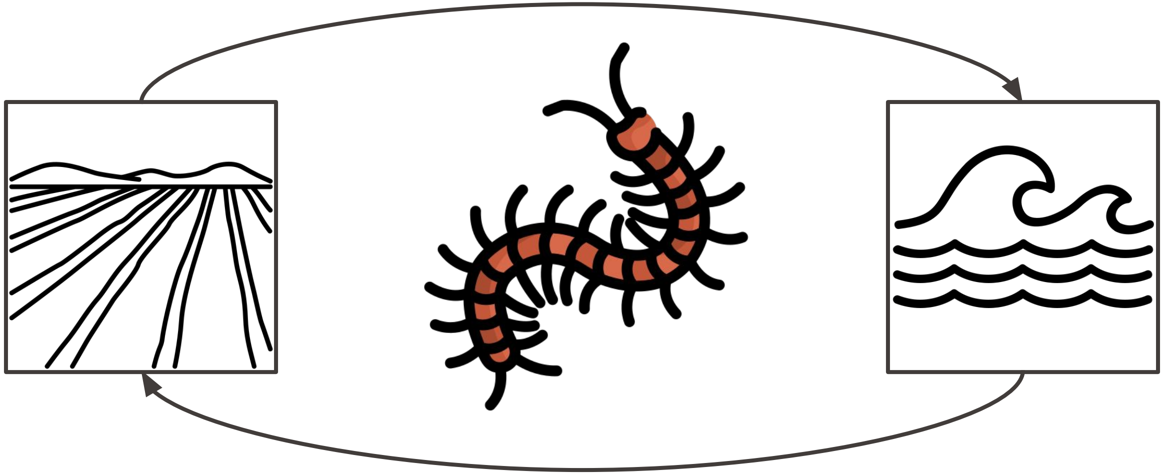
EPFL

Decoding the essential interplay between central and peripheral control in adaptive locomotion of amphibious centipedes

Kotaro Yasui et al.

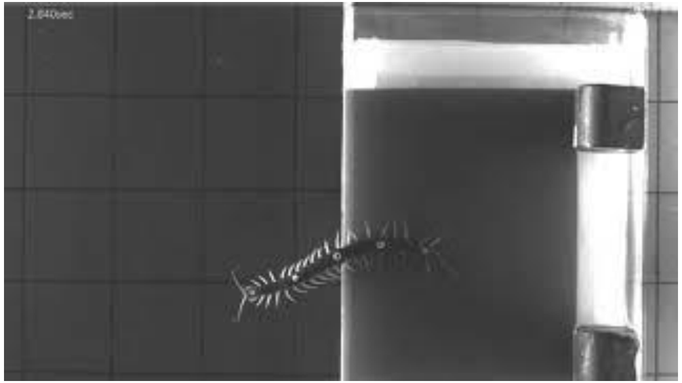
MICRO - 507 Legged Robots



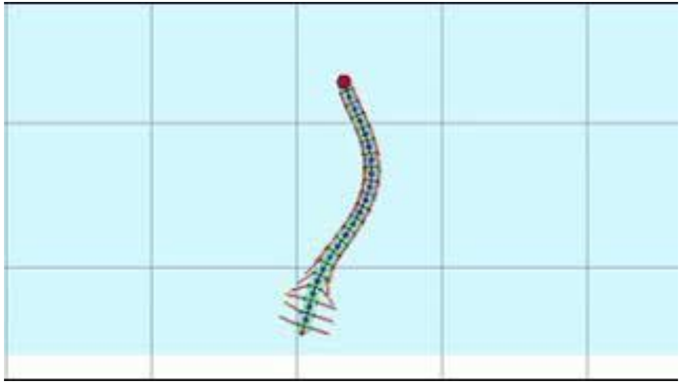
Klose Chloé,
Klose Lucie,
Tafili Mentor
-
Group 29

Videos of the experiment :

Transition from walking to swimming

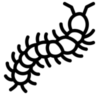


Centipede locomotion during transition

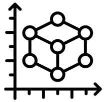


Simulated centipede locomotion during transition

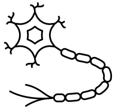
Aim of the study



Simulate and understand the adaptive locomotion of centipedes



Develop a mathematical model that integrates descending control for swimming and with sensory feedback for walking.



Capture the interplay between brain signals, local pattern generators and sensory feedback.

Summary

Robot type : amphibious centipede-inspired model

Control type : hybrid control system

- Descending neural signals for swimming initiation
- Local sensory feedback and CPGs for walking

Design method : mathematical modeling and neuro-mechanical simulations

Gait types : walking / swimming

Main sensors : simulated mechano-sensory feedback mechanisms

Main features : transition behaviors / decentralized control / fault tolerant locomotion

Analysis

1 **Hypothesis 1 :** Each body segment has two locomotor modes, walking and swimming

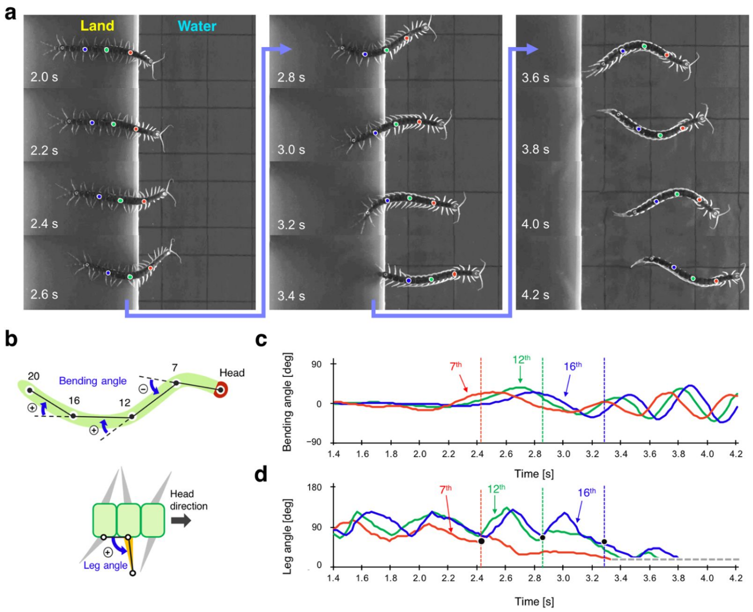
2 **Hypothesis 2 :** The brain can switch between the two locomotor modes and transmit the decision as a descending command to the first body segment

3 **Hypothesis 3 :** Each body segment basically follows the locomotor mode of its anterior segment

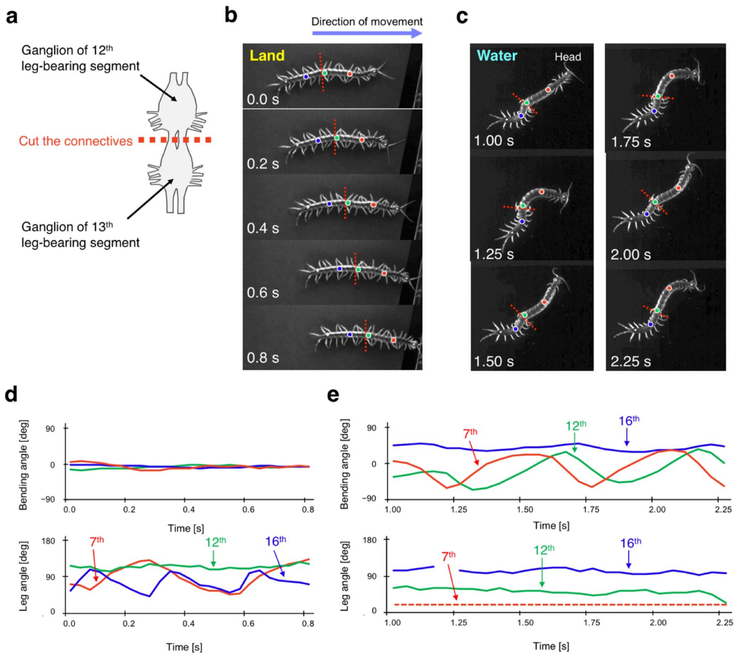
4 **Hypothesis 4 :** Mechano-sensory feedback based on ground contact can inhibit swimming mode and induce walking mode

Results

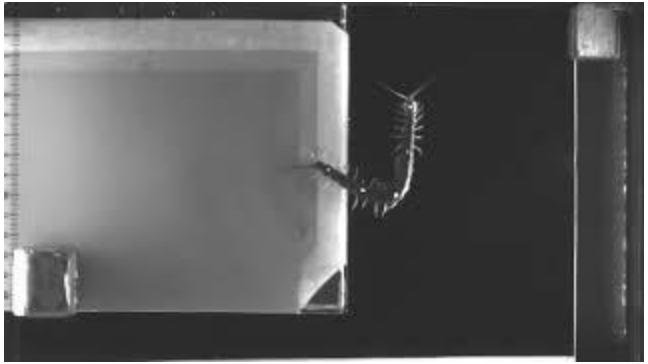
Nervous connection not severed



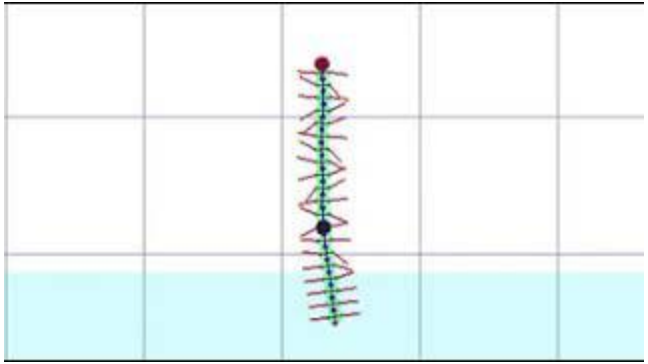
Nervous connection severed



Nerve cord transected illustration



Centipede locomotion when the nerve cord is transected



Simulated centipede locomotion when the nerve cord is transected

Equations 1.0

$$\tau_S \dot{S}_{i,j} = -S_{i,j} + \max[0, \tanh\{c_S(|\overrightarrow{F}^{tip}_{i,j}| - F_{th})\}],$$ 1

Activity level of mechano-sensory neurons in each leg

$$\dot{\varphi}^L_{i,j} = \omega_L + \sigma_1 \sin(\varphi^L_{i-1,j} - \varphi^L_{i,j} - \psi^{ipsi}_L) + \sigma_2 \sin(\varphi^L_{i,k} - \varphi^L_{i,j} - \psi^{contra}_L)$$

$$\dot{\varphi}^B_i = \omega_B + \sigma_3 \sin(\varphi^B_{i-1} - \varphi^B_i - \psi_B)$$ 2

Time evolution of the phase oscillator implemented in each joint

$$\tau^L_{i,j} = k^L(\overline{\theta}^L_{i,j} - \theta^L_{i,j}) - d^L \dot{\theta}^L_{i,j},$$

$$\tau^B_i = k^B(\overline{\theta}^B_i - \theta^B_i) - d^B \dot{\theta}^B_i$$ 3

Join torque at each leg and body trunk according to proportional derivative control

Equations 1.1

$$\bar{\theta}_i^B = \pi - A_i^B \cos\varphi_i^B, \quad (4)$$

Target joint angle for each body trunk

$$\bar{\theta}_{i,j}^L = \theta_{i,j}^{neutral} - A_{i,j}^L \cos\varphi_{i,j}^L,$$

$$\theta_{i,j}^{neutral} = \pi - c_0 M_i, \quad (5)$$

Target joint angle for each leg

$$A_{i,j}^L = c_L(S_{i,j} + S_{i-1,j}),$$

$$A_i^B = c_B M_i, \quad (6)$$

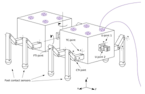
This model describes the switching of locomotor patterns
by varying the amplitudes of the leg and body motion

Further work

Influence on literature :

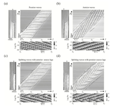
Amphibious locomotion

- *Centipede bio-extremity elastic model control*



Decentralized control systems

- *General Distributed Neural Control and Sensory Adaptation for Self-Organized Locomotion and Fast Adaptation to Damage of Walking Robots*



Hybrid gaits for bio-inspired robotics

- *Gait switching with phase reversal of locomotory waves in the centipede Scolopocrypt rubiginosus*

Conclusion

- **Pros :**
  - Two different locomotions : legged on land and undulatory in water
  - Fault tolerant to physical damages
  - Highly adaptive and resilient

- **Cons :**
  - Not generate walking on slippery surfaces
  - Not reproduce the adaptive locomotion to speed variations

Exam questions

Question 1 : Is the model able to walk on slippery, non-solid surfaces?

Answer 1 : No, the model is not capable of modeling non-contact walking on such surfaces.

Question 2 : Does the brain have the ability to switch between the locomotor modes when the nerve cord is sectioned ? Explain why.

Answer 2 : No, the brain can switch between locomotor modes only in the anterior part. In the posterior part, locomotion relies on mechanosensory feedback from ground contact. While the walking mode remains functional, swimming is not supported.

Thank you for your attention !

Any questions ?