INTERNSHIP PROPOSAL Master 2 (2024-2025)

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Internship directors: Profs X. Jia (xiaoping.jia@espci.fr), A. Tourin (arnaud.tourin@espci.fr), Dr. J.-L.Gennissons (jean-luc.gennisson@universite-paris-saclay.fr)
Thesis possibility after internship: YES
Funding: YES (CNRS Gratification)

Elastography and ultrasonic imaging in soft granular materials[1]

Understanding the microscopic origin of behavior in particulate and particle-fluid systems such as granular materials, foams, and emulsions is of both practical and fundamental importance. In this internship project, we will investigate the mechanical behavior of an assembly of immersed gel beads (isodense) by ultrasound imaging (transient elastography) and rheology [1,2]. Studying such a *soft* granular material or suspension is of interest not only for biomedical applications (muscles and tissues) and for geophysical implications (landslides) [3], but is also relevant to the physics of complex systems where the transition from a liquid state to a solid state [4] remains a highly topical issue.

In this work, we will first use an ultrafast ultrasound scanner to monitor the low-frequency shear wave within an optically opaque dense gel bead packing generated by an oscillating plate (Fig. 1). We will be particularly interested in nonlinear response such as shear elastic softening and fracture dynamics [1] as a function of shear amplitude (Fig. 2a). Such transient elastography was originally developed in our laboratory to track tissue motion induced by low-velocity shear waves in the context of medical imaging [2].

In addition, we will use steady and oscillatory shear rheological measurements (Fig. 2b) [5] combined with ultrasonic imaging to monitor the structure change due to plastic rearrangements of particles. Especially, we will investigate the effects of particle shape (e.g., granular dimers/trimers) and/or anisotropic behavior (i.e., force chains) in response to external loading [6]. In the long-term, this research is linked to the search of a possible system for producing artificial skeletal muscles whose mechanical properties can be modified and produce the desired force to dissipate the mechanical energy of an external impact. Inspired by a proposal from Pierre Gilles de Gennes [7] who exploited a temperature-driven nematic/isotropic phase transition to induce a sudden contraction in an artificial muscle, we will also investigate the possibility to modify these soft particle networks by controlled acoustic perturbations.

This work will be carried out at the Langevin Institute, ESPCI Paris-PSL, in collaboration with Dr. Jean-Luc GENNISSON at the Laboratoire d'Imagerie Biomédicale Multimodale at Paris-Saclay University.

Required background of the student: a good background in physics in general and particularly acoustics and mechanics. The management and interpretation of images generally use the MATLAB and /or Python language with which the candidate should be familiar

[1] J. Brum, J.-L. Gennisson, M. Fink, A. Tourin & X. Jia, "Drastic slowdown of the Rayleigh-like wave in unjammed granular suspensions", *Phys. Rev. E* 84, 020301 (2019)

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[1] Condensed Matter Physics: YES — **Soft Matter and Biological Physics: YES**
Quantum Physics: NO — Theoretical Physics: NO

[2] S. Catheline, J.-L. Gennisson, M. Tanter, and M. Fink, "Observation of shock transverse waves in elastic media", *Phys. Rev. Lett.* 91, 164301 (2003)
[3] P. Johnson and X. Jia, "Nonlinear dynamics, granular media and dynamic earthquake triggering", *Nature* 437, 871 (2005)
[4] A. J. Liu and S. R. Nagel, "Jamming is not just cool anymore", *Nature* 21, 396 (1998)
[5] J. Léopoldès and X. Jia, "Probing intermittency and reversibility in a dense granular suspension under shear using multiply scattered ultrasound", *Soft Matter* (2020), DOI: 10.1039/D0SM01427C
[6] M. Z. Miskin and H. M. Jaeger, Adapting granular materials through artificial evolution", *Nature Materials* 12, 326 (2013)
[7] P. G. de Gennes, "A semi-fast artificial muscle", *C. R. Acad. Sci. Paris* 324, 343 (1997)

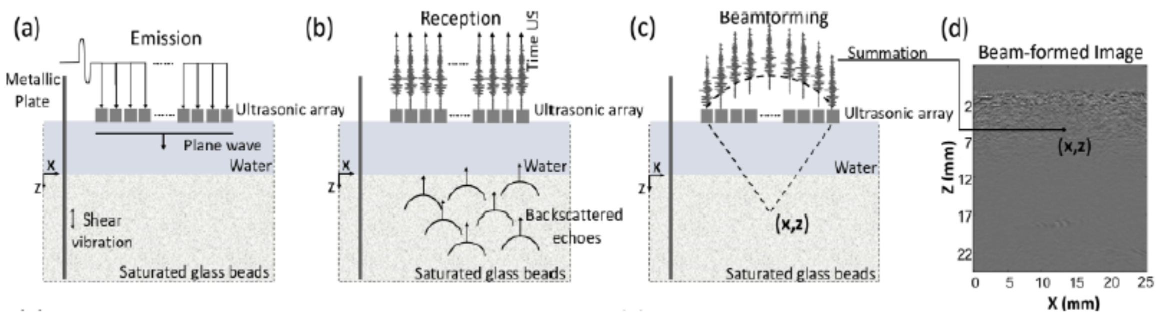

Fig. 1 (a) Ultrasound emission step: all elements in the array emit simultaneously a short pulse centered at 4 MHz, thus generating a pulsed plane ultrasonic wave (b) Ultrasound reception step: the backscattered echoes coming from different locations within the medium are recorded by each element of the transducer array. (c) Beam-forming step: relate the arrival time of an ultrasound echo to a given position within the imaging plane, each point (x, z) in the image is obtained by adding coherently the backscattered signals originating from it (d).

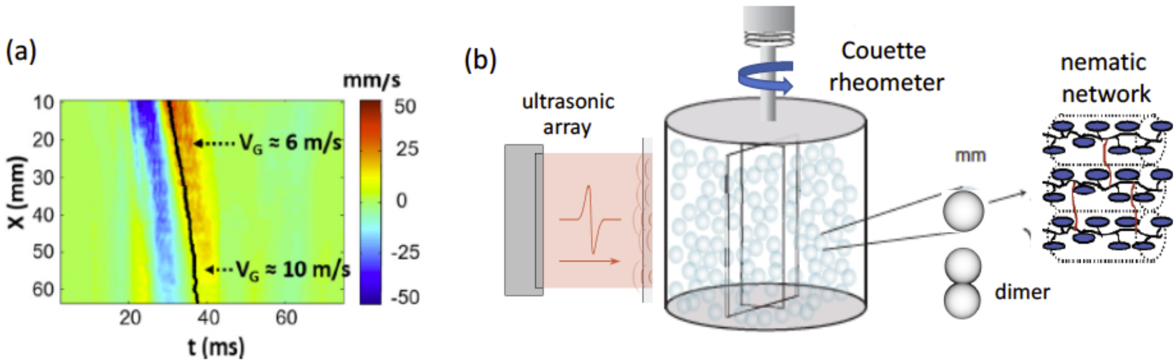

Fig. 2 (a) Particle velocity fields associated with a shear wave propagation inside a granular medium (Fig. 1). (b) The gel bead packing is sheared at constant speed in a Couette-like rheometer and analyzed using ultrasound imaging.