NATIONAL PH.D. PROGRAM IN AUTONOMOUS SYSTEMS

Servo-muscles for human-centric robotics

Ph.D. candidate

Andrea CASTELLANETA

Cycle

XL

Tutors

Prof. Vito Cacucciolo

Dr. Yu Kuwajima

1. Description of the research program

The rise of soft robotics and wearable systems has created a demand for actuators that are flexible, compliant, and versatile, while also being seamlessly integrable into compact devices. Traditional servomotors, commonly used in robotics, are rigid and lack the adaptability needed for soft and wearable applications. This has led to the exploration of artificial muscles, which mimic the function of biological muscles to provide motion in soft robots. Among these, soft fluidic actuators are particularly promising, as they convert energy from pressurized fluids into mechanical movement. These actuators exhibit high power density and can contract like skeletal muscles, making them suitable for applications such as haptic wearables, prosthetics, and exosuits. However, current fluidic systems rely on bulky, rigid pumps and valves, which limit their portability in wearable devices.

The RoboFluid - ERC project aims to address this challenge by replacing the bulky hardware of traditional fluidic systems with solid-state, soft fiber pumps to create lightweight, portable actuation systems. As part of this broader initiative, my research focuses on developing a self-contained module that couples fiber pumps with multifilament Thin McKibben Muscles. The goal is to design a soft actuation system that can be easily controlled, sensed, and interfaced with power electronics. By mimicking the function of servomotors in a soft, modular format, we aim to enhance both performance and integration for untethered soft robotic applications. These servo-muscles, as we refer to them, will combine the flexibility and power of Thin McKibben Muscles with the convenient form factor of fiber pumps to offer precise control and adaptability. A central focus of the project is the development of a compact, high-voltage DC-DC converter that can safely power multiple soft actuators. While current high-voltage converters are small, they lack the necessary safety features for wearable devices. We are rethinking power transmission by working at high voltages but low currents (below 10 mA), ensuring that consistent power (~50 W) is delivered safely. The real innovation lies in redesigning the transformer into a fiber-like form, allowing for seamless integration into the overall system without compromising safety or performance.

To demonstrate the capabilities of this new actuation system, we will develop a prosthetic hand powered by servo-muscles. This proof-of-concept will illustrate the system's ability to deliver both power and precision in a lightweight, portable form, showcasing its potential for real-world applications in untethered robotic devices. In the long term, this research could significantly impact the fields of soft robotics and wearable technology. By addressing challenges in power conversion, actuator design, and feedback control, my work aims to contribute to the creation of safer, more adaptable, and highly integrable robotic systems. Potential applications include personalized healthcare, advanced prosthetics, and other wearable systems, paving the way for a new generation of soft robotic actuators capable of transforming human-machine interaction.

2. Schedule of the research activities

First academic year (planned)

	Description	Period	Activity abroad
Fiber pumps fabrication and initial coupling with fiber actuators	Fabrication of first fiber pumps and evaluation of their performance. Building a setup to test and characterize Thin McKibben Muscles coupled with fiber pumps: single muscle and agonist-antagonist configuration.	6 months	NO
Development of miniaturized electronics for servo-muscles	Working on high-voltage isolated multi-output power delivery. Development of soft sensing strategies for fiber pumps and fiber actuators.	6 months	NO

Second academic year (planned)

	Description	Period	Activity abroad
Multi-component fiber	Design, simulation and testing of multi-component fiber muscles and fiber actuators to	6 months	NO

muscles and fiber actuators	target the performance requirements in terms of force and response time to a given application.		
Prosthetic hand design and testing	Building a prosthetic hand with servo-muscles.	6 months	YES

Third academic year (planned)

	Description	**Period**	**Activity abroad**
Experimental characterization of servo-muscles and prosthetic hand	Characterization of servo-muscles by simple and efficient control and integration in different complex systems, and especially in the prosthetic hand, to ensure modularity and versatility.	6 months	NO
Continuous reliable fabrication	Improving the fabrication pipeline for the servo-muscles to ensure continuous fast and reliable production.	3 months	NO
Thesis	Writing the thesis with the final results.	3 months	NO

3. Training and research activities plan

First academic year (planned)

	Description	**Period**	**Final Exam**	**ECTS**
A. Ph.D. courses	Deep learning (ScuDo)	Feb 2025	Yes	2
	Polymers and biopolymers for sustainable future (UniGE - IIT)	Apr 2025	Yes	4
B. Master's degree courses	Nanomaker (MIT OpenCourseWare)	Jun 2025	No	1
C. Soft skill courses				
D. Participation to seminars	ShanghAI Lectures 2024	Oct 2024	Yes	5
	Advanced Fluid Mechanics 1: Fundamentals (MITx)	Nov 2024	Yes	6
	Advanced Fluid Mechanics 2: The Navier-Stokes Equations for Viscous Flows (MITx)	Dec 2024	Yes	6
	Power Electronics Specialization (CU Boulder)	Nov 2024	Yes	2.5
	Introduction to complexity (SFI)	Nov 2024	Yes	3
	Nonlinear Dynamics: Mathematical & Computational Approaches (SFI)	Jan 2025	Yes	3
	Fundamentals of Material Science (SJTU)	Mar 2025	Yes	5
	DRIM Summer School	Sep 2025		5
E. Participation to international congresses or workshops				
F. Presentation of research products at international congresses or workshops				
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			42.5
G. Individual research activity				11

H. Supervision of students				1
I. Integrative teaching activities				1.5
J. Preparation of manuscripts for conferences or journals				4
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			17.5
	TOTAL OF ECTS			**60**

Second academic year (planned)

	Description	**Period**	**Final Exam**	**ECTS**
A. Ph.D. courses	Scientific Writing (SSSA)	1st Semester	Yes	2
	Fundamental of wearable robotics (SSSA)	1st Semester	Yes	2
	Machine Design: basic principles and applications (SSSA)	2nd Semester	Yes	3
B. Master's degree courses	Electronic bio-sensors (UniBa)	Nov 2025	Yes	3
C. Soft skill courses				
D. Participation to seminars	Modern Robotics: Mechanics, Planning, and Control Specialization (Northwestern)	Nov-25	Yes	12
	Artificial Intelligence for Robotics (Stanford)	Jan-26	Yes	6
E. Participation to international congresses or workshops	IEEE RoboSoft 2026			5
	IEEE ICRA 2026			5
F. Presentation of research products at international congresses or workshops				
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			38
G. Individual research activity				13
H. Supervision of students				2
I. Integrative teaching activities				1
J. Preparation of manuscripts for conferences or journals				6
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			22
	TOTAL OF ECTS			**60**

Third academic year (planned)

	Description	**Period**	**Final Exam**	**ECTS**
A. Ph.D. courses				

B. Master's degree courses				
C. Soft skill courses				
D. Participation to seminars	TBD			3
E. Participation to international congresses or workshops	TBD			5
F. Presentation of research products at international congresses or workshops	TBD			2
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			10
G. Individual research activity				34
H. Supervision of students				2
I. Integrative teaching activities				1.5
J. Preparation of manuscripts for conferences or journals				12.5
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			50
	TOTAL OF ECTS			**60**

4. List of the publications written by the candidate in the triennium

Andrea CASTELLANETA

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Prof. Vito CACUCCIOLO

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Dr. Yu KUWAJIMA

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