MODE TINSAR: AN ESA INCUBATION PROJECT DEDICATED TO THE TERRESTRIAL SAR INTERFEROMETRY

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ABSTRACT

NHAZCA is the promoter of the ESA (European Space Agency) MODE TInSAR incubation project aiming at identify and develop new technological and commercial solutions for the TInSAR (Terrestrial Interferometric Synthetic Aperture Radar) technique. In the frame of the project, all technical aspects of the technique were improved from data collection, management, processing, interpretation and dissemination. In the frame of the project NHAZCA promoted PRIMO®, a prompt intervention monitoring service aiming to provide quantitative data of natural and structural instabilities in emergency conditions. PRIMO® can be considered the main final result of the project since it is based on the main technical and commercial developments achieved in the incubation time.

1. INTRODUCTION

In the frame of the ESA (European Space Agency) Business Incubation platform, NHAZCA S.r.l., spin-off company of the “Sapienza” Università di Roma, is carrying out the MODE TInSAR (MOnitoring DEformation by Terrestrial Synthetic Aperture Radar Interferometry) project. MODE TInSAR is specifically devoted to the technical and commercial development of TInSAR monitoring services. The project started in January 2010 and it is planned to finish on September 30th 2011. By the technical, financial and commercial support of ESA and BIC LAZIO (directly involved in the project development and management) NHAZCA aims at: i) identify new technological solutions for the application of the TInSAR technique to the static and dynamic monitoring of buildings, structures and natural elements; ii) develop new TInSAR based products and services; iii) identify new commercial targets.

2. MODE TINSAR PROJECT: OVERVIEW

MODE TInSAR is a 20 months long incubation project which aims at improve the efficacy of TInSAR monitoring and develop related services for a widespread application in the field of the environment and civil structures. In the frame of the paper, both technical and marketing issues are dealt with.

The following milestones were identified for the project: i) identification of main requirements for the improvement of the TInSAR technique and its efficacy; ii) design of software and methodologies; iii) software development (i.e. engineering and coding of software for the advanced processing of TInSAR data); iv) performance analysis: testing and calibration of the developed software on real cases of landslides, glaciers and buildings; v) market and business plan for TInSAR related services; vi) management: organization of face to face progress meetings for the technical and commercial evaluation of the project.

In what follows, a detailed description of results achieved will be presented.

3. INSIGHTS ON THE TECHNICAL REQUIREMENTS

Terrestrial Interferometric Synthetic Aperture Radar (TInSAR) [1] [2] is a displacement monitoring technique based on the same operational principles of the Satellite SAR Interferometry [3] [4]. The displacement along the instrumental Line of Sight (LOS), is computed as the phase difference between two SAR images (interferometric technique). Hence, TInSAR final outputs are 2D images where the displacement of each pixel can be identified by false colour. Moreover, displacement time histories of each pixel can be derived by multi-stack analyses. The displacement accuracy ranges from few tenths of millimetre to few millimetres, depending on the operational distance and on the atmospheric conditions.

TInSAR is a suitable technique for the detailed and continuous monitoring of small areas (few square kms) such as single unstable slopes and rock scarps, volcanic flanks, buildings etc. [5] [6] [7] [8]. Furthermore, thanks to the high sampling rate (few minutes) TInSAR can be used also for the real-time monitoring finalized to early-warning.

The interferometric sensor can be also set for the vibration monitoring of structures and infrastructures

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by using the RAR (Real Aperture Radar) configuration: thanks to the high sampling rate (up to 200 Hz), the resonance frequencies and the vibration modes of the monitored structures can be identified.

The first steps of the MODE TInSAR project aimed at identify the main limits of the TInSAR technique. In what follows the list of the identified limitations is reported:

i) Data collection: the main limitation for TInSAR data collection was identified in the realization of a suitable monitoring platform. Since the monitoring equipment requires a solid and stable basement to be built before the survey activities, the design and realisation of the installation basement were usually time-consuming and non cost-effective.

As regards the vibration monitoring the main limitation was identified as the very exiguous case history (thus not allowing a suitable data analysis) and the absence of survey protocols.

ii) Data management: the high sampling rate of interferometric data (up to several data per second) implies the acquisition of a large amount of data especially in case of continuous 24/7 monitoring. Therefore, advanced methods suitable for data handling were necessary.

Furthermore, commercial software for data processing make only use of standard algorithms for the data processing, that are not suitable for more complex cases studies.

iii) Data processing: through the analysis of data collected in real case studies, the atmospheric noise affecting the radar signal propagation was identified as the main problem affecting the accuracy of Terrestrial Interferometric data. Fig. 1 shows the correlation between raw displacement data and the air vapour density (g/m^3). As one can see, daily and periodical displacements are closely related to vapour density variations.

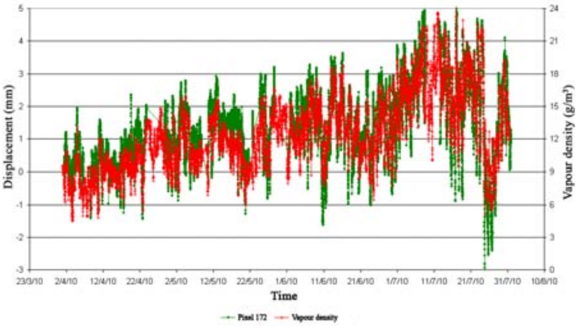

Figure 1. Displacement time series affected by atmospheric artefacts: the air vapour density variations induce periodical displacement cycles.

iv) Data interpretation: 2D images derived from TInSAR monitoring are quite complex to be interpreted because of the distortion induced by the acquisition geometry. Therefore, a precise and correct association between the pixels of the 2D displacement maps and the corresponding sectors on the monitored area is quite difficult (Fig. 2).

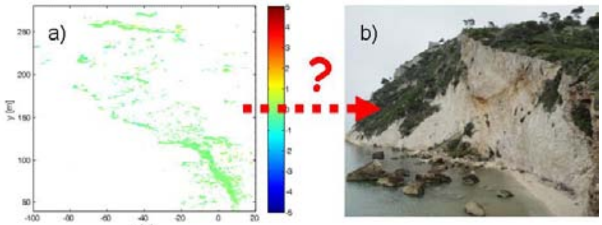

Figure 2. Difficulties in TInSAR maps interpretation: 2D displacement maps are difficult to be georeferenced.

v) Data dissemination: TInSAR data dissemination is a major concern in making this technique accessible to end-users. However, web based platform suitable for collecting TInSAR are not available yet.

4. TECHNICAL DEVELOPMENTS

In the frame of project several testing activities were carried out in order to identify the most suitable solutions to the above mentioned limitations affecting TInSAR monitoring.

i) Data collection: economic and logistic difficulties in the realization of TInSAR monitoring platforms are quite constraining for a widespread and quick intervention monitoring. Hence, NHAZCA designed and manufactured the QUIB^{TM} (Quick Installation Basement) system. The QUIB^{TM} is an easy to transport modular basement that allows the quick installation (about 2 hours) of a TInSAR monitoring platform to be done (Fig. 3).

Figure 3. The QUIB^{TM} (Quick Installation Basement).

Once installed, the size of the system is 280×60x200 cm. The QUIB^{TM} can be installed on different surfaces thanks to its adjustable legs. Furthermore, it can be completely enclosed by polycarbonate or wood panels for the TInSAR equipment safety. The QUIB^{TM} allows the completely autonomous, customizable and low cost TInSAR installation to be performed.
As regards the RAR (Real Aperture Radar) configuration, vibration monitoring protocols by Terrestrial Radar Interferometry were developed: all the instrumental components were predisposed to be easily transported and installed thus allowing quick interventions.

ii) Data management: as mentioned above, Terrestrial Radar monitoring implies the collection of a large amount of data files: up to 100.000 data files/month can be collected. In order to manage such data flow and optimize the processing time, a semi-automatic software named "MODE" was realized with the collaboration of IMG S.r.l. (partner of NHAZCA). The platform is able to manage the interferometric data from the collection to the final visualization and analysis since it is made up of different linked modules:
a) *acquisition module*: the collected weather and interferometric data are saved on the control and management computer unit, directly connected to the sensors;
b) *data transfer module*: both radar and weather data are daily transferred via FTP to an external server;
c) *storage module*: a database was structured on purpose on an external server where raw atmospheric and radar data are daily automatically imported;
d) *processing module*: once imported the raw data in the database, they are processed in order to achieve time series of cumulative displacement of all pixels and of atmospheric parameters. The interferometric data processing is performed by using standard algorithms based on the GCP (Ground Control Point) approach. A specific module for the correction of displacement data by using weather data has been also integrated in the "MODE" software;
e) *visualization module*: "MODE" allows the operator to visualize the displacement and atmospheric data. The x-axis of the plots represents the time, while the master y-axis represents the displacement. Secondary y-axis appear when weather parameters are plotted. Specifically, up to 3 secondary y-axis can be added allowing the plotting of temperature, humidity and vapour density values, respectively. Furthermore, data can be exported in different file formats. In Fig. 4 a screenshot of the "MODE" graphic interface is showed.

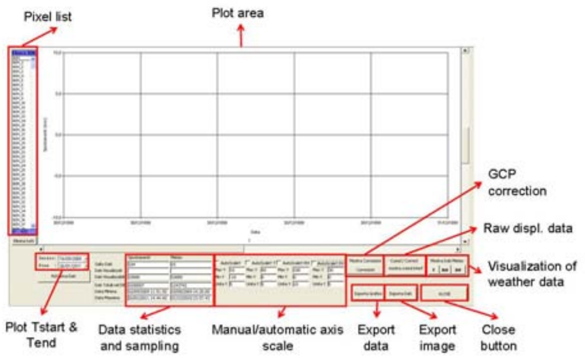

Figure 4. An illustrated screenshot of the "MODE" graphic interface.

iii) Data processing: bibliographic analysis and data from test sites demonstrated that atmospheric noise is probably the main factor affecting the quality and accuracy of TInSAR data. In order to improve the data accuracy, new atmospheric phase screen removal methodologies were developed:
a) the GCP correction method was improved through the application of continuous polynomial interpolation factors;
b) available raw terrestrial interferometric displacement data were related to atmospheric parameters like: temperature, humidity and vapour density. The main controlling atmospheric parameter demonstrated to be the vapour density (Fig. 1). Specifically, the increasing density of the air induces a reduction of the propagation velocity of the radar signal, thus causing an apparent increasing distance of the monitored object, and vice versa. By using vapour density for the correction of raw data a relevant improvement in the displacement accuracy can be achieved. In Fig. 5, an example of the results achieved by the application of the described correction methods is reported: the picture shows both the raw displacement time series of a sample pixel and the results achieved by the application of the GCP and atmospheric correction approaches.

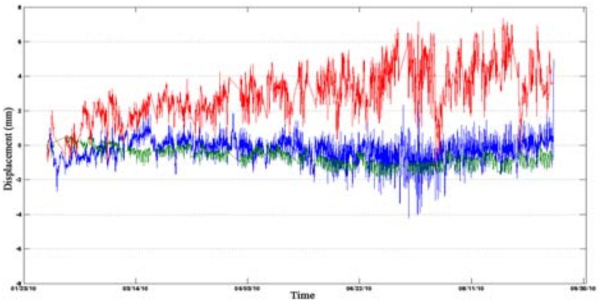

Figure 5. Examples of raw displacement data correction by the application of the two described techniques. In red: raw displacement time series of a sample pixel; in green: Ground Control Point (GCP) correction; in blue: atmospheric parameters correction.

iv) Data interpretation: in order to make TInSAR data easy to be interpreted, the LARAM^{SM} (Laser-Radar Monitoring) approach has been developed. By suitable procedures in the data collection, the rigorous georeferencing of TInSAR maps and 3D TLS (Terrestrial Laser Scanner) derived DTMs can be achieved (Fig. 6).
The precision achievable by the overlapping of TInSAR and TLS data ranges from some decimetres to few meters depending on the acquisition geometry and on the topography of the investigated area. The main advantage offered by the LARAM^{SM} is the easy interpretation of TInSAR maps by their visualization on the 3D model. Hence, small areas affected by displacements can be easily identified and localised.

v) Data dissemination: in order to make TInSAR data accessible on the web for dissemination purposes a specific tool for the GENESI-DEC (Digital Earth Community) platform has been developed. GENESI-DEC (http://www.genesi-dec.eu/) is a web-based platform for open data and services access, that allows European and worldwide Digital Earth Communities to seamlessly access, produce and share data, information, products and knowledge.

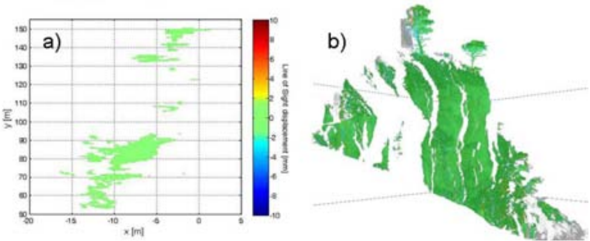

Figure 6. An example of a LARAM^{SM} output: a) 2D TInSAR map standard visualization; b) TInSAR map georeferencing and 3D visualization over a Laser Scanner digital model.

5. PERFORMANCE ANALYSIS

In order to evaluate the efficacy of the new technological solutions and the new tools and methodologies developed in the frame of the project, performance analyses on different test sites were carried out. In what follows, a brief description of the main activities is reported:

i) static monitoring of the Basilica di Massenzio (Rome): 15 months continuous monitoring of the Basilica di Massenzio was performed in the frame of the working activities for the realization of the Metro C line in Rome. An IBIS-S (by IDS S.p.A.) interferometric equipment was installed on a concrete tower (Fig. 7) in Via dei Fori Imperiali (Rome) together with other conventional monitoring instrumentations like an automatic Total Station and a GPS sensor. Furthermore, a weather wireless sensor RTR-53 was installed on the tower for the continuous collection 24/7 of humidity and temperature values.

ii) dynamic monitoring of buildings and heritages in Rome: in order to verify the reliability of the interferometric technique for the identification of the main resonance frequencies of buildings, heritages and infrastructures, a dynamic monitoring was performed in Rome. In one working day, six man-made structures characterized by different geometric and structural properties, were investigated in Rome such as: a) Lateran Obelisk (historical column); b) Ponte dell'Industria and the adjacent railway bridge (bridges); c) Basilica di Massenzio (historical building); d) Colonna Traiana (historical column); e) Colosseo (historical building). The monitoring activity was performed by the IBIS-S equipment (by IDS S.p.A., Fig. 8), thus allowing a high sampling rate survey (up to 200 Hz) to be performed.

Figure 7. The concrete tower for the interferometric monitoring of the Basilica di Massenzio (Via dei Fori Imperiali, Rome).

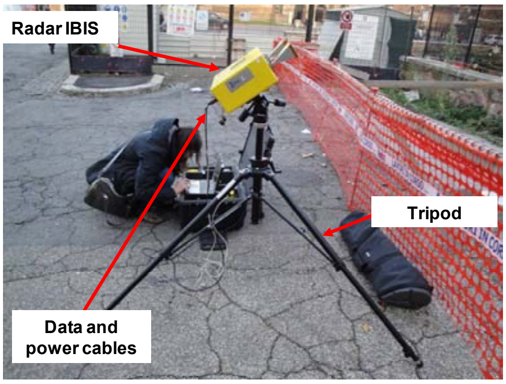

Figure 8. The IBIS-S equipment.

By the analysis of the collected data, the main resonance frequencies and the vibration modes of the investigated structures were identified. The reliability of the achieved results was verified by the comparison with the results achieved by other authors through different monitoring techniques (e.g. accelerometers). In Fig. 9 the main resonance frequency identified for the Lateran Obelisk by the radar survey (1,27 Hz), is reported. The identified values are in agreement with those achieved by Buffarini at al [9].

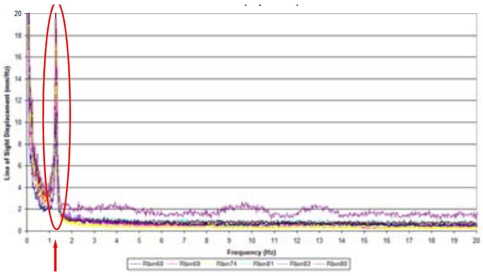

Figure 9. Frequency spectrum of the Lateran Obelisk derived from a radar survey.

Furthermore, by the IBIS-S instrument, dynamic and static monitoring can be simultaneously performed. In Fig. 10, an example of displacement time series of the analysed railway bridge during the transit of some trains is showed.

Figure 10. Displacement time series of a railway bridge. Red ellipses enclose the displacements related to the train transit.

iii) Monitoring of a rock cliff in Vico del Gargano (Apulia, Italy): a short term TInSAR monitoring of a costal rock cliff affected by frequent rock falls was performed at the end of 2010 [10]. By the analysis of TInSAR data, elastic and plastic displacements were identified and then used as state of activity indicators of the cliff. A TLS survey was also performed thus allowing to test the LARAM^{SM} method for TLS and TInSAR data integration (Fig. 6).

iv) Monitoring of the Perarolo di Cadore (Belluno, Northern Italy) landslide: 4 days continuous monitoring of the Perarolo di Cadore landslide (Fig. 11) was performed in January 2011. The achieved results allowed to locate the unstable sectors affected by few millimetres displacements. Furthermore, the reliability of data was verified by the comparison with data collected by conventional monitoring instrumentations. In the frame of this survey the QUIB^{TM} platform was installed for the first time and a TInSAR monitoring platform was set up in two hours thus confirming its efficacy for prompt intervention purposes.

Figure 11. Picture of the Perarolo di Cadore landslide monitoring site.

6. NEW INSIGHTS FROM THE TInSAR MARKET ANALYSIS

The market and business plan development of the MODE TInSAR project has been performed with the collaboration of BIC Lazio. The main objectives of the market analysis were the development of a dedicated business plan for TInSAR services and the evaluation of the economic impact of the new technological developments described above. In what follows, a summary description of the activities performed is reported:

i) estimation of the costs related to services by TInSAR technique for different types of monitoring (based on duration, interval, purposes, required outputs, etc);

ii) identification of the new branches of monitoring that can be reached thanks to the new advanced processing solutions;

iii) identification of national and international customers interested in advanced services provided by the new software and processing tools;

iv) evaluation of the economic impact of the new developed software on the provided services;

vii) suggestion of possible applications to the monitoring of heritages in the city of Rome

(Colosseum, Venezia Palace etc.) in the frame of the Metro C excavation.

A SWAT (Strengths, Weakness, Opportunities and Threats) analysis for the application of the TInSAR technique for the static and dynamic monitoring of heritages was performed. The following features of TInSAR demonstrated to be very attractive for the monitoring of heritages:

i) monitoring of the whole structure instead of single points;

ii) fully remote static and dynamic monitoring (targets or reflectors on the structure are not required), thus reducing time and costs of an operative monitoring system;

iii) accuracy of the displacement measure higher than other topographic techniques;

iv) easy and fast installation of the equipment.

By considering the main advantages and limitation of TInSAR monitoring a dedicated commercial service named PRIMO® (Italian acronym for Prompt Intervention Monitoring) was developed.

PRIMO® is a NHAZCA registered mark and it is an innovative support service for local administrations and private companies in charge of land management and heritages defence. PRIMO® is a prompt intervention service in emergency conditions, developed and promoted by NHAZCA S.r.l. and aimed to the analysis and monitoring of geological (landslides, earthquakes, subsidences, volcanic activities) and structural (bridges, dams, buildings, towers) instabilities. By PRIMO®, NHAZCA aims to support authorities by providing quantitative data (i.e. displacement) suitable for a more accurate diagnosis and for the risk mitigation.

PRIMO® is based on two essential aspects:

i) the combined use of last generation remote sensing techniques such TInSAR and TLS. As a matter of fact, no other conventional monitoring techniques can be adopted for such a purpose since they need a complex preliminary planning phase, the direct access to the areas affected by instability, and the installation of targets and reflectors;

b) the support of highly qualified technicians and consultants with a large experience on both the applied technologies and on the analysed problematic.

7. CONCLUSIONS

The MODE TInSAR project, developed in collaboration with ESA (European Space Agency) and BIC Lazio (Business Innovation Centre), demonstrated the importance of incubation projects for start-up companies in order to develop their business.

Innovative technologies such TInSAR, in fact, require standard protocols, performance tests and market analysis in order to be effectively used and disseminated.

In the frame of the 20 months MODE TInSAR project, NHAZCA improved all the aspects of the TInSAR technique from the data collection (by specific intervention protocols and by the QUIB™ Quick Installation Basement) and processing (by the accuracy improvement achieved through algorithms for the atmospheric noise mitigation) to the data management and analysis (by the realisation of the suitable software platform "MODE"). Data interpretation was then improved by the development of the LARAM℠ (Laser-Radar Monitoring) method, that allows the accurate georeferencing of TInSAR data on TLS (Terrestrial Laser Scanner) 3D digital models to be done. Finally, the dissemination of TInSAR data was favoured by the development (with the collaboration of ESA technicians) of a specific toll for the GENESI-DEC web-based platform.

Moreover, the PRIMO® service can be considered the main final result of the project since it is based on the main technical and commercial developments described above:

i) the use of the QUIB™ for the quick intervention installation of a monitoring platform in emergency conditions;

ii) the LARAM℠ approach that allows the exact detection and location of unstable areas to be performed;

iii) the new intervention protocols developed and tested in the frame of the project;

iv) the new processing solutions for the improvement of the TInSAR data accuracy;

v) the results achieved by the market analysis, that allowed to identify the emergency events as the best commercial target for TInSAR services.

8. ACKNOWLEDMENTS

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