Artificial Bivalves – The Biomimetics of Underwater Burrowing

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Abstract

Biomimetics is a fruitful combination of biology and engineering, leading not only to technological innovations but also new insights into biological questions. In this ongoing project, embodied artificial intelligence (embodied AI), artificial evolution and palaeontology are combined to investigate the functional morphology of bivalves. This cross-fertilization allows to expand biomimetics from current biological systems to the whole evolutionary history and to apply the synthetic approach common in embodied AI as a method to tackle open palaeontological questions. So far, a robotic platform has been built to mimic the burrowing technique applied by bivalves. First results show interesting insights into underwater burrowing. We plan to build a more complex version of the system and to perform evolutionary robotics experiments.

Keywords: Biomimetics; Bionics; artificial evolution; palaeontology; bivalves; burrowing; functional morphology

1. Introduction

Bionics is recognized as a key discipline for the future. Since biomimetics involves the combination of two disciplines, biology and engineering, there may be an information flow in both directions. The predominant path is to draw inspiration from nature to solve technical problems, but adopting an engineering (synthetic) approach can also contribute to biological knowledge. In our project, we work in a disciplinary and methodical matrix of embodied AI, (evolutionary) robotics, artificial and natural evolution, functional and theoretical morphology and sedimentology.

The bivalve burrowing process is complex partly because of the physical properties of sandy sediment. But morphology and motion can be modelled using only a few parameters, such that they lend themselves well to artificial evolution experiments. Verification is supported by a rich fossil record that documents the evolution of bivalve shell morphology.

The goal of this project is to build increasingly complex models of the burrowing process to investigate (a) correlations in morphology, motion and environment and (b) the evolution of bivalve functional morphology.

2. Background

The main components used for burrowing are the overall shell shape, the surface structure (sculpture) and the foot (a tongue-like extension of the soft body). Fig. 2 explains the burrowing process in natural bivalves. Several correlations...
between shell morphology, burrowing motion and sediment have been reported. For instance, discordant or concentric ridges together with the typical rocking motion may cause a downward force similar to that of a screw turned by a screw-driver [1].

Parameter spaces of mathematical models of morphology (morphospaces, [3]) help to artificially rebuild valves of recent and extinct bivalve specimens but also enable us to explore shapes that have never existed in nature.

In embodied AI, morphology is seen as crucial to producing behaviour. Using a synthetic (“learning by doing”) approach, robots are used to test hypotheses of how behaviour emerges. Evolutionary robotics performs artificial evolution not only in simulation but with real robots, because simulations often do not capture all relevant aspects of reality – like in the case of a granular sediment.

There have been many burrowing robots, based on different principles. Recently, a digging robot inspired by bivalves was built at MIT [4].
3. Setup and Preliminary Results

Mathematical models [5] are used to generate bivalve shells in the computer. By changing the parameters either by hand or using evolutionary algorithms it is possible to explore existing and artificial bivalve shapes. Generated morphologies can be used in simulations or turned into real objects using a 3D printer (see Fig. 1).

The printed shell models are used in an experimental setup (Fig. 3) to mimic the burrowing process. Parameters controlling the timing may again be subject to evolutionary algorithms. Preliminary results collected so far suggest that interesting effects on the burrowing efficiency occur and can be investigated, such as the influence of water expulsion (Fig. 2) or a depth-dependent performance of different shapes (Fig. 3).

4. Conclusion

In this biomimetic project, we propose a robotic setup for simulating the burrowing behaviour of bivalves. We are currently performing more experiments using the existing platform and developing a more sophisticated apparatus more closely mimicking natural bivalves. It will feature a mechanism to open and close the valves and an artificial soft foot to make the bivalve mechanically autonomous. Evolutionary experiments adapting morphology and motion for efficient burrowing will be performed with both setups.

By analysing bivalve burrowing, efficient solutions for underwater burrowing may be found. A possible application would be automatic anchoring devices for man-made structures. On the other hand, palaeontological research may profit from a synthetic approach bringing fossil species to life by a robotic device. It is also worth using the platform to further investigate promising ideas such as evolutionary robotics, the co-evolution of morphology and control and the expansion of biomimetics from today’s nature to the entire evolutionary history.

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1 Figs. 1–3 (left) first published in A. Koller-Hodac, D. P. Germann, A. Gilgen, K. Dietrich, M. Hadorn, W. Schatz and P. Eggenberger Hotz, Actuated Bivalve Robot – Study of the Burrowing Locomotion in Sediment, Proceedings of 2010 IEEE International Conference on Robotics and Automation (ICRA), 2010. © 2010 IEEE.
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