InSAR New Generation

Synthetic Aperture Radar Interferometry (InSAR) is an established powerful technique for change detection. Its advantages include competitive spatial resolution, accuracy in millimeter-centimeter scale and spatial coverage. However, there are limitations in using it for detecting the Earth surface changes. Line-of-sight ambiguity (1-D displacement), temporal and geometrical decorrelation (slopes, unstable ground, large deformation gradients, vegetation, etc.) and low sensitivity to horizontal displacement parallel to platform’s flight trajectory are amongst the disadvantages.

Variable tropospheric water vapor can also cause variable phase delay initiated by the impact of water vapor on the speed of microwave signal propagation. The related phase changes are sometimes misinterpreted as surface change in SAR Interferometry. The effects can be too large in tropical and sub-tropical regions. In tropical regions for instance, nearly 10cm of variable path delay over several weeks has been observed.

InSAR exploits several characteristics of radar scattering and atmospheric decorrelation to measure surface displacement in non-optimum conditions. Atmospheric phase contributions are spatially correlated in a single SAR scene, but it gets uncorrelated on time scales of days to weeks. Moreover, surface motion is almost strongly correlated in time. Land subsidence is an example that is very often steady over periods of months and years. Thus, averaging out the temporal fluctuations, the atmospheric effects can be estimated and removed by combining data from long time series of SAR imagery.

InSAR method

Two radar images of the same area with slightly different imaging angles are in practice needed for InSAR. Radar sensors onboard of the flying platforms transmit microwave signals towards a target; some are reflected back to the sensor. The backscattered pulses are recorded by the microwave sensor to form radar images of the target. Pairs of images of the same scene are compared by sophisticated software to detect changes in the land surface such as displacement that have occurred in the time span between the two acquisitions.

InSAR processing consists of the selection of image pairs, co-registration of images, feeding of the external digital elevation model (DEM), interferogram generation and enhancement, phase unwrapping, production of a DEM and movement model, and finally geo-coding. InSAR is a non-intrusive and non-destructive technology measuring relative displacement over time with sub-centimeter accuracy. It is however limited by the impossibility of removing errors introduced by atmospheric effects, orbital errors, thermal and other noises and is only able to measure total displacement and average displacement rates; it is unable to distinguish between linear and non-linear movement.

PSInSAR; a developed technique

To overcome the limitations of InSAR a new technique called Persistent Scatterer InSAR (PSInSAR) is developed. Persistent or Permanent Scatterer (PS) techniques are the recent
development from conventional InSAR that relies on studying pixels which remain coherent over a sequence of interferograms. The new technique applies InSAR and Differential InSAR (DInSAR) for measuring ground displacements to a degree of accuracy and over time periods previously unachievable using conventional InSAR.

PSInSAR makes measurements of ground movement on permanently scattering points. These scatterers are features like the metallic structures, prominent natural features, and the roof of buildings. In urban areas, as many as 600 persistent scatterers per square kilometers can be found. Uniquely, this technique provides the motion history for each individual persistent scatterer.

The applications of these techniques include studying the areas subject to slow landslides or slope instability, monitoring exploration and production activities in oil and gas fields, areas subject to subsidence and uplift, monitoring of major urban activities such as pipelines, transmission lines, highways and railways, seismic faults and volcanic areas, and checking the stability of buildings.

This technique was first introduced in 1999 by the Polytechnic University of Milan (POLIMI) in Italy that produced and patented it as PSInSAR algorithm. It was a new multi-image approach in which the stack of images is inspected for objects on the ground providing consistent and stable radar reflections back to the satellite. The objects could be the size of a pixel or sub-pixel, and are present in every image in the stack. These techniques are collectively referred to as Persistent Scatterer Interferometry or PSInSAR. European Space Agency (ESA) gave the name Persistent Scatterer SAR Interferometry to this technique to define the second generation of InSAR techniques. Tele-Rilevamento Europa (TRE) holds the exclusive license of the PSInSAR algorithm for world-wide applications.

PSInSAR uses radar satellite data acquired by the satellites such as ESA’s ERS and Envisat, Canadian Radarsat, Japanese JERS and newly launched satellites like German TerraSAR-X (TSX) and Italian Cosmo-SkyMed (CSK). Most of the land areas throughout the world have sufficient data to allow PSInSAR processing, with new data being acquired regularly.

**PSInSAR Process**

N interferograms is formed on a common master image using all N+1 available images (InSAR processing). Using a reference DEM the known topographic phase is removed (DInSAR processing). A coarse grid of the best points is then identified and DEM error and displacement is estimated (Preliminary estimation). Using the preliminary estimates the parameters on more points are estimated (Final estimation).

In stake generation all interferograms are formed with relation to the same master image. Afterwards the absolute calibration accounting for range spreading loss, antenna pattern, processor gain is done. In this case the pixels with large amplitude in most images are likely to be point scatterers; a threshold is used to identify a set of pixels for further analysis. Using multi-image datasets allows identifying stable reflectors, referred to as persistent scatterers, which are points on the ground that consistently return stable signals to the satellite sensor. Temporal composites of SAR images are the suitable mean to
locate the PS points. Coregistration is made aiming correlation optimization using a precise DEM. SRTM (Shuttle Radar Topography Mission) data is also used for topographic correction.

Preliminary estimation contains three steps which includes selection, estimation and integration. Only point like scatterers are considered in selection step and the best point in each grid cell are selected. In estimation step a network is constructed to estimate displacement parameters and DEM error difference between nearby points in order to reduce atmospheric signal. The integration step consists of obtaining the parameters at the points by Least Square integration with relation to a reference point. In this step the incorrect estimates or incoherent points using alternative hypothetical tests are identified and removed.

**Removal of atmospheric and topographic influence**

PSInSAR removes atmospheric, orbital and topographic induced errors (related to certain weather conditions and DEM accuracy) by utilizing 30 or more scenes to calculate either an atmospheric correction, which is calculated from the 30 scene archive that removes atmospheric artifacts from the interferograms, and an accurate DEM for the measurement points.

In this technique sub-pixel radar reflections are analyzed, linear and non-linear deformation patterns are identified, and time histories of movement are generated for every radar target. Using multi-image datasets allows identifying reflectors called Persistent Scatterers, which are points on the ground that consistently return stable signals to the orbiting microwave sensor. These scatterers allow measuring the ground displacement velocities with millimeter accuracy. PSs typically correspond to objects on man-made structures such as buildings, bridges, dams, water-pipelines, antennae, and stable natural reflectors such as exposed rocks as well.

**PSInSAR Applications**

PSInSAR common application examples include surface deformation measurements, slope instability, landslide inventory, flood protection, oil field monitoring, CO2 sequestration, seismic faults and surface deformation measurement.

Such techniques are most useful in urban areas with lots of permanent structures. For example the PSInSAR studies of European cities undertaken by the Terrafirma project. The project provides a ground motion hazard information service, distributed throughout Europe via national geological surveys and institutions. The objective is to help save lives, improve safety, and reduce economic loss using the state-of-the-art PSInSAR data. This service has supplied information relating to urban subsidence and uplift, slope stability and landslides, seismic and volcanic deformation, coastlines and flood plains in recent years.

On subsidence or uplift, whether caused by natural or man-made activities, the PSInSAR provides monthly updates on displacement patterns. It is particularly used in monitoring
urban subsidence where conventional methods of survey cannot match the information density at similar cost.

Possibility of updating the PSInSAR data for seismic faults and volcanic areas suits the improvement of early warning systems in matters of civil protection by providing urgently needed data in emergency status.

In land use management, PSInSAR facilitates planning of major infrastructure such as pipelines, transmission lines, highways and railways by identifying stable corridors for these facilities. Similarly, updating the schemes of urban planning can benefit from PSInSAR while in urban areas high density of scatterers is available.

For claim assessing, a historical archive of radar data can contribute to verifying the connection between, for instance the construction of a new tunnel and damage occurring to facilities in the neighborhood of the excavation area. PSInSAR data have already been used as evidence in lawsuits; the insurance firms show interest in the technology as a risk allocation tool.

In checking the stability of buildings, although PSInSAR data cannot substitute for site surveys, nevertheless they emerge as a powerful monitoring tool for large urban areas, where a regular check of all of the buildings would not be feasible. PSInSAR can be used in designing of mitigative measures to reduce the effects of potential geo-hazards.

For landslides and instability phenomena, PSInSAR identifies the extent of the land instability and the corresponding movement rate when movements are slow. The integration of PSInSAR data within a GIS and regular updating of PSInSAR data have significantly increased the potential of radar remote sensing for landslide investigations.

**Advantages and Disadvantages**

Advantages of PSInSAR includes the possibility of regular and financially acceptable measurements of larger areas using this technique, fast data processing with little need for inclusion of end user, high accuracy and simple export into GIS. In this case detection of slow deformations less than 10cm per year in the line-of-sight direction is possible. In the mean time its limitations are that it can not be used in vegetated areas. It is inapplicable on continuous surfaces. Temporal measurements are also limited with the satellites’ orbiting intervals.

To tackle these limitations in recent years PSInSAR has further developed by focusing on the distributed scatterers in the study scene in addition to the persistent scatterers leading to higher accuracies in comparison with PSInSAR itself. The technique that is called SqueeSAR squeezes the effects of both persistent and distributed scatterers.

**SqueeSAR; a new solution**

Ten years after PSInSAR, in 2009 TRE has developed a new algorithm named SqueeSAR, which represents a further advancement for satellite data analysis and a jump in Earth observation capabilities. In addition to PSs, it is noticeable that there are also distributed scatterers that can be used for monitoring ground displacement. Distributed
Scatterers (DS) consist of an wide area where the back-scattered energy is less strong in some way, but statistically homogeneous within the area.

Using SqueeSAR it is also possible to process this energy and detect the movement of areas dominated by DS, with the same accuracy as analysis with PS. DS displacement time series are indeed less noisy too. DSs typically correspond to debris areas, non-cultivated lands and desert areas. It is also important to highlight that the PSInSAR processing chain is maintained and used within the SqueeSAR algorithm; the result is an enhancement of the information output capacity, meaning PS plus DS, to gain an enhanced insight into ground deformation and associated surface movements.

SqueeSAR algorithm in summary includes, (i) identifying ground points; PS and DS, (ii) identifying high density of ground measurement points in urban areas (PS), (iii) identifying high density of ground measurement points in non-urban areas (PS and DS), (iv) providing time series for each ground point (PS and DS), (v) access to millimeter accuracy on ground displacement values, (vi) reducing time series standard deviation (coherence increases and noise decreases), and (vii) increase of confidence on ground behavior because of extensive coverage of points that is particularly significant for landslides, outcrops and generic areas with low reflectivity.

The fast analysis of large areas of land, the high density of measurement points, the precision of measurements and the ability to access an historic database makes SqueeSAR a powerful tool for identifying and monitoring. However it can not be accounted for as the final stage in development of the rapidly growing radar interferometry technologies. No doubt new progresses are in the way to comply the enthusiasm, interest and needs of the remote sensing users community.

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The team conducted by the author used the data provided by ESRIN, and the Earth-View software to generate the above interferometric products by combining the tandem ERS SAR Single Look Complex Images (SLCI) of 16 and 17 September 1999 (normal baseline: 234.44m) of the Izmit area in Turkey.

(Image source: Parviz Tarikhi)
**Image caption:** Persistent Scatterer SAR interferometry model  
*(Image source: Parviz Tarikhi)*

**Image caption:** Persistent Scatterer SAR interferometry flowchart  
*(Image source: Parviz Tarikhi)*
Image caption: The temporal composite that the study team produced using multi-image dataset of Radarsat SAR Standard Beam 4 images of June 22 (red), May 5 (green) and September 2 (blue) 1998 of the south-eastern area of the Caspian Sea in north of Iran. SAR temporal composites are suitable mean for locating the persistent and distributed scatterers in the area of interest for PSInSAR and SqueeSAR.
(Image source: Parviz Tarikhi)

Image caption: 3D view of the study area at the Krechba field (Algerian central Sahara), where integration of 3D seismic techniques with satellite InSAR data has proved to be a powerful tool in tracking the subsurface sequestration of CO2 for reducing greenhouse gas (GHG) emissions. PSInSAR data of ESA Envisat for time span of 2004-2007 were integrated into a GIS environment to generate deformation maps and contour lines of the displacement field.
(Image source: TRE-Tele-Rilevamento Europa)
**Image caption:** PS and DS areas used for SqueeSAR. The inset graph at the top right shows the distribution of the PSs and DSs with their relevant velocity of movement.

*(Image source: Parviz Tarikhi)*