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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.

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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

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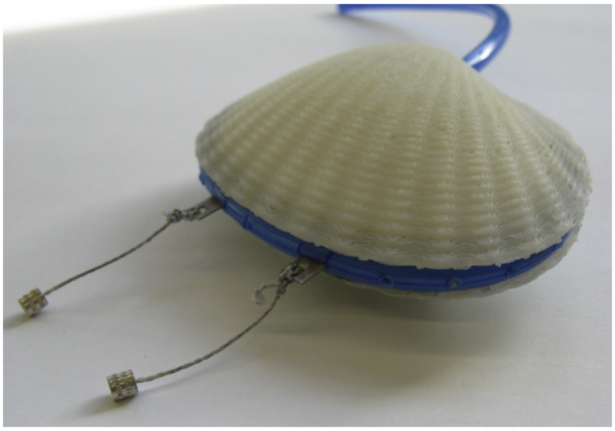

Fig. 1. An artificial bivalve shell, generated with a mathematical model and realized by a 3D printer. The model controls the overall shell shape and surface structure (sculpture). A perforated tube along the edge is used to simulate water expulsion (Fig. 2).[1].

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].

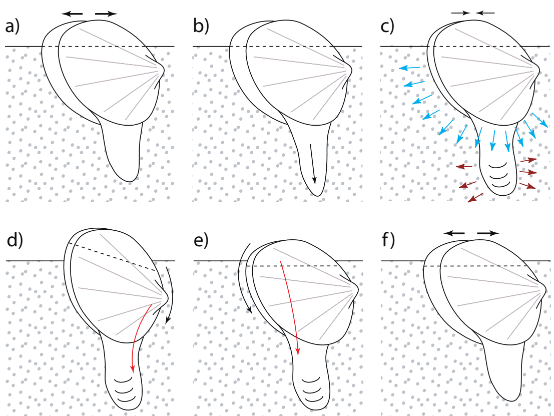

Fig. 2. The *burrowing sequence* [2]. (a) The clam is in erect position, partially buried. The valves are open to anchor the shell. (b) The foot probes deeper into the sediment. (c) The valves are adducted to partially close the shell. The thus ejected water liquefies the surrounding sediment to reduce the drag; blood is pressed into the foot, which is inflated and serves as a new anchor. (d) The front side of the bivalve is pulled towards the foot, rotating the shell. (e) The shell is turned back into the erect position. (f) The two rotations around different axes led to a net downward translation, illustrated by the dashed line. In a recreation phase, the valves open again to allow for another burrowing cycle starting at (a).[1].