. clearly distinguished the target and direction of the transmission tower from the airborne SAR images of the flooded area in the Huaihe River in 2003 [1]; Zhu Junjie compared the SAR image and QuickBird image near the Shangqing Bridge in Beijing's North Fifth Ring. In both images, the iron tower beside the overpass was clearly identified [2]; Yang et al. established an automatic transmission tower recognition model based on high-resolution polarimetric SAR images and accurately extracted the transmission lines in farmland [3] Novak et al. performed polarization whitening filtering on the full-polarization SAR image and identified the transmission tower [4]. Early DInSAR was applied to landslide surveys (Catani et al. 2005; Corsini et al. 2006). However, the time decoherence, spatial decoherence, and atmospheric effects to restrict its widespread use in landslide monitoring.

Permanent Scatterer Interferometry (PSI) uses a large number of SAR images acquired in the same region to analyze ground target phase information with stable scattering characteristics, which can overcome DInSAR temporal decoherence, spatial decoherence, and atmospheric influences. Get high-precision landslide deformation time series. The development of PSI technology has greatly promoted the DInSAR technology in the detection of landslides, the mapping of landslide areas, the monitoring and modeling of landslides, the hazards of landslides and the application of risk assessment.
In this paper, the feasibility and wide-area monitoring of UHV transmission lines and towers using high-resolution SAR technology are studied， using the long-band ALOS-2 PALSAR strips, HH polarizes model and 3m resolution data, uses the tower target detection technology in high-resolution SAR imagery to identify UHV transmission towers and uses DInSAR methods to monitor landslide hazards in the Jinsu transmission channel.

2. TECHNICAL METHODS AND DATA PROCESSING PROCESS

2.1 Data

On May 24, 2014, JAXA Aerospace R&D and Development Agency successfully launched the ALOS-2 satellite. The ALOS-2 is the only L-band high-resolution airborne synthetic aperture radar that can be used to monitor the movement of the earth's crust and the earth's environment. It can obtain observational data regardless of climatic conditions and time. You can get a variety of different resolution images from 1 to 100 meters. The basic parameters are shown in Table 1.

Paramaters	Value
Orbit Hight / km	628
Orbit cycle Time/d	14
Polarization mode	Single Polarization, Double Polarization, Full Polarization, Compact Polarization (Experimental Mode)
Frequency/GHz	1.2
Orbital inclination/(°)	97.9
Track type	Sun synchronous orbit
Side view direction	Left and right side view

Table 1. ALOS-2 PALSAR Related Parameters

L-band wavelength is 150-300mm, and it is highly penetrating to the vegetation. It is suitable for deformation monitoring in dense covered areas with cloudy and rainy vegetation. Therefore, it has significant advantages in the investigation and monitoring of geological disasters in Jinsu transmission channel.

The study area uses ALOS-2 PALSAR image data. The data coverage area is shown in Figure 1 below. The details are shown in Table 2. A total of 11 scenes were used.

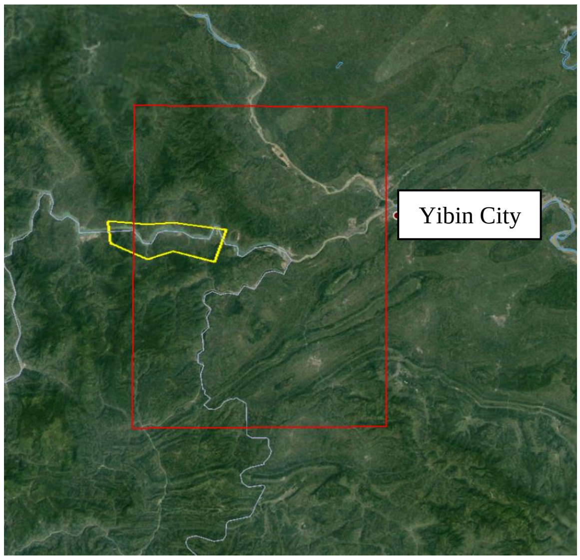


Figure 1. Data coverage (Red rectangle is the data coverage area, yellow area is the transmission channel)

No	Date	Area Name	File Name
1	20160821	No. 550, Jin Su Line, Sichuan	0000108427_001001_ALOS2121330560-160821
2	20161016	No. 550, Jin Su Line, Sichuan	0000115675_001001_ALOS2129610560-161016
3	20161225	No. 550, Jin Su Line, Sichuan	0000127379_001001_ALOS2139960560-161225
4	20170108	No. 550, Jin Su Line, Sichuan	0000128487_001001_ALOS2142030560-170108
5	20170319	No. 550, Jin Su Line, Sichuan	0000139251_001001_ALOS2152380560-170319
6	20170402	No. 550, Jin Su Line, Sichuan	0000142422_001001_ALOS2154450560-170402
7	20170416	No. 550, Jin Su Line, Sichuan	0000143766_001001_ALOS2156520560-170416
8	20170514	No. 550, Jin Su Line, Sichuan	0000143766_001001_ALOS2156520560-170416

https://doi.org/10.5194/isprs-archives-XLII-3-807-2018

9	20170528	No. 550, Jin Su Line, Sichuan	0000147623_001001_ALOS2162730560-170528
10	20170611	No. 550, Jin Su Line, Sichuan	0000148935_001001_ALOS2164800560-170611
11	20170820	No. 550, Jin Su Line, Sichuan	0000156921_001001_ALOS2175150560-170820

Table 2. Data details

2.2 SAR Satellite Monitoring UHV Transmission Tower

SAR imaging systems compared to other imaging systems, in particular optical imaging systems, the two-dimension images with generated have many distinct differences. The SAR image mainly reflects two kinds of characteristics of the target: electromagnetic scattering characteristics and structural characteristics. Its target characteristics large extent depend to radar system parameters and geographical parameters, such as: working wavelength, angle of incidence of the electric wave, polarization direction of the incident angle, regional surface roughness, shape and direction of the regional target, and restoration of regional materials, dielectric constants and so on. Compared with optical images, SAR images have poor visual readability and are affected by speckle noise and geometric distortions such as shadows, overlap, and perspective shrinkage, making SAR image information processing more difficult. Therefore, it is necessary to study the imaging characteristics of ground objects according to the characteristics of SAR imaging. Taking the UHV transmission tower as an example, the characteristics of the UHV tower are studied for SA R images. The characteristics of the tower in the radar image can be summarized as the following two points: The material of the tower is generally a metal material, and there is a strong backscattering characteristic in the SAR image, which appears as a brighter region in the image; The direction of the tower is the same as that of the SAR platform, which makes the structure of the tower target very clear in the image, especially the brightness of the cross-section is extremely high. The tower is shown in Figure 1 below on the SAR image. In short, the UHV transmission tower on high-resolution SAR images is represented by structural information and is no longer a point target. Therefore, the damage status is analyzed through the extraction of information such as its geometric structure, spatial topology and texture features is feasible.

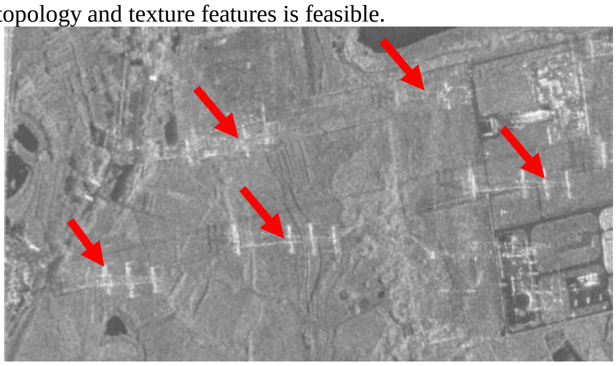


Figure 2. Transmission line tower in SAR image

2.3 DInSAR Technology Transmission Channel Landslide Monitoring Method

According to the monitoring proprotion and the dense vegetation on the ground in the study area, high-resolution L-band ALOS-2 PALSAR radar data and high-precision DEM, based on radar interferometry, combined with high-resolution optical satellite remote sensing data and other multi-source observations comprehensive monitoring of data, improving the accuracy of landslide monitoring, detailed analysis and verification of monitoring results.

By DInSAR technical monitoring of surface deformation, the need to eliminate the delayed impact of the atmosphere, affecting the ground effect, noise, undulating terrain. The phase delay caused by atmospheric fluctuations during the transmission of radar electromagnetic waves can be applied to increase the signal-to-noise ratio between the deformation information and atmospheric interference signals by using the method of superposition of interferograms, and to reduce the phase component; the phase of the ground can be removed by accurately calibrated to the baseline; error noise, which can be used to suppress noise in the interferogram based on adaptive filtering; terrain phase can be removed by introducing external DEM data. Considering the selection of radar data and the actual situation of the monitored area, the "two-pass" differential interferometry technology is adopted, ie, the external high-precision DEM and the two-view radar complex image data are adopted, and the topographic phase is achieved on the basis of radar conformation equation by high-precision DEM, and then removed from the radar interferogram to obtain the surface deformation phase.

In this study, the external DEM used the SRTM-1 DEM data with a resolution of 30m to construct a simulated topographic phase interference fringe map based on the image parameters of the two imaging steps, and then subtracted this information from the overall interference map to obtain ground change information. The data processing flow is shown in Figure 3 below.

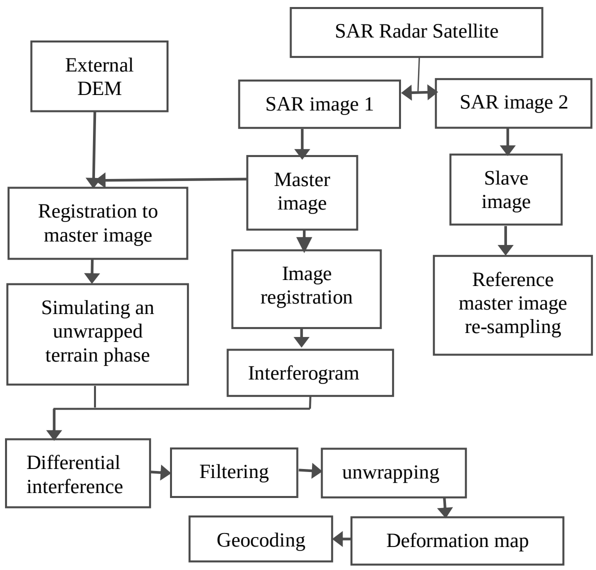


Figure 3. Flowchart of Two-pass DInSAR Technique

3. RESEARCH AREA OVERVIEW

3.1 Scope of Research Area

The No. 550 transmission line of Jin Su line in Sichuan passed through Yunnan and Sichuan province, and he topography is undulating and typical of the karst landscape. The latitude and longitude range is (28.570950°N~28.658069°E 104.007497°E~104.267392°E). The area is approximately 350 square kilometers across the cities of Zhaotong in Yunnan Province and Yibin City in Sichuan Province. The scope of the study area is shown in Figure 2 below.

https://doi.org/10.5194/isprs-archives-XLII-3-807-2018

Figure 4. Research area

The main reasons for landslide formation in the study area are geological structure, stratum lithology, topography, meteorology, hydrology, human activities, etc., and the geological conditions in Sichuan and Yunnan are complex and prone to geological disasters. Therefore, it is necessary to carry out research on the impact factors of landslide geology disaster susceptibility evaluation in the study area.

3.2 Landslide Susceptibility Evaluation Factors in The Study Area

3.2.1 Topography: The study area is located in the southwestern margin of the Sichuan Basin. It is a transitional zone from the hills to the basins and mountains. The overall topography tends to gradually decrease from the west to the east and gradually increase from north to south, and is cut down by the Jinsha River valley to form a landscape of Jiangnan and Jiangbei. Among them, Jiangbei is a hilly area, and Jiangnan is a low mountain and deep hill area. According to the geomorphic morphology and genesis, it is divided into three types of landforms: erosion and accumulation topography, mainly accumulation, also see basement rock beach, banded or lenticular-like silt layer distribution in some areas; erosion denudation topography, topography morphological characteristics controlled by lithology and structure, the ditch is narrow, and the relative height difference between hills and valleys is generally 30-60m; the topography of the erosion structure is consistent with the tectonic line and the mountain trend is long and winding, with steep hill slopes, more horizontal ditch, and more developed vegetation, there are many cliffs on the side, and the collapse is more developed.

3.2.2 Meteorological hydrology: Meteorology: This region has a humid subtropical monsoon climate with four distinct seasons, mild climate, and abundant rainfall, Its characteristics are: winter warm spring, early morning frost less snow, hot summer rain, rain, autumn rain, high humidity, cloud, wind and small sunshine less. The average annual temperature being about 16.2 °C. The annual rainfall ranges from 1205 to 1657 mm and 84.0% of the precipitation occurs during the rainy season (from May to September). The annual maximum rainfall is 1625mm (1954), the minimum rainfall is 726.6 (1972), the annual rainfall guarantee rate is greater than 1000mm, and the annual rainfall guarantee rate is 82.86%, and the annual rainstorm is 1-6 days with an average of 2.71 Most of the rainfall was concentrated from June to September, accounting for 64.83% of the annual rainfall. The average annual temperature in the area is 18°C and the extreme maximum temperature is 39.5°C. The hottest is July and the coldest month is January in a year. The average annual relative humidity in the region is 81%.

Hydrology: The study area belongs to the Jinsha River system. After the Yibin confluence, the Jinsha River and the Lancang River are called the Yangtze River. The average hydraulic gradient of the Jinsha River is 0.26‰. According to observation at the Waipingping Hydrological Station, the average annual flow of the Jinsha River is 4,620m^3/s, and the maximum flow rate is 29,000m^3/s, the minimum flow rate is 1040m3/s, and the annual runoff volume is $1.46\times10^{11}m^3$. The area is rich in surface water resources.

3.2.3 Geological conditions: The Triassic to Quaternary strata are exposed in the study area. The lithology mainly consists of sandstone, sandy mudstone and thin coal seams. The loose deposits are distributed along the small area of the river. The geological structure in the area is relatively simple, with the Lancang River as the boundary. The folds and faults in the northeastern area except for a few twists and twists that intersect the axis of the folds are mostly compressive and pressure-torsional, and the directions are basically parallel to the axes of the folds.

3.3 Geological Disasters

The study area is located in the transitional zone between mid-low mountains and hills and basins. The terrain is high in the west and low in the east, and the relative depth of cut is also relatively large. With the deepening of engineering construction, the development of social and economic conditions and the increase of population, geological disasters are increasingly prominent. The main types of geological disasters in the study area are landslides, collapses and unstable slopes. The landslides mainly occur in the vicinity of the Cuiping Mountain and are located on the left bank of the Jinsha River.

4. RESULTS ANALYSIS

4.1 Identification of SAR UHV Transmission Towers

Figure.5(a) is a differential interferogram along the transmission channel of the study area. The tower appears as a bright fringe in the interferogram. As indicated by the red arrow in the figure, the transmission tower can be identified in the differential interferogram and can be clearly distinguish the basic form of the tower. Figure.5 (b) is the google earth image in the same location, which validated the accuracy of the tower identified by using SAR interferometer. Based on the above analysis, it can be found that it is feasible to identify the tower in the differential interferogram of SAR. In addition, if a large-scale deformation or collapse accident occurs during the operation of the transmission tower, the deformation of the tower can also be monitored by using differential interferometry.

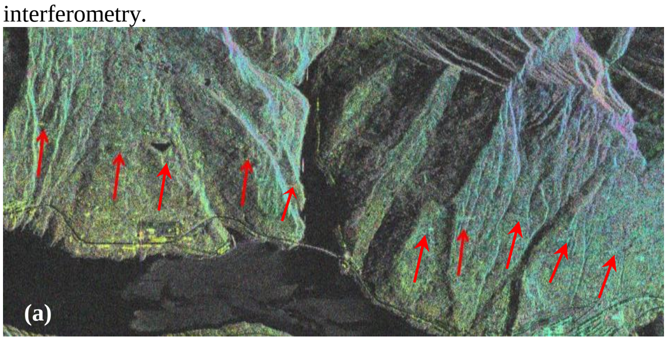
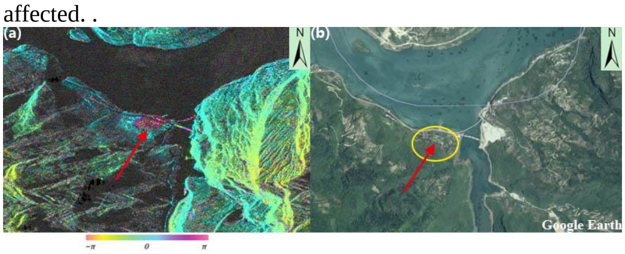


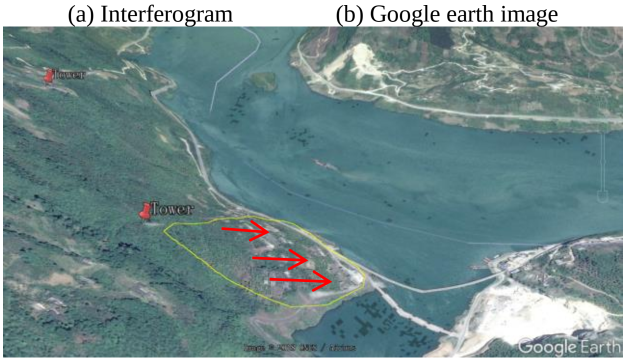
Figure 5. Identification of SAR UHV Transmission Towers

4.2 Transmission Channel Landslide Disaster Monitoring

InSAR interferometry was performed using ALOS-2 PALSAR data from 11 scenes from August 21, 2016 to August 20, 2017. A total of 26 differential interferograms were generated. The hidden point of landslide in the interferogram was found in Xintan Town of Xintan Village Qijiang County Zhaotong, Yunnan Province. The topography of the area is undulating, there are numerous ravines and rivers, mountains and hills. Controlled by structure, lithology, and the Jinsha River water system, it exhibits a variety of landforms such as peaks, mountains, valleys and river valleys. The area is a typical karst landscape, and it is easy to form shadows on radar images. The incident angle of 36.1° can largely avoids the appearance of shadows. Figure.6 (a) shows the differential interference fringe map of Xintan Town. The corresponding geographical location is shown in Figure.6 (b). The monitored geographical position of the landslide area is 28° 36'3.99"N, 104° 5'. 41.25"E, Figure.6 (a) can calculate the deformation is 6.4cm. The lower color scale represents the phase cycle corresponding to 11.5 centimeters (ie, half the wavelength (23 centimeters)) at the ground. Note that we can be observed that several white pixels in all interferograms, which indicate no data values. This is due to the geometric distortion, perspective and shadow effects of radar signals. Figure.6(c) is a magnified view showing that there is a tower in directly above of the mountain and there are villages below the landslide. The trend of the landslide is shown in the red arrow. If a landslide occurs, the tower above the landslide and the village on the landslide will be directly affected. .



(a) Interferogram (b) Google earth image



(c) Landslide area in google earth (The yellow polygon is a landslide body, the red arrow is the development trend of the landslide body, and the red landmark is the power transmission tower)

Figure 6. The result of the DInSAR Xintan Town

The analysis of the 26 differential interferograms can summarize the changes of the landslide body within one year as Table 3 follows. Can be divided into three time segments。

NO.	Date	Deformation value/cm
1	20160821-20161016	5
2	20160821-20161225	8
3	20160821-20170108	8
4	20161016-20161225	3.5
5	20161016-20161225	3.8
6	20161016-20170108	5.2
7	20161225-20170402	2.8
8	20161225-20160416	5
9	20161225-20170514	5
10	20161225-20170528	5.6
11	20170108-20170402	3.5
12	20170108-20170514	5
13	20170108-20170528	5.6
14	20170319-20170611	3
15	20170402-20170528	4.8
16	20170402-20170820	6
17	20170416-20170611	5
18	20170514-20170820	7.2
19	20170528-20170820	8

Table 3. Deformation statistics

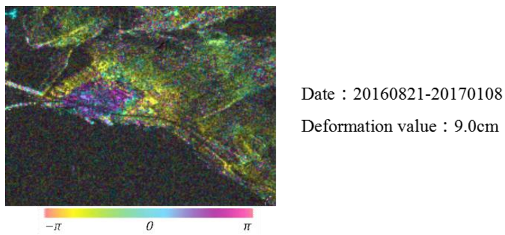


Figure 7. Rainy season to the dry season

4.2.1 Rainy season to the dry season in 2016: During the period from August 21, 2016 to January 8, 2017, significant deformation occurred in this area, the cumulative deformation was 9 cm, and a deformation of 6.0 cm from August 21 to October 16; A slight deformation occurred during October 16 to December 25; no deformation during the period from December 25 to January 8, 2017. We can found that the deformation mainly occurred during the period from August 21 to October 16, which was the local rainy season.

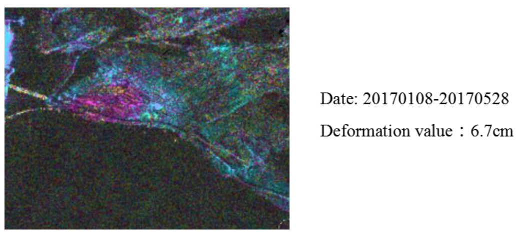


Figure 8. Dry season 2017

4.2.2 Dry season in 2017 : During the period from January 8, 2017 to May 28, 2017, the cumulative deformation was 6.7 cm. From January 8 to March 19, 2017, the deformation was 3.5cm, and from April 16th to May 28th, the value was 3.2cm. Deformation mainly occurs on January 8 - March 19 and April

16 - May 28. It can be found that the deformation of the landslide body is small during the dry season.

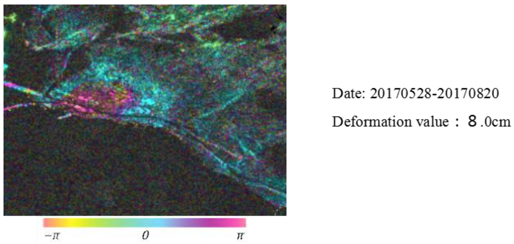


Figure 9. Rainy season in 2017

4.2.3 Rainy season in 2017: During the period from May 28th, 2017 to August 20th, 2017, obvious deformation occurred in the area during the local rainy season, with a deformation of 8.0cm; Furthermore there was a clear acceleration of deformation.

On December 16, 2017, we conducted a field survey of Xintan Town. The verification results are shown in Figures 8, 9 and 10. The dormant landslide area is located near Xintan Village of Qijiang Zhaotong in Yunnan Province. From the on-site inspection photos and local hydrogeological data, it is known that the vegetation cover is thick and the soil layer is thick. The characteristics of the rock mass are the Late Permian-early Triassic siliceous terrigenous clastic and siliceous rocks. The characteristics of soil is yellow clay and its loose structure, develops shrinkage cracks, and has poor stability. It has caused small-scale slippage. The accompanying landslides are yellow mud and some clastic rocks. The average slope of the monitored landslide area is 40 degrees. It can be found that there is a tower located directly above the landslide body in on-site photograph. The bridge below the landslide body has partial landslide debris and the bridge bridge body is 4-5 cm. In the crack, the bridge was forbidden to pass on March 3, 2017. In addition, in the village below the landslide, some cracks occurred in houses, floors, and steps. Once the rainfall increases or heavy rains strike, the soil is loose and landslides may occur at any time.

Figure 10. Landslide body and tower

Figure 11. Deformation of bridge below landslide body(The bridge was banned from traffic on March 3, 2017 due to security risks)

Figure 12. House cracks and ground cracks

5. CONCLUSIONS

SAR imaging is not restricted by clouds, rain and snow, Solar illumination condition, etc., and it has the characteristics of all-weather and all-day working. It is possible to monitor transmission lines and towers in large scale natural disasters such as landslide, ice and snow disasters, earthquake disasters, flood disasters and so on. In this paper, the radar scattering and imaging characteristics of UHV transmission tower are studied by using 3 m resolution ALOS2 PALSAR radar image, and the tower target recognition is carried out in the differential interferogram of high resolution radar image. The feasibility of using high-resolution SAR image to monitor the deformation of iron tower is verified, and the geological hazard monitoring research around transmission tower is carried out by using interferometry technology to verify the accuracy of landslide monitoring of transmission channel measured by interferometry. The results show that the structural characteristics of UHV transmission tower can be extracted by using SAR interferometric target recognition technology under disaster conditions, and can monitor the tower deformation through interferograms; while using differential interferometry technology can accurately monitor the geological disasters near the transmission towers. SAR interferometry provides a new scheme for wide area disaster monitoring of UHV transmission lines and towers.

ACKNOWLEDGEMENTS (OPTIONAL)

We thank the National Natural Science Foundation of China (No. 41571328, 41001276, 41431174, U1303285 and 61471358) for financial support in part. The corresponding author thanks the Team of Institute of Remote Sensing and Digital Earth.

REFERENCES

B. Bayer, A. Simoni, D. Schmidt, L. Bertello, 2017. Using advanced InSAR techniques to monitor landslide deformations induced by tunneling in the Northern Apennines, Italy. *Engineering Geology*, 226, pp. 20-32.

B. Han et al., 2014. Deformation Monitoring and Prediction of a Reservoir Landslide in Sichuan Province, China. *Applied Mechanics and Materials*, Vols. 580-583, pp. 2694-2701.

Guanglin Yuan, Gengyu Yang, Yunfei Zhang, 2009. Influence Regularities of Ground Deformation on Internal Force and Structure Deformation of Transmission Tower. *Journal of China Coal Society*, 34(8), pp. 1044-1049.

Jingjuan Liao, Yun Shao, Shixin Wang. 2004. Monitoring for 2003 Huai River Flood in China Using Multisource SAR Data. *Geoscience and Remote Sensing Symposium*, 4:2, pp.260-2 263.

Junjie Zhu, 2005. High Resolution Optical and SAR Remote Sensing Data Fusion and Typical Target Extraction Methods. Graduate School of Chinese Academy of Sciences. Beijing.

KANG Xin, ZHU Jun, GENG Liu-yong, 2017. Application of InSAR Technique to Monitor Time-series Displacements of Transmission Towers Located in Mining Area. *Electric Power Survey & Design*, 2, pp. 11-15.

Shanchuan Guo, Huping Hou, Shaoliang Zhang, et al., 2017. Surface Deformation Monitoring of D-INSAR in Loess Plateau Mining Area. *Science of Surveying and Mapping*, 42(6), pp. 207-213.

Singhroy V., 2009. Satellite Remote Sensing Applications for Landslide Detection and Monitoring. In: Sassa K., Canuti P. (eds) *Landslides-Disaster Risk Reduction*. Springer, Berlin, Heidelberg, pp. 143-158.

Wen Yang, Haijian Zhang, Jiayu Chen, et al., 2007. Automatic Detection of Power Transmission Series in Full Polarimetric SAR Imagery. Radar Conference, IEEE, Boston, USA.

WANG Mingzhou,LI Tao,LIU Yan, 2014. Study on Monitoring the Subsidence Area above Goaf and the Transmission
Tower Foundation Deformation with L-band Radar Satellite. *Survey Bulletin*, (7), pp. 58-62.

William H. Schulz, Jeffrey A., Pier P. Ricci et al., 2017. Landslide kinematics and their potential controls from hourly to decadal timescales: Insights from integrating ground-based InSAR measurements with structural maps and long-term monitoring data. *Geomorphology*, 285, pp. 121-136.

Wang Zhiyong, Zhang Jinzhi, 2013. *LANDSLIDES MONITORING BASED ON INSAR TECHNIQUE. JOURNAL OF GEODESY AND GEODYNAMICS*, 33(3), pp. 87-92.

Wenbin Guo, Bin Zhen, 2010. Study on the effect on high-voltage transmission line tower of surface horizontal strain. *Journal of Henan Polytechnic University (Natural Science)*, 29(6), pp. 726-733.

Xiaopeng Tong, David Schmidt, 2016. Active movement of the Cascade landslide complex in Washington from a coherence-based InSAR time series method. *Remote Sensing of Environment*, 186, pp. 405- 415.

Yan Liu, Yi Hu, Li Nong, et al., 2009. Surveillance for 1000 kV Transmission Tower Deformation Using High-resolution SAR Satellite. *High Voltage Engineering*, 35(9), pp. 2076-2081.