NATIONAL PH.D. PROGRAM IN AUTONOMOUS SYSTEMS

Mechanical design of dynamically-excited soft interfaces for smart tuning of contact forces

Ph.D. candidate

ALELIGNE YOHANNES SHIFERAW

Cycle

XL

Tutors

Prof. Antonio Papangelo

Prof. Luciano Afferrante

Dr. Michele Tricarico

1. Description of the research program

This research seeks to develop advanced ways for controlling contact forces on silicone-based polymeric surfaces, which may be valuable for precise manipulation tasks. The study uses mechanical micro-vibrations to enhance dynamic adhesion control and permit rapid transitions between strong adhesion and detachment. The work is a part of the "SURFACE ERC" project, which aims to deploy novel approaches for regulating contact forces using dynamically excited soft interfaces.

The main goal is to establish a comprehensive framework that combines boundary element (BEM) and finite element (FEM) techniques to analyze dynamic interactions between objects and viscoelastic polymer surfaces in various scenarios. The impact of several factors on adhesion and detachment behavior, such as vibration amplitude, frequency, surface microstructure, and material properties, will be investigated through the simulations. Sophisticated viscoelastic material models with time-dependent characteristics will be used to understand how pull-off forces are affected by varying loading and unloading rates and indenter geometries. Vibration characteristics will be tuned through parametric investigation to ensure effective adhesion and detachment.

On the experimental front, high-resolution micro-structured polymeric surfaces will be made utilizing the Nanoscribe Photonic Professional GT2 technology, which can create surface features as tiny as 200 nanometers. Adhesion forces and detachment energy will be measured on these surfaces by applying controlled vibrations using a dynamic test rig. To record changes in force responses and contact areas in real time, high-speed imaging and force sensors will be employed. Surface topography and deformation will be studied using atomic force microscopy (AFM) and scanning electron microscopy (SEM) to get a thorough knowledge of how microstructure influences adhesion under dynamic conditions.

The experimental data will validate the numerical simulations and ensure that the models accurately represent real-world behavior. Statistical approaches and machine learning algorithms will be utilized to assess experimental data, detect trends, and provide control mechanisms for dynamic adhesion in soft surfaces. The model's expected accuracy will be improved by using a recurrent simulation and testing technique.

The ultimate goal of the research is to create intelligent polymeric interfaces that can dynamically alter contact forces in order to enhance soft surface manipulation capabilities. The expected benefits include improved methods for simulating dynamic contact interactions, a deeper understanding of the relationship between adhesion, vibration, and material characteristics, and improved real-world adhesion control systems.

2. Schedule of the research activities

First academic year (planned)

	Description	Period	Activity abroad
Literature Review:	Comprehensive analysis of existing studies on dynamic regulation of contact forces in soft robotics, focusing on van der Waals interactions, viscoelastic behaviors, and surface modulation techniques.	November 2024 - April 2025	NO
Numerical Framework Development	Establishment of a simulation framework using finite element (FEM) and boundary element methods (BEM) to model dynamic interactions between polymeric surfaces and objects under varying conditions.	May 2025 - October 2025	NO

Second academic year (planned)

	Description	Period	Activity abroad
Experimental Setup and Testing	Fabrication of high-resolution microstructured polymeric surfaces using the Nanoscribe Photonic Professional GT2 system. Experimental testing to measure adhesion forces and detachment energies under dynamic excitation.	November 2025 - April 2026	NO
Data Analysis and Model Refinement	Application of statistical tools and machine learning algorithms to analyze experimental data and improve numerical models.	May 2026 - October 2026	YES (6 months - with "Julien Scheibert", CNRS Research Director, STMS/LTDS, Ecole Central Lyon); This is an option to be explored and has not been decided yet.

Third academic year (planned)

	Description	Period	Activity abroad
Integration and Validation:	Refinement of models and experimental methods for practical use in soft robotic systems, focusing on optimizing dynamic adhesion control strategies.	November 2026 - April 2027	YES (6 months – with "Prof. Dr.-Ing. Merten Stender", TU-Berlin) - Collaboration for system dynamics and numerical simulation; This is an option to be explored and has not been decided yet.
Final Testing and Dissemination	Evaluation of model performance in real-world applications, and preparation of final reports and publications for academic dissemination.	May 2027 - October 2027	NO

3. Training and research activities plan

First academic year (planned)

	Description	Period	Final Exam	ECTS
A. Ph.D. courses	Spacecraft Structural Dynamics & Loads: (DRISA)	1st semester	Yes	2
	An Introduction to Nonlinear Solid Mechanics: (online via Webex from Politecnico di Milano**)**	1st semester	No	2
	Contact Mechanics: (DRIME)	2nd semester	Yes	2
	Numerical Approaches to Solid and Applied Mechanics: Boundary Element Methods (BEM): (DRIME)	2nd semester	Yes	2
	Non-linear control	2nd semester	Yes	2
	Simulation systems for Engineering Applications: (DAUSY)	2nd semester	Yes	1
	Gaussian processes for modeling and control of robotics systems: (DAUSY)	1st semester	Yes	2
	Machine learning: (DRIEI)	1st semester	Yes	2
	Optimization Theory: (DRIME)	1st semester	Yes	2
	Linear algebra for control applications (opt): (DAUSY)	1st semester	Yes	2
	Distributed/Decentralized Control and Optimization of Large-Scale Systems (opt): (DAUSY)	1st semester	Yes	2
B. Master's degree courses	One relevant MSc course based on availability and recommendation by the tutors (opt): (MSc-Poliba)	2nd semester	Yes	6
C. Soft skill courses				
D. Participation to seminars	Participation to at least two seminar/workshop according to availability			3
E. Participation to international congresses or workshops				
F. Presentation of research products at international congresses or workshops				
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			20
G. Individual research activity	Literature review			25
H. Supervision of students	Supervision of the students under the guidance of a tutor			3
I. Integrative teaching activities	Integrative didactic activities will be carried out under the guidance of the tutor			6
J. Preparation of manuscripts for conferences or journals	Preparation of a literature review paper for international journals and a contribution for international conferences			6
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			40
	TOTAL OF ECTS			**60**

Second academic year (planned)

	Description	Period	Final Exam	ECTS
A. Ph.D. courses	At least one relevant Poliba ScuDo Course	1st semester	Yes	2
	At least one SIDRA course related to Soft Robotics	1st or 2nd semester	No	2
B. Master's degree courses	Bio tribology and Biomimetics: (MSc-Poliba)	1st semester	Yes	6
	Tribology: (MSc-Poliba)	1st semester	Yes	6
C. Soft skill courses				
D. Participation to seminars	Participation to at least one seminar/workshop according to availability			2
E. Participation to international congresses or workshops				
F. Presentation of research products at international congresses or workshops				
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			18
G. Individual research activity	Research work as mentioned in Second academic year under the supervision of the tutors			20
H. Supervision of students				
I. Integrative teaching activities				
J. Preparation of manuscripts for conferences or journals	Preparation of at least two manuscripts for international conferences and journals			22
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			42
	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	Presentation of the results obtained to the international congress or seminars based on availability			2
E. Participation to international congresses or workshops				
F. Presentation of research products at international				

	congresses or workshops				
		TOTAL OF ECTS FOR TRAINING ACTIVITIES			2
G.	**Individual research activity**	Research work as mentioned in the third academic year under the supervision of the tutors			25
H.	**Supervision of students**	Supervision of bachelor and master students			6
I.	**Integrative teaching activities**	Relevant teaching activities under the supervision of tutor			6
J.	**Preparation of manuscripts for conferences or journals**	Manuscript Preparation for One Journal Paper and Thesis			21
		TOTAL OF ECTS FOR RESEARCH ACTIVITIES			58
		TOTAL OF ECTS			**60**

Aleligne Yohannes Shiferaw

_____

Prof. Antonio Papangelo

_____

Prof. Luciano Afferrante

_____

Dr. Michele Tricarico

_____