Arm movements during crawling locomotion of *Octopus sinensis*

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Introduction

Octopuses use eight flexible arms with a high degree of freedom to achieve a variety of movements, e.g., reaching and crawling.

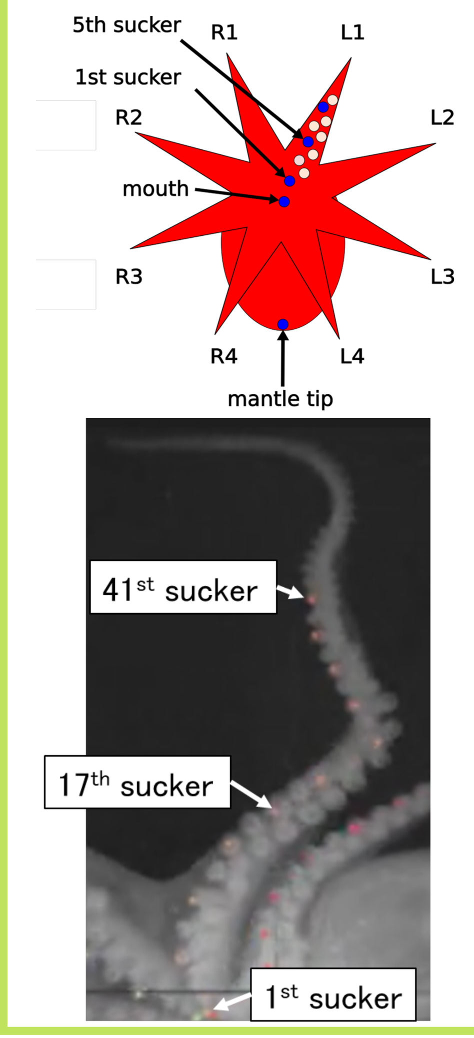
- Reaching was achieved through stereotypical arm movements [1].
- The stereotypical movements are produced by the peripheral nervous system of arms [2].

Even in crawling movements, each arm movements might be combination of stereotypical movements.

Purpose

Identify the patterns of arm movements in the crawling locomotion of octopuses and evaluate their contribution to propulsive force generation.

Method



Experiment: Recording of an octopus crawling

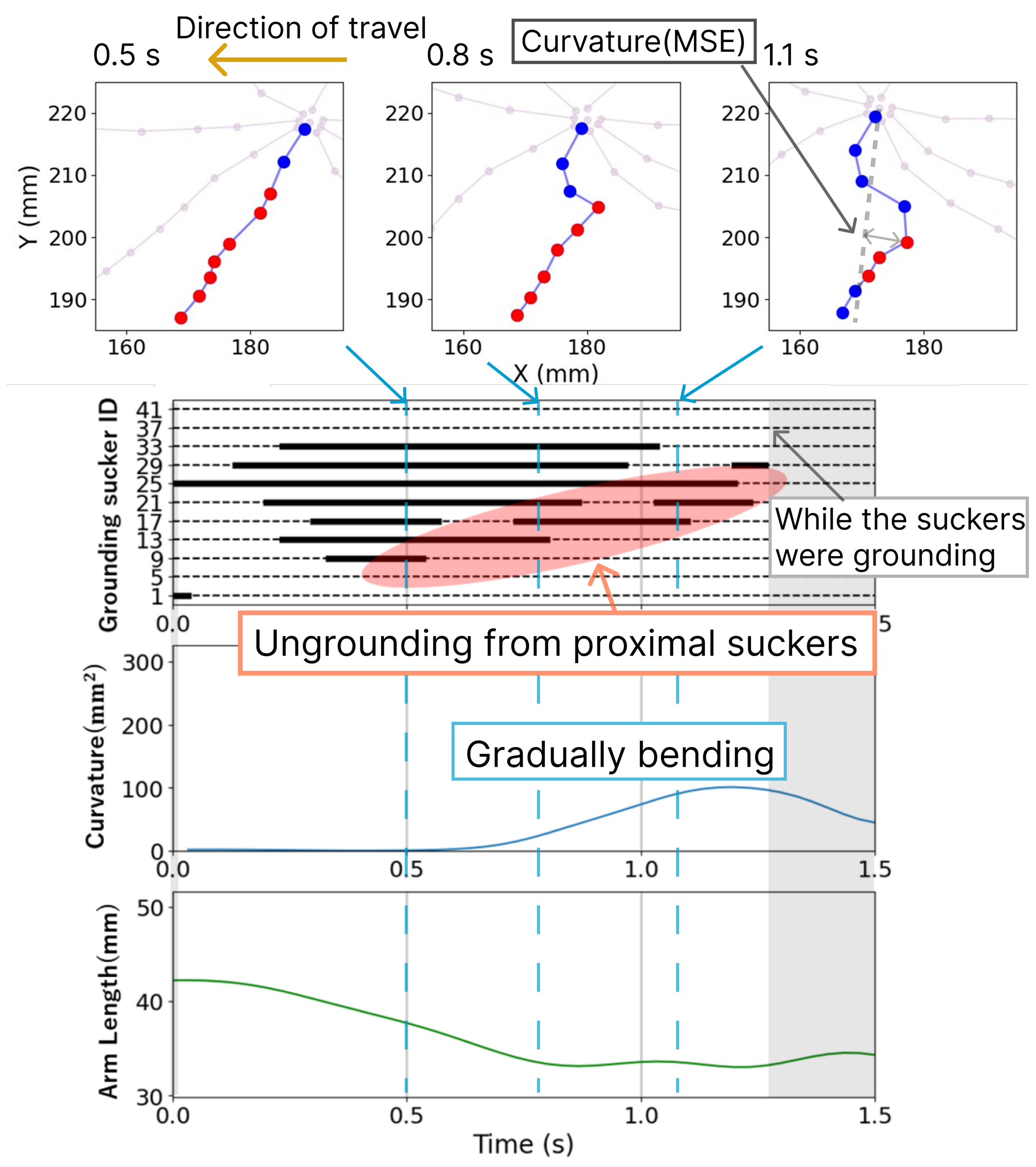
- Subjects: two octopuses (*Octopus sinensis*)
- Experimental tank :
  1200×450×450 mm, filled with seawater 20 mm deep
- Video recording:
  30 fps (DMK 33UX273, Imaging Source)

Data analysis

- Posture estimation: mouth center, mantle tip, and 11 suckers (1st, 5th, ... 37th, 41st) on each arm by DeepLabCut.
- The trajectory and velocity data were low-pass filtered by the 5th-order Butterworth filter with a cut-off frequency of 3 Hz.
- Missing data in trajectory data were interpolated using data of adjacent frames by cubic spline interpolation.
- Suckers with a speed of less than 10 mm/s were considered grounded.

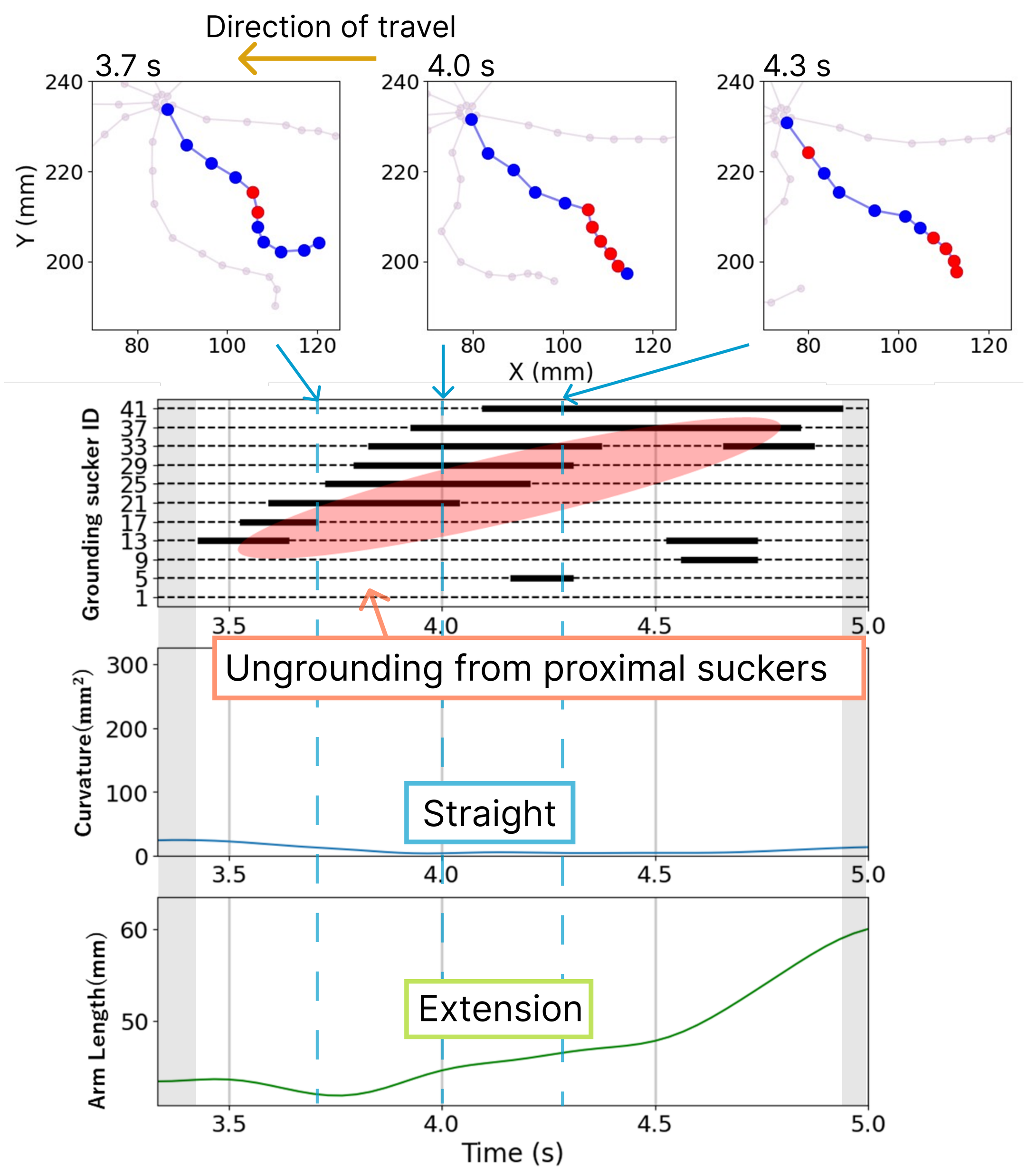
Results

(i) Arm bending movements were observed in the arm extending laterally to the left and right with respect to the direction of travel.



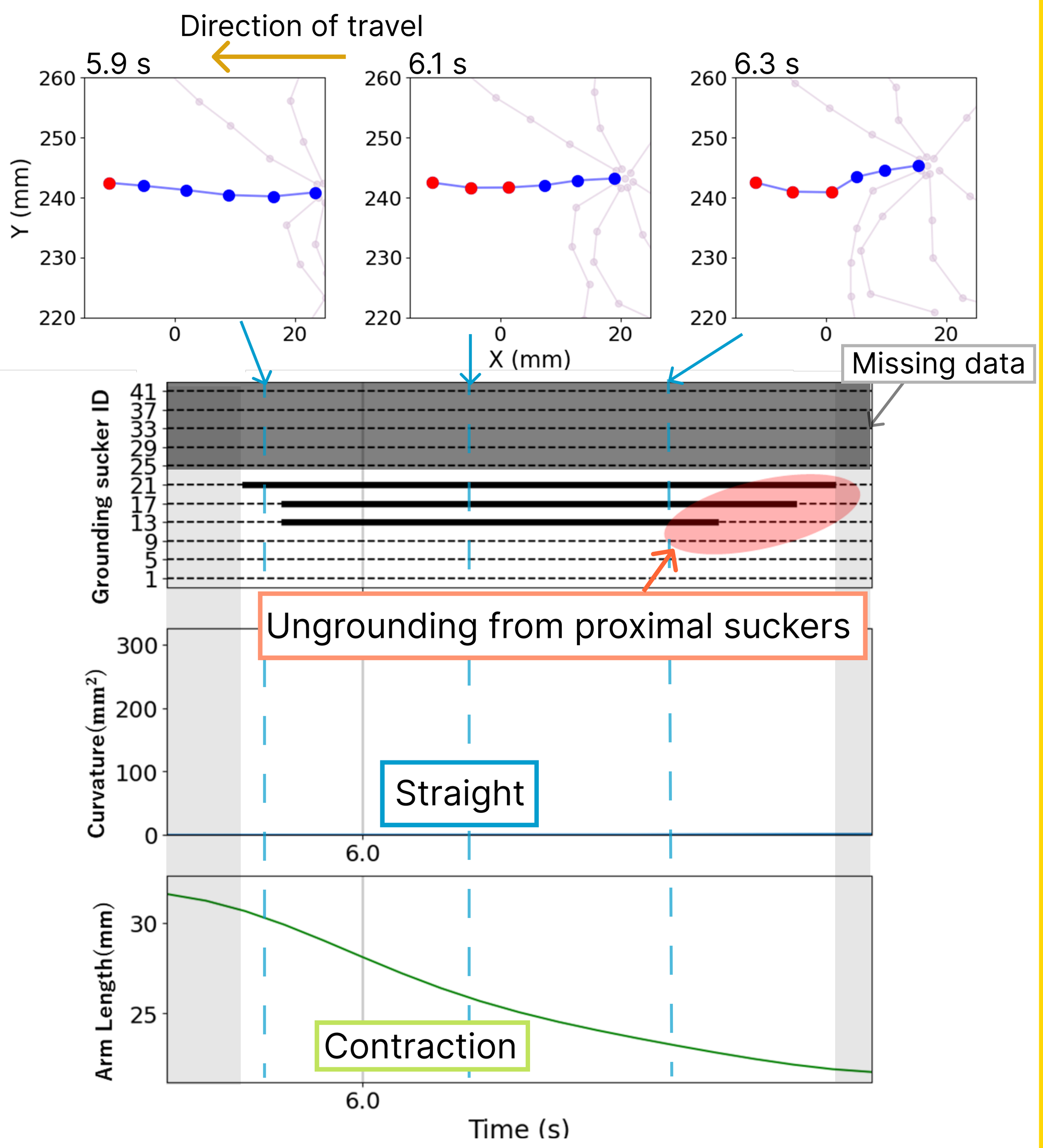
The arm was gradually bending with distal suckers grounded.

(ii) Arm extension movements were observed in the arm oriented in the opposite direction to travel.



The arm was extending with keeping its straight form while ungrounding suckers propagated from the proximal to the distal.

(iii) Arm contraction movements were observed in the arm straightly extended toward the the direction of travel.



The arm was contracted with keeping its straight form and with distal suckers grounded.

Ungrounding of suckers propagated from the proximal to the distal in all arm movement patterns.

Bending movements could contribute to propulsive force generation by the rotational moment.

Extension movements could contribute to propulsive force generation by pushing the body.

Contraction movements could contribute to propulsion force by pulling the body.

Contribution of arm movements to propulsive force generation

Estimation of body acceleration from arm grounding information

Estimated acceleration of the mouth center

Grounding information for part j (proximal/distal) of the i-th arm

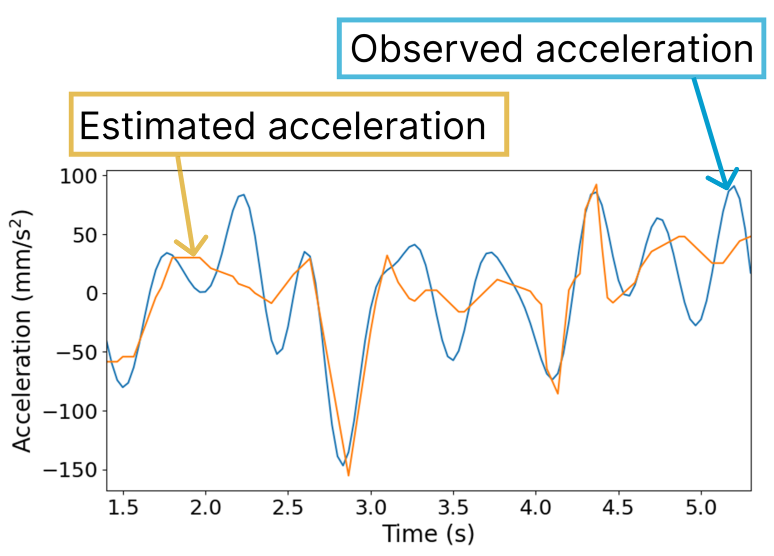
$$a_p(t) = \sum_{i=1}^{8} \sum_{j\in\{pr,dt\}} k_{ij}\bar{F}_{ij}(t)$$

Coefficient

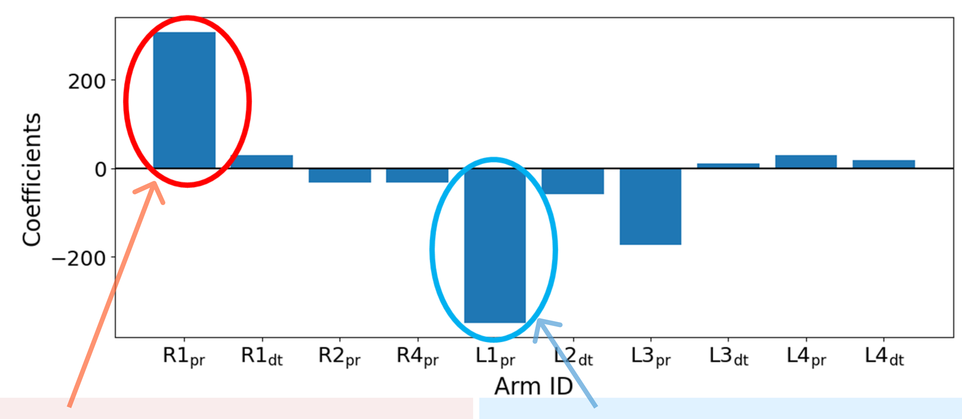
Arm ID

proximal/distal part

Model selection : Akaike's Information Criterion (AIC)



The acceleration was well predicted.



The bending movement (i) contributes to propulsion.

The contraction movement (iii) contributes to deceleration.

The arm that showed extension movement (ii) was not selected by AIC.
Little contribution of the extension movement to the propulsion.

Conclusion

Three typical arm movement patterns were identified in the crawling locomotion of octopuses:

(i) Arm bending : contributes to the propulsive force as suggested in the previous report [3].
(ii) Arm extension : does not contribute to propulsion contrary to previous report [4].
(iii) Arm contraction: contributes to deceleration.

The arm bending movement (i) was similar to the stereotypical reaching movement generated by the peripheral nervous system [2]. Thus, the same peripheral network would realize both the arm reaching and crawling locomotion.

Reference

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[3] J. Nishii and M. Ikeda. Gait analysis of crawling locomotion of *Octopus sinensis*. In Proceeding of the 9th International Symposium on Adaptive Motion of Animals and Machines (AMAM 2019), B3, 2019.
[4] G. Levy, T. Flash, and B. Hochner. Arm coordinationin octopus crawling involves unique motor control strate-gies. Current Biology, Vol. 25, No. 9, pp. 1195–1200, 2015.

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