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Accuracy Testing and Analysis of PS-InSAR and DS-InSAR in Monitoring Urban Land Subsidence

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Abstract. InSAR is a new technique in the field of land subsidence monitoring,and the application is more and more widely. In order to evaluate the monitoring accuracy of InSAR objectively，it is necessary to use leveling results to test and analyze the monitoring results of InSAR.Two sets of datas of the surface subsidence of Shangyu are acquired by using PS-InSAR technique and DS-InSAR technique to process the datas of the 23 scenes sentinel-1 images covering Shangyu area respectively.The accuracy of the results is tested and analyzed by using the second-order leveling results of Shangyu area. The results show that the mutual difference between the second-order leveling results and PS-InSAR or DS-InSAR results is mainly distributed in the range of - 5 ~ + 5mm / year, which demonstrate that the monitoring results of PS-InSAR and DS-InSAR are reliable.It provides basic information and data for the construction of land subsidence monitoring network and comprehensive treatment of land subsidence, and provides decision-making basis for government departments to prevent and control geological disasters of land subsidence.

Keywords: PS-InSAR,DS-InSAR,land subsidence

1. Introduction

Leveling is a traditional elevation measurement technology [1],which matures， is easy to master,needs simple instruments, and has reliable results and high measurement accuracy. The disadvantage of leveling is that only scattered deformation values of monitoring points can be obtained.InSAR（Synthetic Aperture radar Interferometry）Technology is an emerging interdisciplinary subject developed in the late 20th century [2]。In the 1990s, InSAR and DS-InSAR technologies achieved unprecedented development and were widely applied [3]. Domestic research on the application of InSAR technology in surface deformation monitoring began in recent years, and mainly focused on urban land subsidence monitoring [4].

InSAR technology has advantages such as high precision, large coverage area and all-weather and all-day earth observation, and has been increasingly widely applied in the field of land subsidence monitoring [4]. In order to objectively evaluate the accuracy of InSAR ground settlement monitoring results, it is necessary to use the leveling results to test the accuracy of InSAR monitoring results, that is, to compare the measured data of leveling points with the InSAR ground settlement monitoring results, and calculate the mean and median errors of InSAR ground settlement monitoring results relative to the leveling results [6]，which are used for accuracy assessment of monitoring results to ensure the accuracy and reliability of monitoring results. In this paper, the methods of PS-InSAR (Persistent Scatterer InSAR permanent Scatterer Interferometry) [6] and DS-InSAR (Distributed Scatterer InSAR interferometry) [7] are cited. The accuracy test and analysis of InSAR monitoring results were carried out with second-class leveling data in Shangyu District.The accuracy test method and analysis method are innovative to some extent.

2. Experimental Area and Data Introduction

2.1.Experimental area profile

The experiment area is Shangyu District, Shaoxing City, Zhejiang Province. Shangyu is located in the east of Shaoxing City, east longitude 120° 36 '23 "~121° 6' 9", north latitude 29° 43 '38 "~30° 16' 17".The basic outline of the territory is north-south rectangular, the longest north-south is about 60

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kilometers, the widest is about 46 kilometers, and the area is about 1403 square kilometers. Shangyu topography is high in the south and low in the north, the south of the low hills and the north of the water network plain area is mixed, commonly known as "five mountains, one water and four fields".The southern low mountains and hills belong to two branches. It is low-lying and flat, with an average elevation of about 5 meters. In recent years, due to the continuous growth of population and economy in Hangzhou Bay New District and Shangyu urban planning Area, a large number of large-scale engineering construction, high-rise and super high-rise building construction, and quicksand soil quality in some areas, some areas of Shangyu have a certain degree of ground collapse and subsidence.

2.2. Experimental data

2.2.1 Second class leveling data

In order to verify the accuracy of the monitoring results of urban land subsidence based on InSAR, it is necessary to obtain the actual settlement amount of the monitoring points of land subsidence in the same period.According to the needs of the InSAR land subsidence monitoring, considering the cost and the accuracy verification, the results of second-class level routes in 2013 within the monitoring area are fully utilized, and the second-class level routes laid near Shangyu high-speed railway, expressway, Jiashao Bridge and 104 National Highway in 2014 are retested,which are used for the Reference and accuracy verification for InSAR land subsidence monitoring. The revelant technical requirements refer to GB/T12897-2006 National Standard for the first and the second class Level.

InSAR linear deformation model inversion processing for land subsidence monitoring [8] needs to find stable and reliable datum points in the monitoring area, and conduct unified spatio-temporal datum processing for linear deformation field data to obtain accurate deformation information. In order to ensure the scientificity and rationality of the deformation results, the leveling point "II Shanggong Shui 08" is selected as the reference base of the deformation rate.

In order to make full use of the existing settlement observations in the monitoring area, historical level data consistent with InSAR settlement monitoring data and newly measured level data were selected for verification and evaluation. A total of 37 field level points with historical observation values in 2014 were qualified in the monitoring route by leveling comparison.

2.2.2 PS-InSAR and DS-InSAR land subsidence monitoring data

In this experiment, ESA Sentinel-1 high-resolution radar data was selected for InSAR monitoring of land subsidence in Shangyu District, Shaoxing City.

Sentinel-1 is an Earth observation satellite in the Copernicus Project (GMES) of the European Space Agency. It consists of two low-orbit near-polar solar synchronous satellites, the first of which was launched in April 2014 , the second in April 2016. The working band is C-band (3.1cm).Sentinel-1's imaging system uses four imaging modes (resolution up to 5 m and width up to 400 km) to provide dual-polarization, short revisit periods, rapid product production, and accurate determination of satellite position and attitude Angle. It adopts a pre-programmed, conflict-free operation mode, which can realize high-resolution monitoring of global land, coastal zones and shipping routes, as well as large regional coverage of the global ocean, which also provides technical support for a variety of applications and long time series monitoring of the same area.

Sentinel-1 radar data with IW imaging mode covering the whole territory of Shangyu District was ordered. The polarization mode was VV polarization. According to the principle of uniform distribution of SAR data acquisition time, SAR data were selected, and 1 scene was obtained in 24 days, with a total of 23 scenes spanning from April 2015 to November 2016.

Due to the adoption of the new radar distributed target recognition method and filtering algorithm [9], DS-InSAR technology finally obtained 3,226,377 measurement points (about 2700 / km 2), while the conventional PS-InSAR technology only obtained 956,428 measurement points (about 790 / km 2). The density of the former is about 3.5 times that of the latter. The increased measurement points are mainly concentrated in non-urban areas. For example, in areas with radar distributed target characteristics such as bare soil and asphalt pavement, especially in the newly reclaimed area in Hangzhou Bay Industrial Park, Shangyu, the density of monitoring points by DS-InSAR method is 7.5 times that by PS-InSAR method.

3. Accuracy Test Method

3.1.Accuracy test method

The ground deformation monitored by InSAR technology in time series is the line of sight direction of SAR satellite (LOS) [10], while the deformation monitored by leveling is the vertical direction. Therefore, the leveling results should be projected into the line of sight direction of SAR satellite, and then compared with the monitoring results of InSAR [11].In order to make full use of the existing settlement observations in the monitoring area, historical level data and newly measured level data that are consistent with the InSAR settlement monitoring data are selected to verify and evaluate the accuracy of InSAR monitoring results:

(1) Take the level point as the center, search for the nearby high coherence point (PS-InSAR point or DS-InSAR point) [12] within 100m for comparison and verification with the corresponding level point. If the distance exceeds 100m, this point will be abandoned for verification, as shown in Figure 1. The main evaluation criteria are the mean error and median error of InSAR ground subsidence monitoring results relative to ground measured results.Its calculation formula is as follows:

$$\text{Mean error:}\quad \vartheta = \pm \frac{\sum_{i=1}^{N} \left| d_{Li} - d_{Ii} \right|}{N} \tag{1}$$

$$\text{Median error:}\quad m = \pm \sqrt{\frac{\sum_{i=1}^{N} (d_{Li} - d_{Ii})^2}{N-1}} \tag{2}$$

Where dLiis ground measured data and dIiis InSAR monitoring result [13].

（2）Kriging interpolation [14] was carried out on the results of PS-InSAR points and DS-InSAR points to obtain the results of spatial continuous deformation, and the measured values of PS-InSAR and DS-InSAR corresponding to the position of level points were extracted for comparison with the leveling results. Figure 2 shows the verification method. In this way, all the leveling data in the monitoring area can be used for accuracy verification.

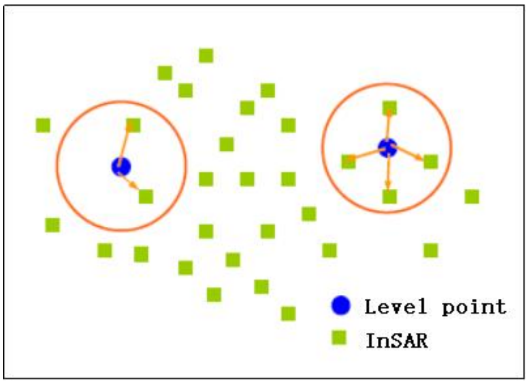


Fig. 1: Schematic diagram of adjacent point verification method

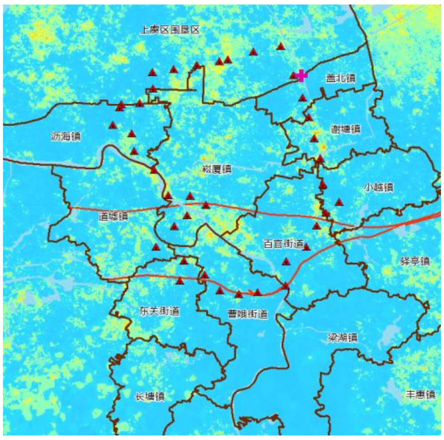


Fig. 2: Schematic diagram of Kriging interpolation result verification

4. Accuracy Test Result

InSAR settlement monitoring results can provide time series settlement amount, and the settlement amount between any two phases of image acquisition period can be calculated , which can fully guarantee the spatial-temporal consistency of settlement amount comparison between field level data and InSAR data.

The inversion processing of InSAR linear deformation model for land subsidence monitoring needs to find a stable and reliable datum point in the monitoring area, and carry out unified spatio-temporal datum processing on the land subsidence rate results to obtain accurate deformation information. In order to ensure the scientificity and rationality of the deformation results, the leveling point "II Shanggong Shui 08" is selected as the reference base of the deformation rate.

Table 1, Table 2, Table 3 and Table 4 show the accuracy test results of second-class leveling results on

PS-InSAR results, DS-InSAR results, PS-InSAR interpolation results and DS-InSAR interpolation results. In the verification of PS-InSAR results, level points with a distance of more than 100m were excluded ,and a total of 34 level points were included for comparison. In the DS-InSAR result verification, a total of 36 level points were included for comparison,while the level points with a distance of more than 100m were excluded. Table 5 shows the accuracy test results of InSAR land subsidence monitoring. The histogram of mutual difference between level and InSAR results is shown in Figure 3.

Table 1: Accuracy test results of PS-InSAR ground subsidence monitoring points

S/N	Point name	Level Average annual rate （mm/year）	Annual rate of PS-InSAR （mm/year）	count	Mean absolute deviation （mm/year）
1	Shangyu national bedrock point	0	3	82	3
2	IIShangShui07	-5.2	-0.8	45	4.4
⋮	⋮	⋮	⋮	⋮	⋮
34	IHangWen20（06）	0.7	-1.6	14	2.3
Mean error(mm/year)		±4.4			
Median error(mm/year)		±3.2			

Table 2: Accuracy test results of DS-InSAR ground subsidence monitoring points

S/N	Point name	level Average annual rate （mm/year）	DS-InSAR annual rate （mm/year）	count	Mean absolute deviation （mm/year）
1	Shangyu national bedrock point	0	0.9	78	0.9
2	IIShangShui07	-5.2	-1.8	71	3.4
⋮	⋮	⋮	⋮	⋮	⋮
36	IHangWen20（06）	0.7	-3.5	26	4.2
Mean error(mm/year)		±4.1			
Median error(mm/year)		±2.8			

Table 3: Accuracy test results of PS-InSAR interpolation results

S/N	Point name	level Average annual rate（mm/year）	Annual rate of PS-InSAR （mm/year）	Mean absolute deviation （mm/year）
1	Shangyu national bedrock point	0	3.4	3.4
2	IIShangShui07	-5.2	-0.4	4.8
⋮	⋮	⋮	⋮	⋮
37	IHangWen20（06）	0.7	-3.5	4.2
Mean error(mm/year)		±4.5		
Median error(mm/year)		±3.1		

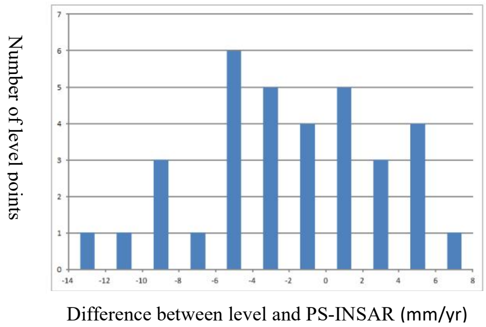
Table 4: Accuracy test results of DS-InSAR interpolation results

S/N	Point name	Level Average annual rate （mm/year）	DS-InSAR annual rate（mm/year）	Mean absolute deviation （mm/year）
1	Shangyu national bedrock point	0	0.8	0.8
2	IIShangShui07	-5.2	-2.1	3.1
⋮	⋮	⋮	⋮	⋮

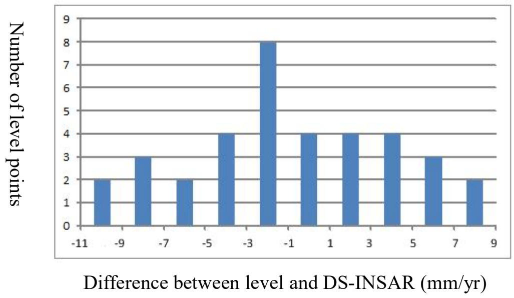
37	IHangWen20（06）	0.7	-3.1	3.8
Mean error(mm/year)		±4.0		
Median error(mm/year)		±2.7		

Table 5: Comparison of accuracy test results of different methods

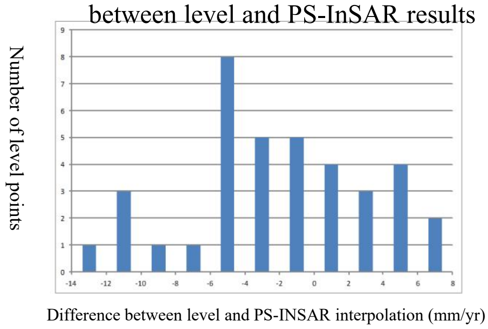
Comparative method		Mean error（mm/year）	Median error（mm/year）
Adjacent point	PS-InSAR	±4.4	±3.2
	DS-InSAR	±4.1	±2.8
Kriging interpolation	PS-InSAR	±4.5	±3.1
	DS-InSAR	±4.0	±2.7



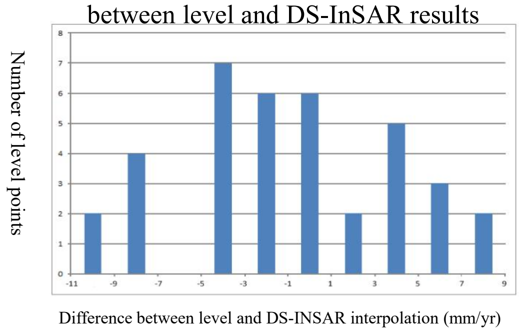
(a) Histogram of cross difference between level and PS-InSAR results



(b)Histogram of cross-difference between level and DS-InSAR results



(c)Histogram of mutual difference between leveling and PS-InSAR interpolation results



(d)Histogram of mutual difference between level and DS-InSAR interpolation results

Fig. 3: Histogram of mutual difference between level and InSAR results

5. Discussion and Conclusion

In order to objectively evaluate the accuracy of InSAR ground settlement monitoring results, field leveling results were used to test the accuracy of InSAR monitoring results. In other words, the measured data of field leveling points were compared with the InSAR ground settlement monitoring results, and the mean and median errors of InSAR ground settlement monitoring results were calculated. Used for accuracy assessment of monitoring results to ensure the accuracy of monitoring results. Compared with the traditional land subsidence monitoring method, this method has the characteristics of reliable accuracy and high efficiency. Due to my limited energy, the number of level points in the paper is too small, and the later research will be improved.

The monitoring accuracy of land subsidence in Shangyu urban district takes the average annual subsidence rate as the index, and the median error of InSAR monitoring annual average subsidence rate is less than 5mm compared with the second-class leveling data.Table 4-5 shows that the average error of PS-InSAR point target and level monitoring results is ±4.4mm/year, and the median error is ± 3.2mm /year. The average error of Kriging interpolation points and level points monitoring results of PS-InSAR is (±4.5mm/year), and the median error is ±3.1 mm/year. The average error of DS-InSAR radar target and level monitoring results is ±4.1 mm/year, and the median error is ±2.8 mm/year. The mean error of Kriging interpolation point and level point monitoring results of DS-InSAR is ±4 mm/year, and the median error is ±2.7 mm/year.The accuracy test results based on near point method show that the mean error and median error of DS-InSAR monitoring results are ± 4.1mm /year and ± 2.8mm /year respectively, which is slightly better than that of PS-InSAR method. In addition, it can be seen from Figure 4-1 that the difference between second-class leveling survey and InSAR results is mainly distributed within -5~+5mm/year, which also indicates the reliability of InSAR land subsidence monitoring results.

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