

Advanced Remote Sensing Method for Landslide Modeling and Prediction

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Abstract— The effects of landslide and erosion can be detected and monitored by airborne-based systems, and in particular by satellite using InSAR (interferometry by Synthetic Aperture Radar). The interferogram is applied here as an innovating tool to predict mid and long term effects of landslide and erosion. SAR images are generally found to be contaminated with a special type of highly unordered and chaotic noise pattern termed as speckle noise. When an object is illuminated by a coherent source of radiation and the object has a surface structure that is roughly of the order of the wavelength of the incident radiation, the wave reflected from such a surface consists of contributions from many independent scattering areas. Even though, the research has used them with appropriate sub-techniques improve their efficiency in landslide and erosion detection.

Index Terms - Landslide monitoring, remote sensing, SAR, InSAR, modeling, soil contamination, environmental monitoring

I. INTRODUCTION

The acronym InSAR stands for interferometry by Synthetic Aperture radar, and it includes a variety of diverse techniques. Interferometry is, in the strict sense, the measurement of variations of SAR signal between two distinct variations, coming from the same target. A movement of terrain [1] changes the distance between sensor and target, and this modification implies a variation in the signal phase, as represented in Fig.1. We can denote the interferometric phase variation ($\Delta\varphi$) with a simple mathematical relationship as

$$\Delta\varphi = \frac{4\pi}{\lambda} \Delta R + \alpha \quad (1)$$

where λ is the wavelength, ΔR is the displacement while α represents the phase variation related to the atmosphere in the two acquisitions (with an inevitable noise contribution). Eq.(1) illustrates a displacement equal to half of the wavelength, generated by interferometric phase of 2π , that is a phase cycle. That is because the displacement ΔR is carried out twice by the radar pulse: once on one way and on return towards the sensor. Nowadays, it is generally appreciated that SAR [2] interferometry is an extremely powerful tool for mapping the Earth's land, ice and even the sea surface topography [3]. The so-called differential InSAR method (D-InSAR) represents a

unique method for detection and mapping of surface displacements over large temporal and spatial scales with precision in the cm and even mm range [4]. This is of great importance for earthquake and volcanic research, glaciology and ice sheet monitoring, studying tectonic processes, monitoring land subsidence [5] due to mining, gas, water, and oil withdrawal, etc. Repeat-pass interferometry allows the detection and mapping of changes of spatial and/or dielectric properties of the land surface by using the temporal and spatial coherence characteristics, which can be successfully used for land cover classification, mapping of flooded areas, monitoring of geophysical parameters, etc.

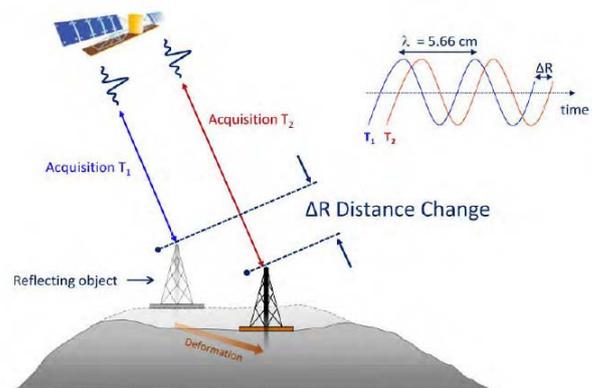


Fig.1. InSAR operating principle.

Since, SAR imagery is directly based on interference and reconstruction through coherent microwave source; therefore, speckle is the dominating noise factor [6] in these images. Speckle noise is caused by the inherent characteristic of SAR and is a kind of multiplicative noise. It gets multiplied randomly with pixel values (in an image), resulting in a granular pattern. This not only makes the SAR images blurred and less important in terms of information content; but also poses difficulties in edge detection, segmentation and subsequent features extraction. In SAR systems, the speckle noise is generally referred as the difference between the measured and true mean values of the image pixels which degrade the visual quality of the images. In spite of being important for various purposes, SAR images are

generally found to be contaminated with a special type of highly unordered and chaotic noise pattern termed as speckle noise. Fig.2 depicts an example of interferometric representation by means of SAR.

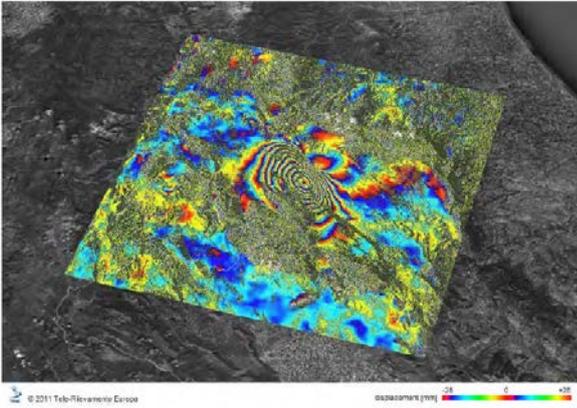


Fig.2. SAR interferogram example.

When an object is illuminated by a coherent source of radiation and the object has a surface structure that is roughly of the order of the wavelength of the incident radiation, the wave reflected from such a surface consists of contributions from many independent scattering areas. Many different flavours of SAR interferometry have recently been developed rendering an exact definition of InSAR difficult [7]. We use the term SAR interferometry for all methods that employ at least two complex-valued SAR images to derive more information about the object than present in a single SAR image by exploiting the phase of the SAR signals. For a second SAR image to provide additional information at least one imaging parameter must be different compared with the first image. There are parameters (e.g. flight path, acquisition time, wavelength) determine the type of the interferometer. The aforementioned phase difference ($\Delta\phi$), between two acquisitions, can be considered, in analytical viewpoint, as sum of four distinct contributions:

- a) baseline effect, that is, the diverse position of the satellite at acquisition instants t ;
- b) effect due to atmosphere (α) that introduces spurious delays during flight time;
- c) effect related to the eventual movement (ΔR);
- d) the induced noise by instrumentation that constitutes the SAR system, and by eventual variations of target reflectivity, noise.

All the four contributions are summarized in the following:

$$\Delta\phi = \frac{4\pi}{\lambda} \Delta R + \alpha + t + noise \quad (2)$$

II. PROCESSING ISSUES

Only in the presence of a good coherence among images it possible to observe interferometric fringes. When the area under test is detected by the radar, through subsequent observations, it preserves homogeneous characteristics in terms of backscattering of electromagnetic wave, or interaction

with radar pulse is the same up as the satellite flies over the area under test, in this case we use the term "coherence". A coherent area allows the generation of good quality interferogram; moreover, only with a good coherence, it is possible to perform reliable interferometric measurements. Coherence of interferogram is a measurable characteristic, and it is a parameter ranging from 0 up to 1. The lower value corresponds to an interferogram with no coherence while 1 stands for totally coherent interferogram. This parameter plays an important role in all interferometric applications [8]. Many elements contribute to determine the level of coherence of a generic interferogram, in particular:

- i) topography: high slope with unfavorable orientation brings to low coherence;
- ii) specific characteristics of terrain, for instance, high absorption of radar pulse, high sensitivity to radar backscattered signals to small variations of acquisition geometry like foliage of trees, and vegetal areas;
- iii) time between used acquisitions to generate interferogram, high temporal intervals yield to loss of coherence because of changes of scenario;
- iv) high baselines: approaching critical baselines, there is a loss of coherence, and after these critical baselines there is no coherence.

In general, the reasons for which there is a risk of coherence loss are summarized by the so-called factors of decorrelation (here, coherence and decorrelation have the same meaning) and in this context, they are summarized below:

- a) vegetation: seasonal evolution of vegetation is sufficient to determine a variation of surface illuminated by the radar. decorrelation effect induced by vegetation is just as pointed out as the decreasing of the wavelength, hence the radar works in C-band, and especially in X-band; in L-band we have less decorrelation;
- b) constructions and housing: areas subject to ongoing constructions always look different in terms of terrain;
- c) erosion: decorrelation is pointed out in regions where erosion is induced by natural and/or artificial phenomenon;
- d) quick deformation: landslide and earthquake can bring to quick variations of the surface, changing reflectance characteristics. If the displacement, between two subsequent acquisitions, is greater than half of the wavelength of signal, there is probably a decorrelation.

As it has been indicated before, the coherence assumes values between 0 and 1, but to establish which is the minimum value that can bring to reliable data is easy; in general we can consider values of coherence less than 0.5 are critical, and they can bring most probably to erroneous estimations of movements. It is necessary to underline that coherence cannot give information on the atmospheric effects, that is, we can have high coherence even in presence of strong atmospheric disturbance.

Passing from interferogram map to displacement one is shown in Fig.3, where we can see what has been explained in this section. The displacement map also includes clear indications of the situation on the ground.

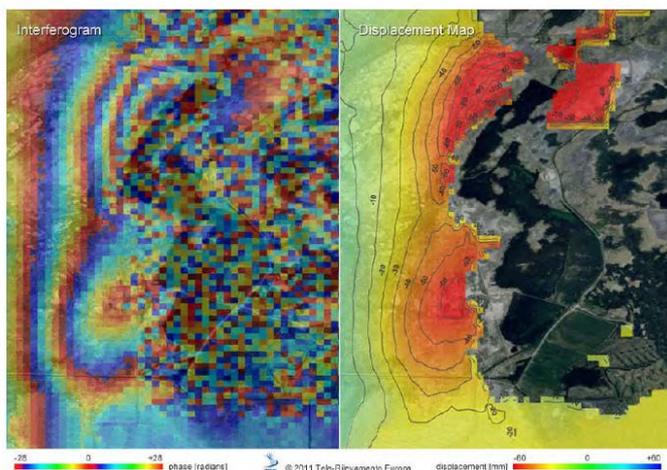


Fig.3. Interferogram and displacement effect.

III. DISCUSSIONS AND FINAL OUTLOOK

In the introduction we have recalled differential interferometer or D-InSAR. It is not more different with respect to normal interferometry; differential indicates the results are obtained prior a subtraction of phase contribution related to local topography (DEM). The subtraction means the interferogram phase has undergone a difference of known term related to baseline and topography. This idea is expressed in the following way:

$$\Delta\varphi = \frac{4\pi}{\lambda}\Delta R + \alpha + \varepsilon + noise \quad (3)$$

in which ε is the phase contribution that derives from possible errors in DEM (digital elevation model), and that has been used to remove topography effects. D-InSAR is a good method for qualitative analysis but not for quantitative evaluation. To overcome its limitations, interferogram staking [9] is considered. Its main objective is to reduce the negative effects of atmospheric disturbance by means of signal filtering. It is necessary to find drawbacks between the increasing of SNR (signal-to-noise ratio) and the loss of resolution.

Persistent scatterer interferometry (PSI), has recently demonstrated to be a valuable and successful tool to detect slope instability and map geomorphological processes, such as slow-moving landslides [10]. The PSI approach is applied to process the available dataset. The PSI analysis requires that at least 25 images available. All images referring to one common master image. The PSI analysis is conducted by the processing software StaMPS [11]. The applied processing steps are as follows: master image selection, SAR data focusing and registration, baseline construction, digital elevation model (DEM) simulation, differential interferogram generation, persistent scatterers candidate (PSC) selection, multi-image sparse grid phase unwrapping, atmospheric phase screen (APS) estimation and removal, PSI point selection, PSI point displacement history analysis, and average deformation estimation. Fig.4 is yielded thanks to the above steps.

The deformation time series represent the most advanced PSI product. They provide the deformation history over the observed period, which is fundamental for many applications [12] [13] [14], e.g., studying the kinematics of a given phenomenon (quiescence, activation, acceleration, etc.), correlation with driving factors, etc. In order to properly use, interpret and exploit the deformation time series it is important to consider that they are a zero-redundancy product. In fact, they contain one deformation estimate per each SAR acquisition, i.e. per each observation. For this reason, they are particularly sensitive to the phase noise. X-band time series show a remarkable quality improvement over C-band time series [15] [16]. It is important to consider that, if used, the linear deformation model can considerably dominate the time series patterns [17] and this issue needs to be carefully considered during data interpretation.

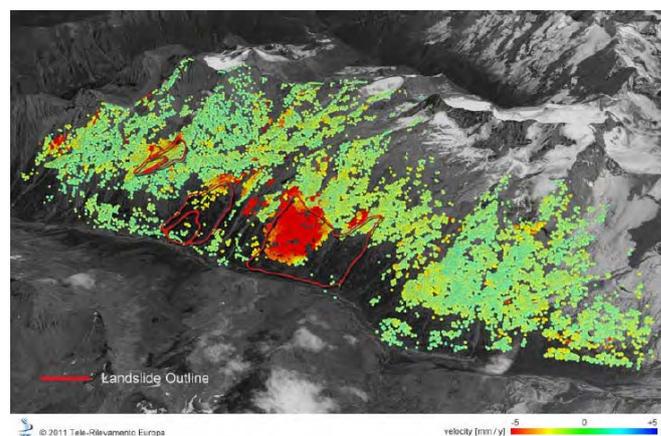


Fig.4. Landslide contouring and detection processed by PSI

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