Embodied intelligence and mechanical modeling of soft robots using AI

Context:

Soft robotics is taking advantage of compliant materials to better adapt to their environment, manipulate fragile objects, interact safely with humans, or navigate through tight spaces for example. This principle is inspired by nature where living organisms have naturally evolved to adapt their shape and structure to their environment.

Embodied intelligence [1] [2] is an emerging topic in soft robotics. The classical vision of artificial intelligence in robotics essentially concerns the control and dexterity of robots on various tasks. Yet part of the difficulty of this control can be addressed by design choices or local distributed mechanisms allowing morphological feedback. These mechanisms can be found in nature at different scales with, for example, the functioning of the intestines at the macro scale (coordination of muscles to create a peristaltic movement), the range of mechanoreceptors at the meso scale (allowing to pre-sort the type of stimulus), the cellular mechanisms at the micro scale (cells are able to communicate and coordinate their activity).

The DEFROST team at Inria has developed simulation tools for dedicated to soft robotics that gained recognition and are widely used both in France and internationally. We were pioneers in numerical modelisation for soft robots control [5,6]. Recently, we started to look at design methods, for example by using 3D-printed anisotropic meta-materials [4]. We also started some works on the optimisation of soft robots shape [7].

Challenge:

During the design process of a soft robot, the space of possibilities is very large: what shape should the robot have? Where should it be compliant and where should it be stiff?[3] Where should be placed the actuators? Should we use some anisotropy? [4]… However , it is clear that in nature, some of the mechanisms described above are reproduced and adapted (size, morphology…) whatever the animal.
The challenge is therefore to be able to reduce the complexity of the design by the automatic assembly of pre-designed mechanisms that could be provided as an input. This optimization process will require the automatic evaluation of reward functions and a work on model parametrization. The second challenge is then to provide automatically new FEM simulation of these mechanisms without the need of

manual intervention when the morphology of the robot is modified by the optimization.

Thesis goals and methods:

Several research directions will be explored during this thesis:

1/ Automatic modeling using data-base: we will investigate the use of machine learning to help soft robot design and mechanical simulation together. The goal is to be able to have to learn not only the shape the robot should have, but also the numerical model associated with it, which would allow for a smooth transfer from the robot design to the control of the real robot. Indeed, depending on the robot shape, different mechanical models may be used for simulation(elastic, hyperelastic, anisotropic, inhomogeneous,... etc), and different FE models may be used (tetrahedron, beams, shells, ...). The integration of actuators may vary depending on the model used, or a combination of these models. In the DEFROST team, we have a database of mechanical simulations of soft robots with very different shapes (see figure below) . From that database, learning could be made to combine these models to find a soft robot design suitable for a specific task, with the advantage that we would directly have a FEM simulation ready to test the robot.

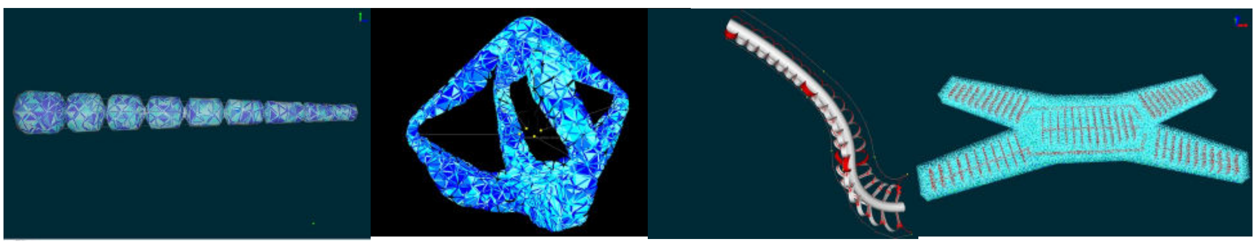

Fig: Various designs of soft robots simulated in our framework . Our wish is to increase the database of simulated robots and decompose it into reusable templates.

2/ Reward functions: Depending on the uses of the robot (handling, locomotion, interface...), depending on the environment in which it evolves (complex , fragile, dangerous...) it is necessary to be able to evaluate the performance of the robot's digital twin in order to compare different designs and to allow optimization. However, the way we will choose to provide rewards will strongly influence the final design in an optimization approach. We often look for the best compromise between several design constraints. The objective will therefore be to make a gathering of these constraints and to propose simulation tools able to evaluate them in a reward function. In addition, we will work to combine the constraints (by weights or priorities) in order to propose more global optimizations.

3/ Performance : Particular attention will be paid to the performance of the simulations. Indeed, these optimization processes are, in general, very demanding in terms of data. In our case, this means testing a large number of simulations. We will therefore take care to keep computing times short for each of these simulations. It is important, on the one hand, to maintain an eco-friendly approach, and on the other hand, to be able to propose optimizations within a reasonable timeframe. For this we will build on our expertise on fast computation of deformable models.

Profile of the candidate:

We are looking for a candidate with a Masters degree or Engineering school degree in computer science and/or Robotics and/or computational mechanics.
The candidate should be motivated by scientific research, and motivated to work within a research team, taking part in the team dynamics.

Programming: Good level in C++ , Python, Git

Scientific skills in at least one of the following domains:

- Finite element modelling (FEM)
- Machine learning
- Applied mathematics

Interpersonnal skills :

- Good communication skills
- Good writing skills for scientific reports
- Ease to explain et present scientific results

Languages: Fluent in english (French is not compulsory but appreciated)

If interested, please contact :

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Bibliography:

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[7] Morzadec, T., Marcha, D., & Duriez, C. (2019, April). Toward shape optimization of soft robots. In 2019 2nd IEEE International Conference on Soft Robotics (RoboSoft) (pp. 521-526).