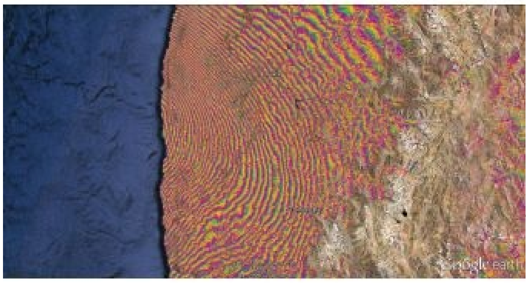
Satellite Radar Interferometry



Despite first being published a couple of years ago, this article on InSAR is still topical, accurate and extremely relevant in the context of aerial mapping and Earth observation.

Interferometric Synthetic Aperture Radar (InSAR), an active remote sensing technique that acquires images of the Earth, is a beautiful and powerful technology for surface deformation modelling and elevation mapping. However, InSAR also has the reputation of being a complex technology which is challenging to understand. This edition of Technology in Focus aims to explain the concept of InSAR.

Synthetic Aperture Radar (SAR) acquires images of the Earth in the microwave spectrum with wavelengths in the order of centimetres. Electromagnetic waves of this size can penetrate clouds, which makes SAR an all-weather remote sensing system operating day and night. SAR instruments for Earth observation are found on airborne, space-borne and even terrestrial platforms and are based on the same principles, but this article will focus on satellite radar systems. Various SAR satellites have been developed and launched since the 1990s, with the European Sentinel-1A satellite being the most recent addition to the skies.

Baselines

SAR satellites orbit the Earth at an altitude of about 500-800km and revisit every location on Earth after a specific time. The time period between two successive visits – the repeat cycle or 'temporal baseline' in InSAR terminology – depends on the satellite orbit and is usually in the order of several days to roughly a month. However, the satellite may not be in the exact same location again during acquisition of the next radar image due to limitations in orbit control. The distance between two acquisition spots perpendicular to the satellite viewing direction is known as the 'perpendicular baseline'. With InSAR, this distance causes a 3D effect (similar to how we see depth with our eyes) which can be used for topographic mapping.

Most SAR satellites operate with C-band wavelengths, but in the last decade X-band and L-band systems have been launched as well. Knowing both the wavelength and the baselines between SAR image acquisitions is important for using InSAR and interpreting the results, as will be explained further on in this article.

Phase information

SAR satellites emit radar waves and measure the amplitude and phase (fraction of the full wave) of the reflected waves for each pixel in the image. The phase information can be measured very precisely by the satellite and forms the basis for radar interferometry. In its simplest form, InSAR combines two (accurately aligned) SAR images of the same scene into an 'interferogram' by computing the differences in the phase of the radar waves. The resulting interferogram is usually displayed in colour, based on the differences in phase between the two images – resulting in the colourful imagery which InSAR is famous for (Figure 1). The phase difference cycles in an interferogram are called 'fringes' and are caused by phase wrapping as the observed wave fraction is never more than one wave cycle. Depending on the viewing direction of the satellite, each fringe corresponds to a decrease or increase in range of half the SAR wavelength along the line of sight of the satellite. These wrapped phase differences are often suitable for visualisation purposes, but many other applications need unwrapped (continuous) phase difference information which can be obtained by applying advanced mathematic phase unwrapping algorithms.

Boundary Conditions for InSAR

The temporal and perpendicular baselines (in combination with the region of interest and the availability of data) set boundary conditions for applying InSAR. As the technique relies on comparing the phase of each pixel in two or more images, the phases should still be coherent enough in their radar reflection in order to be comparable. The more time that has passed between two images, the larger the chance that some object or element which contributes to the reflection within that pixel will have changed. This causes a loss of coherence and eventually leads to complete decorrelation between the two pixels. The maximum temporal baseline depends on the region, but ranges between weeks in areas with growing crops to years for arid areas. Loss of coherence also occurs with larger perpendicular baselines, since objects look different when seen from different viewing angles.

Contributions to Interferograms

To understand the results of radar interferometry it is important to know the factors that influence phase differences. The most important contributions to the observed phase differences are caused by local topography (through the 3D effect of the perpendicular baseline), surface deformation over time, uncorrected satellite orbit errors and atmospheric signals due to spatial and temporal differences in atmospheric delay. These contributions are always present they have a highly variable influence on the result. For example, an interferogram with a moderate perpendicular baseline and small temporal baseline will show local topography very well, but only limited surface deformation. Which part of the phase difference needs to be corrected for depends on the application (although satellite orbit errors always need to be corrected during post-processing). When modelling surface deformation, for example, one typically uses an elevation model of the area in the interferogram and calculates the phase differences that are caused by the topography. When this interferogram is subtracted from the original interferogram, only the signals for surface deformation and atmospheric delay differences will remain visible.

PS-InSAR

Long-term deformation monitoring works with a special form of InSAR known as persistent scatterer interferometry (PS-InSAR). An example of its application is the monitoring of subsidence of buildings, an effect which can be as small as just a couple of millimetres over the course of several years. PS-InSAR finds objects in the area of the image that produce a constant and characteristic radar reflection over time. Such 'persistent scatterers' are points that are tracked over time in a stack of many radar images. However, the number and distribution of these points depends on the region of interest and they can be difficult to find in dynamic areas where many changes occur (such as vegetation growth).

Potential

Satellite radar interferometry has many different applications, ranging from natural hazard mapping (such as earthquakes and volcanoes) to monitoring subsidence and stability in structural engineering. With the ability to measure and monitor down to centimetre-level or even millimetre-level scale using satellites that are hundreds of kilometres away, InSAR is both a very useful and a very impressive technology with large potential for the geomatics industry.

***Figure 1**, Interferogram showing the Chilean earthquake that occurred on 16 September 2015. The SAR images that have been used to create this interferogram are Sentinel-1A images from 24 August 2015 and 17 September 2015. Each fringe corresponds to a displacement of approximately 2.8cm in the viewing direction of the satellite. Image courtesy: ESA SEOM INSARAP study PPO.labs/NORUT. Contains modified Copernicus Sentinel data (2015).*