Bifurcation and gait transition induced by hydrodynamic sensory feedback in an anguilliform swimming robot

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The diversity and beauty of animal locomotion have always been a source of inspiration and fascination for biologists, physicists, and engineers. Here, we aim to understand how sensory feedback can explain the animal adaptability to a physical medium. Yet, our understanding of the role of the sensory feedback is limited by the complexity of the intertwined relations between central (brain and spinal cord) and peripheral nervous systems (somatic sense) for animals, as well as its numerical implementation in robots [1]. To tackle this problem, we propose to disentangle their respective roles by introducing an artificial antagonism between them in a serial swimming robot (Fig. 1, left). To do so, we design a network of oscillators controlling the robot's actuation to maintain a fully synchronized state without phase lag between the servomotors. Hence, the central nervous system will produce an even bending mode, commonly observed by walking reptiles and amphibians on the ground (see Fig.1, right b).

To reproduce the somatic system, the robot is equipped with a differential hydrodynamic force sensor on each module. This sensory feedback will modulate the phase dynamics of the corresponding oscillator. When the gain of the hydrodynamical force feedback σ exceeds a threshold, a sudden bifurcation leads to a sharp gait transition. Surprisingly, we observe the progressive set-up of undulatory swimming, significantly increasing the robot's velocity(Fig. 1, right). In short, when the robot detects the fluid response, it adapts its gait to improve its swimming performance. Furthermore, we show that this transition is produced by a global symmetry breaking, both in the oscillator chain and body motion. Finally, we will discuss the implication of these results on network stability and its relevance for biological systems.

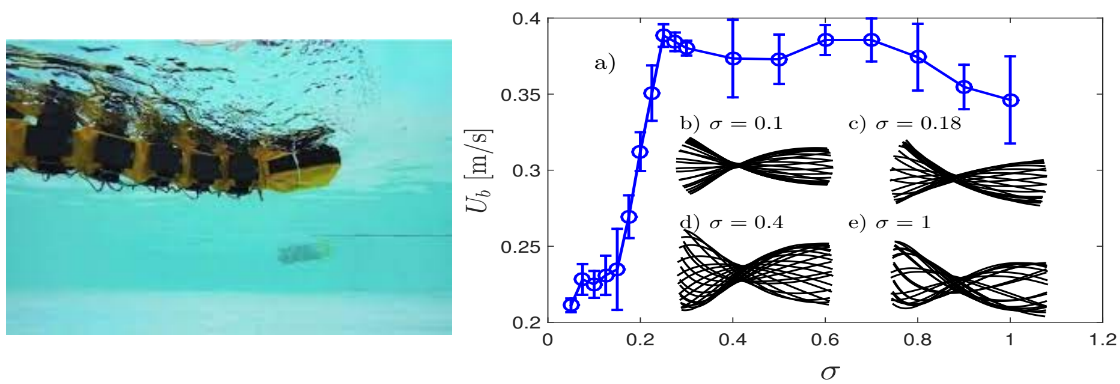

Figure 1. Left : the robot *Agnathax* [1] with its lateral force sensors. Right : transition of the robot's velocity U_b as a function of the weight of the sensory feedback in the oscillator chain. The body shapes are represented in black, indicating the transition from oscillating to undulating swimming modes.

Références

1. R. Thandiackal, K. Melo, L. Paez, J. Herault, et l. *Emergence of robust self-organized undulatory swimming based on local hydrodynamic force sensing*, Science Robotics 6 (2021).