Shaping the body to shape the behavior: a more active role of the morphology in the brain-body trade-off

Francesco Corucci[1], Marcello Calisti[1], Helmut Hauser[2] and Cecilia Laschi[1]

[1]The BioRobotics Institute, Scuola Superiore Sant'Anna, Pisa, Italy
[2]Department of Engineering Mathematics, University of Bristol, Bristol, United Kingdom
Contact: f.corucci@sssup.it

Abstract

In recent years the concepts of embodiment and morphological computation brought an important paradigm shift in a number of research fields such as robotics, artificial intelligence, and artificial life. One of the most remarkable implications of these theoretical frameworks is the idea that the body has indeed an active role in the emergence of intelligent and adaptive behavior. It has been shown that in many cases it is possible to achieve complex behaviors with no "brain" at all (i.e. with no control – as in the case of passive dynamic walkers, or with a simple, periodic, open-loop control – as in the case of many walking and running robots). This view opens a number of intriguing questions, like: to what extent can we outsource intelligence to the body? What kind of behaviors can we achieve without introducing control? These questions fall under what is sometimes called the *brain-body trade-off*. With this abstract we aim at contributing to such a discussion by presenting some recent results of our work from an original perspective. The ultimate goal is to show that the body can have a more active role in achieving diverse behaviors. To stress this concept, we operate at one of the extremes of the brain-body continuum in which the role of the brain (or controller) is close to zero, i.e. the one of self-stabilizing robots with periodic open-loop control. There are many examples of such robots in robotics research, characterized by some common features. First, those robots have a morphology that is typically carefully engineered by human experts, often following heuristic design criteria and trial and error tests. This appears to be limiting if we consider the complexity of a robot's design space and the fact that such approaches are not able to explore many possibilities with respect to morphology and behavior. Second, although facilitating control, morphology usually has a *passive* role: once the design is fabricated morphology stays unchanged over the life span of the robot, and often operates in one or few, fixed, working regimes (or *attractors*, in a dynamical systems' view). Third, their behavioral diversity is usually limited, and where it is not the case, it is achieved by varying the controller, not by exploiting the morphology. Here we propose a systematic procedure that allows to design self-stabilizing robots exploiting the full potential of the morphology to achieve a diversity of behaviors. The key idea is to actively and dynamically involve the morphology in producing diverse behavior, resorting to the concept of *morphosis* or *morphing*, i.e. the possibility for a robot to control/experience a morphological change during its life span. The idea is to allow the robot to *change its shape to change its behavior*, in presence of a fixed controller: a walking robot may morph to switch to a running gait, while an arm performing a limit cycle movement (e.g. exploration behavior) may morph to perform a reaching or a grasping movement. Given a basic morphological structure, an evolutionary process maximizing a metric of *behavioral novelty* is first ran to explore the space of morphology-enabled behaviors. This process allows to simulate a very large space of robot configurations without the restriction and the biases of the common trial and error, heuristic design procedures. Then an automated clustering procedure is executed to group the results of the evolutionary process into subsets of similar morphologies. Inside these clusters we search for functional robot configurations that are close in the morphology space, but far apart in the behavior space. Those configurations are selected as candidate morphologies to apply morphing, implemented as a gradual transition from one morphology to another: this way a slight morphological change can result in a macroscopic change in the behavior. In what follows some details regarding the procedure and the achieved results are provided. It is worth noting that there are considerable differences among this study and others in which novelty-based search is adopted to evolve morphologies (the closest one being Lehman and Stanley (2011b), where the focus is on combining the pressure towards novelty with the one towards performances). In addition to differences in the goals and in the applied methodology, the most notable, general, difference is that these works do not consider morphing, being instead the core of this work. For further details the interested reader is encouraged to refer to Corucci et al. (2015).

Case Study

The case study is the locomotion of the PoseiDRONE robot, an octopus-inspired soft-bodied underwater robot (Fig.1a). The robot is composed of a central body, a floating module, and four compliant limbs. Each leg is actuated by a dedicated motor, whose control signal consists of a constant open-loop rotation. PoseiDRONE is an interesting case study for a number of reasons. First, it operates in water, where the body-environment dynamic coupling is stronger than in a terrestrial setting. In this setting a slight morphological change can result in a dramatic change in the behavior, which is desirable in order to experiment with morphing. Second, the robot morphology is simple enough to envisage a reconfiguration mechanism informed by the present results in future work.

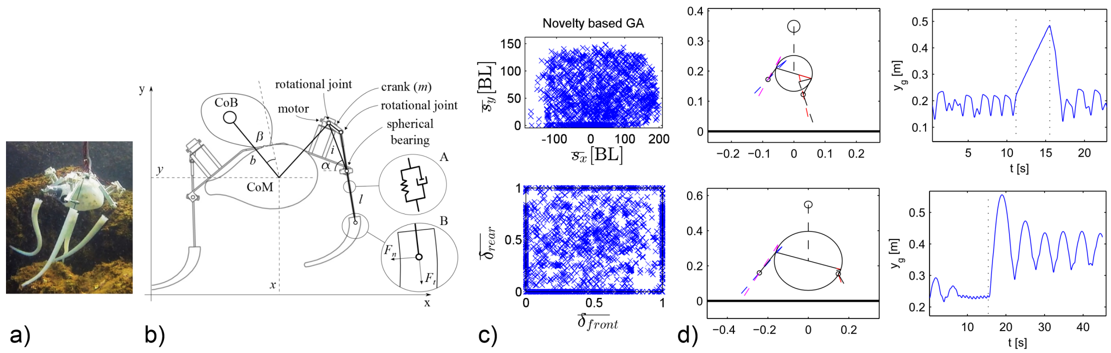

Figure 1: The PoseiDrone robot (a) and a schematic view of its model (b) (CoB stands for Center of Buoyancy, CoM stands for Center of Mass). c) Behavior space exploration: each cross represents the behavior of an individual of the final population. d) Example of two morphing robots selected by our procedure. Solid lines represent the CoM trajectory, while dashed ones identify morphing events. In the top row, the β parameter is morphed at $t = 11s$, entailing a transition from hopping to swimming. At $t = 15s$ β is brought back to its original value: the robot returns to its original gait. In the bottom row, the ratio between two geometrical parameters (m and i) is changed at $t = 15s$, entailing a transition from walking to hopping.

Methods

A dynamical model of the robot is adopted for this study (Fig.1b): the interested reader may refer to Calisti et al. (2014)). The model embeds a number of parameters, such as the one defining the geometry of the mechanism driving each leg, the dynamical properties of the legs (stiffness, damping, friction), the mean density of the robot, etc. A novelty-based evolutionary process appeared particularly suited to explore the space of morphology-enabled behaviors of the robot: the *novelty search* algorithm (Lehman and Stanley (2011a)) was thus adopted for this study, in combination with genetic algorithms (GAs). The algorithm is used to maximize novelty in a space of locomotion-specific behavioral features defined as $(\overline{s_x}, \overline{s_y}, \overline{\delta_{front}}, \overline{\delta_{rear}}) \in \Re^4$, where $\overline{s_x}$ and $\overline{s_y}$ are, respectively, the normalized space traveled in the horizontal and vertical directions, and $\overline{\delta_{front}}$ and $\overline{\delta_{rear}}$ are the mean duty factors of front and rear legs (i.e. the percentage of time legs stay in contact with the ground). Model parameters are directly encoded into the genome. A methodology is then implemented to search inside the results of the evolutionary run (i.e. in the final population). Hierarchical clustering is applied in the morphology space to group similar morphologies. Then, inside each cluster, a search procedure is performed in order to find similar morphologies that maximally differ in terms of behavior (i.e. that are far apart in the behavior space defined by the features). Those morphologies are candidates for morphing, that is implemented as a feed-forward, gradual transformation from one morphology to another. The behavior of the robot is completely self-stabilizing, also during morphing.

Results and Conclusions

Results highlight that a novelty-based approach is indeed suitable to explore the space of morphology-enabled behaviors of a robot, producing a heterogeneous final population of functional robots in which it is possible to search for candidate morphologies for morphing (Fig.1c). Two morphing robots selected by our search procedure are presented (Fig.1d), in which a macroscopic change in the behavior is observable as a result of a slight morphological modification applied to just *one* parameter.

In this work we have pointed out that it is indeed possible to systematically exploit morphology to improve the behavioral diversity of a robot through morphing, leaving the control unchanged. The way this is done exploits the natural dynamics of the body and its self-stabilizing properties, in presence of a fixed control signal. In a dynamical systems view, instead of having the brain guiding the body towards different attractors, the body itself gains the freedom to shape the attractor landscape to change behavior. This entails a more active role of morphology, opening several intriguing possibilities for future research on embodiment, morphological computation, and adaptive behavior.

References

Calisti, M., Corucci, F., Arienti, A., and Laschi, C. (2014). Bipedal walking of an octopus-inspired robot. In *Biomimetic and Biohybrid Systems*, pages 35–46. Springer.

Corucci, F., Calisti, M., Hauser, H., and Laschi, C. (2015). Novelty-based evolutionary design of morphing underwater robots. In *Proceedings of the 2015 conference on Genetic and Evolutionary Computation (to appear)*. ACM.

Lehman, J. and Stanley, K. O. (2011a). Abandoning objectives: Evolution through the search for novelty alone. *Evolutionary Computation*, 19(2):189–223.

Lehman, J. and Stanley, K. O. (2011b). Evolving a diversity of virtual creatures through novelty search and local competition. In *Proceedings of the 13th annual conference on Genetic and Evolutionary Computation*, pages 211–218. ACM.