PhD subject

Geometric analysis of multitemporal PolInSAR images

Context

PolInSAR (Polarimetric Interferometric SAR) combines polarimetry and radar interferometry for Earth observation [1]. This technique leverages the polarimetric sensitivity to scattering mechanisms and the interferometric sensitivity to the vertical structure of targets, enabling the estimation of forest height and biomass over large spatial areas [2, 3]. PolInSAR image processing is classically performed on $N \times N$ blocks, where statistical properties are assumed to be stationary. Analyzing the phase of these blocks involves estimating and tracking the phase of multivariate observations (of size N^2) over time or across different interferometric configurations. In standard PolInSAR, the block covariance matrix of the multichannel observations decomposes into a polarimetric covariance subblock (capturing within-acquisition scattering diversity) and a cross-covariance subblock Ω_{12} encoding the interferometric relationship between acquisitions.

As noticed by De Zan et al. [4] in classical InSAR, with three coherent SAR images forming three interferograms, the averaged phases can exhibit significant inconsistencies (lack of triangularity). They demonstrated that this phenomenon requires at least two independent scattering mechanisms and that the temporal covariance matrix is then not inherently Hermitian. This effect does not exist for single pixels and is actually due to the multivariate nature of the processed $N \times N$ blocks. This peculiar behaviour of the phase in the multivariate case is actually due to the presence of a geometric phase accumulated along time. Such phenomenon, also called Berry phase [5], was experimentally observed for light [6] or elastic waves [7] amongst many examples.

In signal processing, it was recently demonstrated that bivariate/polarized signals can exhibit a geometric phase [8]. PolInSAR datasets being multivariate and polarized, they are subject to acquire a geometric phase during the recording of multitemporal images. To model, understand, track and estimate this phase, it is necessary to rely on differential geometry concepts from fiber bundle theory together with concept from Riemannian geometry [10]. In particular, the geometric phase can be related to the path in a complex projective space (the space of instantaneous normalized covariance matrix of the studied signal). Geometric tools have shown their ability to handle InSAR image processing recently [9] and the proposed work aims at taking advantage of a geometric approach to model and analyze multitemporal PolInSAR images with a holistic point of view.

Objectives

This PhD project is structured around two complementary phases: (1) modeling and estimation of the geometric phase in PolInSAR image time series, and (2) exploitation of this geometric phase for machine learning tasks on polarimetric image sequences.

In the first phase, the research will establish a rigorous model for the appearance of the geometric phase in PolInSAR image time series. The statistics of this phase together with robust estimators to evaluate it will be investigated. Then, we will study how to potentially compensate and/or control the dynamical evolution of the phase in image sequences using for example geodesic regression schemes on the manifold of covariance matrices. Riemannian geometry tools will be used to propose tracking algorithms for the geometric phase. Connections between geometric phase values and physical properties of the PolInSAR illuminated zones will also be part of the investigations of this work.

In the second phase, the work will investigate the ability of geometric phases to characterize PolInSAR time sequences and their potential in machine learning tasks. In particular, non-commutative geometric phases [10] will be studied to provide new sets of features for tasks such as classification or detection. Non-commutative geometric phases estimated on nested subspaces could have the potential to provide new sets of features for PolInSAR images with properties such as invariance to time reparametrization and invariance to global phase change (gauge invariance). Defining multi-dimensional features based on such phases will require developing new metrics on nested manifolds to perform classification for example.

The algorithms developed in this PhD project will be tested on simulated datasets as well as on real SAR datasets acquired by a range of spaceborne and airborne sensors spanning multiple frequency bands: TerraSAR-X[1] (X-band), Sentinel-1[2] (C-band), and UAVSAR[3] (L-band). This multi-sensor, multi-band experimental design allows a rigorous assessment of the theoretical results across diverse physical conditions and vegetation types. The experimental validation will follow standard scientific methodology: signal processing algorithms derived in the first phase will first be applied to controlled benchmark scenes, before evaluation on heterogeneous real-world sites, enabling quantitative comparison of geometric phase estimates against independent reference measurements.

Candidate profile

Candidates should hold a Master or engineering degree in one or more of the following fields: applied mathematics, signal and image processing, computer science, remote sensing. The candidate should have good written and oral communication skills as well as programming proficiency in Python. A strong interest and solid background in linear algebra, in particular matrix theory and Lie group methods, is highly desirable.

Location

The PhD will be conducted in the GAIA department of the Gipsa-lab in Grenoble and in collaboration with the LISTIC laboratory at Université Savoie Mont Blanc in Annecy.

[1] TerraSAR-X is a German Aerospace Center (DLR) X-band high-resolution SAR satellite mission. https://www.dlr.de/en/research-and-transfer/projects-and-missions/terrasar-x

[2] Sentinel-1 is an ESA Copernicus C-band SAR mission providing freely accessible imagery. https://sentinel.esa.int/web/sentinel/missions/sentinel-1

[3] UAVSAR is a NASA JPL airborne fully polarimetric L-band SAR system. https://uavsar.jpl.nasa.gov/

Application procedure

To apply to this position, please send a cover letter, a CV as well as the last available academic transcripts of grades in your possession to:

- nicolas.le-bihan@cnrs.fr
- ammar.mian@univ-smb.fr
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References

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[10] D. Chruściński, and A. Jamiołkowski, *Geometric Phases in Classical and Quantum Mechanics*, Birkhäuser Boston, 2004.