SLAM, A SERVICE FOR LANDSLIDE MONITORING BASED ON EO-DATA

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Abstract

Every year slope instabilities cause large socio-economic losses on life and property worldwide. Indeed, the casualties caused by mass movements are among the highest in the industrialized world. In this contest the SLAM project is aimed to the implementation of landslides mapping and monitoring service that can be integrated into the current landslide management procedures.

The innovative aspect of the SLAM project is the integration of the SAR techniques and EO data with the in situ documentation currently in use for the landslide monitoring. In particular, SLAM is designed to realise three types of products: Landslide Motion Survey, Landslide Displacement Monitoring and Landslide Susceptibility Mapping. The realization of SLAM project, entirely funded by ESA, is carried out by an international Consortium led by Planetek Italia (I) and formed by other five partners: Tele-Rilevamento Europa (I), Gamma Remote Sensing (CH), Spacebel (B), Geotest (CH) and Earth Science Department of the University of Firenze (I). For the Italian service cases the interferometric analysis is based on the PS technique, developed and patented by the Politecnico di Milano (Italy) and improved by Tele-Rilevamento Europa. For the Swiss service cases, multi-pass SAR interferometry, including the Interferometric Point Target Analysis (IPTA), is applied by Gamma Remote Sensing.

1 Objectives

The main objective is to develop and qualify a complete service meant to supply products, mainly derived from satellite data that can be integrated into the operational activities of those Institutions that are in charge of landslide risk management. In fact, a peculiarity of the SLAM project is the active involvement of the end-users. The service is tailored to the requirements proposed by some national and local organizations, involved in landslide risk assessment and management in Italy and Switzerland (i.e. Italian Ministry of Environment, GNDCI, Arno National Basin Authority, in Italy and FOWG and Swiss Cantonal Authorities in Switzerland).

2 Methodology

The innovative aspect of the SLAM project is the integration of the SAR techniques and EO data with the in situ documentation currently in use for the landslide monitoring. In particular, SLAM is designed to realise three types of products: *Landslide Motion Survey*, *Landslide Displacement Monitoring* and *Landslide Susceptibility Mapping*.
The development of the project activities requires the employment of different methodologies summarized hereafter:

- Differential SAR Interferometry;
- Permanent Scatterers Technique;
- Interferometric Point Target Analysis;
- HR/VHR Imagery Analysis;
- Geological Analysis.

The methodologies applied for the Swiss test sites are the DInSAR and the Interferometric Point Target Analysis (IPTA), developed by Gamma Remote Sensing. These methodologies allow the land motion phenomena monitoring within the area of interest.
The Differential SAR Interferometry is an advanced interferometric technique that can usefully be applied to map surface displacements as well as those associated with landslides. The interferometric phase is sensitive to both surface topography and coherent displacement in between the acquisitions of an image pair. The basic idea of differential interferometric processing is to separate the two effects, allowing, in particular, to retrieve a differential displacement map. This goal is achieved by subtracting the topography related phase.
An important drawback of the Differential SAR Interferometry is the decorrelation. In order to limit the effects of spatial and temporal decorrelation the differential pairs with short baseline (about 100m) are usually preferred between SAR data acquired in the snow free period. But in this way the number of available differential pairs for the product generation will be reduced.
The Interferometric Point Target Analysis (IPTA) is a method to exploit the temporal and spatial characteristics of interferometric signatures collected from point targets to accurately map surface average deformation rates, deformation histories, terrain heights, and relative atmospheric path delays. The advantage of using point targets is that these do not exhibit geometric decorrelation such as distributed targets, permitting a more complete use of the data as even pairs with very long baselines (longer than the critical baseline) can be interpreted. This in turn it results in an improved accuracies and temporal coverage. Consequently, more observations are available permitting reduction of errors resulting from the atmospheric path delay and leading to better temporal coverage. An important element of the IPTA is the analysis across the data stack, respectively in the time dimension. For alpine areas (i.e. above 2000 a.s.l.) IPTA may be limited by the presence of snow cover during many months of the year. In these cases, conventional differential SAR interferometry may be considered for integration with IPTA.

The methodology employed for SAR data analysis in the Italian test sites is the Permanent Scatterers technique. It has been developed and patented by the Politecnico di Milano (Italy) and improved by Tele-Rilevamento Europa. This technique overcomes the main limits of DInSAR conventional approaches to surface deformation detection, allowing to identify single radar benchmarks (called Permanent Scatterers) where very precise displacement measurements can be carried out. These objects usually correspond to man-made structures such as buildings, dams, penstocks, antennas, pylons as well as stable natural reflectors (i.e. exposed rocks) present on the Earth surface.
The PS technique is a powerful tool to detect and monitor different geophysical phenomena such as: subsidence, landslides, seismic faults etc. and even to verify individual building stability.

The analysis of the optical images with high spatial resolution (acquired by IKONOS and SPOT5), is carried out by SPACEBEL and Planetek Italia and allows the automatic extraction of features related to landslide presence. The main interpretation technique applicable to a single optical satellite image is visual interpretation. Different features detectable on optical imageries indicate newly occurred landslides in the region.
Morphological features related to landslides, such as scarps, landslide crowns, terraces, slump blocks, concave surfaces of rupture, drainage lines, the slide body and the tong are to be detected on the image. Anomalous patterns and vegetation differences (disarranged drainage systems, tilted trees, etc.) characterizing damaged terrains are other indicators of landslide occurrence on optical images.
Other spatial aspects known as triggers for slope failure like vegetation, land use and slopes (derived from the DEM) can be added to the image to redirect the visual interpretation.

When multi temporal series of optical satellite images are available for the interpretation, change detection is very useful to indicate landslide occurrence. Further on, some enhancement techniques like masking of irrelevant zones (e.g. flat zones) and image sharpening can be applied to improve the interpretation.

The Geological Analysis is performed by UNIFI (Earth Science Department) for the Italian service cases and by GEOTEST and FOWG for the Swiss service cases. This analysis foresees the integration of the data coming from the interferometric techniques with the ground based information in the user GIS environment, in aim to facilitate their use within the current monitoring practices.
The project is envisaged to produce, as first output, the updating of the current landslide inventory map. This product is realized through a compliance analysis in a GIS environment of the measurement points, the existing landslides map and the geologic lineaments. The observation is supported also by visual interpretation of the SPOT5 image rendered on DEM and by aerial photo interpretation.
Furthermore, the geological analysis provides the users with information about the current state of activity of the phenomenon under observation and its evolution. As a result a monographic report includes all the useful data: general information, geological/geomorphological features, monitoring data (integration of traditional and EO-derived) and interpretation of the deformation field.
The final output of the geological analysis for the Swiss test sites is the *susceptibility map*, meanwhile for the Italian test sites the analysis foresees the realization of the *hazard map*. The susceptibility map aims to predict where failures are most likely to occur with indication to the temporal factor. The landslide hazard map is used to indicate a quantitative prediction of landslide over a region and in a defined time period. The landslide hazard evaluation is connected to the geological characteristics and the typology of the slope instability problems interesting the studied area. In particular for the SLAM project it EO data has been integrated within landslide hazard assessment procedures mainly in relation with the *spatial prediction* and the *temporal prediction*. The Spatial prediction consists in the assessment of a relative hazard of a slope with respect to the others. It does not signify the probability of occurrence from an absolute point of view or in temporal sense. The use of different criteria, such as the analysis of landslide inventory maps, heuristic methods, statistical analysis or neural networks analysis can allow to identify the relative hazard classes. The temporal prediction refers to the assessment of the probability of landslide occurrence in a given time interval and it provides an absolute hazard that could be expressed in terms of annual probability values, return periods or nominal scales.
Due to the lack of a general and scientifically proved methodology for landslide hazard assessment, the official documentation for the landslide risk management within the legislation framework of the countries involved in the SLAM project, has been chosen as the reference base to implement the hazard map (i.e. the P.A.I. Plan Document for the Italian End Users).

3 SLAM Products

The SLAM products have been defined according to the user requirements, and developed starting from the methodologies actually employed in the risk management; in this way they can be easily merged in the user database. For these reasons SLAM could be considered a service adaptable to the current landslide management procedures compatible with the traditional methodologies actually adopted by the end-users.

<u>The Landslide Motion Survey</u> is a large-scale inventory map and could be a useful support for the geological risk service agencies in their activities related to the update their current landslide inventories and the planning of structural intervention. This product enables to distinguish the state of activity of identified landslide areas, drawing a distinction between active and dormant phenomenon by means of the average line-of-sight velocity measured in the last 2 years, and between dormant and inactive phenomenon by means of the average LOS velocity measured in the last 5 to 10 years.

<u>The Landslide Displacement Monitoring</u> allows the monitoring of the areas of interest on a reduced scale basis. The objective is to accurately quantify the deformation field of unstable areas through the displacement rate measurement of some points located within the landslide body. The outputs consist of a monographic report of each area of interest that includes a reduced scale geomorphologic map of unstable areas.

The report will include the following items:
- Synthetic sketch: table with information about geographic locations, spatial extension, volume, topographic reference, instability causes, involved infrastructures, mitigation, activity periods, average deformation rates, etc.;
- Geological features: materials, structural geology, etc.;
- Geomorphological features: morphological characterization of the site, land-use, etc.;

- Description of the phenomenon: temporal evolution, main evidences, damages, history of the mitigation intervention;
- Monitoring data: traditional in-situ data, EO-derived data, integration and comparison;
- Interpretation of the deformation field: geological modelling of the landslide, distribution of activity and geomorphologic zonation;
- Bibliography.

In addition to the above described monographic report the EO-derived local measurement of the line-of-sight surface deformation and its temporal evolution monitoring data will be delivered to the users.

Landslide Susceptibility Mapping classifies the area of interest with respect to different classes of landslide susceptibility/hazard. The landslide hazard represents the probability of occurrence within a specified period of time and within a given area of a potentially damaging phenomenon. The product is realized through the integration of the information concerning the spatial distribution of landslide, resulting from the two products previously described, with the thematic maps of land use, slope, geomorphology, and more. The Landslide Susceptibility Mapping could support geological hazard mapping and could be considered as an important tool for land use planning and environmental impact assessment.
Zonation of the analysed area in classes, characterized by different levels of landslide hazard is evaluated by integrating the EO-derived data with traditional information.
With reference to the hazard map proposed by the Arno Basin Authority for the updating of the P.A.I, currently in progress, the Type 3 product will be produced in this region by identifying five different levels of hazard, as summarized in the following table.
Landslide susceptibility/hazard mapping in Switzerland follows a different philosophy with basically three hazard levels (yellow, blue and red) corresponding to weak, middle and strong landslide intensity. Hazard is linked to motion fields of < 0.02 m/yr, 0.02 - 0.1 m/yr, and > 0.1 m/yr total movement. White means absence of evidence of instability.

Level	Description	Return period	Annual probability
H0	Hazardless area, in which geomorphological processes and soils physical features are not favourable to landslide trigger	-	-
H1	Areas with geological and morphological conditions unfavourable to slope stability, without morphological indicators of movement at the present	1000	0,001
H2	Areas with geological and morphological conditions very unfavourable to slope stability, without morphological indicators of movement at the present; areas in which only stabilazed landslides are present	100	0,01
H3	Areas in which geomorphological indicators of slope instability occur, so new trigger-landslides are possible within a long-term period; areas with dormant landslides subject to long-term reactivation	10	0,1
H4	Areas in which active landslides are present; areas with indications of incipient movement; areas involved by expansion of an active landslide	2	0,5

Fig. 1 The table summarizes the meaning of each hazard class.

4 The SLAM Service

The following diagram shows the active role of the end-users throughout the project. In fact, the service is tailored to the requirements proposed by some national and local organizations, involved in risk assessment and management. The products provided by SLAM service are obtained from a complex data fusion process. A scientific team constituted of senior geologists realises integration of different information sources and geological analysis and interpretation of the data output from SAR inteferometric processing and optical imagery processing. This analysis needs the integration of the EO data with further geological information to be provided by the end users: e.g landslide inventory map, in-situ monitoring data, historical sources and bibliographic data, historical information (AVI, SCAI and IFFI databases). The result is a geological characterisation of the area of interest.

The SLAM service is structured in order to provide validated products. For this purpose a validation team constituted of senior geologists (UNIFI and GEOTEST) carries out the process of product validation to verify the accuracy and estimate the level of reliability of the information contents provided with the SLAM service. Also for this step as for the production phase, it is foreseen the user participation. In particular the SLAM users will be involved during the field activities and their in-situ measurements (e.g. GPS, inclinometers, etc) will be used.

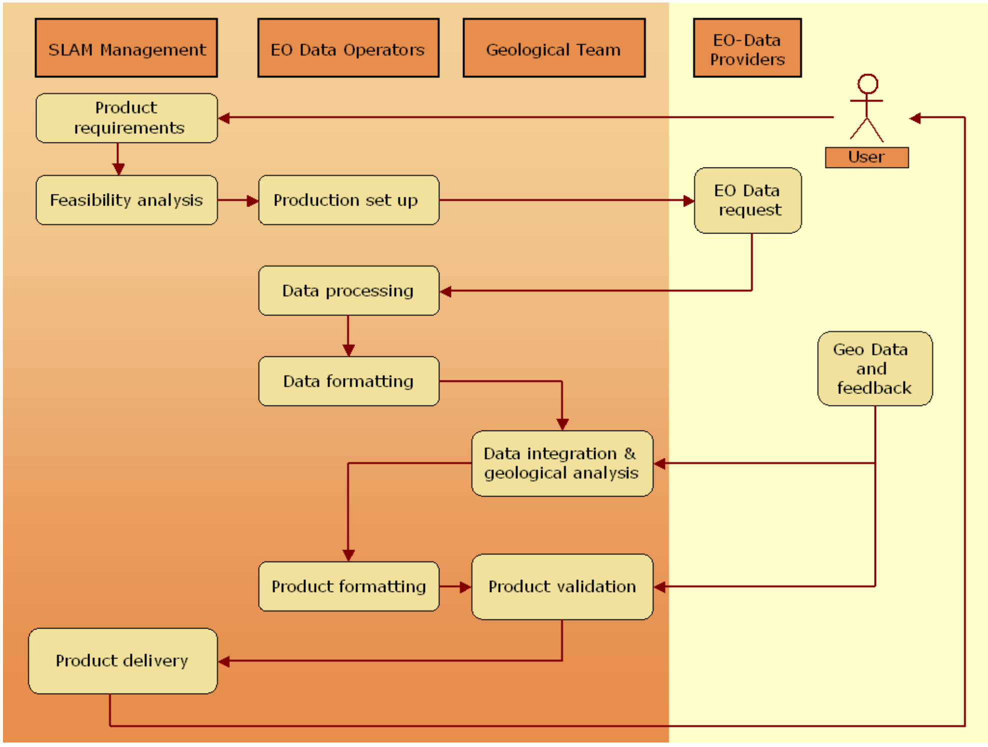

Fig. 2- SLAM Service Structure

5 Conclusions

SLAM products are innovative instruments for the identification of the unstable areas on a large scale basis, easy to manage by the public administrations and to some extend by the civil protection authorities. In fact they are defined and developed according to the user requirements (e.g., scale, information contents, and updating frequency), as well as the requirements indicated in the Italian and Swiss legislation.
The integration of the data acquired by traditional methodology and by Earth Observation into the user GIS environment, allows a comprehensive spatial analysis for areas subject to slow movements on regional and local scale. Furthermore SLAM will allow to enhance the database of the hydro-geological risk agencies building an historical data collection of the area of interest. This in turn could be useful for the future studies and for a more objective land management.

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