Mission pour les Initiatives Transverses et Interdisciplinaires	**80|PRIME 2025** Action *DynaTrop* Proposition de Thèse

IDENTIFICATION

Civilité/NOM/Prénom du porteur ou de la porteuse du projet*		M. ZANCHI Drazen
Section du comité national de la recherche scientifique		28
Etablissement de rattachement (CNRS, Université de Nantes, CEA, etc.)		Université Pris Cité
Code Unité (UMR, UPR, etc.)		UMR7057
Nom du laboratoire et/ou de l'équipe		Laboratoire Matières et Systèmes Complexes (MSC), UMR 7057 du CNRS; équipe Dynamique et Organisation de Matière Molle (DOMM)
Rattachement de l'unité	Institut principal (INSB, INSU, …)	CNRS Physique INP
	Délégation régionale	DR01

Projet

Titre long du projet (150 caractères maximum)	La bionique des plantes thigmotropiques
Acronyme du projet	DynaTrop

Identification des équipes travaillant sur le projet

Etablissement de rattachement (CNRS, Université de Nantes, etc.)	Code Unité (UMR, UPR, etc.)	Nom du laboratoire et/ou de l'équipe	Pour les unités rattachées au CNRS**		Civilité, NOM et Prénom des personnes impliquées
			Institut principal	Délégation régionale	
Université de Paris Cité	UMR7057	MSC/DOMM	INP	DR01	M. ZANCHI Drazen
ENS Lyon	UMR5667	RDP/Mosaic	INSB	DR07	M. DERR Julien

***Bref curriculum vitae* du porteur ou de la porteuse du projet ET du ou de la responsable de l'équipe partenaire principale**

DZ: Head of the DOMM team in the MSC laboratory, 30-year-long experience in theoretical and experimental physics, participation and coordination of transversal/interdisciplinary and international actions in biophysics, soft-matter, chemical engineering, food science and pharmacology, since 2020 joins the MSC lab (group Dynamics and Organisation of Soft Matter) from his former affiliation (ENS Paris) to initiate and develop transversal actions focussed on dynamics and mechanics of living and soft matter systems: plant tendrils and related bioinspired devices (grant IDEX UPC "Dynavine" 2021-2022, Labex SEAM UPC « DynaSnap » 2025), bacterial adhesion (collaboration with University of Split, Erasmus Plus grant), microalgae dynamics in foams and near surfaces (CNRS grant Dynamique Plastisphère).

JD is a physicist working on morphogenesis and self-organisation. He is part of the MOSAIC team in the RDP laboratory of ENS Lyon. He works at the interfaces between physics and biology. He has been working on plant motions and growth for over a decade. He has expertise in fine kinematics (including managing 3D projection effects) and mechanics measurements. JD will benefit from plant dedicated infrastructures at RDP including growth chambers and greenhouses. JD will be mostly involved in the experimental part of the project : Design, set-up, kinematics tracking, mechanics measurement, data processing. He will also be involved in tutoring of the PhD student.

PROJET DE RECHERCHE

Résumé accessible aux non spécialistes (10 lignes maximum)

Climbing plants, such as vines, cucumbers, squash, watermelons, and peas, have rod-like, flexible structures called tendrils that enable them to attach to supports through thigmotropism, adopting helical conformations. Our preliminary results indicate that singular snapping-like events can occur in both bioinspired synthetic helices and living tendrils. This serves as proof of concept for our proposal: transitioning from bioinspired to bionic snapping-prone systems : human-conditioned living systems with specifically designed mechanical properties. We will begin by developing a fundamental understanding of instabilities in elastic rods to determine the conditions under which living plant tendrils reach critical snapping-prone conformations. This knowledge will enable us to create a "tendril motor" : a bionic device without frictional articulation (i.e., no pistons or rotating parts) that leverages thigmotropic differential growth to generate rapid mechanical action through snapping.

Mots-clés

Plant tendrils, Helical rods, Snapping transition, Thigmotropism, Plant robotics

Exposé scientifique du projet

L'état de l'art. Our larger area is the plant growth dynamics and mechanics in the context of bio-inspired, bionic and hybrid systems : vegetal muscles, bionic plants, plant robots [see e.g. Fabian Meder et al 2023]. Therein, biophysics of tendrils is timely topic (Gerbode et al., 2012; Goriely and Neukirch, 2006; Isnard et al., 2009; Isnard and Silk, 2009) which in part motivated renewal of experimental and theoretical interest for twisted elastic rods (Goriely and Neukirch, 2006; Moulton et al., 2020) including soft robotics context (Jones et al., 2021; Lutz-Bueno et al., 2020; Mehling et al., 2006). Snapping occurring in elastic rods and plates (Gomez et al., 2017) has been identified in plants (Forterre, 2013). The snapping events in writhing tendril has also been identified in our experiments (see figure 1).

Les verrous scientifiques et les objectifs mettant particulièrement en évidence le caractère interdisciplinaire, structurant, exploratoire du projet ainsi que la prise de risque associée.
In engineering, any actuator or motor that avoids friction and is sustainable and « green » is a challenge. That is the case for instance of artificial bio-degradable (or bionic) muscles. A tendril-based system has no rotating parts (avoiding friction), the energy is provided by daylight and rain, and, finally, the device is bio-degradable. The **challenge** is invoking snapping in hybrid bionic plant devices, opening the possibility to produce and control rapid generation of force and torque by typically slowly and continuously evolving plant. The **originality** of present project is twofold : 1) we focus on *living tendrils* as a convenient system for experimental and theoretical study of snapping due to their linear structure; 2) the snapping in plant tendrils is to our knowledge new topic. We identified two types of snapping. Both are theoretically described in E. Dilly's thesis work [Dilly 2024]. The first is the writhing transition, a supercritical jump of the tendril from straight to writhed conformation. The second type of snapping, always subcritical, corresponds to the jump of the perversion (connection between helices of opposite chirality) from regular to self-contact conformation. The project is **interdisciplinary,** since the research actions are articulated between non-linear mechanics (mostly MSC) and plant development (mostly RDP). The **structuration** of the collaboration already gives results, attracting attention on national GDR Phyp and international level (Dilly 2024, Dilly 2025). Altogether, presently proposed actions are natural continuation of on-going successful collaborative efforts between the two partners. Nevertheless, exploratory character of our project invokes **risks**. The latter are mostly associated with poorly controlled dynamics of mechanoperception and thigmotropism of living tendrils. This very point will be treated separately, in order not to hamper the progression of the proposed PhD thesis. Experiments on time response of cucumber tendrils to mechanical stimuli are actually in progress in RDP lab, involving one M2 intern.

Les méthodologies à mettre en place.
Snapping in synthetic tendrils. Physics-mechanics interdisciplinary. MSC (mechanics experiments, theory, dissemination, vulgarisation), RDP (3D reconstruction)
Objective is to understand the richness of elastic snapping instabilities in homemade elastomeric helical rods. Setup is shown in fig. 1 [adapted from (Dilly et al., 2023)]: the extension, winding number, axial load and torque are controlled, combined with stereo time-lapse photography. Snapping is triggered when a perversion (handedness reversal) is injected in the helical rod (online video 2), or by changing the load when the perversion is already present (online video 3).
Thigmotropism for snapping. Interdisciplinary biophysics-mechanics-plant physiology. MSC (mechanics experiments, time-lapse, theory, dissemination, vulgarisation), RDP (kinematics experiments: time-lapse, 3D reconstruction), participants: DZ, PhD student, WB, TS, JD, JLD, FB.
After our preliminary results, mechanoperception-triggered (thigmotropism) writhing of plant tendrils is due to (i) short-time (minutes) hydraulic (turgor driven) reversible phenomena (online

video 4) and (ii) slow (days) structural changes linked to irreversible structural growth (online video 1), both inducing differential strain within tendril. In this task we want to identify and understand these two stages, with the aim to trigger the snapping transitions.
Mechanics experiments on living cucumber tendrils will be carried out by the MSC partner using the setup described in figure 1. in which load and torque provoked by tendril will be monitored. Feasibility is proven by preliminary experiments within DynaVine action [Dilly 2024].
2a) Hydraulic thigmotropism: the tendril's dynamical response will be triggered by mechanical stimuli and the subsequent response will be monitored by time-lapse imaging and mechanics measurements.
2b) Structural thigmotropism, long term irreversible tendril coiling in snapping-prone configurations will be studied as described *supra*. Partner RDP will benefit from the plant imager built by ROMI project (See online) in order to track the 3D kinematics of the tendril. The 3D aspect is necessary to follow curvature changes in time and accurately measure the growth field along the tendril (experimental challenge), eg. adapting the CarboTag method. RDP partner will also adapt microscopic probing / light sheet to monitor time evolution of 3D structure (experimental challenge).
From bioinspired to bionic. Interdisciplinary biophysics-mechanics-plant physiology. MSC (mechanics experiments, time-lapse, dissemination, vulgarisation), RDP (kinematics experiments: time-lapse, 3D reconstruction), participants: DZ, TS, WB, JD, JLD, FB, PhD student.
We will apply described methods to living tendrils at two different stages of development. The objective is to provoke, control and quantify the force and work performed by plants upon snapping events using the cucumber and *passiflora* as plant models. Experiments will be done at MSC and RDP. The final aim is to construct a bionic hybrid plant device in which the living tendril is a motor, while the regulation is man-made. Interesting option is to use the synthetic helix for torque regulation (Dilly et al., 2023). The power is created by living tendril (possibly detached from plant and conditioned artificially, as done in preliminary experiments), while the torque is maintained by synthetic part. Along the tendril development the synthetic helix is loaded, and snapping events can trigger, for instance, the modification of water supply, or can be exploited by other means.

Les résultats attendus.
Scientific contribution : numerical simulation for growing, non-uniform, elastic rods with self-contact (theoretical challenge and open source dissemination, see for example our first python package released [PyPerv]), kinematics of 3D structure of the tendril by multi-angle photography and by light-sheet imaging (experimental challenge). *Knowledge production*: perversion-driven snapping of curved rods (fundamental aspect, mechanics), understanding biophysics of 2 phases (hydraulic and structural) of tendril writhing (fundamental, plant mechanics and growth); design of a new bionic device "tendril motor" (mechanical engineering, soft robotics and bionics). Finally, the topic is particularly adapted for dissemination and vulgarisation for its visual and mathematical attractiveness (see teaser) .

La complémentarité des équipes et la contribution des participants.
Proposer : MSC laboratory (UMR 7057 UPC and CNRS)
Participants: Scientific coordinator Dražen Zanchi 60%, Thierry Savy (role = growth field 3D imaging, IR CNRS) 25%, Williams Brett (role = interface and automatization of experimental setup for mechanics experiments, IR CNRS) 30%, PhD student, one Master intern
Since its very beginning back in 2004 Laboratoire Matière et Systèmes Complexes (MSC, 100 permanent scientists and research accompanying staff), as one of its main axis it gathers and continuously develops cutting edge competences in plant morphogenesis, growth, biomechanics at a cellular and macroscopic level.

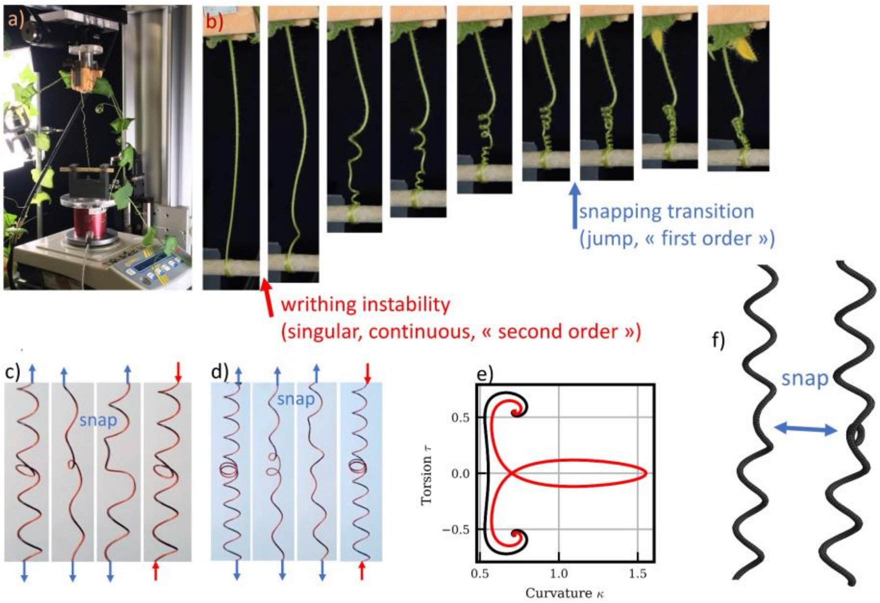
Involvement: coordination of tasks, including organisation of mobilities and semestral meetings (DZ) ; mechanics experiment design and measurements (DZ, TS, WB) PhD and Master intern co-supervision at MSC (DZ) ; theoretical modelling (DZ).

Partner : RDP laboratory at ENS Lyon
At ENS de Lyon, the RDP laboratory conducts mainly fundamental research aiming at a multiscale and quantitative understanding of the development and evolution of plant reproductive structures. Participants: Julien Derr (PI) 50%, Fabrice Besnard (MOSAIC team leader, CR INRAE, role = upgrade the platform to allow timelapse imaging) 5%, Jean-Luc Duteyrat, (AI CNRS, Platim, SFR biosciences, ENS de Lyon, role= light sheet imaging), 10 %, PhD student.
Involvement : RDP will be mostly involved in the experimental part of the project : Design, set-up, kinematics tracking, 3D reconstruction and growth field assessment ; image processing.

Complementarity summarized: MSC partner = mechanics, synthetic and living systems ; RDP partner = imaging and living plants

Le rôle du ou de la doctorant.e
The student is expected to participate in two sets of experiments. The first set will take place at MSC, primarily supervised by DZ on a daily basis and by JD through weekly meetings (mostly via Zoom). These experiments will focus on mechanics, as described above (cf. supra). The second set will be conducted at RDP, with regular supervision by JD and weekly Zoom meetings with DZ. The schedule for these experiments will be organized to minimize unnecessary travel while ensuring efficient progress in the PhD. Details of the experimental work are provided in the project description (cf. infra). The thesis will be equally divided between MSC and RDP (50/50), with DZ and JD contributing equally to its supervision. Twice a year, joint meetings between the MSC and RDP teams will be held alternately in Paris and Lyon. These meetings will provide an opportunity to enhance the PhD’s progress and foster collaboration. In addition to the regular annual thesis committee (CDT) meetings, these gatherings will offer valuable training in oral communication and presentation skills. Furthermore, the student will participate in GDR Phyp meetings and attend at least one international symposium on plant biophysics.This PhD structure will equip the student with the necessary skills and flexibility to work on both the physical (mechanical) and biological aspects of this inherently multidisciplinary topic. The dynamic French plant physics community, particularly around the GDR, will provide an excellent environment for the student to build a strong professional network for the future.

__Figure 1__ a) Experimental setup for studying mechanics of living tendrils or synthetic helices. b) The proof of the concept "Bionic tendril motor": living tendril undergoing a snapping transition during its development upon controlled load. c) Principles of "Tendril motor" in synthetic rods based on snapping transition involving two configurations of the perversion: snapping of a (…,1,1,-1,1,1,…) topological fold in the notation of [Domokos and Healey,2005].



d) Snapping of the fold (…1,1,1,-1,-1,1,1,1,…). e) Calculated heteroclinic trajectories in curvature-torsion space corresponding to open (black) and closed (red) conformations of perversion. Fixed points for left- and right-handed helices have positive and negative torsion respectively. f) Calculated conformations corresponding to these trajectories. Snapping can occur between the two.

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