Title: Tensegrity and Embodied Intelligence for a flexible, agile robot

Most existing robots are rigid, heavy and dangerous. Ecological issues and the need to interact with humans are increasingly driving the need for robots to be lighter (to save materials and energy) and more compliant so that they can interact with humans in a more collaborative way.

Tensegrity is an interesting approach to achieving this objective. A tensegrity structure is a set of rigid elements subjected to compression and brought into equilibrium via elastic elements in tension. Most biological elements are tensegrity structures [1].
Bio-inspired tensegrity robotic structures are often actuated via cables (which model muscles) whose length and the forces being exerted will vary. This will form the basis of a new equilibrium. This is often how a tensegrity structure is transformed into a tensegrity mechanism or robot. Actuation by cables imposes conditions of unilaterality on the forces that the cables can exert.

A stack of vertebrae can be used to form a tensegrity manipulator robot with interesting mobility. Various examples exist in the literature, inspired by the necks of birds [2,3] or human vertebral columns [4], snakes [5] or fish [6].

Intelligence is often associated with the brain, solving complex problems and learning. There is another form of intelligence: that of the body interacting with the environment, known as embodied intelligence [7]. It is widely exploited in nature and is important in robotics for exploiting the properties of robots' bodies.
In the context of this thesis, various elements can contribute to embodied intelligence, such as the postural balance of bird legs. This balance can be seen as a passive tensegrity system that allows them to sleep upright, see a balance on one leg and resist gusts of wind while balanced on a branch or a wire [8].
Stacked tensegrity structures can filter and dampen vibrations to prevent walking vibrations from being transmitted along a bird's neck to its head [3].
Cable actuation is generally antagonistic, to overcome the limit due to the unilaterality of the forces and draw inspiration from the antagonistic actuation of the muscles. It is known that the co-activation of antagonistic muscles in biological systems increases muscle stiffness. However, this interesting property can only be found in mechanical systems if there is a suitable choice of joint shape and muscle attachment [9].
Systems built by stacking tensegrity systems controlled by a limited number of actuators can become unstable if their control is built on classical model inversion methods, and it is more appropriate to use the natural stabilization of the system to obtain stable control [10]. Learning and predictive control models [11, 12], exploiting body physics [4,5], can cope with the complexity of such systems in order to achieve compliance in action and flexibility in interaction [11].
The general aim of the thesis is to put forward the principles of embodied intelligence and to combine different tensegrity techniques for building an agile robot and for carrying out tasks in safe collaboration with humans in the context of Industry 4.0. The types of tasks considered will be manipulation, wind-up grasping and mechanical actions on the environment (external forces). Bio-inspiration will guide actuation choices: actuation will be adapted according to the

task and during movement, in the same way as muscles are activated in different groups depending on the case.

The objectives of this thesis will therefore focus on the following aspects:
- Robot design, with particular emphasis on the choice of actuation;
- Control of such a system; with predictive learning and generative model
- Interaction with the environment.

The schedule for the thesis is as follows
1st year: familiarisation with and design of a system, studying in particular the effect of the choice of actuator (on base or on cables)
2nd year: implementation and control of the system
3rd year: physical interaction tasks

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The thesis will be carried out in collaboration with LS2N in Nantes and the ETIS laboratory in Cergy. The PhD student will work mainly at LS2N and will be supervised by C. Chevallereau (LS2N), A. Pitti(ETIS) and P. Wenger(LS2N).

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