Numerical analysis, Machine Learning and Control for Micro-Swimmers into Complex Environments

Keywords	Mathematical Modeling, Control and Optimization, Theory, Numerical simulation, Micro-swimming
Advisors	Laetitia Giraldi Mickael Binois Laurent Monasse
Hosting Team	Team CaliSto, Inria Center at Université Côte d'Azur

Context

The medical field stands at the brink of a revolutionary change with the development of micromachines specifically designed for minimally invasive interventions, such as precise drug delivery to otherwise inaccessible areas within the human body [1]. Micro-robot swarms are particularly promising for these applications due to their small size, making them ideal for localized drug delivery.

However, controlling even a single micro-robot in the human body presents significant technical challenges due to the complex nature of biological fluids, with varying viscosity and composition, necessitating highly adaptable navigation strategies. These challenges multiply when controlling a collective of such micro-robots, as typical control mechanisms apply uniform actions across the entire swarm, limiting the precision of individual control. This position is offered within the framework of the NEMO ANR project.

Objectives

This postdoc covers a broad scope, allowing the objectives to be tailored according to the research interests of the candidate. The core focus is on investigating control strategies for micro-swimmers within complex environments, spanning multiple areas:

- **Control and Optimization**: Leveraging machine learning techniques to develop control strategies that enable one or more micro-swimmers to navigate effectively within complex environments [2].
- **Numerical Analysis**: Expanding the Feel++ codebase for simulating deformable elastic objects in fluid environments, with potential extensions to a group of swimmers and into a non-Newtonian fluids. This includes developing finite element methods or boundary element methods, such as CUTFEM, for structural analysis [3].
- **Mathematical Modeling**: This development framework also supports the study of individual or multiple micro-swimmers, with options to extend toward swarm modeling and interactions [4].

Candidate profile

We are looking for candidates with a strong background in applied mathematics (Numerical methods, Numerical simulations, Control and Optimization) or in physics (Fluid dynamics, Modeling). Candidates should be fluent in English, have a good experience in programming and in data analysis. We will appreciate candidates with the following skills (optional): knowledge in fluid dynamics, knowledge in statistical physics, interest in biological applications

Duration and period

The internship will cover an initial period of 12 months, renewable once. It could start from January 2025. The exact start and end dates are flexible and can be adjusted according to the student's constraints.

Host institution

The internship will take place within Team CaliSto, located in Inria Centre at Université Côte d'Azur. The student will be in contact with researchers that collaborate with the team members on this topic across both France (in particular Strasbourg, Paris) and Europe (mostly in Germany and in Italy).

To apply

Interested candidates are required to send a cover letter, a CV and at least one recommendation letter to laetitia.giraldi@inria.fr.

References

[1] S. Palagi and P. Fischer, *Bioinspired microrobots*, **Nat. Rev. Mater.** 3(6):113-124, 2018, DOI.

[2] Z. El Khiyati, R. Chesneaux, L. Giraldi and J. Bec, *Steering undulatory micro-swimmers in a fluid flow through reinforcement learning*, **Eur. Phys. J. E.**, 2023. DOI.

[3] C. Van Landeghem, L. Berti, V. Chabannes, C. Prud'Homme, A. Chouippe, Y. Hoarau and L. Giraldi, *Mathematical and computational framework for moving and colliding rigid bodies in a Newtonian fluid*, **AMSA**, 2024, DOI.

[4] C. Calascibetta, L. Giraldi, Z. El Khiyati and J. Bec, *Effects of collective patterns, confinement, and fluid flow on active particle transport*, **accepted in Phys. Rev. E**, arXiv preprint.