SUBWAY TUNNELS IDENTIFICATION THROUGH COSMO-SKYMED PSINSAR ANALYSIS IN SHANGHAI

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ABSTRACT

Synthetic Aperture Radar Interferometry (InSAR) is an alternative technique to obtain measurements of surface displacement providing better spatial resolution and comparable accuracy at an extremely lower cost per area than conventional surveying methods. InSAR is becoming more and more popular in monitoring urban deformations, however, the technique requires advanced tools and high level competence to be successfully applied. In this paper we report important results obtained by analyzing new high resolution SAR data in urban areas. Using the SARPROZ InSAR tool and integrating the results with Google Earth, we discovered the (not public) precise tracks of new subways lines in Shanghai by detecting the millimetric surface subsidence caused by tunnel excavation. The data used in this work have been acquired by the Italian sensor Cosmo-SkyMed. About 1.2 million of individual and independent targets have been detected in 600 sqkm, revealing impressive details of the ground surface deformation. Through the high spatial resolution (about 2m) and millimetric sensitivity in the Line Of Sight (LOS), Cosmo is able to highlight very localized subsidence with remarkable accuracy.

Index Terms—PSInSAR, Urban Monitoring, High Resolution, Cosmo SkyMed

1. INTRODUCTION

1.1. Shanghai subway development

Shanghai, as one of the most populated city in the world, made an aggressive effort in expanding its underground railway network. In the six months leading up to the opening of the Expo on May 1, 2010, the Shanghai Metro has undergone major expansions [1]:

(1) Line 2, with separate sections opening on February 24, March 16, and April 8, 2010, is now over 63 km in total length and connects the two city's airports -- Hongqiao and Pudong.

(2) Line 7 opened on December 5, 2009

(3) Line 9's Yishan Road to Century Avenue section opened on Dec. 31, 2009, followed by the extension to Middle Yanggao Road on April 7, 2010.

(4) Line 10 opened on April 10, 2010 and Longxi Road to Hongqiao Railway Station section opened on November 30, 2010.

(5) Line 11 opened on December 31, 2009 and the Anting Branch followed on March 29, 2010.

(6) Line 13 temporary opened on April 20, 2010 through November 1, 2010.

From 1995 to Apr. 2010, Shanghai has developed its subways from a single line to twelve, 268 total stations and 420 km. The system is still under development. A big amount of news can be found on internet about the metro plans of Shanghai. However, no precise map of the location of stations and subway tracks has been delivered. What can be found is a scheme of the current lines (see Figure 1), but without precise geolocation of the stops. It has been reported that the length of the metro network would reach over 500 km in length in 2010 and by the end of 2020 the network would comprise 22 lines spanning 877 km. The underground of Shanghai seems going to be filled by metro tunnels. For this reason, subsidence caused by excavation is becoming a major issue in Shanghai.

1.2. Subsidence monitoring in Shanghai

Shanghai is located on the deltaic deposit of the Yangtze River. Compaction of the 40-m-thick, upper Shanghai soft clay contributes to land subsidence in the Shanghai region [2]. A lot of attention has been focused on the subsidence caused by the groundwater pumping since 1921 [3]. However, the subsidence in urban area could also be caused by many other anthropogenic factors, such as construction of high rise buildings, subways excavation and so forth. A large amount of people (Shanghai population is more than 18 million) travels by metro and moves via subways everyday. The terrain surface is disseminated of high-rise sky scrapers, that pierce a network of highways and bridges. Subsidence caused by excavation could thus cause disasters with tremendous consequences. Shanghai's competent offices spent a considerable amount of money for installing different kind of instruments to monitor the stability of the terrain in construction areas [4].

Synthetic Aperture Radar Interferometry (InSAR) can provide alternative measurements of the surface displacement with better spatial resolution and comparable accuracy than conventional surveying methods [5]. In particular, the Permanent Scatterers InSAR technique (PSInSAR) [6], which was introduced and developed at Politecnico di Milano (POLIMI) in the late 1990s, is a highly efficient tool for investigating temporal variation in the subsidence pattern by processing series of images and reducing the effect of decorrelation and atmosphere. InSAR has already been applied in different sites in China, as Tianjing, Shanghai, Suzhou, Wuhan [7-10].

Meanwhile, new high resolution satellites (like the German TerraSAR-X and the Italian Cosmo SkyMed) have been launched in orbit, opening to new horizons in monitoring urban areas with InSAR techniques. The availability of archives of X-band data makes it now possible to apply successfully multi-image processing techniques.

Fig. 1 Subway map of Shanghai updated at 30th, Jun. 2010 [1]

1.3. The SARPROZ InSAR tool for urban subsidence

SARPROZ [11,12] is a versatile software for processing SAR and InSAR Data. Programmed in Matlab, offers easy way to extend the existing library of functions. At the same time, it is parallelized and it can run on multiple processors or computer clusters. The tool implements various kinds of multi-temporal techniques, as PS and Quasi-PS [6,7], and any kind of multi-master interferometric combination and stacking. The software is based on graphical interfaces (an example is shown in Figure 2), and it provides modules for coherent-uncoherent processing, including multi-platform data combination, time series analysis (both of phase and amplitude data), DEM-DSM analysis, target characterization and classification, change detection. The software offers also several tools for data analysis, data plotting and data exporting in different formats, among which in Google Earth.

In this work, we exploited the PSInSAR module of SARPROZ to process the Como data set in Shanghai, and we exported the results to correlate them with optical imagery.

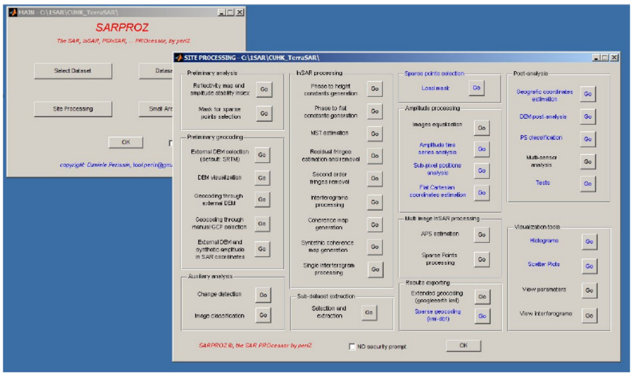

Fig. 2 Example of the SARPROZ interface [11,12].

2. DATA SET AND METHODOLOGY

2.1. Data set

The dataset analyzed in our work consists of 36 images acquired by Cosmo-SkyMed between December 2008 and June 2010 along an ascending orbit. The processed area corresponds to Huang Pu, Lu Wan, Jing An and Zha Bei districts of Shanghai and covers around 600 sqkm.

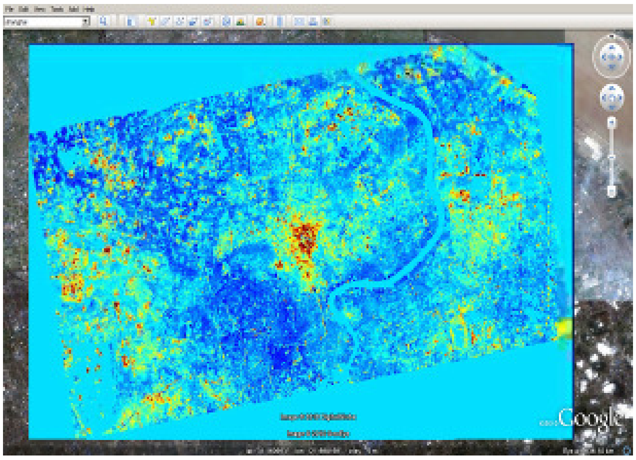

Fig. 3 Surface deformation results processed by SARPROZ [11,12]. The color scale ranges from -20mm/year (red) to 5mm/year (blue).

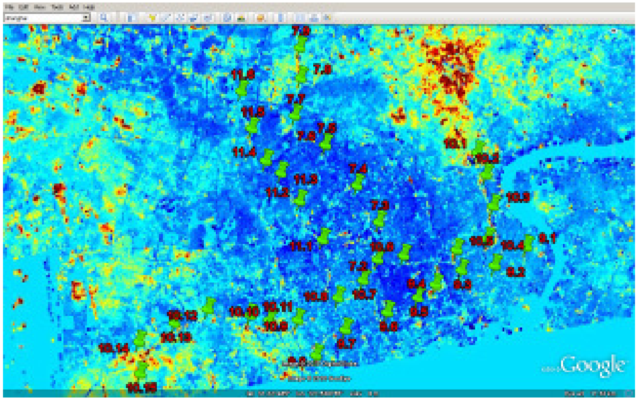

Fig. 4 Close up of the subsidence map and superposition of the subway stations of Metro Lines 7, 9, 10 and 11.

2.2. Methodology and procedure

The technique used in this analysis is a classical InSAR multi-temporal processing, in which the adopted model of the deformation is linear in time. The only advanced options we selected are relative to the urban character of the analysis with high resolution SAR data:

- Identification of independent targets (discarding dependent pixels) [13]. This option is particularly useful to avoid ghost mislocated targets.
- Estimation of double scatterers in a single resolution cell [14]. The skyline of Shanghai causes often the mixing of reflections from buildings facades and ground targets.
- Estimation of a seasonal trend for targets laying on high buildings [13]. Long vertical structures are affected by thermal dilation and high amplitude elongation can prevent from finding coherent targets on high buildings.
- Estimation of target life time to detect also temporary targets [15]. Though the time span of the analyzed data is short, Shanghai is developing at a very fast rate and new constructions would not be accounted as permanent scatterers without estimating their actual life time.

Beside the common results of the processing (average ground deformation trend and terrain height) it is worth to mention the Atmospheric Phase Screen that we obtained in the area. It is known that Shanghai is characterized by strong humidity and X band is particularly sensitive to atmospheric delay. Strong turbulence has been detected and removed by the multi-temporal processing, providing very interesting details of the concentration of water vapor in Shanghai. The topic deserves further studies that we will report in future works.

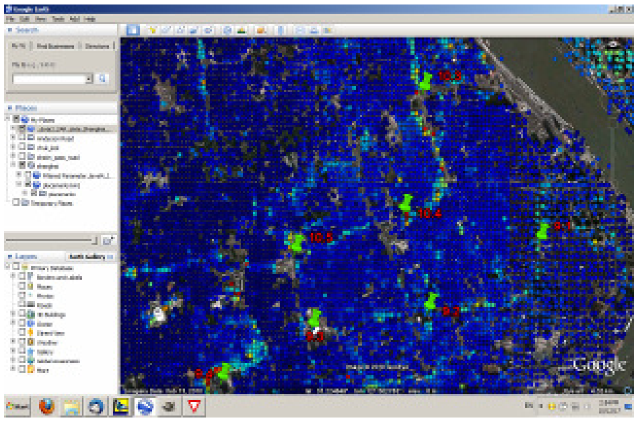

Fig. 5 Close up of the subsidence map along Metro Lines 9 and 10. PS points have been interpolated on a regular grid, since the density is so high that at this level of resolution Google Earth cannot manage the original points

3. RESULTS

As a result of the analysis carried out, about 1.2 million of independent targets have been detected in circa 600sqkm. For each target, height, average deformation trend and displacement time history have been estimated. The task to be faced at this point is the visualization of the processing result. Google Earth cannot load at the same time million of points, so we applied different kinds of resampling procedures to facilitate displaying the result. Figure 3 shows the average subsidence rate, in a color scale ranging -20 ÷ 5 mm/year from red to blue, after resampling on a regular grid in geographical coordinates. Red and yellow spots show actual moving areas, while blue identifies stable targets (the slight positive rate is with respect to a reference point selected in the middle of the scene). The highest rate in the center of the plot is well in agreement with previous studies [7]. Figure 4 shows a close up together with a series of place-marks in correspondence of metro stations. In particular, in Figure 4 we can notice lines 7,9,10 and 11. More precisely, stations "10.1", "10.2" indicate "Tiantong Rd.", "East Nanjing Rd." along line 10; "9.1" is the station "Xiaonan Men" of line 9 opened in early 2010; "11.1" and "7.2" are stations "Longde Rd." and "Changping Rd." on lines 11 and 7 opened in December 2009. Figure 5 reports then a smaller area with a higher level of details, where the PS points have been interpolated on a half regular grid of sparse points. From Figure 5 it is easy to notice two strips of yellow color that go exactly through the marked metro stations. It is worth to stress here that the actual path of the subway tunnels has not been disclosed yet and even the position of the stations had to be manually geolocated, since no geocoded map can be found from public sources. The subsidence detected by the PSInSAR analysis with Cosmo data, on the contrary, shows precisely two lines connecting the stations, delineating with impressive details the curvatures of the tunnels.

Finally, Figure 6 shows a smaller area reporting the actual detected PS targets. From Figure 6 one can appreciate the good alignment of PSs along linear features like roads and highways.

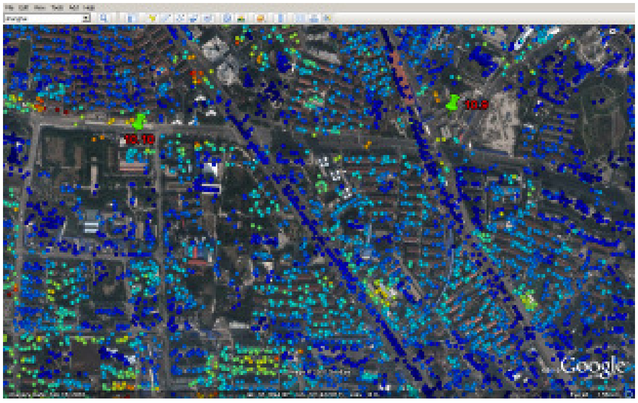

Fig. 6. Actual density of Permanent Scatterers detected in Shanghai by SARPROZ with Cosmo data.

4. CONCLUSIONS

In this work 36 high resolution SAR Cosmo SkyMed images have been processed by the SARPROZ software to detect 1.2 million of permanent targets in the city of Shanghai. The displacement trend estimated from the targets reveals the subsidence of Shanghai with impressive details, making it possible to track the path of newly excavated subway tunnels by looking at the surface motion. The result geocoded in Google Earth maps in this way an information (the actual metro tube) not yet disclosed by the Shanghai municipality.

5. ACKNOWLEDGMENTS

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