Subsidence in Houston Observed by Satellite Radar Instruments

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Subsidence can be caused by a diverse set of human activities and natural processes, including mining of coal, withdrawal of ground water, petroleum, and melting of permafrost. More than 80 percent of the identified subsidence in the Nation results from underground water pumping. The increasing development of urban area and need of water resources threaten to exacerbate existing land subsidence problems and initiate new ones (Galloway et al., 1999). Local collapse may damage buildings, roads, and utilities, and either impair or totally destroy them, leading to expensive repairs. The Nation Research Council estimated that annual costs in the United States from flooding and structural damage caused by land subsidence exceeded $125 million (National Research Council, 1991). Thus, it becomes vital to monitor the land subsidence in high spatial and temporal resolutions to be able to assess its impacts on civil infrastructure. In this study, we focus on mapping land deformation over the Houston area that has been caused by the withdrawal of groundwater, oil and gas using an innovative satellite radar imaging technique.

Differential interferometric synthetic aperture radar (DInSAR) has already been proven to be a useful technique for measuring ground displacement. Among various multitemporal DInSAR techniques, persistent (or permanent) scatterer InSAR (PSInSAR) has been widely used in a variety of cases due to its high accuracy and resistance to temporal and spatial decorrelations. The basic idea of PSInSAR is to find and analyze the pointwise time-coherence targets with long-time-span differential interferograms. One major drawback of PSInSAR technique is the low spatial density of PSs, especially for rural areas without man-made structures. Unlike dominant persistent scatterers, the distributed scatterer (DS) pixel normally contains a coherent sum of individual small scatterers. The interference of these small scatterers causes the variation in the returned signal, which leads to temporal and geometrical decorrelations. The distributed scattering mechanism usually covers several pixels with similar statistically homogeneous behaviors. Hence, it is possible to get sufficient coherence by processing these DSs statistically.

Several PSInSAR methods have been proposed to improve the PS network density by extracting information from the distributed targets. For example, the Small Baseline Subset (SBAS) method aims at reducing the geometrical decorrelation by analyzing the interferograms with short time interval and small normal baselines. The StaMPS (Stanford Method for Persistent Scatterers) method utilizes the spatial and temporal correlation of the phase, combining with proper filtering and unwrapping methods, to extract the deformation signal at more locations. One merit of SBAS and StaMPS method is that the deformation time series can be obtained without prior knowledge of the deformation model. Many efforts have been made to improve the spatial density of PSs by jointly processing PS and DS. SqueeSAR applies the phase triangulation algorithm to get the best estimates of the N phases associated with the deformation of DS from N(N-1)/2 off-diagonal interferometric phases of the coherence matrix. Then, this optimized phase is used to perform the conventional PSInSAR processing. Quasi-PS (QPS) technique uses spatial coherence as weight in the estimate process to extract information from partially coherent targets. An improved PS approach is also proposed to use homogenous patches to estimate the gradient for deformation velocity and residual DEM errors. Then the deformation velocity is obtained by performing an integration process. A major disadvantage of this method is that the deformation pattern must be known.

The distributed scatterer interferometry approaches mentioned above only concern one dominant scatterer (One PS) and small homogeneous scatterers. In reality, it is possible to have two or more dominant scatterers (Multiple PSs) within the same resolution pixel. This multiple dominant scatterering mechanism can occur in rural areas and some urban areas with low spatial resolution. Extracting information from DS with multiple dominant scatterers is difficult because of the constructive and destructive interference between them. Especially for images with low spatial resolution, it is more likely that multiple dominant scatterers exist in the same pixel. Usually, average filtering is implemented in DInSAR process to improve the SNR. This average filtering process would decrease the resolution and enhance the interference. The multiple dominant scatterering mechanism has already been analyzed and corresponding signal models are also proposed in the literatures. But this higher-order PS method assumes that all scatterers within the same pixel experience the same deformation.

In order to deal with the multiple dominant scatterering mechanism, a phase-decomposition-based PSInSAR method is proposed in this study. For the sake of simplicity, we name this approach as PD-PSInSAR. The general idea is to use Eigen-decomposition to estimate the phases corresponding to the multiple dominant scatterers, and then to implement these estimated phases in conventional PSInSAR process. Even though all the phases for the multiple dominant scatterers are estimated, we only use the primary PS (the dominant scatterer with the largest eigenvalue and best coherence) to do the PSInSAR processing. Comparing with the existing DS techniques, the proposed PD-PSInSAR method is expected to have the following advantages:
1) More number of PSs can be detected because the multiple dominant scatterers are included,
2) Because the phase of the primary dominant scatterer can be distinguished from the secondary dominant scatterer, the interference between different dominant scatterers are mitigated, and the obtained phases are expected to have better coherence.
3) Simplicity and portability. The decomposition process is simple and straightforward without the need for significant changes in the conventional PSInSAR technique. The estimated phases can be utilized as the input of other DS techniques.

This PD-PSInSAR technique is used to estimate the land deformation over the Houston area using ENVISAT ASAR data spanning from 2004 to 2010. Comparison between the conventional, SqueeSAR, and PD-PSInSAR techniques verifies that the proposed PD-PSInSAR method can detect more PSs and provide better coherences. The deformation map reveals that the northwestern part of Houston has significant subsidence over the past six years, which is consistent with the estimates from published GPS measurements. Our subsidence hazard map can be used as a basis for mitigation efforts to reduce its damage to the civil infrastructure.

References

1. Galloway, D., D.R. Jones, and S.E. Ingebritsen, Land Subsidence in the United States, U.S. Geological Survey Circular, 1182, 1999.

2. National Research Council, Mitigating losses from land subsidence in the United States, National Academy Press, Washington, DC, 1991.