PhD thesis position in microrobotics: Structural shaping of fully integrated microrobots using multi-material topology optimization

Context: Position opened in the framework of the RoboTop project funded by the National Research Agency (ANR)
Employer: University of Marie and Louis Pasteur, Besançon, France
Location: FEMTO-ST Institute, AS2M department, 24 rue Alain Savary, 25000 Besançon, France
Salary: gross salary around 2300 € per month
Duration: three years full-time employment, starting 1st October 2026
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Supervision team:
Abdenbi MOHAND OUSAID, Aude Bolopion and Michael Gauthier

Context:

Microrobots are tiny robots specifically designed, fabricated and controlled to perform complex tasks in confined and hard-to-reach environments. With their ability to position, manipulate, sort and characterize objects with sizes ranging from 1 µm to 1 mm, they offer potential solutions across scientific (e.g., scientific tools), industrial (e.g., accurate manipulation and assembly, inspection), environmental (e.g., water treatment) and societal domains (e.g., medicine and biology). The first attempts to design microrobots focused on the miniaturization of classical robotic systems. However, this approach was rapidly met with fundamental technological barriers. Homothetic reduction of classical robots often introduces mechanical play and friction that affect their accuracy. In addition, the designer's intuition is no longer sufficient to ensure the microrobots' performances in terms of precision, reliability and compactness. The need for miniaturization leads naturally to microrobots with a high functional integration density. This becomes even more critical as the boundaries between the microrobots structure and their actuation and sensing mechanisms become increasingly blurred with miniaturization. In this regard, optimizing the microrobots topology presents new potential solutions. Unlike traditional optimization methods, it involves systematically distributing a predefined quantity of material (or multiple materials) without topological constraints, while maximizing or minimizing a cost function subject to one or several constraints [1].

Objectives:

To address design challenges of microrobots, several methodologies have been proposed such as optimal arrangement of actuators/sensors, interval method or blocks method. However, these strategies are not well-suited, particularly due to the lack of degrees of freedom and generalization. They are either limited to the optimization of a finite number of parameters or relied on the expertise and the intuition of the designer. Thus, it is difficult to design heterogeneous microrobots that incorporate materials with different properties. For example, failing to properly balance the material distribution could result in a microrobot that is too flexible to perform its task or too rigid to adapt to its environment. In this regard, structural optimization, and particularly topology optimization approach is a promising solution. Unlike classical methods, this powerful mathematical tool consists of distributing material in areas where it is necessary and removing it from areas where it is not needed. Instead of direct imitation of nature, this method relies on a pure mathematical process to produce structures with similarities to those of biological organisms [2].

In this context, FEMTO-ST institute/AS2M department aims to propose a multi-material topology optimization framework to design fully integrated microrobots. Building upon our previous works [3,4], the thesis explores the potential of multi-material topology optimization to revolutionize microrobots, enabling unprecedented integration level of actuation and sensing directly in the material. The ambition consists in taking advantage of active materials, with a particular emphasis on piezoelectric materials. Having multi-functional properties, these materials can be used for: (i) actuation with high dynamics and high displacement resolution and (ii) sensing of strain and stress [1]. To demonstrate the usefulness of
the framework, the thesis targets one application related to biological sample using correlative microscopy. Specifically, the thesis aims to design a high speed monolithic XY piezoelectric sample holder that integrates actuation and sensing capabilities.

To reach these objectives, the thesis core hypothesis stipulates that strategical distribution of multiple materials within a design domain will permit to embed the microrobot's functionalities directly into the material, which may fail when a single material is used. This can be achieved through the combination of materials with different physical and mechanical properties to perform specific functions such as structural support, actuation and sensing.

[1] Martin Philip Bendsoe and Ole Sigmund. Topology Optimization : Theory, Methods and Applications. Springer, February 2004.
[2] Hiroki Kobayashi et al. ,Computational synthesis of locomotive soft robots by topology optimization. Sci. Adv.10,(2024).
[3] Homayouni-Amlashi, A., Schlinquer, T., Mohand-Ousaid, A. et al. 2D topology optimization MATLAB codes for piezoelectric actuators and energy harvesters. Struct Multidisc Optim 63, 983–1014 (2021).
[4] Homayouni-Amlashi, A., Sigmund, O., Schlinquer, T. et al. Matlab codes for 3D topology optimization of multi-material piezoelectric actuators and energy harvesters. Struct Multidisc Optim 67, 165 (2024).

Tasks:

First the candidate will conduct a deep investigation of the state of the art of multi-material topology optimization approaches with a particular emphasis on the interpolation schemes enabling strategical distribution of multiple materials. Second, the work will consist of deriving the mathematical models of materials, which are essential for finite element discretization and sensitivity analysis. Third, hybrid penalization schemes will be proposed to distribute multiple materials simultaneously. Fourth, the work will focus on the sensitivity analysis and the computational implementation of the topology optimization framework. In that way, the topological optimization MATLAB codes published by FEMTO-ST [3,4] will constitute a strong starting point for this thesis. Finally, numerical and experimental validations will be carried out.

Working environment:

The PhD student will be hired by the university of Marie and Louis Pasteur and will be working in the FEMTO-ST research laboratory / AS2M department. He/she will work in the context of the ANR PRC RoboTop project. All expenses related to this thesis work will be covered by this project.
The FEMTO-ST Institute is a CNRS laboratory (https://www.femto-st.fr/en) that involves 750 persons.
FEMTO-ST includes many research departments, among which AS2M (Automation and MicroMecatronic systems) will host the PhD candidate. FEMTO-ST also includes cleanroom microfabrication facilities (https://www.femto-st.fr/fr/Centrale-de-technologie-MIMENTO/Centrale-de-technologie-MIMENTO/presentation), a microrobotic center (https://platforms.femto-st.fr/cmnr/fr) as well as a network of local manufacturing industries.

Responsibilities and Qualification:

The candidate will be responsible for the development, the numerical implementation, and the validation of a multi-material topology optimization algorithm. He/she will also be responsible of all reporting and communication related to the work.
Solid background in one or more of the following areas and having a Master/Engineer degree in related field:

- Microrobotics or Robotics,
- Mechatronics or Mechanics or Finite elements modeling
- Structural optimization/topology optimization

Any of the following skills will be considered as an asset:

- Previous experience in microrobotics or structural optimization
- Autonomy and communication skills
- Teamworking and autonomy

Position open until filled. Candidates should provide a cover letter, a CV and a list of references via email to abdenbi.mohand@femto-st.fr