Embodied Perception in Modular Soft Robots for Affective and Social Human–Robot Interaction

Partners: FEMTO-ST (Besançon) and ETIS (Cergy-Pontoise)
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The thesis will be hosted at FEMTO-ST, with extended stays (up to half the duration of the PhD) at ETIS.

Summary

Modular soft robots offer unique potential for human-robot interaction and robot-robot cooperation due to their morphological adaptability and intrinsic safety. This thesis aims to design and develop soft robots integrating advanced sensors capable of accurately capturing motion and contact, and to leverage this information to enrich social and collaborative interaction [1].

Within the framework of the structuring axis “Material, Architecture, and Embodied Intelligence” (AS1) of the PEPR O2R program, and more specifically WP2 dedicated to deformation for motion and interaction, this PhD project aims to create new soft robot solutions for human interaction with expressive movement capabilities and perception of their movement during interaction. To this end, we will develop: 1. Sensors integrated directly within the structures of modular soft robots, to provide enhanced perception, cooperation, and communication with their environment. 2. Human-robot and robot-robot interaction scenarios to test the robots and explore new forms of affective and social interaction in collaborative tasks.

Context

WP2 of the structuring axis “Material, Architecture, and Embodied Intelligence” (AS1) of PEPR O2R is dedicated to deformation serving motion and interaction. Its goal is, during and for the time of interaction, to explore a paradigm shift in motion generation, motion capture through proprioceptive means, and the development of interaction augmented by aesthetic and/or emotion-generating dimensions. New solutions are sought to move the robot through deformation, with embodied intelligence guiding the system not only for motion purposes but also for aesthetic and emotional considerations.

Scientific Content

This thesis aims to develop modular soft robots integrating advanced sensors capable of providing precise perception of motion, contact, and shape to facilitate collaborative and social interactions [2].

Technological Approach

Modular soft actuators will be developed using additive manufacturing techniques with flexible materials. These actuators will form the building blocks of larger soft robotic structures that can reach several tens of centimeters in size. The objective will be to achieve multiple degrees of freedom with kinematics inspired by serial robotic systems, enabling manipulation capabilities. Different types of actuation mechanisms, such as extension, bending, and torsion, will be explored.

By combining these modular elements, the work will aim to develop reconfigurable and versatile soft robotic structures.

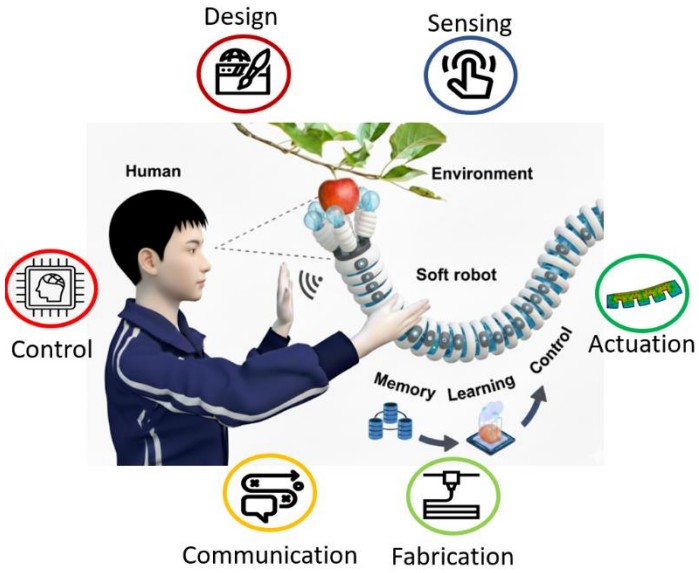

Figure 1. This figure highlights the main components involved in the design of an intelligent modular soft robot, namely actuation, sensors, electronics, and communication. It also illustrates key aspects such as the precise perception of motion, contact, and shape, which are necessary to facilitate collaborative and social interactions.

Perception

The thesis will investigate the integration of sensors directly onto soft actuators using additive manufacturing techniques [3]. These sensors, based on conductive materials such as graphene or carbon composites, will allow the measurement of deformation and tactile interactions. The student will explore strategies for sensor placement, number, and dimensions to achieve robust and sensitive measurements. In addition, the project will study how sensor signals, combined with changes in actuator shape or appearance, can be used to investigate robot–robot and human–robot interactions, including collaborative tasks involving contact and tactile sensing. The resulting data may be used to explore adaptive or affective responses during interaction.

PhD Objectives:

1. Explore a paradigm shift in motion generation, motion sensing through proprioceptive means, and the development of interactions enriched with an aesthetic and/or emotion-evoking dimension in a soft robot interacting with humans and/or other robots.

2. Develop deformation sensors that are directly integrated into modular soft actuators through 3D printing using carbon- or graphene-based conductive materials.

3. Study the relationship between sensor electrical resistance and mechanical deformation to extract reliable information for robot perception and control [4].

4. Design, model, and simulate modular soft actuators with optimal sensor integration, combining soft material mechanics and finite element methods.

5. Fabricate hybrid modular soft robots with integrated sensors, optimizing their number, dimensions, and placement.

6. Implement closed-loop control algorithms exploiting sensor signals to improve motion accuracy, inter-robot cooperation, and social interaction with the human environment.

7. Validate and characterize a functional demonstrator illustrating the feasibility of the integrated approach and its potential in collaborative and social scenarios.

Candidate Profile

The candidate should be motivated, creative, and ambitious, interested in interdisciplinary research combining engineering and human/social sciences, with good written and spoken English, able to work independently or in a team, and able to quickly acquire knowledge in new topics.

Requirements:

- Master's degree in mechanical engineering, mechatronics, robotics, or a related field, with strong academic performance
- Solid background in mechanics (including solid mechanics and soft materials), applied mathematics, and manufacturing techniques
- Experience with MATLAB, Python, or C++, as well as CAD software and finite element methods
- Strong interest in robotics, soft robotics, and human–robot interaction
- Innovative and entrepreneurial mindset, with curiosity for interdisciplinary research

Application

Interested candidates should send their Curriculum Vitae (CV), a motivation letter including a description of their research projects, transcripts from their last year of studies, and two reference letters or the name of two referees, to the three supervisors:

- Wissem Haouas: wissem.haouas@femto-st.fr

- Lola Cañamero: lola.canamero@cyu.fr

- Kanty Rabenorosoa: rkanty@femto-st.fr

References

[1] L. L'Haridon and L. Cañamero, "The effects of stress and predation on pain perception in robots," in *2023 11th International Conference on Affective Computing and Intelligent Interaction (ACII)*, Cambridge, MA, USA: IEEE, Sep. 2023, pp. 1–8. doi: 10.1109/ACII59096.2023.10388190.

[2] J. Yi, W. Haouas, and K. Rabenorosoa, “ModSoftBot: Design, Modeling, and Control of a Modular Pneumatic Serial Soft Robot,” in *2025 International Conference on Manipulation, Automation and Robotics at Small Scales (MARSS)*, West Lafayette, IN, USA: IEEE, Jul. 2025, pp. 1–7. doi: 10.1109/MARSS65887.2025.11072776.

[3] G. De Luca *et al.*, “Soft Robots Proprioception Through Stretchable Laser-Induced Graphene Strain Sensors,” *Advanced Intelligent Systems*, vol. 7, no. 10, p. 2401071, Oct. 2025, doi: 10.1002/aisy.202401071.

[4] P. Abbasi, M. A. Nekoui, M. Zareinejad, P. Abbasi, and Z. Azhang, “Position and Force Control of a Soft Pneumatic Actuator,” *Soft Robotics*, vol. 7, no. 5, pp. 550–563, Oct. 2020, doi: 10.1089/soro.2019.0065.