Dipartimento di Ingegneria
Dottorato in Ingegneria civile - Ciclo XXXIV

ROMA TRE UNIVERSITÀ DEGLI STUDI

Transport Infrastructure Monitoring by Interferometric Synthetic Aperture Radar (InSAR) and Non destructive testing methods (GPR)

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Problem statement

- *Recent and dramatic events which occurred on the European transport network, e.g., viaduct collapses or convoy derailments, have pointed out the urgent need for assessing the actual state of health along the transport assets. Analogous considerations can be addressed towards the high exposition and vulnerability of the transport system to major natural disasters, such as foods or earthquakes*
- *Most of highway and railway assets were constructed between the 1960s and the 1980s, which shows that their nominal service life (typically 25–30 years) has already elapsed.*
- *Enormous investments have been made over the last decades to bring results on the early-stage assessment of decays. In this framework, use of **non-destructive testing (NDT) methods** for health monitoring of civil engineering infrastructures is gaining momentum in the last decades*
- *Integration of datasets collected with different NDTs through a "data fusion" logic stands as a viable approach to fill technology-specifc gaps, thereby ensuring a more comprehensive assessment of the infrastructure*

Objectives

- *Provide a viable methodology capable to identify potential decay areas through **satellite remote sensing** data using **multi-temporal interferometric approaches**, e.g. PS-InSAR, and investigate the **sources of damage** using the data collected by the **various NDTs (e.g. GPR)** for monitoring of transport infrastructure networks.*
- *Define an innovative methodology for monitoring transport infrastructure network, such as highways and railways, monitored by various methods in its different components*
- *Resolution ranging between the territorial to the millimeters scale, in view of an evaluation of the overall network resilience*
- *Test-site application of both Synthetic Aperture Radar interferometry (InSAR) and Ground Penetrating Radar (GPR) as both self-standing and integrated survey methodologies*

Time Scheduling

First year | **Second year** | **Third year**

State of the Art

Literature Review about:

- *Traditional and Innovative Non Destructive testing methods*
- *Remote sensing technique for transport infrastructure monitoring*
- *Definition of datasets of SAR mission*
- *Software and Algorithm for PSI processing*
- *Ground Penetrating Radar applications*

Experimental activities

Processing of SAR images through PS-InSAR techique

- *Acquision of SAR dataset in medium and high resolution (C-band and X-band)*
- *Data-processing (PSI technique)*
- *Selection of possible transport infrastructures for monitoring purpose and in particular:*
- *Highways, Railways, Bridges and Airport Runways Monitoring*

Analysis and results

Integrated interpretation

- *Analysis of PS-Insar result*
- *Creation of velocity maps and critical spots*
- *Automatization of the process*
- *Geo-statistical interpretation of the results*
- *Highways. Railways, Bridges and Runways Monitoring*

Risk Assesment for priority of maintenance activities

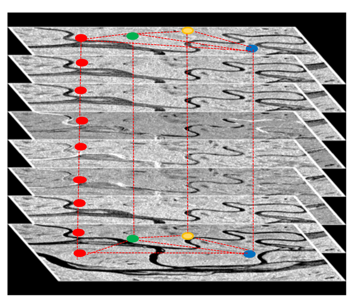
Experimental activities

Proposed solution: "Data-Fusion" Methodology

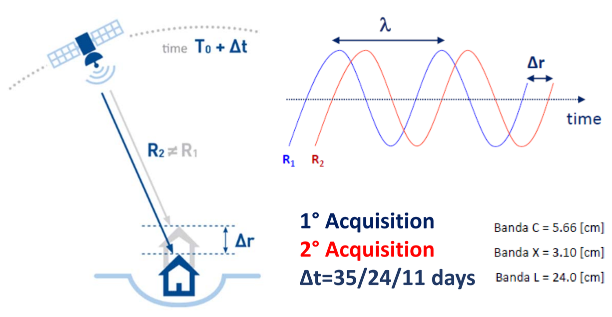
Satellite Remote Sensing
Permanent Scatterers Interferometry

Non-destructive testing
Ground Penetrating Radar(GPR)

1. Detection of statistically stable scatterers over an inspected area



2. Analysis of the range variation between the images



Interferometric phase

$$\Delta\Phi = \Delta\psi + \frac{4\pi}{\lambda}\Delta r + \Delta\alpha + \nu$$

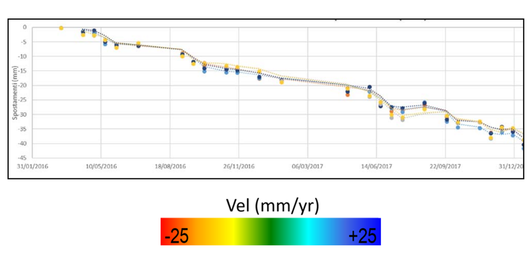
$\Delta\psi$ Reflectivity of the target

$\frac{4\pi}{\lambda}\Delta r$ Propagator: depends on the radar-target distance r

$\Delta\alpha$ Atmospheric contribution

$\Delta\nu$ Noise

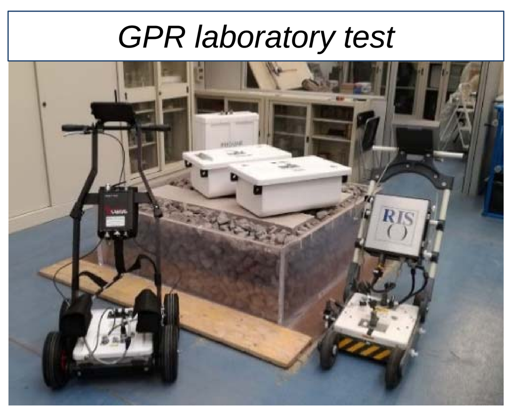
3. Displacement velocity assessment



Methodology: Data Fusion

- Acquisition of SAR dataset → Application of PSInsar techniques → Detection of spots subjected to subsidence
- On-site GPR surveys → Topographic analysis in-situ → Analysis on the critical spots
- → Integrated Interpretation
- → Health monitoring approach fro transport infrastructures

GPR laboratory test



GPR Antennas for different penetration depht

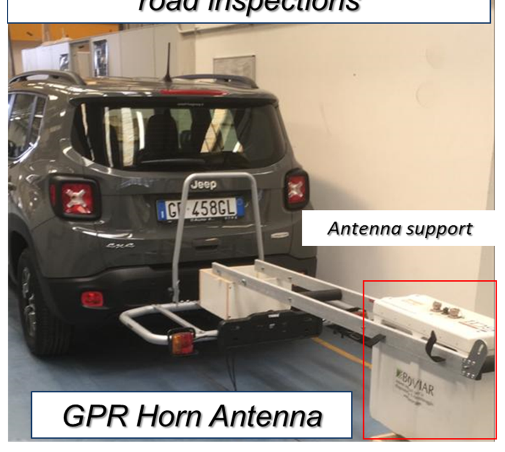
Maxwell Equation

$$\nabla \cdot \boldsymbol{D} = \rho$$
$$\nabla \cdot \boldsymbol{B} = 0$$
$$\nabla \times \boldsymbol{D} = \frac{\partial \boldsymbol{B}}{\partial t}$$
$$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t}$$

Constitutive Equations

$$\mathbf{J} = \sigma \mathbf{E}$$
$$\mathbf{D} = \varepsilon \mathbf{E}$$
$$\mathbf{B} = \mu \mathbf{H}$$

Instrumented vehicle for GPR road inspections

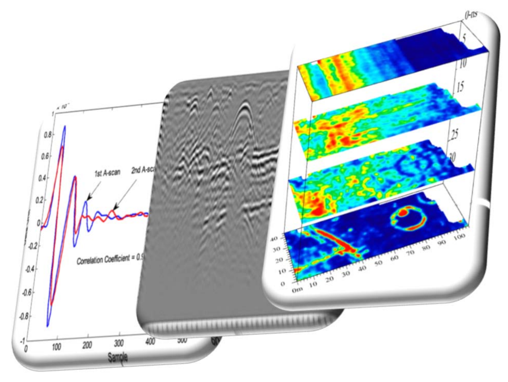


GPR Horn Antenna

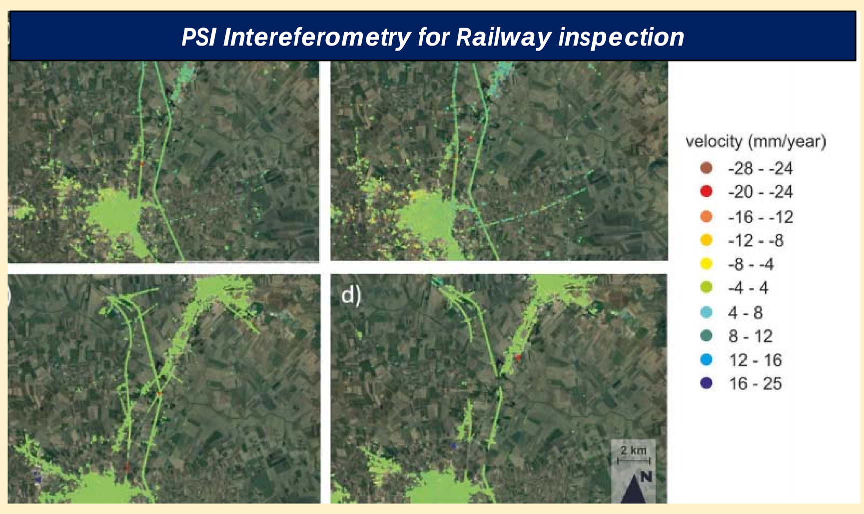
Examples of GPR results:

- Pavement thickness and Road Condition Assessment

- Highways and Bridge-deck evaluations

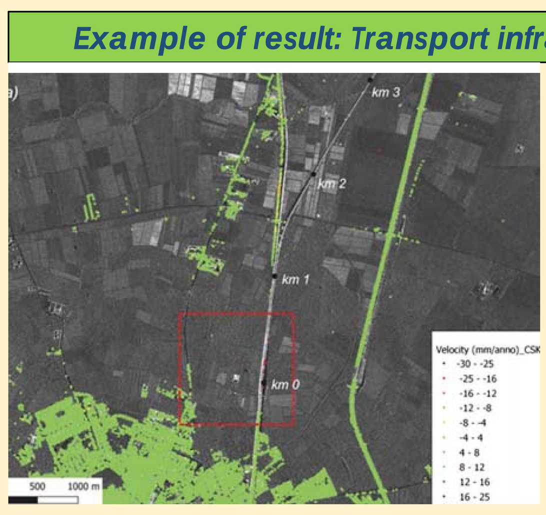


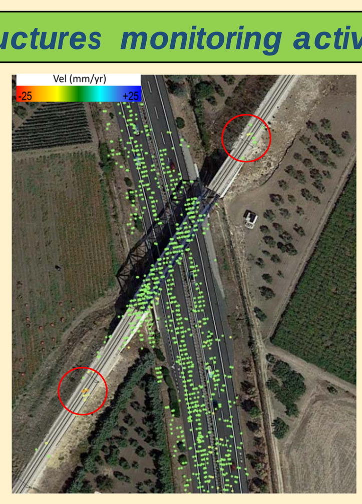
PSI Intereferometry for Railway inspection



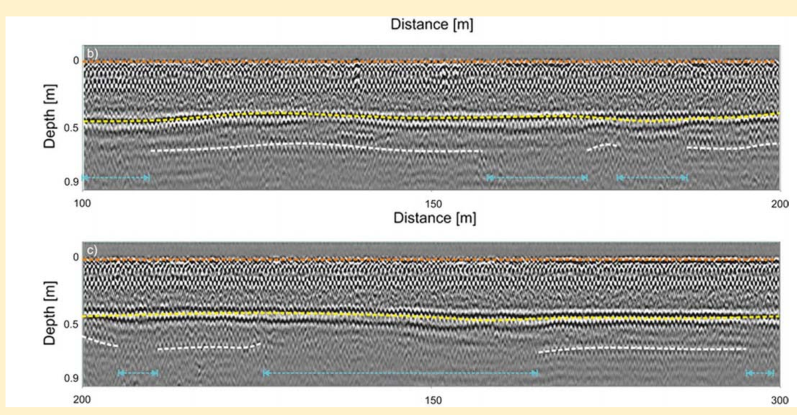
Application of PSI technique to both Sentinel 1 (ESA) datasets in a ascending and b descending geometries, and COSMO-SkyMed (ASI) data in c ascending and d descending acquisition geometries

Example of result: Transport infrastructures monitoring activty by integration of InSAR and GPR technique





GPR in-situ Railway inspection



Investigation about the track-bed condition and the cause of subsidence detected by satellite remote sensing

Scientific Publications

International peer-reviewed journals papers

*1, Bianchini Ciampoli, L., **Gagliardi, V.,** Clementini, C. et al. Transport Infrastructure Monitoring by InSAR and GPR Data Fusion. Surv Geophys 41, 371–394 (2020). https://doi.org/10.1007/s10712-019-09563-7. IF: 5.226*

*2. D'Amico F, **Gagliardi V.**, Bianchini Ciampoli L., Tosti F. Integration of InSAR and GPR for Monitoring Transition Areas in Railway Bridges, 2020. NDT & E International. https://doi.org/10.1016/j.ndteint.2020.102291*

*3. Bianchini Ciampoli, L., **Gagliardi, V.**, Ferrante, C., Calvi, A., D'Amico, F., & Tosti, F., Displacement monitoring in Airport Runways by Persistent Scatterers SAR Interferometry.2020. **Remote Sensing**. (Accepted, in press).*

International Project:

MoBI: Monitoring Bridges and Infrastructure Networks. The project is approved by **ESA (European Space Agency)** -Eohops Proposal id 52479. Principal investigator (PI): **Valerio Gagliardi**.

MoTIB : Monitoring Transport Infrastructure Network and Bridges, (Open call for science, ID 742) accepted by **ASI: Italian Space Agency.** Co-investigator

Conference publications

*4. **Gagliardi V.**, Benedetto A., Bianchini Ciampoli L., D'amico F., Alani M., Tosti F., Health-Monitoring Approach for Transport Infrastructure and Bridges by Satellite Remote-Sensing Persistent Scatterers Interferometry (PSI). Proc. SPIE 11534, Earth Resources and Environmental Remote Sensing/GIS Applications XI, 115340K (2020). https://doi.org/10.1117/12.2572395*

*5. **Gagliardi, V.**, Bianchini Ciampoli, L., D'Amico F., Tosti, F., Alani, A. , & Benedetto, A., (2020). "A novel geo-statistical approach for transport infrastructure network monitoring by Persistent Scatterer Interferometry (PSI)" . In 2020 IEEE Radar Conference (RadarConf20).*

*6. **Gagliardi V**, Bianchini Ciampoli L, Tosti F, Benedetto A, Alani A. Health monitoring of masonry arch bridges by integration of GPR and InSAR techniques. To: EGU General Assembly Conference (EGU 2020). Geophysical Research Abstracts Vol. 22, Wien, Austria, May 2020. DOI: 10.5194/egusphereegu2020- 13899*

*7. Tosti F., **Gagliardi V.**, D'Amico F., Alani A.M., Transport infrastructure monitoring by data fusion of GPR and SAR imagery information. Transp Res Proc 2020; 45:771-778. 721, (2020). https://doi.org/10.1016/j.trpro.2020.02.097*