MSc Research Intership

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Passive imaging in terrestrial and solar seismology

> **Master internship ($\sim$ 6 Months)**;
> **Location:** INRIA Makutu – University of Pau and Pays de l'Adour.
> **Supervision:** Hélène Barucq, Florian Faucher, Ha Pham.
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> **Keywords:** Wave equations; Passive imaging; Nonlinear inversion; Ambient noise seismology; Helioseismology.
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> **Contact:** Applications with a CV and motivation letter to send to florian.faucher@inria.fr. The internship takes place in the framework of the ERC Starting-Grant Project INCORWAVE, and can possibly lead to Ph.D. funding.

Scientific project   In terrestrial and solar seismology, surface oscillations are measured and used to infer the inner structures. These oscillations relate to the propagation of waves through the medium, propagation that depends on the inner physical properties such as density, bulk modulus, meridional circulation, etc. Therefore, observing the waves allows us to reconstruct the properties we cannot access. In the problems we consider, the waves originate from natural/stochastic events in the interior, and to extract information from the oscillations, we work with the cross-correlation of signals. The cross-correlation can be related to deterministic Green's functions which are solutions to wave equations, [2, 3, 4], giving us the relation between the physical properties and the observations.

The first objective of this internship is the accurate simulation of cross-correlation data in realistic solar and terrestrial backgrounds. It involves the following tasks.

(1.a) The derivation of the mathematical relations between the cross correlations and the Green's function depending on the wave equation considered and on the assumption regarding the stochastic nature of the source. This task first includes a bibliographic review.

(1.b) The development and implementation of the numerical workflow in the open-source code `hawen` [1] developed in the team Makutu.

(1.c) The validation of the numerical simulations with respect to measurements.

Following completion of the first part, the inverse problem will be considered, that is, for passive imaging. The objective is here to reconstruct the internal structures of the medium from the measured oscillations. The reconstruction follows a nonlinear iterative minimization approach (e.g., inherited from Newton's method). Namely, the physical properties describing the system (such as the bulk modulus for the Earth, or the meridional circulation for the Sun) are iteratively updated to minimize a discrepancy criterion between the measurements and the numerical simulations. The following tasks are planned.

(2.a) Formulation of the inverse workflow, in particular with the writing of the adjoint-state method for gradient computation in the context of cross-correlation data.

(2.b) Implementation in the open-source code `hawen` and preliminary experiments on toy problems (with the scalar acoustic wave equation).

(2.c) Depending on the progress, the selection of misfit criterion and/or the choice of regularization will be investigated.

Expected skills   The applicant must have a solid background in applied mathematics, in particular in partial differential equations for wave propagation; knowledge in iterative optimization is also warmly recommended. Numerical implementation will be part of the internship, within the open-source platform `hawen`, it is necessary that the applicant is familiar with coding, including parallel computer architecture to launch experiments. In addition, the applicant is expected to review scientific bibliography and write reports/documentation for its progress, hence a good level in english for all aspects of communications is required.

References

[1] F. FAUCHER, `hawen`: *time-harmonic wave modeling and inversion using hybridizable discontinuous Galerkin discretization*, Journal of Open Source Software, 6 (2021, https://ffaucher.gitlab.io/hawen-website/).

[2] L. GIZON AND A. C. BIRCH, *Local helioseismology*, Living Reviews in Solar Physics, 2 (2005).

[3] N. M. SHAPIRO AND M. CAMPILLO, *Emergence of broadband rayleigh waves from correlations of the ambient seismic noise*, Geophysical Research Letters, 31 (2004).

[4] N. M. SHAPIRO, M. CAMPILLO, L. STEHLY, AND M. H. RITZWOLLER, *High-resolution surface-wave tomography from ambient seismic noise*, Science, 307 (2005), pp. 1615–1618.