Artificial motion by growth: how plants can inspire a new generation of robots

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Although plants lack muscles, they generate many different kinds of movement in a timescale spanning from days to milliseconds (Forterre, 2013). Moreover, plants have the capability to respond to a wide range of signals. In fact, being sessile, one way plants adapt to the changing environmental conditions (e.g. light, gravity, water and chemicals) is in responding to external stimuli through a differential growth of particular organs. The driving force of these movements mainly results from water absorption and release, as well as from an inhomogeneous structure - including differences in the tissue density and the cellulose fibre arrangements (Fratzl and Barth, 2009) - which leads to different volume or shape change. Hence, even though plants mobility is different from animals, it is being more and more acknowledged that an increased understanding of how they move in response to different inputs from the environment, will contribute to developments in applied sciences and engineering, particularly towards novel biomimetic actuation and sensing devices (Burgert and Fratzl, 2009).

Considering the plant from a system point of view, there are a number of aspects being studied by our research group, with the aim of obtaining artificial motion by growing mechanisms towards a new generation of robots (Mazzolai et al., 2014). Several basic characteristics are being considered, specifically in plant roots, such as: the capacity of directional growth and exploration in response to external stimuli (i.e. tropisms) with high plasticity and morphological adaptation to the environment; the growth from the root tip by adding cells and lateral hairs production (which reduces friction/pressure needed to penetrate the soil); the osmotic actuation principle (used for plant cells elongation and omnidirectional steering); the sensory capabilities to a wide amount of different physical and chemical quantities; the efficient use of energy resources; the capability to penetrate and anchor the soil; and, the emergent behaviour given by coordination of the whole organism towards optimal targets. Our multidisciplinary research effort is focusing on developing robotic solutions that are called “PLANTOIDs”, which are robotic systems equipped with distributed sensing, actuation, and intelligence to perform soil exploration and monitoring tasks. We aim at taking advantage of strategies to penetrate and explore soil as well as maintaining good performance in terms of energy efficiency.

Figure 1. The PLANTOID robot implements two types of bioinspired artificial roots: one root (right) achieves soft bending and integrates soft tactile sensors at its tip (in addition to humidity, gravity and temperature sensors); a second root (left) embodies the artificial growing concept. The branches are connected to soft bending leaves actuated by means of conducting polymers (Taccola et al., 2013).
In our research, an important aspect of growth that was tackled regards the sloughing of cells from the tip, and a simple but effective artificial method was implemented (Sadeghi et al., 2013). It is based on a tubular shaft and a soft continuum skin, which is kept inside the shaft and slips out, sliding on its external body. This outward skin movement opens the soil in front of the tip and helps the system to penetrate. The interaction between the external skin and soil gives to the system self-anchorage capabilities, which are increased by adding artificial hairs. The robotic system was able to penetrate a granular substrate using the movement of the soft skin without adding any external force, and increasing the hair density the efficiency of the penetration increased to approximately 30%. Also, the axial penetration force decreased owing to the skin movement. Focusing on the root-growth approach at the apical region, it was verified that an “elongation from the tip” strategy (Tonazzini et al., 2013) allows a reduced energy for penetration (about 30%), as compared to inserting the entire artificial root body in artificial soil. Hence, a system that grows at the apical area by the addition of new material was recently developed (Sadeghi et al., 2014) which represents a totally new approach in robotics, embodying artificial growth. The growing capability at the tip is achieved by means of an additive manufacturing technique, which creates what is called a ‘mature zone’.

In parallel to the above developments, we will show how soft tactile sensing is an important building block of a sensitive artificial apex. When a plant root penetrates into the soil, it is subjected to mechanical stimulations, and when it comes into contact with obstacles which impair its growth, it adopts efficient strategies to circumnavigate them and to direct its growth towards low impedance pathways (Monshausen and Gilroy, 2009). The apex is the first part of an artificial root that comes into contact with barriers during the growth; therefore, it must be able to experience and sense changes in soil mechanical impedance. We addressed this by developing a soft tactile sensor and integrating it in an artificial tip. Results show that the sensorized tip is able to discriminate between mechanical impedance differences in both artificial and real soil (Lucarotti et al., 2014). The soft robotics approach that was undertaken led to a sensitive yet robust touch sensitive apex. From these initial achievements the basic principles learned from the natural root behavior will be validated. In future work, by integrating the developed solutions and by adding flexibility, the system will be designed to change the direction and navigate around the obstacles.

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References