PROPOSITION DE SUJET DE THESE

Intitulé : Robust and scalable interferometric phase linking for Earth deformation monitoring with SAR satellite image time-series

Référence : **PHY-DEMR-2024-05**
(à rappeler dans toute correspondance)

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Mots clés

Interferometric SAR, multi-temporal, phase linking, earth deformation, statistical signal processing, robust statistics, machine learning, optimization.

Profil et compétences recherchées

Présentation du projet doctoral, contexte et objectif

Topic: Multi-Temporal Interferometric Synthetic Aperture Radar (MT-InSAR) techniques are becoming very popular, as the availability of SAR data is increasing. Leveraging the coherency allows for the measurement of Earth deformation up to millimeters accuracy (see example fig. 1). MT-InSAR techniques aim at exploiting all dimensions of the acquired SAR data, spatial and temporal, to optimally estimate the InSAR phases while retaining the spatial resolution. Phase linking (PL) driven by a maximum likelihood estimation (MLE) approach has been developed to jointly estimate InSAR coherence and phases (Minh et al. 2023). Most PL algorithms are built upon the sample covariance matrix, due to the assumption of an underlying Gaussian distribution. Recently, more general statistical models have then proposed and yielded new PL algorithms more robust to non-Gaussian data, yielding more accurate phase displacement estimates (Vu et al. 2023). One downside is that these robust methods involve a relatively high computational cost (compared to the standard PL), which can be limiting when processing large areas, or long baselines. This motivates the development and application of new methods that can achieve the best of both worlds.

Thesis plan: In this Ph.D thesis, we propose to study PL approaches in the framework of covariance fitting methodology, which has the potential to achieve the aforementioned goal. The thesis will be structured around two axes. The first one is dedicated to algorithm development (formulation, and resolution). The second axis is about the application and the performance assessment of these methods on real data.

Part 1 - Developing covariance fitting based PL

Our team achieved promising preliminary results by formulating variants of PL as a covariance fitting problem (Vu et al. 2023). This framework provides more flexible solutions by allowing the choice of a variety of distances/divergences, plug-in covariance matrix estimators, and regularizations. As InSAR data exhibit a variety of statistical properties according to the resolution and the type of observed scene, covariance fitting approaches should be designed to achieve good performances in all cases. In this scope several developments need to be explored: formulation with new (robust) fitting objectives, and the automatic selection of the covariance regularization parameters. These problems will be addressed by leveraging and adapting the literature on robust estimation, and covariance matrix regularization (Ollila & Breloy 2022), that has not yet been explored in the scope of MT-InSAR.

A second point concerns the numerical resolution of the newly formulated covariance fitting optimization problems. In the present state, the method is limited to several fitting cost functions that can be solved using majorization-minimization algorithms (Sun et al. 2016). Such an approach can be suboptimal in terms of convergence speed, and cannot be applied to any arbitrary fitting function. In order to address this issue, we will develop optimization algorithms for PL by leveraging the framework of Riemannian optimization (Boumal 2023), that appears well suited to optimize phase vectors (Smith 1999). In this scope, distributed schemes (Yang et al. 2019) should be beneficial in order to achieve low-computational-cost algorithms (by splitting large time-series into smaller overlapping batches). Last, we will study the possibility to train neural networks to replicate the output of PL algorithms. This can be achieved by considering the framework of unrolled algorithms (Monga et al. 2021), from which we can expect a “compressed number of iterations”, and thus, a potentially a more efficient implementation for processing large MT-InSAR data.

Part 2 - Application to real-world data

New methods will be applied to real MT-InSAR data for earth deformation with a focus on high resolution data and urban area monitoring. MT-InSAR are mainly available from satellite sensors such as Sentinel-1 for example. Earth deformation monitoring has been widely studied on low resolution MT-InSAR on land areas. With the development of new satellite constellations for high resolution SAR, there are more interests in urban areas monitoring. Ground deformation in cities is a significant problem to manage flood risk and effects of underground constructions (tunnelling). We will specifically work on TerraSAR-X data in X-band with a resolution of a few meters over Paris city area acquired between 2019 and 2021. The application of MT-InSAR methods requires the development of some pre-processing algorithms to generate the interferograms. Other algorithms are also necessary to produce ground displacement maps from the InSAR phase estimates. As urban areas yield spatially heterogeneous data, we expect the accuracy of the phase estimation to be improved by the developed robust algorithms and the density of measured displacement points as well. Finally another application of PL approaches is found in tomographic SAR. Tomographic SAR allows 3-D imaging by combining phases acquired at different altitudes. Calibration of these phases is crucial to focus the image in the vertical dimension and developed methods can improve it. Tomographic SAR data are available from ONERA airborne Sethi sensor for different bands and for different resolutions.

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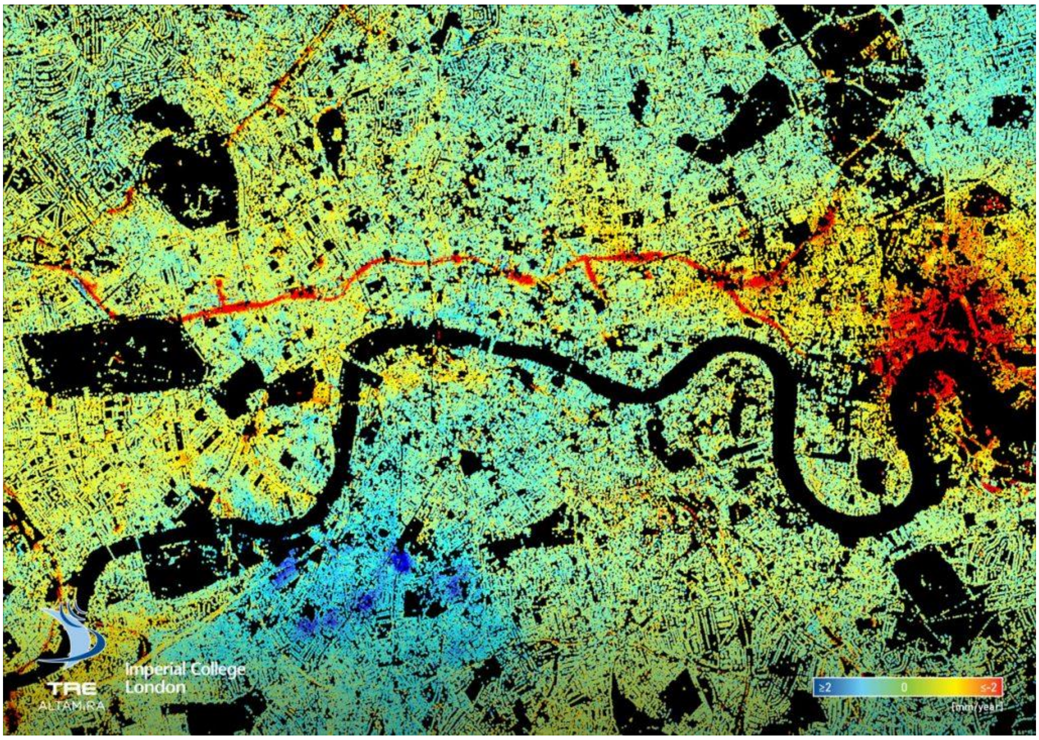

Figure 1 InSAR Ground Deformation Map of London city from TerraSAR-X data. The red line shows high displacements due to tunnel construction. (from TRE ALTAMIRA)

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Collaborations envisagées

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