Embodied Behavior of Plant Roots in Obstacle Avoidance

Liyana Popova[1,2], Alice Tonazzini[1,2], Andrea Russino[2],
Alì Sadeghi[1], and Barbara Mazzolai[1]

[1] Center for Micro-BioRobotics@SSSA, Istituto Italiano di Tecnologia (IIT),
V. Piaggio 34, 56025 Pontedera, Italy
[2] The BioRobotics Institute, Scuola Superiore Sant'Anna, V. Piaggio 34, 56025 Pontedera, Italy
a.russino@sssup.it, {liyana.popova,ali.sadeghi,alice.tonazzini,
barbara.mazzolai}@iit.it

Abstract. Plant roots are a new paradigm for soft robotics. Study of embodied behavior in roots may lead to the implementation of movements guided by structural deformations and to the use of sensors and actuators as body parts. In this work the obstacle avoidance in roots and its interplay with the gravitropism were studied both from biological and robotic viewpoint. Living roots resulted to achieve the maximum pushing force on an obstacle before starting circumnavigation (30 mN in 100 min), thus indicating the existence of a triggering threshold. Tip-to-obstacle angle (20°) was not influenced by the gravity. A robotic mockup capable to bend like living roots was build on the basis of current knowledge and our results on obstacle avoidance behavior. Exploitation of morphological features and passive body deformation resulted to be useful for implementing a simplified control of the robot during gravitropism and obstacle avoidance.

Keywords: robotic root, plant root embodied behavior.

1 Embodied Behavior in Roots and Its Implementation in Robot

Plants are often seen as passive organisms. Actually they are able to move, perceive the environment, and respond to it. In particular, the apical region (RA) of plant roots moves by growing and has a rich sensing system which enables complex tropic behaviors without any control unit. For these reasons the plant root can be a biological model for the development of new generation of soft robots [1]. One of the most important features to be implemented into an exploratory robot is an obstacle avoidance behavior, similarly to that observed in the biological counterpart.

Roots are able to follow the gravity (gravitropism) and to react to touch stimulations (thigmotropism). Integration of these sensing capabilities allows roots to find low impendence pathways in the soil, circumnavigate obstacles, and grow downward for anchoring and finding water. Gravity perception mainly occurs in the root cap (RC) by sedimentation of statoliths inside cells [2]. This stimulus is also partially enabled by stress sensing on cell walls in the body of root apex (RA), due to the weight of the cytoplasm inside cells and to the weight of RA [2]. RA has two

N.F. Lepora et al. (Eds.): Living Machines 2013, LNAI 8064, pp. 431–433, 2013.

bending regions (BRs) which allow achieving an S-shape configuration during obstacle avoidance [2]. When the root approaches the obstacle, RA buckling activates the first bending response. Then tip bending occurs during root growth parallel to the barrier, thus allowing the RC to be continually in contact with obstacle and explore it. During this phase RC orientation is the result of interplay between gravity and touch perception.

Some experiments with the primary maize roots were performed in order to better understand obstacle avoidance by evaluating: (i) forces that root applies to the obstacle (the setup is described in Fig. 1a) (ii) the root tip orientation with respect to the obstacle during its circumnavigation (the setup is detailed in [3]). Roots resulted to reach the maximum pushing force (approximately 30 mN after 100 min contacting the obstacle) before starting the circumnavigation (Fig. 1b). This suggests the existence of a threshold, which may be dependent on the root mechanical properties related to buckling (e.g., root diameter and length). We found that tip-to-obstacle angle stabilizes on approximately 20° after 1.5 h for differently oriented obstacles (Fig. 1c). The results are coherent with the work of [2] and suggest that the touch is a driving-stimulus for tip orientation in this case.

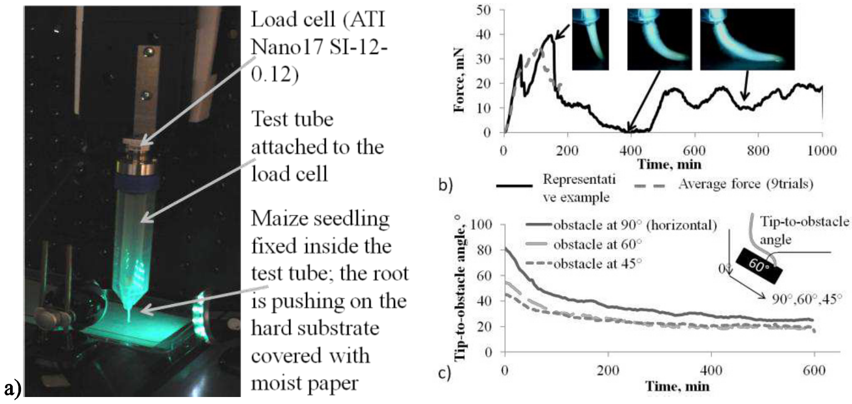

Fig. 1. a) Experimental setup to measure the root pushing force during obstacle circumnavigation. b) Representative example and average of root pushing (9 trials) forces. c) Tip-to-obstacle angle with respect to three obstacle orientations (9 trials). (For methods and setup see [3]).

The mechano-gravity response shows to have different elements of embodiment: (i) sensing and actuation performed by the same part of body; (ii) structural passive deformation, such as buckling, that drives the bending; (iii) touch-gravity interplay in the root cap without any control unit. Implementation of these aspects into the robotic root may decrease the complexity of control of its soft body. A robotic mockup without any control unit was build to observe root embodied behaviors in a mechanical system. It is able to implement the shape of root obstacle avoidance and its interplay with gravitropism (Fig. 2). It has two BRs which can bend separately. When the mockup is positioned horizontally, both BRs actively bend downward due to gravity sensing (distal BR) and body deformation (proximal BR). When the mockup is pushed vertically towards the obstacle (the pushing action resembles root elongation), it assumes the S-shape configuration. First, the proximal BR curves due to its buckling and, then, the distal BR bends by following the gravity. When the pushing force becomes high enough to activate the touch sense at the tip, the tip stops bending and maintains its configuration.

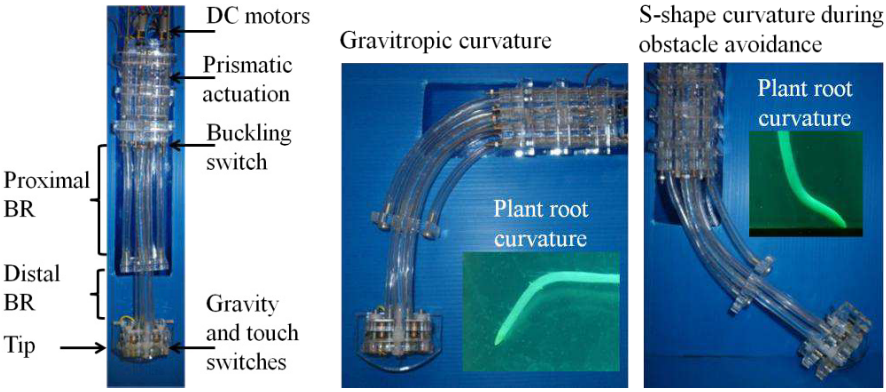

Fig. 2. Mockup consists of two soft bending regions (BR). Each BR consists of nut-screw prismatic mechanism with sliding part made by soft tube to enable the bending during prismatic movement. Bending is performed by differential elongation similarly to the plant roots. Sensing capability of system is provided by three mechanical switches. Buckling switch is activated by the buckling of proximal BR. Gravity switch situated in the tip is activated by floating connector that moves under its weight. A touch switch situated in the tip is activated by root pushing force. It disables the gravity sensing and activates an opposite bending.

Morphology and passive body deformation are the keys for improving mechanical design and simplifying the control of the robotic root. Complex S-shape was obtained in a control-less mechanical soft system by exploiting the embodied behavior of plant roots. This configuration allows the robotic root to explore while passing the obstacle. Next step will be to implement sensors and actuators which are parts of robot body (e.g., smart textiles, electro active polymers) to better exploit the movement activation by the structural deformation by touching and buckling.

Acknowledgments. This work was supported by the FET Programme within the 7th FP for Research of the European Commission, under the PLANTOID project FET-Open n. 293431.

References

1. Mazzolai, B., Mondini, A., Corradi, P., Laschi, C., Mattoli, V., Sinibaldi, E., Dario, P.: A Miniaturized Mechatronic System Inspired by Plant Roots. IEEE Transaction on Mechatronics 16(2), 201–212 (2011)
2. Gilroy, S., Masson, P.H.: Plant tropisms. Blackwell Publishing Ltd., Oxford (2008)
3. Russino, A., Ascrizzi, A., Popova, L., Tonazzini, A., Mancuso, S., Mazzolai, B.: A Novel Tracking Tool for Analysis of Plant Root Tip Movements. Bioinspiration and Biomimetics (accepted)