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Department of Informatics

Artificial Bivalves

ai lab

The Biomimetics of Underwater Burrowing

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1. Biological Background

Burrowing bivalves use a two-anchor mechanism to dig themselves into sandy underwater sediment.

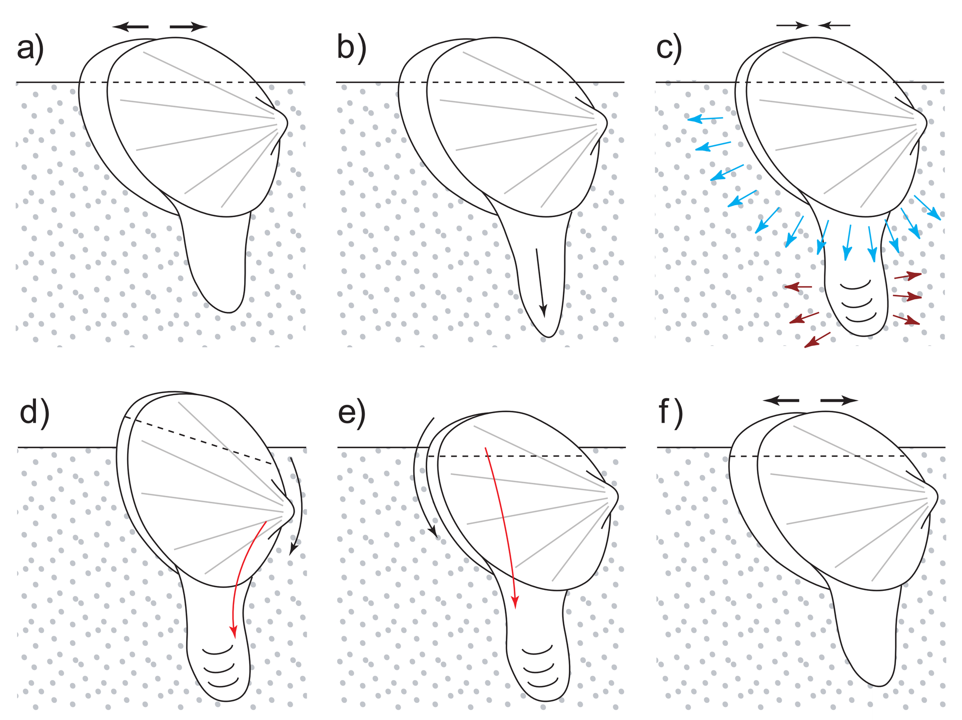

Fig. 1: Bivalve burrowing [1]. (a) erect position, anchored by open valves, (b) foot extends, (c) valves are adducted causing water expulsion and foot expansion (anchoring), (d) front muscle contraction causing forward rotation, (e) back muscle contraction causing backward rotation, (f) valves are reopened now in a deeper position. Another burrowing cycle starts again at (a).

The bivalve functional morphology for burrowing essentially consists of the overall shell shape, the shell surface structure (sculpture) and the shape of the foot.

2. Project Goals

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

3. Models of Bivalve Morphology

Bivalve shell shapes are generated using a mathematical model [2] based on only a few parameters. It produces an overall shape and a surface structure. Different shapes generated by this model are realized using a 3D printer.

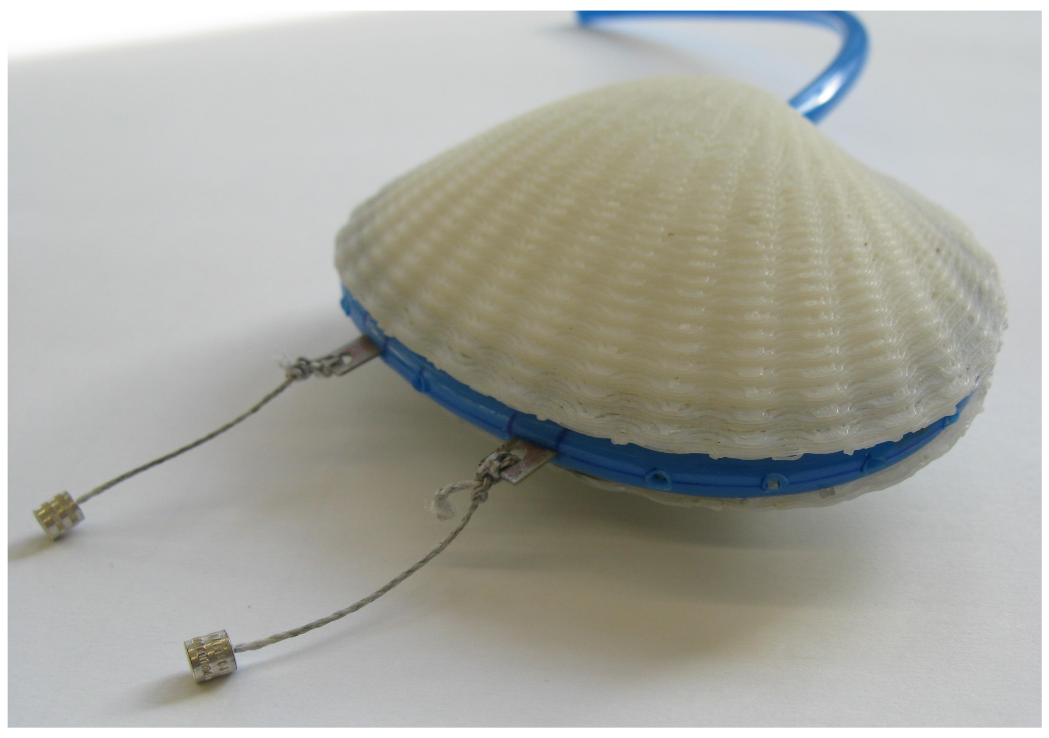

Fig. 2: A printed bivalve model consisting of the shell morphology (white plastic), a perforated rubber tube to simulate water expulsion (blue) and two attachment sites for the actuation strings.

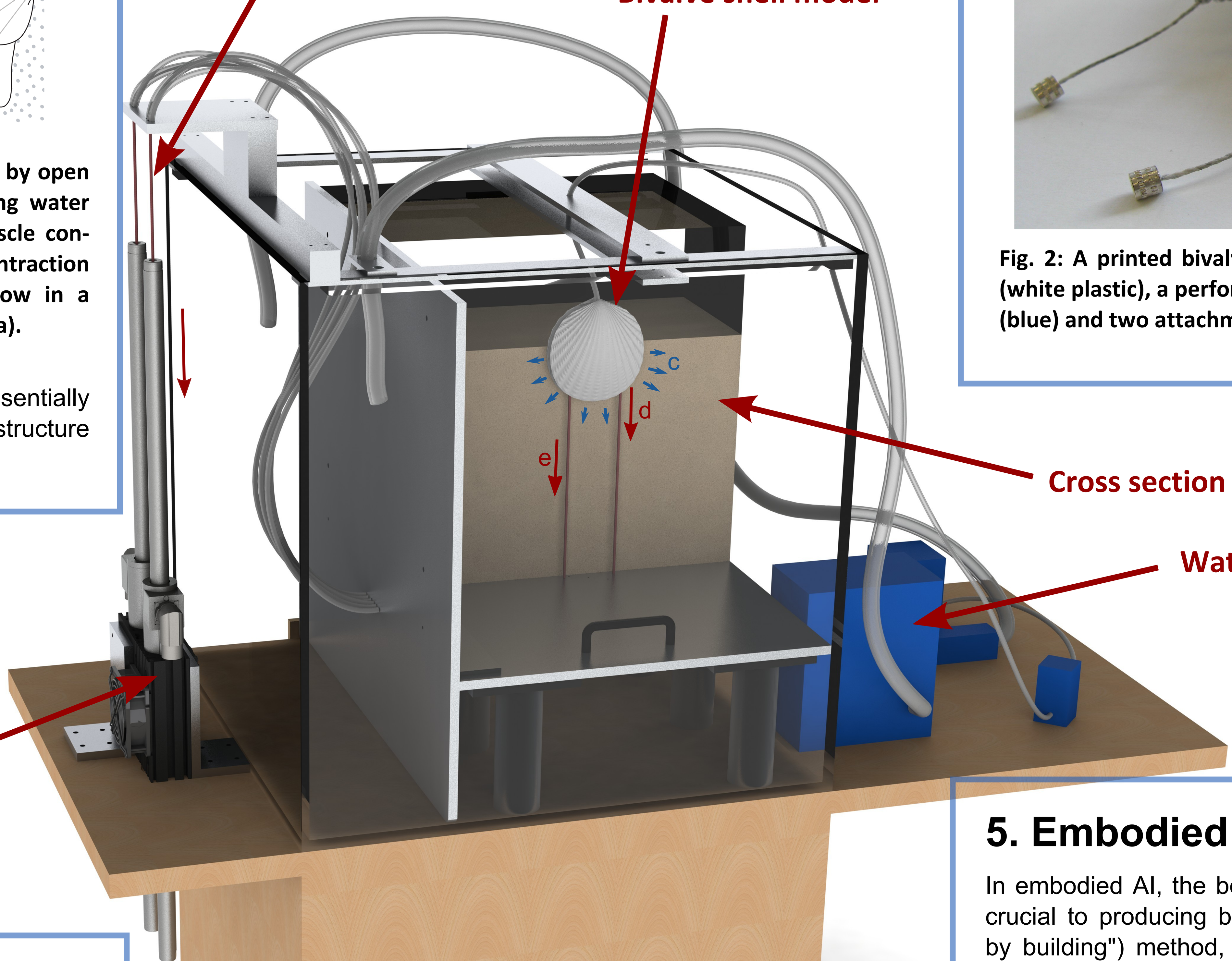

Fig. 4: The setup built to mimic bivalve burrowing. A burrowing motion similar to the one described in fig. 1 is induced by two linear motors attached on the left side. They pull the bivalve model into the sediment by alternately moving one step down. Water expulsion is simulated using a pump and a perforated tube as shown in fig. 2. The letters c-d correspond to the respective steps in fig. 1.

4. Preliminary Results

Proof of concept experiments show that the setup can be used to mimic bivalve burrowing. Systematic experiments with a full statistical analysis have not yet been done.

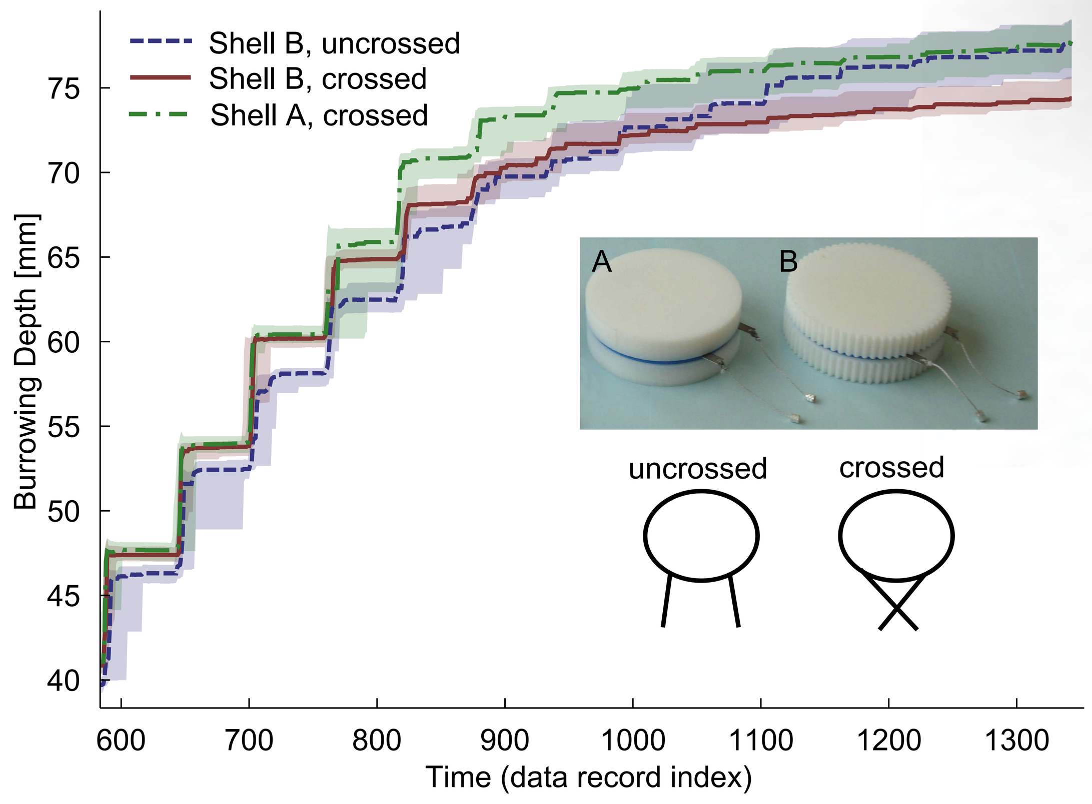

Fig. 3: Graph showing the result of a burrowing experiment to compare three different configurations. The burrowing depth is shown vs. burrowing time. The pulling force was restricted such that higher depth means better burrowing performance. The curves show the median burrowing depth and 0.1/0.9 quantiles of 10 repeated runs for each configuration. The burrowing cycles are clearly visible as steps in the curves. The step size decreases with time like in natural bivalves because the penetration resistance of the sediment increases with burrowing depth. The burrowing performance may not only depend on the configuration but also on burrowing depth.

5. Embodied Artificial Intelligence

In embodied AI, the body morphology of an organism is seen as crucial to producing behaviour. With a synthetic ("understanding by building") method, behaviour is reproduced in real robots; in this project the burrowing behaviour of bivalves.
Using the setup built in this project, it is also possible to pursue other interesting ideas in AI and robotics:
a) apply the synthetic methodology to other diciplines such as palaeontology
b) evolutionary robotics, i.e. artificial evolution performed with real robots as opposed to simulated software agents. This is essential in cases where simulation is difficult, such as in granular materials
c) co-evolution of morphology and controller, instead of only evolving the controller for a fixed robot.

6. Possible Applications

- Locomotion through granular media
- Autonomous underwater burrowing robots
- Automatic anchoring of ships and platforms (see also [3])
- Application as tool in other fields, e.g. palaeontology: identify mode of life of fossil bivalves, compare the rich fossil record of bivalves with results from artificial evolution.

7. Future Work

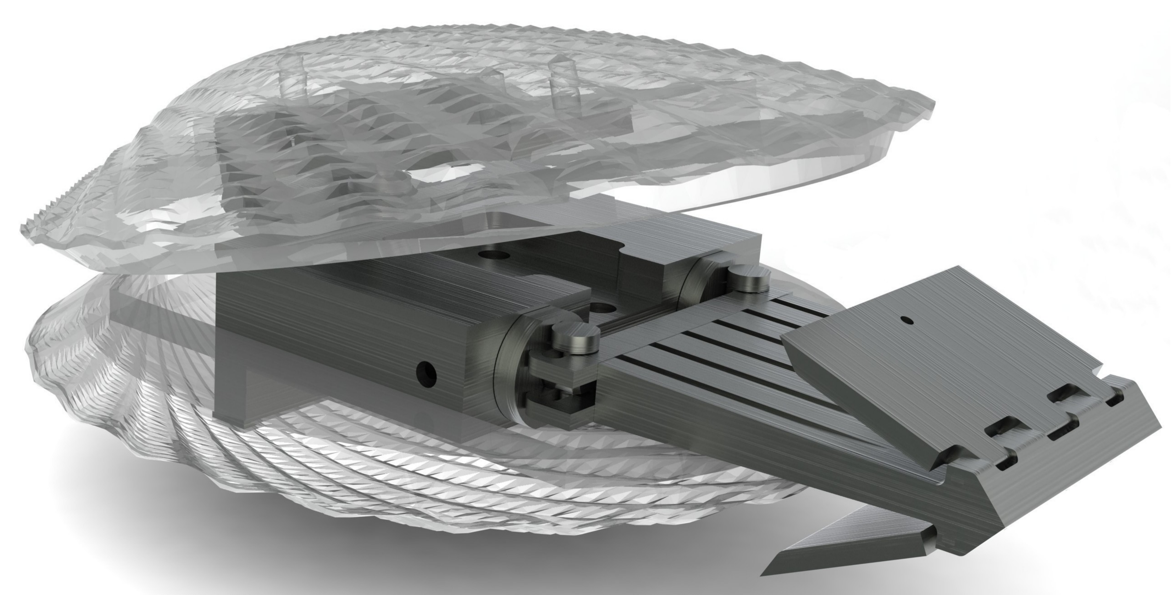

Fig. 5: We plan to build an improved setup that features (a) valve opening and closing and (b) an artificial foot. This would make the burrowing robot mechanically autonomous.
We also plan to perform evolutionary experiments with both setups. This includes (a) reconstruction of the bivalve morphological evolution, (b) tackling palaeontological questions and evolving "optimal" burrowing morphologies and motion patterns.

Acknowledgements

We would like to thank Rolf Pfeifer and the Artificial Intelligence Laboratory as well as Agathe Koller-Hodac from the University of Applied Sciences in Rapperswil (HSR) for their support. We also thank the Swiss National Science Foundation (SNF) for funding this project.

Picture Credits

Fig. 1: This figure is inspired by the figure on page 46 of M. Amler, N. Rogalla and R. Fischer, "Muscheln", ISBN 3-13-118391-8.
Fig. 2: Photo by Alexander Gilgen and Katja Dietrich, HSR.
The CAD parts shown in the images (excluding the shells) were created by Alexander Gilgen, Katja Dietrich (Fig. 4) and Christoph Philipp (Fig. 5) from HSR.
Shell models and renderings by Daniel Germann.

References

[1] E.R. Trueman. Bivalve mollusks: Fluid dynamics of burrowing. Science, 152(3721): 523-525, 1966.
[2] D. R. Fowler, H. Meinhardt and P. Prusinkiewicz. Modeling seashells. In E. E. Catmull and B. H. McCormick, editors, *SIGGRAPH '92 conference proceedings*, volume 26.1992,2 of *Computer graphics*, 379-387, New York, 1992. ACM Press.
[3] A. G. Winter, R. L. H. Deits, D. S. Dorsch, A. E. Hosoi and A. H. Slocum. Teaching roboclam to dig: The design, testing and genetic algorithm optimization of a biomimetic robot. In *2010 IEEE/RSJ International Conference on Intelligent Robots and Systems*, 4231-4235, Piscataway, NJ, 2010. IEEE.

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