Simple robot suggests physical interlimb communication is essential for quadruped walking

Owaki et al. (2012)

Group 11:

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Main contribution

- Unconventional CPG model ➡ 4 **decoupled** oscillators + local force **feedback**/leg
- **Physical** interaction is essential for interlimb coordination

$$\dot{\theta}_i = 2\pi \nu_i + \cancel{\sum_j r_j w_{ij} \sin(\theta_j - \theta_i - \phi_{ij})}$$

Tigh Interaction

- **Neural** systems
- **Musculoskeletal** systems
- The **real-world** environment

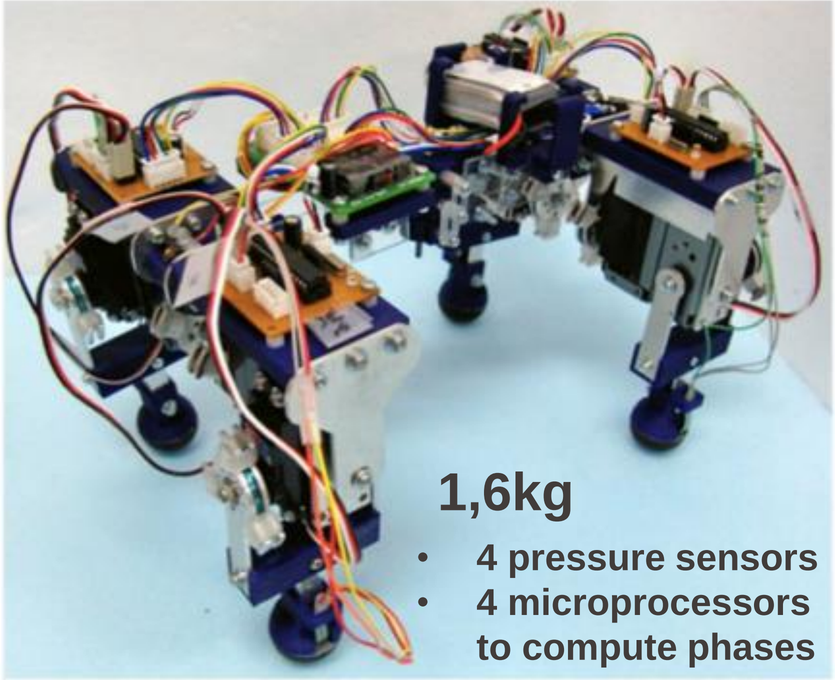
Objectives:

- Good **adaptability** to changes in weight distribution and walking speed
- **Mimic** the walking pattern of actual quadrupeds
- Stablish a design principle for **adaptable** and **multifunctional** robots
- Insight into **biomechanical** locomotion mechanisms in animals.

Design strategies

- **Quadruped** robot with a phase oscillator in each leg
- **Simple** leg structure (no knee, no ankle) with 2 servomotors/leg
- Interlimb **neural** connection ignored

- **Assumptions:**
  1. **Minimalistic** approach. **No** intralimb coordination
  2. **Physical** interaction with ground **reaction** force sensors



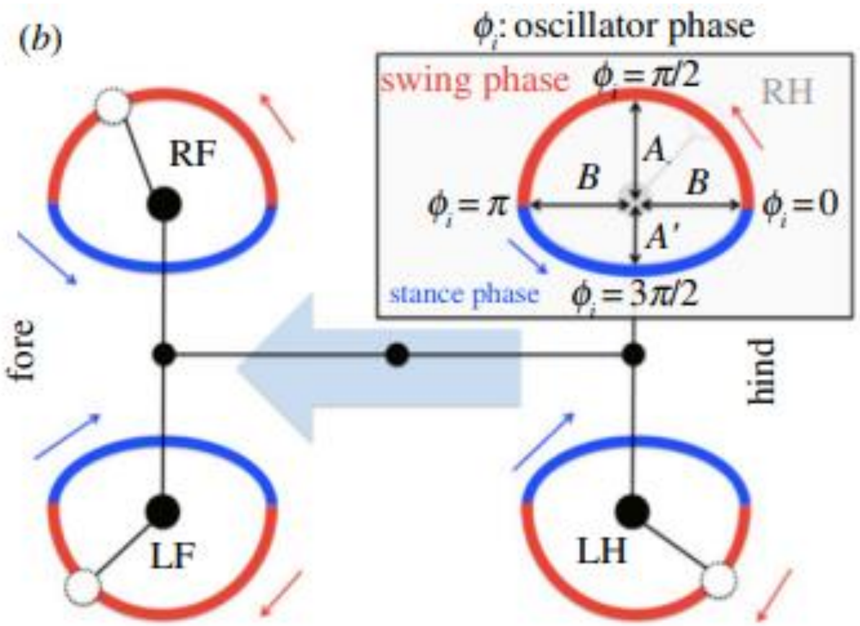
Control Algorithm

Intrinsic angular velocity

Local sensory feedback

$$\dot{\phi}_i = \omega - \sigma N_i \cos \phi_i ,$$

Ground reaction force



- **Phase delay** is introduced preventing **unstable** two-legged support state
- Leg movements alter **CoM** to change phases

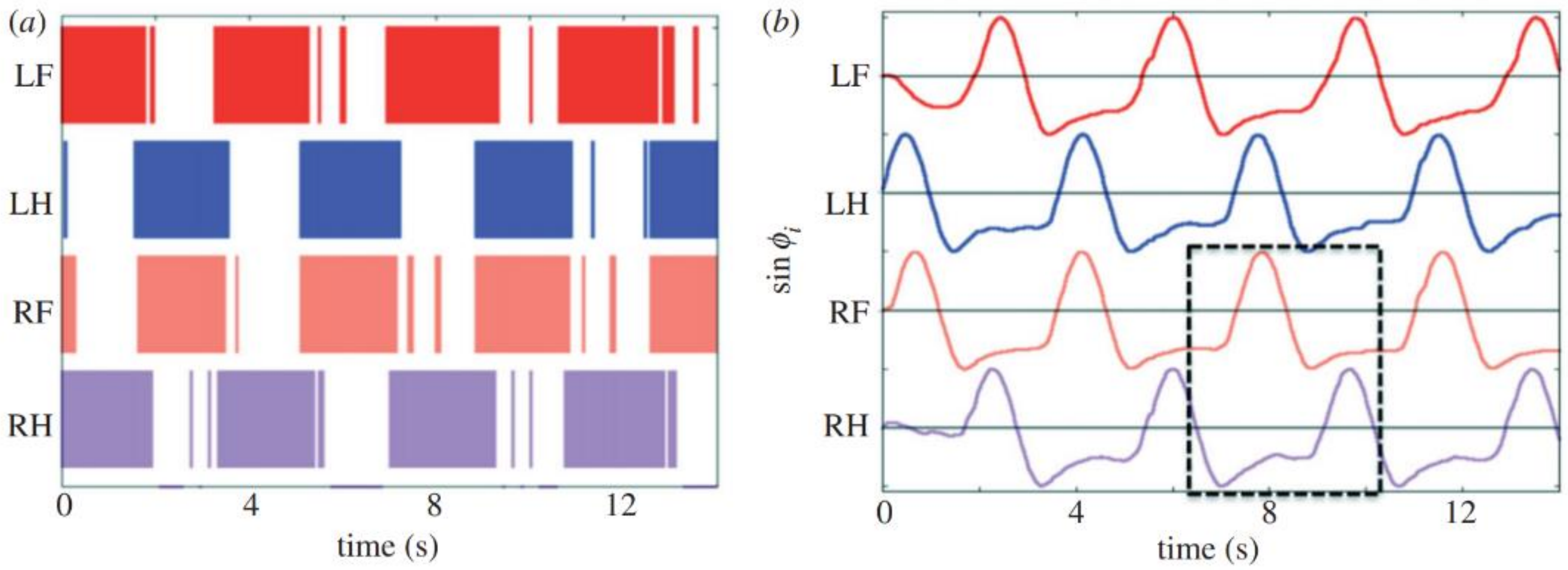
$$X_i = B \cos \phi_i \quad (0 \le \phi_i < 2\pi),$$
$$Y_i = A \sin \phi_i \quad (0 \le \phi_i < \pi)$$

$$Y_i = A' \sin \phi_i \quad (\pi \le \phi_i < 2\pi),$$

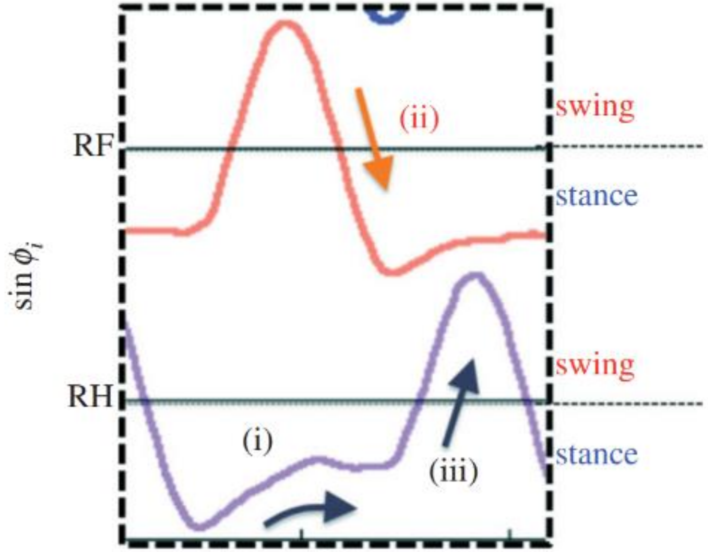
Experimental results – Steady gait

- Steady walking gait
- Initial conditions:

	parameters	values	units
ω	intrinsic angular velocity	0.04	rad s^{-1}
σ	magnitude of sensory feedback	0.0052	rad s^{-1} N^{-1}
A	positive y-direction amplitude of leg motion in a swing phase	0.09	m
A'	negative y-direction amplitude of leg motion in a stance phase	0.03	m
B	x-direction amplitude of leg motion	0.04	m
$\phi_0(0)$	initial phase on LF leg's oscillator	0	rad
$\phi_1(0)$	initial phase on LH leg's oscillator	0	rad
$\phi_2(0)$	initial phase on RF leg's oscillator	0	rad
$\phi_3(0)$	initial phase on RH leg's oscillator	0	rad

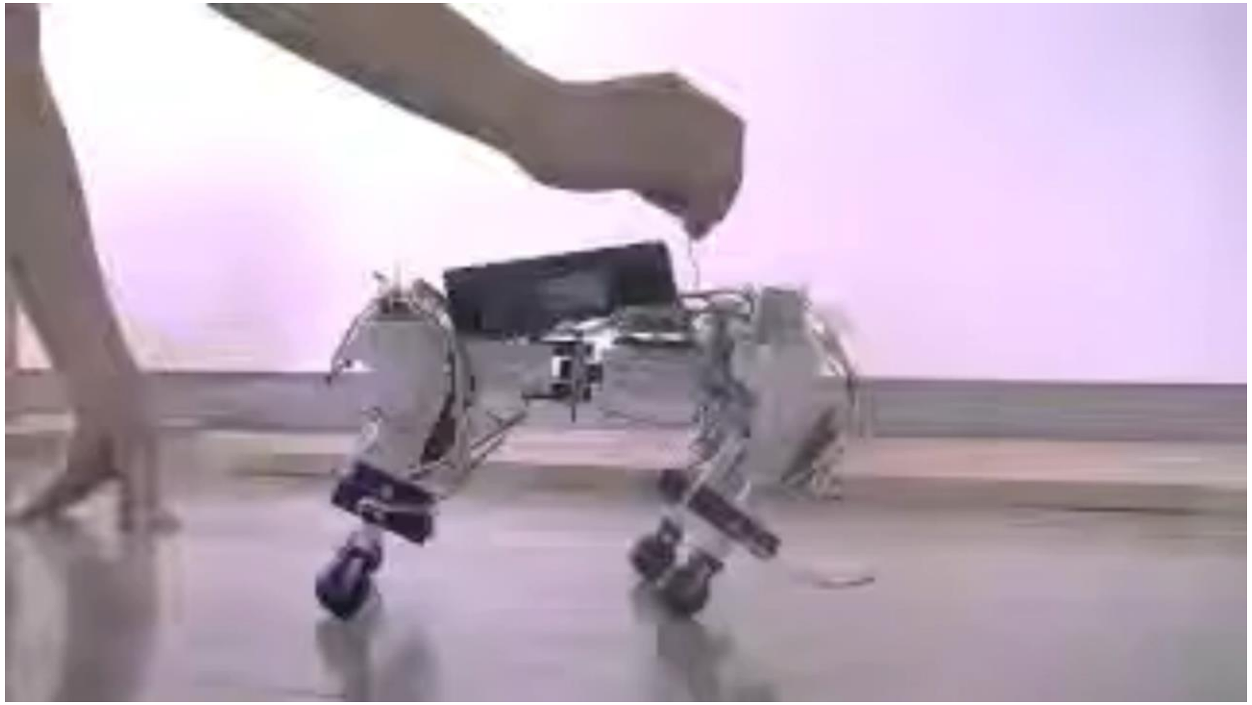


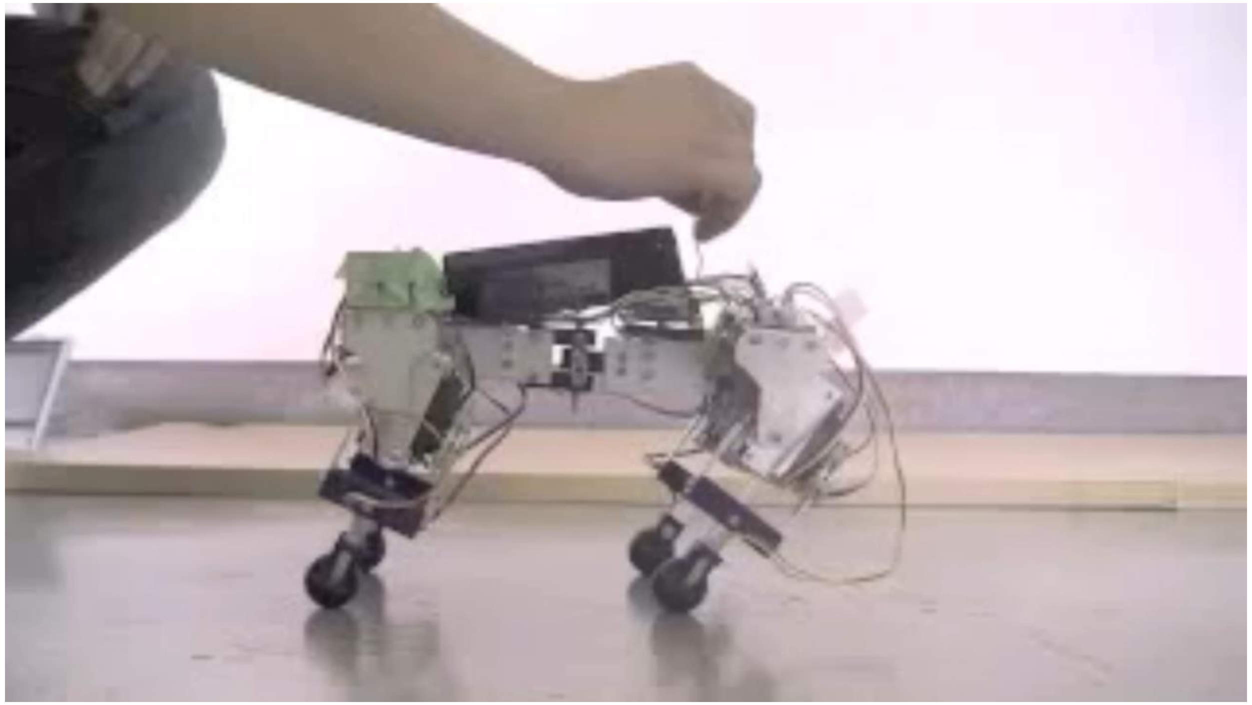
- ✓ Convergence to an adaptive walking gait
- ✓ Phases of oscillators effectively modified through local sensory feedback
- **Conclusion**: adaptive behavior even in the absence of direct interlimb neural connections between the oscillators and the CPG



Experimental results – Adaptability to body changes

- 0.12kg load on forelegs
- 0.29kg load on hindlegs





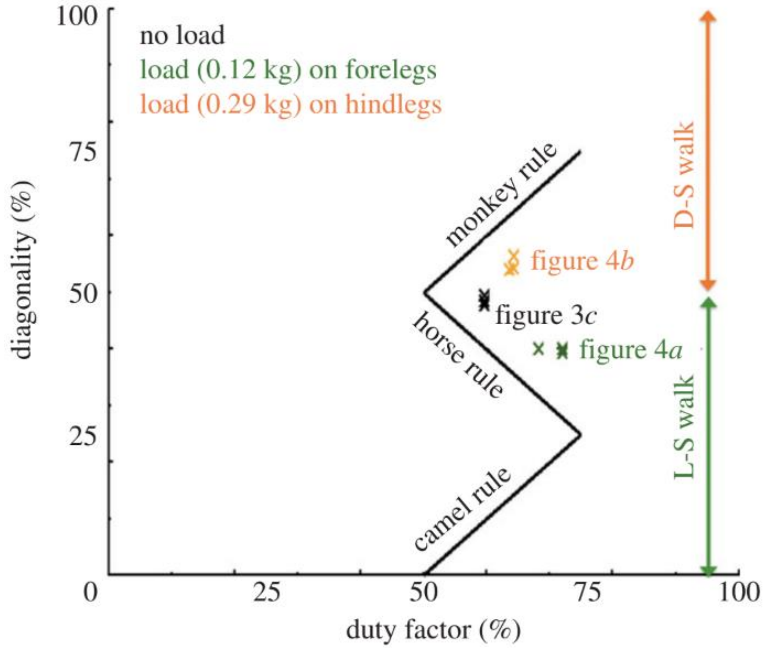
- Lateral-Sequence (L-S) walk
- Diagonal-Sequence (D-S) walk

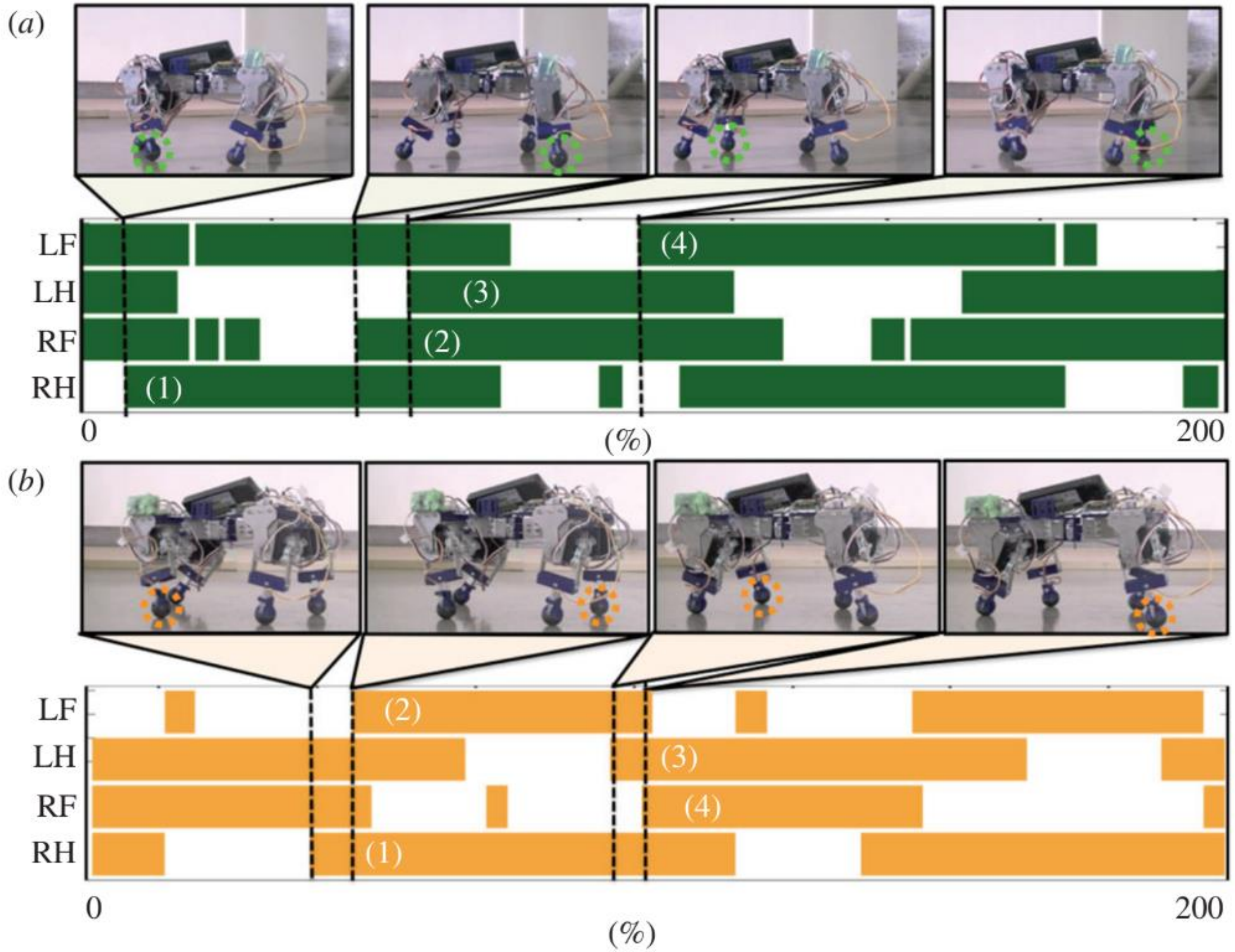
✓ High adaptability to changes in the body properties

Experimental results – Adaptability to body changes

- Gait quantification by:
  - Duty cycle
  - Diagonality

configurations	leg LF	LH	RF	RH
no load	0.66	0.52	0.59	0.61
foreleg load	0.81	0.63	0.85	0.58
hindleg load	0.53	0.75	0.52	0.75





- **Conclusion:** mass distribution of a body plays a crucial role in the generation of quadruped walking patterns

Experimental results – Adaptability to velocity changes

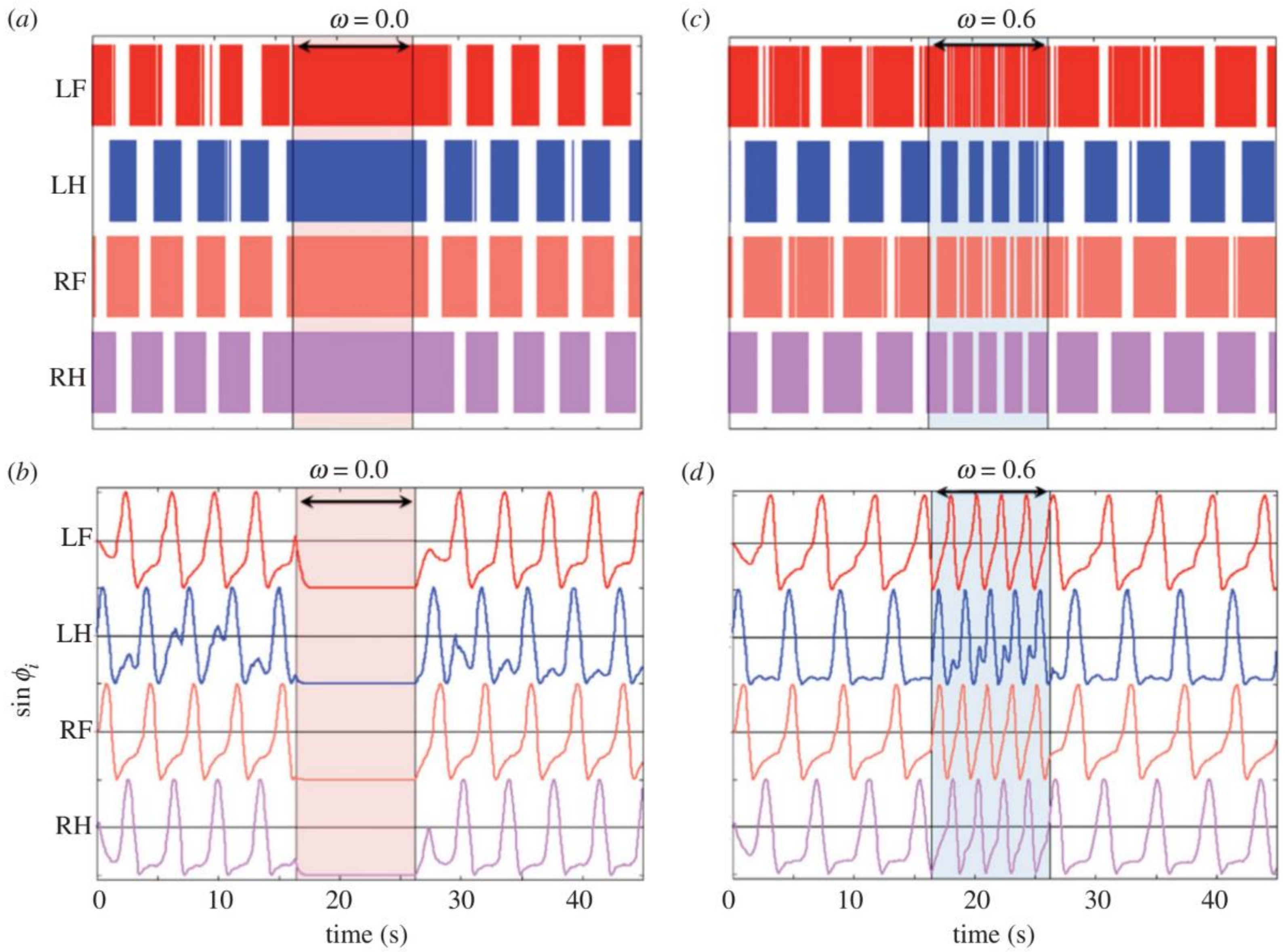
- 2 experiments:
  1. Standing ↔ walking

✓ Rapid transitioning between gaits

  2. ω : 0.4 ↔ 0.6 rad/s

✓ Smooth transitioning between gaits

- **Conclusion:**
  - Duty factor reduced in response to velocity change
  - Force feedback has less impact with higher velocities



Mathematical Interpretation

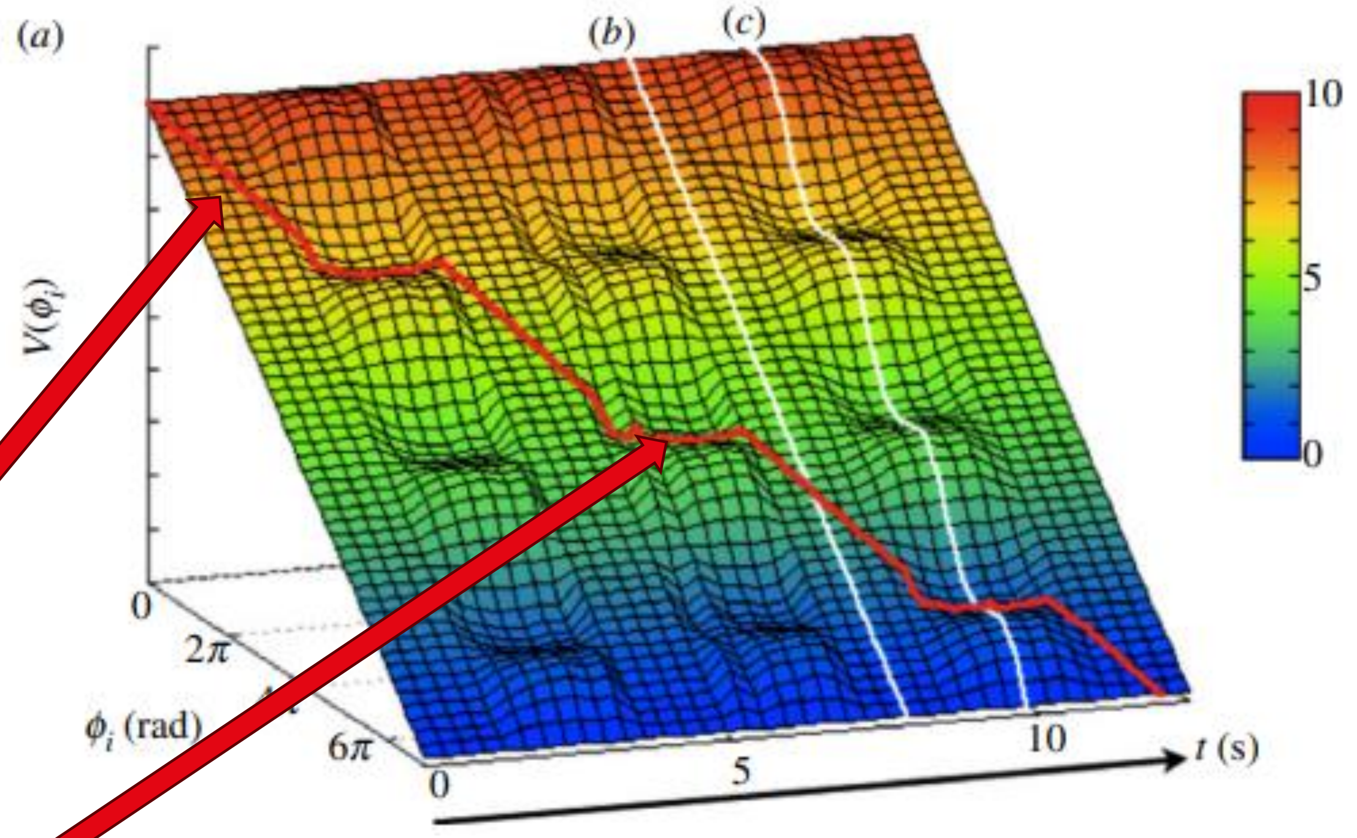
1. **Oscillatory Regime ($\sigma N_i < \omega$):**

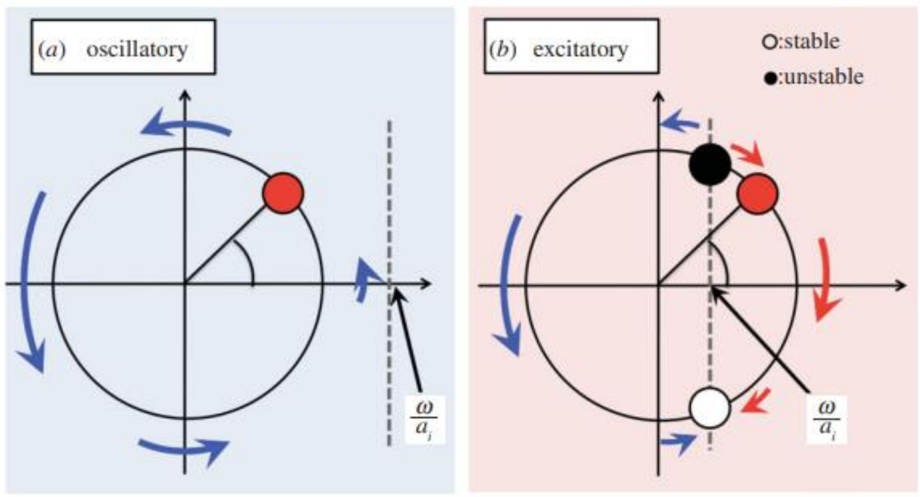
   1. The oscillator moves continuously, producing **periodic** motion.
   2. This corresponds to the **swing phase** of the leg.

1. **Excitatory Regime ($\sigma N_i > \omega$):**

   1. The phase is temporarily "**trapped**" at a stable equilibrium point.
   2. This corresponds to the **stance phase**, where the leg supports the robot's weight and there are no periodic movements.

- The switching between these regimes allows the robot to dynamically adjust its gait depending on the ground reaction forces.





Article citation

156 citations

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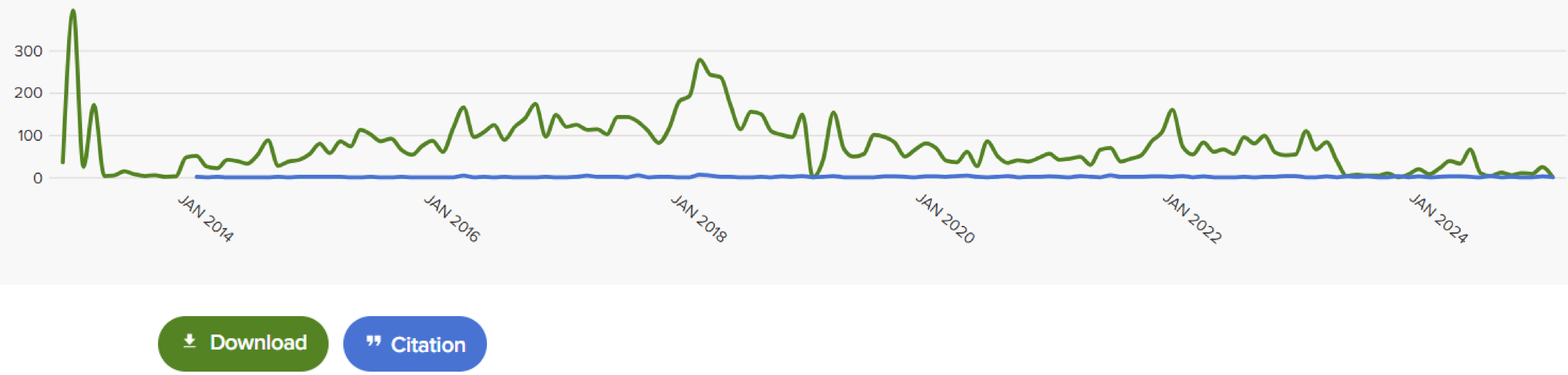
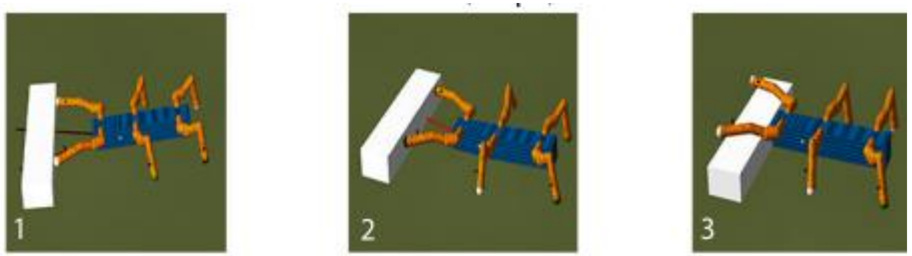
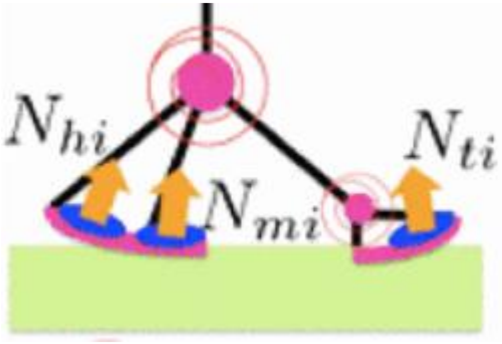


Influence

- Hexapod walking system: achieves stable gait walking, stable walking while pushing an object, deals with morphological changes and collaborative tasks
  - "Multiple Decoupled CPGs with Local Sensory Feedback for Adaptive Locomotion Behaviors of Bio-inspired Walking Robots". Barikhan, S.S., Wörgötter, F., Manoonpong, P. (2014).
- Bipedal walking: local force feedback from soft deformable feet
  - "Adaptive bipedal walking through sensory-motor coordination yielded from soft deformable feet," D. Owaki, H. Fukuda and A. Ishiguro, 2012
- Following work: continues to explore gait transition by tuning omega, interlimb coordination analysis and energy efficiency
  - "A Quadruped Robot Exhibiting Spontaneous Gait Transitions from Walking to Trotting to Galloping." Owaki, D., Ishiguro, A., 2017

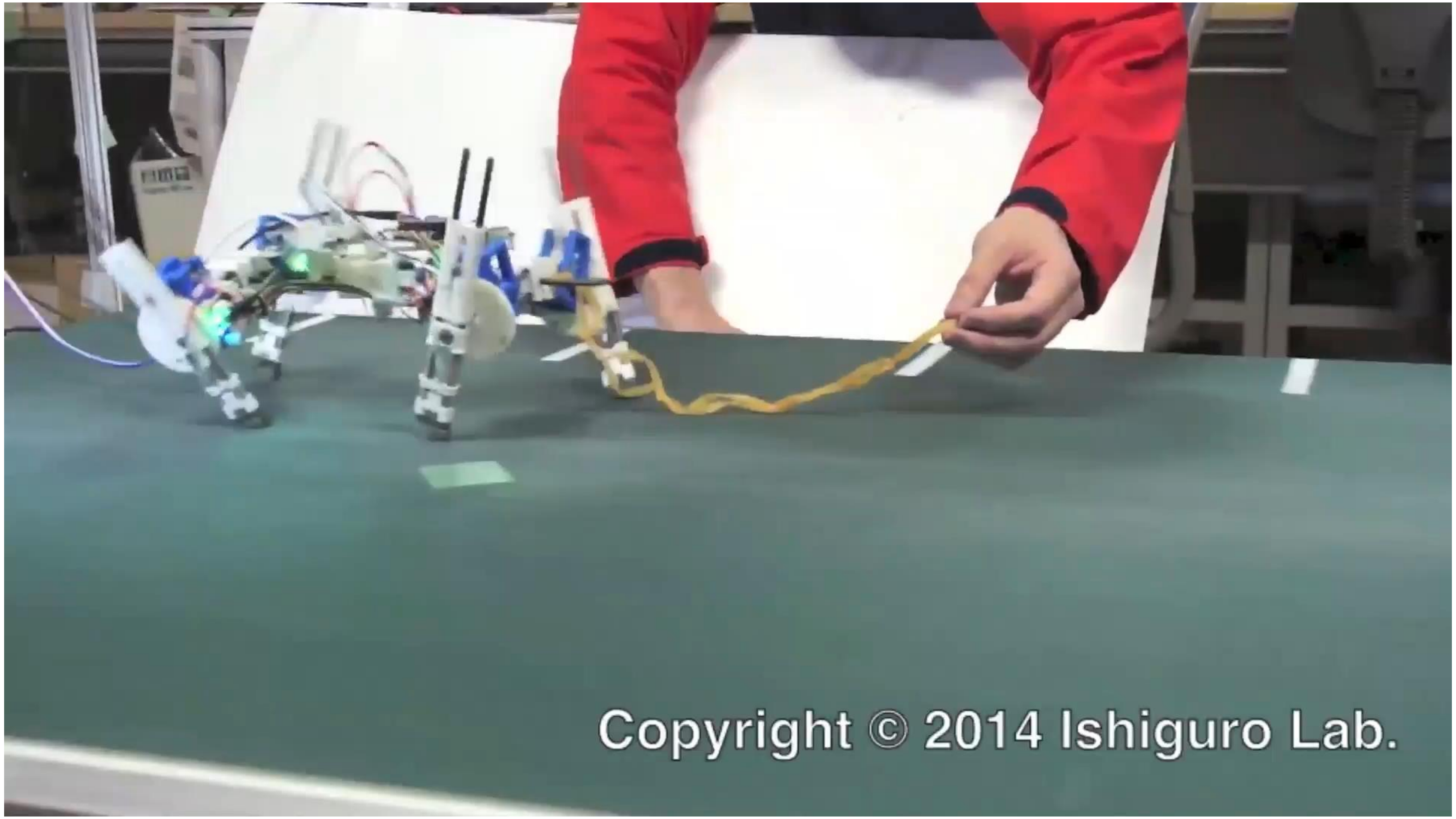




Quadruped Robots Developed for Experimental Verification

Influence

- Newer version of our robot, OSCILLEX 3.5!
- Gait transition:



Pros and cons

ADVANTAGES

- Good adaptability to changes:
  - Weight distribution
  - Walking speed
- Quantitative information in sensory feedback through pressure sensor
- Potential role of sensory feedback as task coordination mechanism

DISADVANTAGES

- Differences with actual quadruped gait
- Limited terrain adaptability
- Simplistic sensory feedback implementation
- Lack of neural integration

Exam questions

- **QUESTION 1:** How is the relationship of the phases of the decoupled oscillators and leg movements established?
  - It is established through the local sensory feedback, which allows the leg to maintain stance phase while bearing a load by exploiting the local force sensory information from the foot.
- **QUESTION 2:** Do gait patterns depend exclusively on the CPG?
  - No, gait patterns are the result of the interactions of the robot with the environment, musculoskeletal system and intraspinal neural networks

Thanks for listening!

Any questions?