Doctoral Dissertation
Doctoral Programme in Civil and Environmental Engineering (38th Cycle)

From Space to Action: Satellite Interferometric SAR for Structural Health Monitoring

Decision-ready diagnostics for existing structures

Raffaele TARANTINI

Supervisor:
Prof. Giuseppe Andrea Ferro

Doctoral Examination Committee:
Prof. Giuseppe Carlo Marano, Member, Politecnico di Torino
Prof. Filippo Ubertini, Referee, Università di Perugia
Prof. Giuseppina Uva, Referee, Politecnico di Bari

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Abstract

The translation of satellite multi-temporal Interferometric Synthetic Aperture Radar (MT-InSAR) measurements into actionable structural diagnostics is one of the principal open challenges in contemporary Structural Health Monitoring (SHM) of existing structures. Persistent Scatterer Interferometry (PSI) has matured rapidly as a source of millimetric displacement information. The gap between satellite displacement records and the diagnostic categories required by structural engineering practice has nevertheless remained largely unresolved, particularly at the building scale that underpins decision-making on existing assets.

The present thesis develops a coherence-aware methodological framework that articulates the diagnostic value of satellite InSAR observations across four progressively more demanding levels. The first level is screening. The second is displacement characterisation. The third is diagnostic interpretation. The fourth is continuous monitoring with automated anomaly detection. The framework rests on the principle that temporal coherence is a modelling variable rather than a quality filter, and that progression between levels depends on data conditions, complementary information sources, and explicit uncertainty quantification.

The framework is tested through three completed case studies and one ongoing research direction. The *Santissima Trinità* in Turin establishes that a null finding of structural stability is a meaningful monitoring outcome, and that the apparent point-density advantage of standardised European Ground Motion Service (EGMS) products on heritage masonry conceals a coherence cost that user-driven processing of raw Single-Look Complex (SLC) data systematically recovers. The retrospective forensic analysis of the *Himera Viaduct* and the *Albiano-Magra Bridge* formalises the Temporary Scatterer (TS) as a systematic diagnostic category. Lifecycle boundaries of TS encode the chronology of structural events at the resolution of the satellite revisit cycle. The *Sanctuary of Vicoforte* achieves the most complete realisation of the framework, identifying an application-specific coherence threshold of 0.56 through a Sparse Bayesian Learning (SBL) surrogate model. The same case operationalises the satellite displacement record as a stochastic oscillator monitoring statistic with continuous prediction capability. The ongoing application to the 2025 Palisades Fire in Los Angeles, conducted in collaboration with the Qualcomm Institute at the University of California San Diego, within the Cultural Heritage Engineering Initiative (CHEI) and ALERTCalifornia, extends the framework into a post-event regime by fusing PS-InSAR scatterer lifecycle indicators with airborne Light Detection and Ranging (LiDAR) geometric change metrics at the per-building scale.

Four transferable methodological contributions emerge from the work. The first is the formalisation of the Temporary Scatterer as a systematic diagnostic category. The second is the coherence-aware SBL surrogate modelling framework. The third is the four-level diagnostic articulation that maps satellite observables onto decision-support categories. The fourth is the multi-modal fusion architecture for post-event building-scale damage assessment. The decision-ready

diagnostic capability that gives the thesis its title is offered to the discipline as a contribution from which further developments in operational satellite-based SHM may proceed.

Keywords

Structural Health Monitoring; Satellite InSAR; Persistent Scatterer Interferometry; PS-InSAR; Multi-temporal Interferometry; EGMS; Sentinel-1; COSMO-SkyMed; Temporal Coherence; Sparse Bayesian Learning; Temporary Scatterer; Masonry Heritage; Bridge Monitoring; Infrastructure Collapse; LiDAR Fusion; Wildfire Damage Assessment; Decision-Ready Diagnostics