

Multi-Source Integration of Advanced InSAR and Geotechnical Modeling for the Detection and Monitoring of Geohazards Affecting Anthropogenic Assets

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High-resolution Earth observation technologies represent a key tool for the monitoring and assessment of geohazards (i.e., land subsidence and landslides) affecting the built environment and exposed elements at risk. In particular, satellite-based Synthetic Aperture Radar (SAR), through Interferometric SAR (InSAR) analysis, provides systematic observations of the Earth's surface with high spatial resolution and millimeter-scale precision, enabling the measurement of ground deformation over large areas.

Recent advances in satellite missions and processing algorithms have significantly expanded the potential of InSAR techniques for the detection and monitoring of ground instability processes, enabling multi-temporal analyses that provide long-term (years), regular (weekly to monthly), and highly precise measurements of surface displacement, thereby supporting multi-scale investigations from regional to local scales based on consistent radar datasets. These capabilities make InSAR a powerful tool for detecting ground deformation associated with geohazards and assessing their potential impact on anthropogenic assets such as infrastructure, buildings, and cultural heritage sites.

Despite these advances, significant challenges remain. Fully exploiting the potential of InSAR requires addressing the difficulty in effectively interpreting the derived displacement signals, which often reflect the superposition of multiple deformation components acting across different temporal scales (long-, medium-, and short-term processes). In this context, advanced data-driven approaches, including artificial intelligence and machine learning techniques, offer promising tools to disentangle multi-component signals and extract meaningful deformation patterns from complex time series. However, their application remains challenging due to the limited availability of ground-truth data, the need for physically consistent models, and the integration with geotechnical knowledge.

Moreover, the effective integration of satellite-derived measurements with ground-based investigations and geotechnical models remains limited, primarily due to the complex, heterogeneous mechanical behavior of natural terrain and anthropogenic structures. Combining InSAR observations with complementary datasets (e.g., geological, geotechnical, and land-use data) through hybrid and data-driven approaches introduces additional challenges related to data heterogeneity, scale mismatch, and model uncertainty.

In particular, attributing ground deformation signals to specific physical processes remains challenging, as ground deformation and structural responses reflect the coupled effects of natural and anthropogenic drivers acting across multiple spatial and temporal scales. In this framework, integrating machine learning models with physically based geotechnical approaches represents a key research challenge to improve process attribution and predictive capabilities.

The main objective of this research is to integrate multi-temporal InSAR analyses with geological, geomorphological, and geotechnical investigations to model geohazard processes and evaluate the response of exposed anthropogenic elements. Particular attention will be devoted to the quantitative assessment of the relative contributions of natural and human-induced factors controlling ground deformation and structural response.

The research activities will include:

- geological, geomorphological, and geotechnical field surveys;
- processing and analysis of satellite SAR data and validation through ground-based observations (e.g., GNSS/GPS measurements);
- evaluation of horizontal and vertical displacement components affecting natural and anthropogenic elements;
- quantitative analysis of displacement rates and spatial distribution of deformation;
- classification and interpretation of displacement time series;
- identification of conditioning and triggering factors controlling the observed processes;
- development of geotechnical models to quantify the relative contribution of natural and anthropogenic factors;
- assessment of the relationship between geohazard processes and the response of exposed anthropogenic elements.
- application of machine learning and artificial intelligence techniques (e.g., Random Forest, deep learning, and time-series decomposition methods) for the analysis and classification of InSAR displacement time series;
- integration of SAR-derived deformation data with complementary datasets (e.g., geological, geotechnical, land-use, and environmental data) through data-driven and hybrid modeling approaches;
- development of predictive models for ground deformation evolution based on multi-source data fusion and AI-driven approaches.

The project adopts a multidisciplinary approach combining geological, geomorphological, geotechnical, and remote sensing expertise. Within this framework, the candidate will have the opportunity to focus on specific aspects of the proposed research themes. The supervision of the PhD candidate will be carried out by experts in different fields of geology and engineering from CNR-IGG in Padova and from the ICEA Department of the University of Padova.

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