SORBONNE UNIVERSITÉ

PROGRAMME INSTITUTS ET INITIATIVES

Appel à projet – campagne 2021

Proposition de projet de recherche doctoral (PRD)

IBEES - Initiative Biodiversite Evol Ecolo Société

Intitulé du projet de recherche doctoral (PRD): Modeling of the elephants' trunk: From evolution to soft robotics

Directrice ou directeur de thèse porteuse ou porteur du projet (titulaire d'une HDR) :

NOM : Pouydebat Prénom : Emmanuelle
Titre : Directeur de Recherche ou
e-mail : epouydebat@mnhn.fr
Adresse professionnelle : UMR 7179 MECADEV, 55 rue Buffon, CP55, 75005 PAris
(site, adresse, bât., bureau)

Unité de Recherche :
Intitulé : MECADEV
Code *(ex. UMR xxxx)* : UMR 7179

École Doctorale de rattachement de l'équipe (future école doctorale de la doctorante ou du doctorant) : **ED227-Sciences vie homme : évolution écolog**

Doctorantes et doctorants actuellement encadrés par la directrice ou le directeur de thèse (préciser le nombre de doctorantes ou doctorants, leur année de 1e inscription et la quotité d'encadrement) : Deux étudiantes en 2ème année (Directrice, avec co-direction), une étudiante en 1ère année (Co-direction, CIFRE). Quotité 1.5 en octobre 2021

Co-encadrante ou co-encadrant :

NOM : Cornette Prénom : Raphaël
Titre : Choisissez un élément : ou Docteur HDR ☒
e-mail : cornette@mnhn.fr

Unité de Recherche :
Intitulé : ISYEB
Code *(ex. UMR xxxx)* : 7205

École Doctorale de rattachement : **ED227-Sciences vie homme : évolution écologie**
Ou si ED non Alliance SU :

SORBONNE UNIVERSITÉ

Doctorantes et doctorants actuellement encadrés par la directrice ou le directeur de thèse (préciser le nombre de doctorantes ou doctorants, leur année de 1e inscription et la quotité d'encadrement) : 1 étudiant en 1ère année (Directeur), 1 en 3ème année (Directeur), 2 en 2ème année (Co-directeur). Quotité 1.5 en octobre 2021

Co-encadrante ou co-encadrant :

NOM : Chablat | Prénom : Damien
Titre : Directeur de Recherche ou | HDR ☒
e-mail :

Unité de Recherche :
Intitulé : Laboratoire des sciences du numérique de Nantes
Code *(ex. UMR xxxx)* : 6004

École Doctorale de rattachement : **Choisissez un élément :**
Ou si ED non Alliance SU : 602

Doctorantes et doctorants actuellement encadrés par la directrice ou le directeur de thèse (préciser le nombre de doctorantes ou doctorants, leur année de 1e inscription et la quotité d'encadrement) : Trois étudiants en 3ème année (deux Directeur et un co-directeur), un étudiant en 2ème année (Directeur), deux étudiants en 1er année (Un Directeur et un co-directeur). Quotité 2 en octobre 2021.

Cotutelle internationale : ☒ Non ☐ Oui, précisez Pays et Université :

Selon vous, ce projet est-il susceptible d'intéresser une autre Initiative ou un autre Institut ?
☐ Non ☒ Oui, précisez SCAI - Sorbonne Center of Artificial Intelligence

Description du projet de recherche doctoral ***(en français ou en anglais) :***

Ce texte sera diffusé en ligne : il ne doit pas excéder 3 pages et est écrit en interligne simple.

Détailler le contexte, l'objectif scientifique, la justification de l'approche scientifique ainsi que l'adéquation à l'initiative/l'Institut.

Le cas échéant, préciser le rôle de chaque encadrant ainsi que les compétences scientifiques apportées. Indiquer les publications/productions des encadrants en lien avec le projet.
Préciser le profil d'étudiant(e) recherché.

MODELING OF THE ELEPHANTS' TRUNK: FROM EVOLUTION TO SOFT ROBOTICS

1) State of the art

The manipulation of objects and food is a complex function that has played a major role in the adaptive strategies of the Tetrapods and their survival. Amphibians, marsupials, rodents, carnivores and primates use their more or less developed hand capabilities in relation to their anatomical characteristics and performance. Some species developed very high manipulative capacities without the benefit of fingers! This is the case for many bird species and elephants that use their trunks, or proboscis, in various contexts such as communication, use and manufacture of tools, manipulation of food, etc. Equipped with about 150,000 muscle bundles, precise and powerful at the same time, they are able to handle a peanut and uproot a tree! The trunk performs fundamental functions in the survival of elephants and its diversified evolution remains obscure. How and why did this trunk develop in different ways depending on the species and the population? What is the variability of uses of the trunk according to the environment? How do elephants optimize their movements according to the properties of the grasped or manipulated object?

At the same time, the industry needs new technological solutions to improve the movement of heavy loads in congested environments. To do so, there is a need for new robotic arms that are flexible and robust, capable of lifting heavy loads and moving them with precision to ensure the safety of places and people. The solutions found by elephants to survive the various constraints of their changing environments over the course of evolution are all potential bio-inspired solutions. Understanding the links between tasks (pushing, squeezing, pulling, unscrewing, small or large objects, etc.), contexts (with obstacles, without obstacles, open or congested environment, etc.) and biological solutions (anatomy, functional morphology, kinematics, etc.), will help us to develop robots reproducing the movement of the trunk but also the functioning, when existing robotic trunks only reproduce the movement.

2) Objectives of the project

The objective of the project is to quantify the morpho-functional and biomechanical repertoire of trunk uses of the current elephant species in order to understand 1) the morpho-functional and biomechanical 3D parameters of trunk grip according to the objects properties and the tasks, 2) how the musculoskeletal system of the trunk can produce such precision, strength, elasticity and shock absorption, 3) to design a mechanism capable of reproducing the movement but also the functioning of the trunk to obtain. This PhD project will conduct to better understand elephant evolution and make the prototype operational for moving heavy loads in the presence of obstacles by doing experimentations on the universal effector and manipulator prototype.

3) Methodologies to reach the scientific objectives

To reach evolutionary and robotics objectives, we need to develop several challenging methodologies. The funding CNRS – PRIME 80 (ELEPHANTMAN project) allowed us to acquire a unique expertise on African elephants in captivity as in the wild (Lefeuvre et al. 2020, in prep.; Soppelsa et al., in prep.) and to propose this new innovative idea. We will exploit our interdisciplinary innovative procedure (AI, markerless 3D kinematics & functional morphology, grasping force quantification) and new experimental designs in zoological parks (i.e. Beauval & La Palmyre). It will allow us to quantify these interdisciplinary parameters during several tasks such as: flexing, pulling, contracting, twisting, and screwing/unscrewing, with vertical obstacles to be moved (to see how the elephant can change direction), manipulation with the tip of the trunk in hyper-extension etc. Finally, we need to explore the detailed anatomy of the trunk by a dissection, muscle properties analyses, and an MRI. This step will help us to build a unique musculo-hydrostatic-skeletal model (based on e.g. Hill-type and/or continuum mechanics modelling approaches) that will be used to identify the existing physiological solutions as a model to develop novel soft robotics applications.

4) Innovative, ambitiousness and originality nature of the project

It is the first time that a project explores the behaviour, form and function of the elephants' trunks with an interdisciplinary approach. The objectives are new and highly challenging: evolution of one of the most amazing animals, and bio-inspiration toward soft robotics. The scientific challenge to inspire such new robotic prototype is huge and resides both in understanding and modelling the trunk' complex muscular architecture and its control, as well as in the ability to transfer such biomechanical knowledge into efficient industrial solutions. Several technological bottlenecks will be rise through innovative and complementary methods: 3D geometric morphometrics, markerless 3D motion analyses, trunk dissection, active 3D finite element modelling of the musculo-hydrostatic-skeletal system, trunk-robot including movement and functioning…

From a general point of view, the evolution of elephants remains a mystery (first elephants had no trunk…) and this novel approach will shed new light on this enigma while meeting a major methodological and bio-inspired challenge. Most of the existing flexible arms, supposedly inspired by the trunk, are polyarticulated structures driven by actuated joints or by cables. The only similarity to the elephant trunk is the external morphology, but not well quantified, and not the functioning. Everything remains to be discovered. The measured kinematic and anatomical data can be used to create a musculo-hydrostatic-skeletal model to which the robotic approach will aim to get closer. Thus, by exploring manipulation capabilities in an interdisciplinary manner using multifactorial data analysis methods (multivariate analysis such as PCA, MCA…), we not only propose a unique approach to understanding the adaptive mechanisms associated with this organ and its uses but we also address another challenge: bio-inspiration and novel solution for industrial robotics.

5) Position of the project in regard to the iSiM objectives

Our project is federative and transversal and proposes an interdisciplinary research, bringing together several disciplines in order to give the researchers involved (with different skills) the opportunity to compare their knowledge and experiences. This project also proposes societal issues and involves various keywords and themes from several Sorbonne University institutes:

- Initiatives Biodiversity, Evolution, Ecology, Society (IBEES): this project will allow a better understanding of the adaptation capacities of an emblematic species whose survival is largely threatened today. Our interdisciplinary approach will involve the processing and modeling of our data and will offer a privileged field in the bio-inspiration domain.
- Institut Sciences du Calcul et des Données (ISCD) & Sorbonne Central for Artificial Intelligence (SCAI): this project involves complex data analysis, the use of Artificial Intelligence, algorithmic analyses involved in the robotic bio-inspired part of the project.
- Initiative "Mastering Safe and Sustainable Technological Systems": the ultimate applied goal of this project is to design a flexible robotic arm that ensures the safety of people when moving heavy loads, despite the presence of obstacles. Finally, the scientific community gathered around this project is a definite factor of success.

6) Partners complementarity

Emmanuelle Pouydebat (DR, UMR 7179 CNRS-MNHN) will supervise this PhD project. She has supervised more than 18 interdisciplinary projects, and has obtained more than 1.000.000 euros in total. More than 65 international publications and 60 talks have valorised her work. She is one of the world's leading specialists in the field of animal grasping and handling (ethology, biomechanics) and has been awarded several prizes (i.e. 2019: CNRS Silver Medal and Chevalière de la légion d'honneur). Our project, extremely innovative, is structured around main collaborations essential to its originality, involving people recognized in their respective fields: functional morphology (AI-HDR Raphaël Cornette, Co-supervisor, ISYEB-UMR 7205 CNRS-MNHN), robots-manipulators & bio-inspired robotics (DR Damien Chablat, Co-supervisor, LS2N-UMR6004, Ecole Centrale de Nantes), Musculoskeletal modeling & 3D movement analysis (PR. Laurence Chèze, collaborator, LBMC-UMR T9406, Univ. Lyon 1 & Gustave Eiffel).

Bibliography

Fasquelle, B., Furet, M., Khanna, P., Chablat, D., Chevallereau, C., & Wenger, P. (2020). A bio-inspired 3-DOF light-weight manipulator with tensegrity X-joints. In IEEE ICRA'2020.
Hanot, P., Herrel, A., Guintard, C., & Cornette, R. (2017). Morphological integration in the appendicular skeleton of two domestic taxa: the horse and donkey. Proceedings of the Royal Society B: Biological Sciences, 284(1864), 20171241.
Lefeuvre M., Cornette R., Gouat P., Mulot B., Pouydebat E. (2020). Behavioural variability among captive African elephants in the use of the trunk while feeding. Peer J. 8: e9678.
Moissenet F, Chèze L, Dumas R. (2017). Individual muscle contributions to ground reaction and to joint contact, ligament and bone forces during normal gait. Multibody System Dynamics 40(2):193–211.

Reghem E., Chèze L., Coppens Y., Pouydebat E., (2013). Grasping's kinematic in five primates: Lemur catta, Sapajus xanthosternos, Gorilla gorilla, Pan troglodytes, Homo sapiens. Journal of Human Envolution 65: 303-312.
Sustaita, D, Pouydebat E., Abdala, V., Manzano, A., Herrel A., (2013). Getting a grip on tetrapod grasping: Form, function and evolution. Biological reviews 88(2): 380-405.
Venkateswaran, S., Chablat, D., & Boyer, F. (2019). Numerical and experimental validation of the prototype of a bio-inspired piping inspection robot. Robotics, 8(2), 32.

Profile of the desired candidate

The candidate should have a strong motivation for interdisciplinarity and ideally have experience with morphological and biomechanical analyses. A good theoretical knowledge in evolutionary biology and the field of bio-inspiration related to robotics will be an advantage. Finally, of course, a knowledge of elephants, their evolution and their behaviors is the basis of this project.