Towards New Interactions with Robots using Physical Intelligence in Active Soft Surfaces

PhD Thesis Proposal – starting october 2026

ICUBE (Strasbourg, France) & FEMTO-ST (Besançon, France) labs

1. Outline

The proposed PhD work is part of the Organic Robotics (O2R) program, a research initiative aimed at developing new forms of robotics. More specifically, it is proposed within the framework of Project AS1, "Material, Architecture, and Embodied Intelligence", to develop new **solutions by leveraging the softness of materials to create flexible components and robots**, using their softness to implement functions and to build **new relationships between humans and robots.**

This thesis focuses on issues related to the **design, modeling, fabrication, and control of active soft surfaces**. By integrating functionality into the material, the goal is to achieve **physical intelligence that simplifies the creation of human-robot interaction** and then to explore new modes of interaction between humans and robots,

The PhD work will benefit from the expertise and long-term collaboration of FEMTO-ST and ICube, with strong research expertise in **modeling for robotics, soft robotics design and manufacturing, in particular with additive manufacturing technologies, and control for robotics**. The PhD student will be part of a **multidisciplinary research consortium, gathering 8 labs in France** that have unique expertise in robotics, human sciences, art and design.

2. Scientific Context

Physical interaction between humans and robotic systems is becoming increasingly important in many emerging technological fields such as robotic teleoperation, virtual and augmented reality, medical assistance and rehabilitation, and collaborative robotics. Among human sensory modalities, touch plays a fundamental role in interacting with the environment. It can enrich human–machine interfaces primarily that can also be elaborated using visual and auditory feedback.

Existing haptic devices are often rigid, bulky, and restricted to small stimulation areas, limiting their usability, for instance in wearable applications. Recent advances in soft robotics open new opportunities to develop conformable haptic interfaces capable of safely interacting with the human body while providing rich tactile sensations [1]. Also, the creation of soft surfaces to convey information is currently actively considered to create tangible interfaces and embodied information.

Soft pneumatic actuators are particularly promising for creating active surfaces because they offer high mechanical compliance, safe interaction with human skin, large-area integration capability, and relatively simple fabrication using materials such as silicone, textiles, or additive manufacturing techniques. Recent research has for instance demonstrated the possibility of creating wearable pneumatic haptic devices capable of generating tactile stimulations up to 100 Hz and forces around 1 N [2]. Despite these advances, several scientific challenges remain open, including the design of distributed modular haptic surfaces, the generation of complex deformation patterns using a reduced number of control inputs, the integration of soft sensors for bidirectional interaction, and the ability to modulate stiffness to simulate different types of contact [3].

3. Objectives of the PhD

The objective of this PhD thesis is twofold:

i) to develop **active surfaces based on soft components and materials that integrate mechanisms to ease generation of dynamic motions** and patterns of the surfaces, to introduce novel ways to have robot-human interaction. Dynamic modification of shape, texture, and haptic properties is considered a possible channel for interacting with the user. The use of physical intelligence—i.e., integration at the material and component levels—is considered a promising approach for designing such functions.

ii) to exploit the designed surfaces to enhance human-robot interaction in case of **physical contact, by using elaborated active surfaces to detect physical interaction and adapt accordingly to the properties** of a robot, typically with a change of stiffness of joints to modulate the arm behavior. Using a pneumatic network to have actuation and sensing is a promising approach, and here it is considered to modulate the robot's properties, particularly its stiffness, at the joint level of the link level.

4. Work program

The research will be structured accordingly in two main phases. The case study will involve **robotic manipulation** using a robot arm, either in close proximity to a human or in physical contact during **co-manipulation**. The first phase will focus on the development of an active surface exploiting physical intelligence, while the second phase will extend the concept to control arm properties, namely arm stiffness, directly from perceived information with the active surface.

Phase I – Active Surface Based on Physical Intelligence

The first phase aims to develop a **modular, soft active surface** that operates **with a minimal number of pneumatic inputs by exploiting physical intelligence**, also known as morphological computation. Instead of relying on complex electronic control, the system will use physical phenomena such as pressure propagation, pneumatic delays, fluidic resistances, and actuator chamber geometry to generate programmable spatio-temporal deformation patterns [4].

For this phase, design of solutions will benefit from the expertise of FEMTO-ST and ICube, in particular to link design and fabrication processes. Possibilities offered by additive manufacturing of soft components from the microscopic level with Nanoscribe process to macro level with proprietary silicone DIW platform developed at ICube will be favored. Concepts of surfaces will be generated, for example in the form of a **robotic patch, which will be discussed in the framework of AS1 with partners from robotics and design communities**. Two proofs of concept are anticipated: a modular surface generating **visual patterns** to convey information to the user, and a modular surface generating dynamic textures to convey **tactile information** to the user.

Phase II – Modification of arm behavior using the active surface

The second phase of the thesis aims to **transform the surface into an intelligent interactive interface to modify the behavior of a collaborative robotic arm** embedding the active surface. This investigation will be considered focusing on a proof of concept to associate one joint and one active surface. **Three levels of coupling between the active surface and the joint will be considered**: i) the active surface is used as a sensor, ii) The information collected using the active surface is being used to modify the joint stiffness at a hardware level, iii) the active surface is connected at a hardware level with the actuator in the robot joint. The nature of the developed options will depend on the results of phase 1 and will be discussed with partners.

5. Methodology, Challenges and Applications

The thesis will combine **modeling, design, fabrication, and experimental validation**. The modeling activities will include fluidic network models, material models, and pneumatic actuator models. Mechanical design and modular architecture optimization will be conducted to improve the performance and scalability of the proposed designs.

Experimental validation will include mechanical characterization, evaluation of performance, and user perception studies to assess the effectiveness of the interface in delivering tactile feedback.

This research addresses several key scientific challenges including the generation of deformation patterns with minimal actuation inputs, the miniaturization of soft modules, the integration of sensing and actuation within flexible surfaces, and the development of high-resolution distributed interfaces.

The resulting technology could enable new applications in immersive virtual reality, robotic teleoperation with tactile feedback, neurological rehabilitation devices, tactile communication systems, and assistive technologies for visually impaired users.

6. Profile

We are looking for a highly motivated, creative, and ambitious student with strong communication skills in English (both written and spoken). The candidate should be able to work both independently and within a multidisciplinary research team, and demonstrate the ability to quickly acquire knowledge in new scientific and technological domains. Interest for experimental work, fabrication is a necessity.

The ideal candidate should meet the following requirements:

- Master's degree in mechanical engineering, mechatronics, robotics, or a related field, with strong academic results
- Strong background in solid mechanics, soft materials mechanics, 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
- An innovative and entrepreneurial mindset, with curiosity for interdisciplinary research

8 Additional Information

The PhD will be conducted within a collaborative research environment involving the Robotics, Data Science and Healthcare Technologies group at ICube Laboratory and the AS2M Department of the FEMTO-ST Institute. The PhD work will take place in both labs, typically with first 18 months in Strasbourg, and then 18 months in Besançon. The exact arrangement can be discussed with the PhD applicant.

The Robotics, Data Science and Healthcare Technologies group is part of the ICube laboratory and conducts interdisciplinary research at the intersection of robotics, data science, and medical technologies. The group has developed a strong expertise in design for robotics, design for additive manufacturing, design and control of new solutions for additive manufacturing of soft materials. The PhD work will benefit from the facilities of IRIS technological platform, part of ROBOTEX2.0 national infrastructure. The work will take place in IHU Strasbourg, at the center of Strasbourg.

The AS2M Department at the FEMTO-ST Institute offers a dynamic and stimulating research environment in robotics and automation. The RoMoCo team is a growing research group focusing on the design and control of next-generation robotic systems that exploit compliance and morphology as part of their intelligence, enabling robots to adapt to complex environments and tasks.

This joint environment provides strong expertise in robot design, soft robotics, human–robot interaction, and advanced fabrication technologies, offering the PhD candidate access to state-of-the-art facilities and interdisciplinary collaborations.

Application

Interested candidates should send the following documents:

- Curriculum Vitae (CV)
- Cover letter describing motivation and research interests
- Academic transcripts from the last years of study

Applications should be sent to:

- Wissem Haouas – wissem.haouas@femto-st.fr
- Laurent Barbé laurent.barbe@unistra.fr
- Kanty Rabenorosoa – rkanty@femto-st.fr
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References

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