Monitoring slow mass movements with the Permanent Scatterers technique

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Abstract – In this paper we wish to show a few exemplificative results obtained in the framework of a wide area Permanent Scatterers analysis financed by Regione Lombardia. The core purpose was the identification and description of slope instability/failure phenomena in a relevant part of the Lombardy alpine territory (Northern Italy).

1. PS AND SLOPE INSTABILITY

STATE OF THE ART AND RESEARCH ISSUES

The Permanent Scatterers (PS) technique is an advanced fully operational tool allowing the joint exploitation of long time series of interferometric SAR data. The PS approach is aimed at detecting and monitoring ground deformation with millimetric precision on a high spatial density grid of phase stable privileged radar targets (the so called PS).

A detailed description of the approach can be found in [1] and [2]. In [3] PS results are compared with data from GPS permanent stations and optical leveling measurements.

The PS approach shows properties that turn out being very attractive aiming at the exploitation of spaceborne interferometric SAR data for measuring surface deformation effects induced by slope instability and/or failure phenomena. Despite some spectacular results (e.g. [4], made possible by the 3-day ERS revisiting time operation mode)) and well defined application areas (e.g. in high mountainous relieves well above the tree line, exploiting summer acquisitions [5]) conventional differential SAR interferometry (DInSAR) cannot be considered as a really operational tool for monitoring landslide phenomena.

The most relevant limiting factor is usually temporal decorrelation induced by the vegetation cover. Rather often the sliding phenomena that mostly deserve being monitored take place on slopes immediately above human settlements, likely densely vegetated (e.g. Alps and Appennines).

Temporal decorrelation is due to time varying scattering properties of the SAR sampling cells as a whole (of course induced by reflectivity and/or position variations of the individual scatterers within the sampling cell). It prevents the reflectivity phase term from canceling out while generating the interferogram and makes the interferometric phase un-exploitable.

As well known, the PS approach focuses the attention on privileged radar targets only slightly affected by both geometrical and temporal decorrelation [1], [2]. Provided that a sufficient number of SAR acquisitions is available (e.g. at least 15-20) and that the PS spatial density is high enough to allow the estimate and removal of atmospheric artifacts, phase values relative to individual PS are analyzed on a pixel by pixel basis without spatial averaging. This is, of course, a crucial advantage since it allows one to exploit successfully isolated phase stable radar targets.

As a matter of fact individual man made structures and outcrops often behave as PS and allow for the retrieval of (high precision) deformation data even in low coherence vegetated areas.

On the other hand the monitoring capability are still limited:

1. In absence of outcrops and/or isolated structures the PS density drops to zero.
2. It should be reminded that deformation is measured along the sensor-target Line of Sight (LOS) whereas, of course, at least both the displacement along (translational) and normal (rotational) to the slope are particularly relevant for landslide monitoring purposes.
3. Moreover, the PS approach is well suited for detecting only slow surface deformation phenomena. The theoretical limit posed by the sampling theorem depends on the revisiting time and on the wavelength of the SAR platform used. For ERS and RADARSAT the values are respectively $0.5 \lambda = 1.4$ cm in 35 days and 1.4 cm /24 days (practical limits are, of course, lower, e.g. 10 cm/yr.).

These limiting factors can be partially circumvented. Exploiting different platforms and both ascending and descending passes (depending on the slope aspect and on the geometric distortion) projections along different LOS directions can be gathered. Moreover, exploiting data acquired with a lower operating frequency, in particular L-band SAR data (first PS experiments on JERS data have already been carried out), the difficulties in solving the ambiguity of phase measurements arise only at higher displacement rates (theoretical limit for JERS data ~6 cm/44 days) and a sufficient capability to penetrate the vegetation cover might allow one to identify additional PS corresponding to underlying features (rocks etc.).

Finally, exploiting the (eventual) spatial correlation of the surface deformation phenomenon at hand, the limit posed (in time) by the sampling theorem can be partially overcome. Provided that the spatial gradient of deformation is gentle enough, time series that would be aliased in time can be correctly reconstructed. In practice, the problem of solving phase ambiguity can be transferred from time to a joint time-space domain, leading to constraints on the spatial gradient of...
the phenomenon at hand (in analogy with [6], but depending on the local PS spatial density) and on its temporal evolution. This suggests that, for really optimizing the performances, PS results should be combined with all available other data sources in order to provide the best possible input data for modeling. Subsequently the PS analysis could be refined taking advantage of the model developed for the deformation dynamics.

II. PS ANALYSIS IN VALCAMONICA AND VALTELLINA: RESULTS

The PS analysis subject of this paper has been financed by Regione Lombardia in the second half of year 2001 and is the first experiment of wide area application of the PS technique in mountainous environment. The test area covers Valcamonica and Valtellina and most of their lateral valleys. The total area investigated amounts to around 4,900 km$^2$. Two distinct ERS-1/2 data sets covering the time span 1993-2000 have been exploited (51 descending mode data + 29 ascending mode). More than 380,000 PS have been identified, mainly along the partially urbanized valley bottoms. It is worth pointing out that the PS analysis has been carried out as “blind” experiment, without any a priori information. A wide set of ground deformation phenomena has been mapped: above all numerous slope instability phenomena, but also some cases of subsidence, especially in industrial areas in the bottom of the valleys. The results have been evaluated by the technical staff of the regional geological survey and by the geologists of the “Dipartimento di Scienze Geologiche e Geotecnologie – Università di Milano Bicocca”. In particular, PS results have been integrated and compared with the information gathered in the regional landslide inventory map enriched by means of photo interpretation (carried out independently). In some cases, for a finer assessment of particularly interesting results, in situ inspections have been organized. Here we wish to illustrate very briefly a couple of interesting results. A first very relevant phenomenon mapped by means of the PS analysis is the deep seated slope gravitational deformation (DSSGD) affecting the north facing slope of Monte Padrio – Monte Varadega in Valtellina (between Tirano and Sondalo). The Varadega DSSGD is part of a larger phenomenon affecting an area of about 30 km$^2$. Around 300 PS have been identified within the boundaries of the DSSGD. In situ surveys revealed that PS correspond both to natural and man made features: bedrock outcrops as well as alpine huts (probably parts of their corrugated iron roofs) as well as pylons. The LOS velocity values range from 0 to ~16 mm/yr and have been superimposed on aerial photography (Figure 1) as and on the landslide inventory map (Figure 2). Localized differential deformation dynamics can be recognized clearly (Figure 2). Very interestingly PS groups with homogeneous deformation rates fall within the same landslide bodies (Figure 2), in agreement with what expected. Moreover, from the displacement time series, periods of major activity and quiescence of the sliding phenomenon can be recognized clearly (Figure 1). Finally, the fact that the LOS (in a first rough approximation nearly vertical) velocity decreases moving downslope, even allowed a first very initial kinematic interpretation, suggesting that the sliding phenomenon could be taking place along a subcircular failure surface, steeper in the upper sector of the slope and nearly horizontal at the toe (Figure 2). As reported in [7], PS displacement data showed a good agreement with optical leveling data acquired along the penstock of a hydroelectric power plant in the neighborhood of Groso. Due to the wide area application of the technique, PS results allowed the identification of some previously unknown phenomena. This is, for instance, the case of the villages Sacco and Rasura in Val Gerola (a lateral valley of Valtellina), within an area that was not highlighted in the inventory maps. Moderate average LOS displacement rates have been measured (~1 to ~4 mm/yr.). During a successive in situ inspection performed by the technical staff of the
regional geological survey evidences of damages to buildings and infrastructures could be found, indirectly confirming the reliability of the PS data.

![Figure 2: PS results (Varadega DSSGD) superimposed on the landslide inventory map enriched with features identified by means of photo interpretation. Sketch of the initial kinematic interpretation.](image)

III. CONCLUSIONS

Permanent Scatterers proved being a precious and operational tool for ground deformation analysis also in scarcely urbanized mountainous areas. As a matter of fact further areas have been and will be analyzed by means of the PS technique in Lombardy. The major advantages of the PS approach are the suitability for wide area monitoring coupled with the capability to provide deformation data relative to single targets (very useful for a local description of phenomena), the millimetric precision and the possibility to investigate past phenomena (exploiting the ESA ERS archive).

On the other hand, results can be ensured only in presence of (at least) isolated man made structures and/or rocky outcrops. Moreover, the performances are limited by the intrinsic ambiguity of phase measurements (enabling the detection of slow deformation only) and by the capability of providing one dimensional displacement data.

Anyway, as mentioned in the previous section, currently active research lines (in particular the exploitation of different SAR platforms operating with different looking angles and frequencies) promise to enhance significantly the PS performances.

![Figure 3: Average LOS displacement rate of PS in Sacco and Rasura. Single PS time series. Damages to structures and buildings were identified during an in situ survey.](image)

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REFERENCES