To answer these challenging issues, the proposed work is divided into three parts.

A propos du centre ou de la direction fonctionnelle

The Inria Sophia Antipolis - Méditerranée center counts 34 research teams as well as 7 support departments. The center's staff (about 500 people including 310 Inria employees) is made up of scientists of different nationalities (50% of nationalities), engineers, technicians and administrative staff. 1/3 of the staff are civil servants, the others are contractual agents. The majority of the center's research teams are located in Sophia Antipolis and Nice in the Alpes-Maritimes. Four teams are based in Montpellier and two teams are located in Bologna in Italy and Athens. The Center is a founding member of Université Côte d'Azur and partner of the I-site MUSE supported by the University of Montpellier.

Contexte et atouts du poste

The proposed work will be carried out in the research team CALISTO, which is common between Inria and the CEMEF Research Center of CHRS/MINES ParisTech. The team is located at the Inria research center in Sophia-Antipolis, France.

The selected candidate will evolve in a strongly interdisciplinary context (applied maths, physics, fluid dynamics, statistics, data analysis, scientific computing), at the edge between basic and applied research.

This environment will provide the PhD student with a unique opportunity to diversify his/her expertise through strong scientific links with the team members. The foremost research activities will allow him/her to build up an international network by developing relations with teams located in Germany, India, Italy, Japan and Sweden.

Mission confiée

Keywords: statistical learning, reinforcement learning, optimization, active particles, flagellated micro-swimmers, fluid-structure interactions, chaotic dynamics, turbulent flows

Scientific Context:

Swimming bacteria, spermatozoa, or plankton are natural examples of self-propelled, active particles. These living micro-organisms have the ability to deform or alter their internal features according to the environment, in order to achieve a specific goal. Finding inspiration from such adaptive behaviors is key for the design of artificial devices used in medicine for micro-surgery, targeted drug delivery or diagnosis [1].

Many questions are still open on how these micro-swimmers optimize their displacement, in particular when they are embedded in a complex environment [2]. In practice the swimmers navigate in a fluctuating medium comprising walls and obstacles and possibly with non-Newtonian properties. They sometimes form swarms, synchronize and display collective behaviors.

In such situations, the dynamics of the swimmers involve a number of physical effects (hydrodynamics, elasticity, contact and lubrication forces, mutual interactions), non-linearly coupled with each other. Such a high-dimensional, often chaotic dynamics hinders the use of classical techniques from optimal control. A promising alternative is given by strategies based on machine learning [3,4].

Objectives:

This PhD focuses on flagellated micro-swimmers that move by waving their tail and pushing the fluid in which they are immersed [5]. They are modelled as semi-elastic slender bodies whose curvature varies by prescribing a locomotion force. The aim is to use machine-learning techniques in order to find optimal force controls that will allow the swimmer to efficiently swim and navigate in complex media. The plan is to address simultaneously the questions of finding an efficient swimming strategy and of optimizing the swimmers navigation. The combination of these two aspects is particularly novel. This is justified by the focused applications, in which the size of swimmers is comparable to the scales on which the environment varies. Developing such aspects will require an important modelling effort and to design innovative optimization tools.

Various environments will be considered. They are characterized by variations of the fluid flow around the swimmers that originate from the presence of walls, from non-Newtonian elastic turbulence, or from hydrodynamic interactions between several swimmers. The dynamical system formed by the swimmers and the fluid is then expected to exhibit a chaotic behavior, jeopardizing the convergence of learning algorithms. A part of the thesis consists in addressing this issue by developing original learning algorithms based on multiagent approaches. Applying techniques borrowed from Artificial Intelligence to deformable swimmers is particularly challenging and promising. This will shed new lights on observed behaviors of living organisms. Reversely, some strategies observed in nature are expected to inspire specific choices of models or learning process. This thesis is timely, relevant to applications, in particular for the design of artificial micro-swimmers used in medical care, and will lead to publications in international journals of the highest level.

Principales activités

To answer these challenging issues, the proposed work is divided into three parts.

1. The first step will consist in using existing codes to simulate the dynamics of isolated flagellated swimmers in turbulent flows, in the presence or not of boundaries, and to test various learning strategies. Particular attention will be paid to quantify the convergence of adversarial reinforcement learning methods that have shown their efficiency in time-dependent flows [6]. This will require developing appropriate statistical tools and will lead to design new procedures that improve this convergence.
2. The second part of the PhD will study the effects of a non-Newtonian fluid rheology. This will require modifying the simulation codes and to implement visco-elastic effects in the interactions between the swimmer and the fluid [7]. The goal is to understand how this alters swimming and navigation strategies.

3. Finally, the last step will consist in addressing optimal collective motions of micro-swimmers. This will require implementing interactions between swimmers in the code. Optimization will be achieved using Kriging methods [8]. This approach will permit emulating the swarm dynamics as a function of each individual deformation strategy from a few number of selected simulations.

References


Compétences

- Master of Science or equivalent in applied mathematics, physics, or engineering, with competences in fluid dynamics, statistics, optimization, or scientific computing
- Basic knowledge in programming (C, C++, Python) and in data analysis
- Rigorous, autonomous, creative

Avantages

- Subsidized meals
- Partial reimbursement of public transport costs
- Leave: 7 weeks of annual leave + 10 extra days off due to RTT (statutory reduction in working hours) + possibility of exceptional leave (sick children, moving home, etc.)
- Possibility of teleworking (after 6 months of employment) and flexible organization of working hours
- Professional equipment available (videoconferencing, loan of computer equipment, etc.)
- Social, cultural and sports events and activities
- Access to vocational training
- Social security coverage

Rémunération

Duration: 36 months
Location: Sophia Antipolis, France
Gross Salary per month: 1982€ per month (year 1 & 2) and 2085€ per month (year 3)