Master 2 internship 2024-2025
Structured low-rank approximation for bivariate signals: application to polarization analysis of gravitational waves

Keywords Bivariate time series, polarization, gravitational waves, Hankel and Löwner matrices, low-rank approximation, optimization

Location Grenoble, France.

Supervision

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Application procedure Send a detailed CV and motivation letter to `nicolas.le-bihan@cnrs.fr`, `ecm@apc.in2p3.fr` and `philippe.flores@gipsa-lab.fr`

Context The detection of gravitational waves by the LIGO and Virgo detectors is one of the major scientific breakthroughs of the early 21st century [1]. This discovery has opened a new observational window into gravitational astronomy, allowing for the study of compact objects such as neutron stars and black holes. Binary systems composed of compact stars emit gravitational waves as they lose energy, gradually altering their orbital trajectories and ultimately leading to the merger of the two stars. In the final moments before the merger, an intense burst of gravitational waves is produced, which can be detected by the LIGO and Virgo interferometers.

This burst culminates in what is known as the "ringdown" signal, which corresponds to the relaxation of the newly formed black hole into equilibrium. During this phase, the remnant black hole emits gravitational waves characteristic of its fundamental resonant oscillations, referred to as quasi-normal modes [5].

According to general relativity, gravitational waves exhibit two degrees of freedom or polarizations. As such, they can be modeled as bivariate signals, and their polarization state can be effectively described using a geometric framework [3, 4].

Project summary The objective of the internship is to investigate novel methods for estimating polarized signal components from noisy measurements.

This internship focuses on the challenge of extracting the elementary modes that compose a bivariate signal. To analyze the modal structure, extensions of classical structured low-rank approximation (SLRA) techniques, based on Hankel [6] or Löwner matrices [7], will be explored. These techniques will be adapted using the framework developed in [2, 3] designed for handling bivariate signals.

The resulting polarized versions of SLRA will be developed and tested on simulated data under realistic noise conditions. The ultimate goal is to apply these methods to gravitational-wave data to extract the quasi-normal modes from the ringdown phase of gravitational-wave signals.

Candidate profile He/she should be enrolled in a M2R or engineer diploma in one or more of the following fields: applied mathematics, signal and image processing, astrophysics. The candidate should have good writing and oral communication skills.

Environment Position can be started anytime from February, 2025 and duration is up to 6 months. The candidate will be based in Gipsa-Lab, Grenoble. This internship will be hosted by the RICOCHET ANR project, with regular meetings and exchanges with researchers from the project. The internship could be pursued through a PhD.

References

[1] B. P. Abbott et al., "Observation of Gravitational Waves from a Binary Black Hole Merger", Phys. Rev. Lett., 116(6) 2016.

[2] C. Cano, "Mathematical tools and signal processing algorithms for the study of gravitational waves polarization", PhD thesis, University Grenoble Alps, 2022.

[3] J. Flamant, "A general approach for the analysis and filtering of bivariate signals ", PhD thesis, Ecole Centrale Lille, 2018.

[4] J. Flamant, N. Le Bihan and Pierre Chainais, "Time-frequency analysis of bivariate signals", in press, Applied and Computational Harmonic Analysis, vol. 46, issue 2, 2019.

[5] R. Abbott et al., "Tests of general relativity with binary black holes from the second LIGO-Virgo gravitational-wave transient catalog", Phys. Rev. D, vol. 103, issue 12, 2021.

[6] J. Gillard and K. Usevich, "Hankel low-rank approximation and completion in time series analysis and forecasting: a brief review", Statistics and Its Interface, vol. 16, no. 2, 2023.

[7] O. Debals, M. Van Barel and L. De Lathauwer, "Löwner-Based Blind Signal Separation of Rational Functions With Applications", IEEE Transactions on Signal Processing, vol. 64, N. 8, 2016.