Climbing Plants, a New Concept for Robotic Grasping

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Abstract. Climbing plants represent an outstanding example of a grasping strategy coming from the plant Kingdom. Tendrils are the filiform organs devoted to the task and are extremely flexible and sensitive to touch. In this preliminary contribution we present some of the observed key features of tendrils. Then a robotic approach is exploited to describe and simulate a bio-inspired robotic tendril from a kinematic point of view.

Keywords: Climbing plants, tendril, robotic grasping.

Over the last several decades the research on robotic manipulators has focused mainly on designs that resemble the human arm. But, if we examine the manipulators available in nature, we will see a plethora of other possibilities. Animals such as snakes, elephants, and octopuses can produce motions from their appendages or bodies that allow the effective manipulation of objects, even though they are quite different in structure compared to the human arm. Several serpentine and continuum robots have already been designed and developed, taking inspiration from animals world: some examples are elephant trunks, octopus and squid tentacles, snakes and caterpillars.

Moving from the animal to the vegetal world, we can also find some examples of grasping structures that have been overlooked so far. Climbing plants are capable to grasp and climb the surrounding environment with the goal to achieve maximum sun exposure while avoiding the energy expenditure of developing a supporting trunk [1]. The dedicated climbing organs are called tendrils and their strategy represents an evolutionary success. In fact, it allows them to succeed with the ability to ascend over would-be competitors at the cost of relatively small energetic investment.

Plants lack of a nervous system, and the exploration of the environment and the execution of mechanical actions rely efficiently on simple reflex-like behaviours [3]. Tendrils are highly touch-sensitive, and after the mechanical stimulus has been perceived by epidermal cells, plant hormones serve as mediators of the coiling response [2]. Using this basic sensory-motoric loop without centralized sensing and control, plants can blindly rely on organs that will eventually find and coil around supports, providing a successful grasping method.

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In the present contribution we studied the basic rules that govern the tendrils of *Passiflora spp.* (Passion vine, Figure 1.a). In particular we addressed a set of experiments to understand the three different stages of the grasping: (i) the circumnutation is important to find the support; (ii) the contact coiling to grasp it; and (iii) the free-coiling to secure the hold and get closer to the support. For our biomimetic purposes the latter two are of major interest and to our knowledge, no biomimetic results or attempts to reproduce them can be found in literature. *Passiflora* tendrils are able to recognize supports and obstacles on the overall surface bending in different directions; the capability to produce multiple coils allows the plant to work as a winch. Thanks to the multiple coils, in fact, the tendril apex experiences a small and negligible tension, that increases from the apex to the inner touching point. Furthermore, the increased touching surface avoids the slippage due to the related increased friction. The signal transmission is yet not well known even if experimental observations show a sort of modular behavior. This means that the zone that senses a support induces a contraction phase to the near fibers; after that, if the contact increases, i.e. the touched nearest zones sense a contact, the bending signal is transmitted creating the overall tendril motion and grasping. Thanks to this, a distributed reflex control is made, allowing the activation of the motion locally and only when necessary. This is surely an advantage from an energetic point of view since the modules sleep in a normal phase and are activated only when necessary. Moreover, if the free-coiling phase is considered, other important features can be highlighted. The free-coiling phase allows to pull the stem towards the grasped support, by creating a zero-torsion helical spring. Indeed, by coming back to the original-intrinsic helical shape, the tendril shortens the distance between the fixed end-points. Finally, the helical-spring shape is perfectly tuned to resist to external loads and disturbances. Thus, all these desirable characteristics induced us to evaluate and investigate how to mimic the plant tendril system structure.

Here we propose a preliminary bio-robotic tendril that encapsules the sensing and actuating ability of colimbing plants. The overall structure has been considered from a kinematic point of view. The model is conceptualized and simplified dividing the tendril in two main parts (Figure 1.b): the first part (FC) mainly devoted to the free-coiling and pulling phase, which can be viewed as a single actuator that changes its shape from a linear wire to a helical spring; and the second part (GC) devoted to the coiling and grasping phase and considered as subdivided in n-sections. Kinematics of GC involves two main steps: first, the GC tendril kinematics problem is approached by means of a series of substitutions applied to a modifed homogeneous transformation based on the Denavit-Hartenberg (DH) notation; second, velocity kinematics could be solved by computing the Jacobian using standard techniques and then by chaining together the Jacobians (Figure 1.c). In order to simulate the kinematics of a bio-inspired tendril, the exploited formulas have been implemented in a Matlab simulator. The contact has been implemented by searching for each module if there is intersection between the segment that connects the two

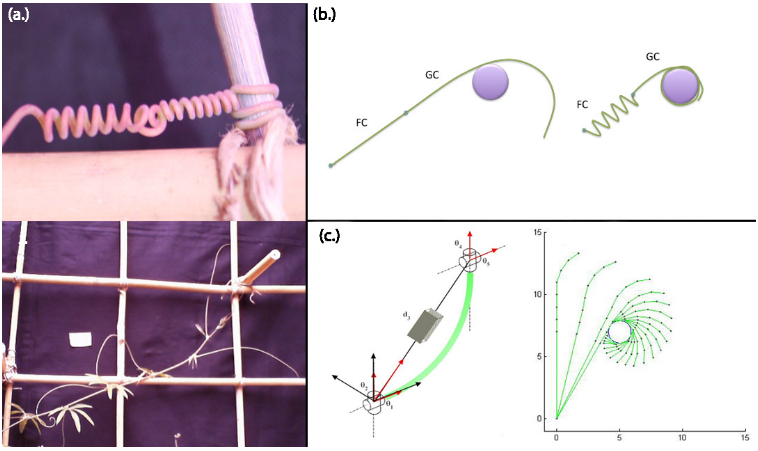

Fig. 1. The morphology of a tendril and its conceptualization. (a) A *Passiflora* tendril grasped to a support; (b-c) GC and FC modules; (d) a *Passiflora* plant; (e) equivalence wire - robot; (f) Kinematics of grasping.

universal/revolute joints. The FC behavior has been implemented as a pulling motion driven by the prismatic joint.

The sensory and actuation system may be less dynamic than our human senses and muscles but still have the advantage of greater autonomy. Although no work to mimic specifically climbing plants via coiling has been found within bio-inspired robotic literature. Some interesting results have been obtained in [4], where an hyperredundant serpentine robot able of pole climbing have been developed. Tactile sensing and new decentralized control law are indeed the main innovative points of this preliminary study. The possibility of relying on neuromorphic devices able to process information locally and at the same time actuate the single unit for producing a global coiling behaviour would be a desiderable feature that could advance the tecnology of grasping.

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