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Optimiser la locomotion des robots hexapodes en s’inspirant des fourmis

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Résumé

La polyvalence avantageuse des robots hexapodes s’accompagne souvent d’une consommation énergétique excessive, alors que les animaux ont développé une locomotion économe. On observe, néanmoins, un manque de méthodes capables de comparer les différentes formes d’optimisations énergétiques des animaux à pattes aux robots. Dans cette étude, nous proposons une procédure expérimentale évaluant la performance énergétique d’un hexapode basé sur des servomoteurs. En utilisant un cadre théorique basé sur les lois de la thermodynamique appliquées à la locomotion, nous avons estimé quatre métriques en utilisant un banc d’essai dédié, dénommé MIMIC-ANT. Nous avons alors analysé les caractéristiques d’une seule patte afin de façonner le profil énergétique du robot complet pour une tâche donnée. L’économie d’énergie réalisée est de 18 % grâce à l’ajustement continu du rapport cyclique de marche, avec un bénéfice de 56 % lors de la maximisation de la puissance mécanique. En outre, l’ajustement de la vitesse du robot en fonction de la longueur de la foulée et du changement de style de marche permettent seulement de réduire les pertes énergétiques de 7 % à faible vitesse. Contrairement aux animaux dotés de muscles, un seul point de fonctionnement optimal a été révélé dans une patte articulée par des servomoteurs, ce qui constitue un inconvénient majeur dû à la faible efficacité énergétique des servomoteurs employés en robotique. Par conséquent, les robots à pattes sont sévèrement limités pour optimiser leur locomotion lors du changement de tâches. Cette conclusion est contre-intuitive pour des robots hexapodes réputés polyvalents.

Mots-Clés: locomotion, marche, optimisation, biomimétisme, bioinspiration, biorobotique, imitation, bionique, robotique à pattes, robotique bio-inspirée.

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Optimizing the locomotion of hexapod robots by taking inspiration from the ants

Julien R. Serres, Ilya Brodoline, et Stéphane Viollet

Presented on 22 May 2024 in Albi, France

Optimizing the locomotion of hexapod robots by taking inspiration from the ants

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« How to build a new **hexapod robot**, better than **AntBot** »

What types of robots are there?



What is a high-performance robot?



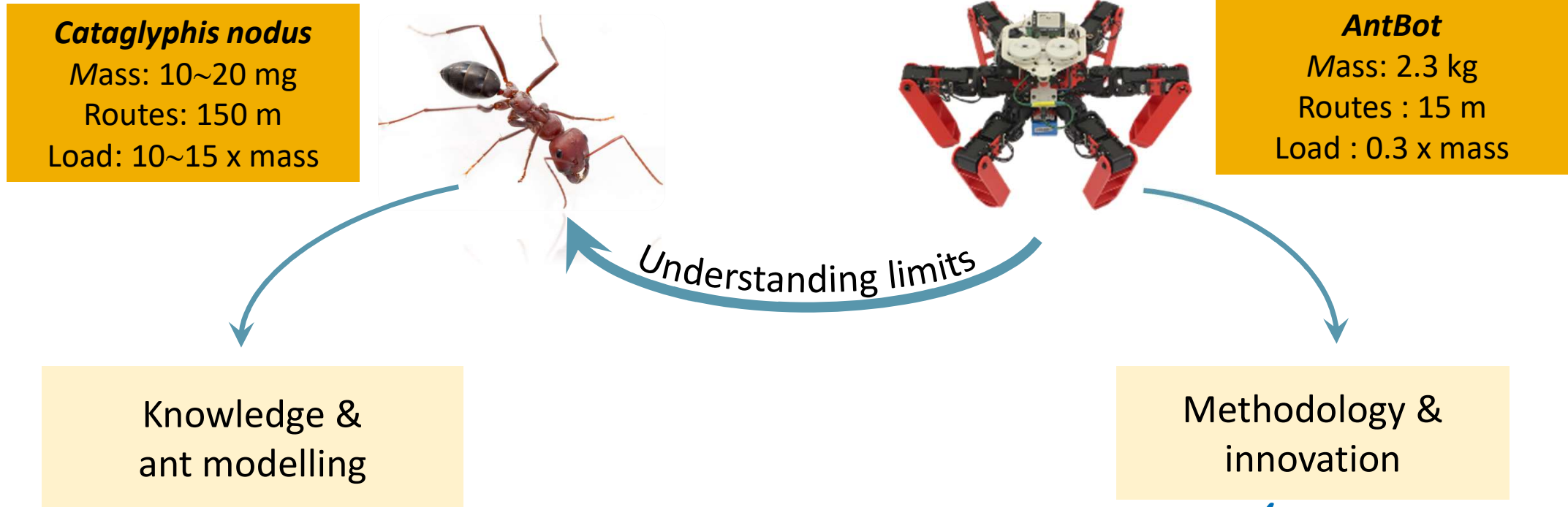
What are the special features of this robot?



State of the art of hexapod robots

I. Brodoline, P. Moretto, S. Viollet, V. Fourcassié, and J. R. Serres, *IEEE Instrumentation & Measurement Magazine*, 2022.
J.R. Serres, V. Fourcassié, I. Brodoline, P. Moretto, S. Viollet, *Projet MiMiC-ANT, PEPS INSIS* 2020.

The challenges of biorobotics: building a robot that explains how animals work



State of the art of hexapod robots

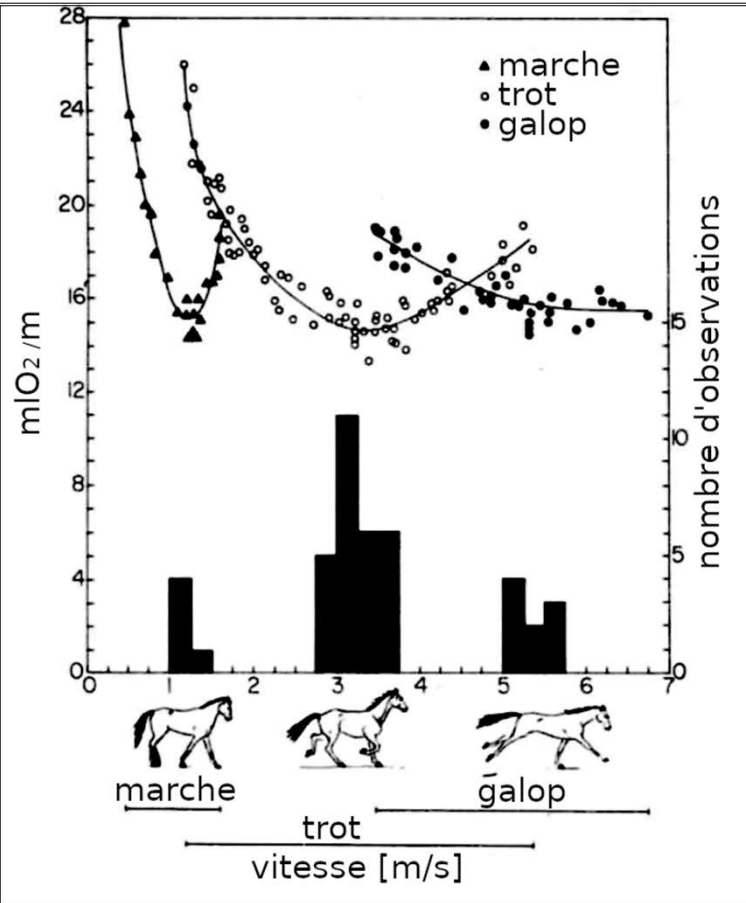
What is a high-performance robot?

animal Cost of Transport (CoT)

$$CoT [ml \cdot m^{-1} \cdot kg^{-1}] = \frac{\Phi_{O_2}}{v \cdot m}$$

Specific resistance

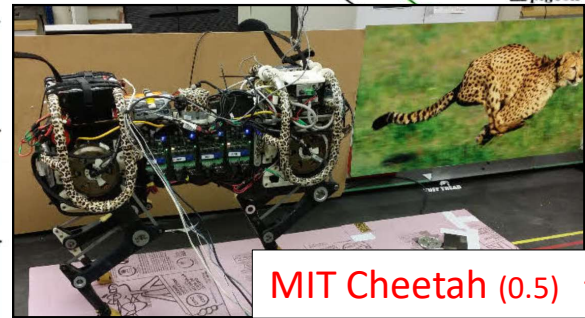
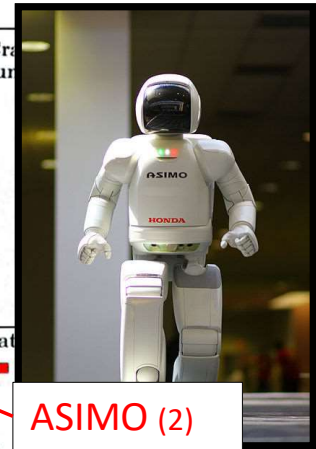
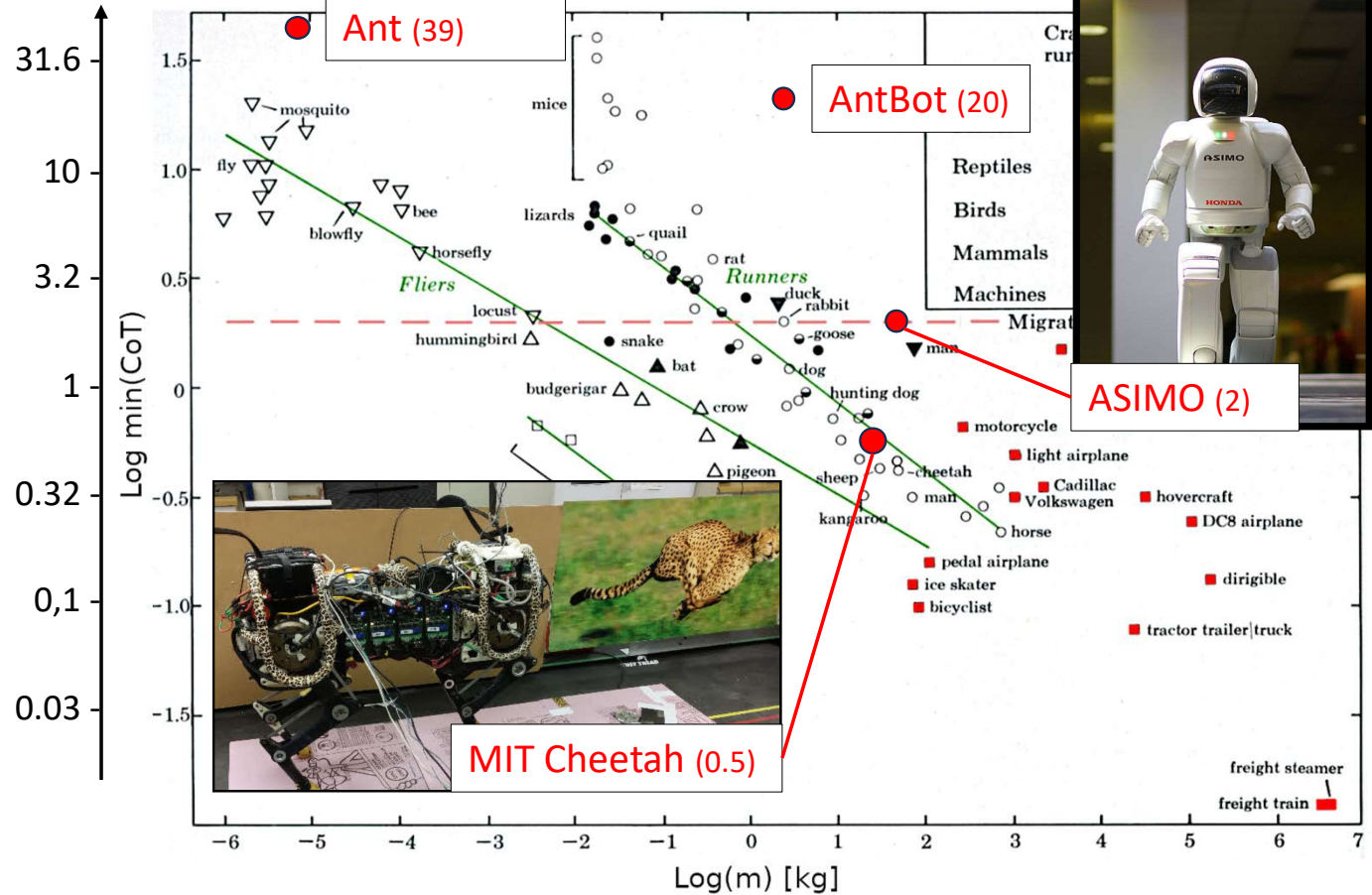
$$\varepsilon [\emptyset] = \frac{P_{in}}{m \cdot g \cdot v}$$



Cost of transport in horses
D. F. Hoyt et C. R. Taylor, Nature, 1981.

Minimum transport costs for some species

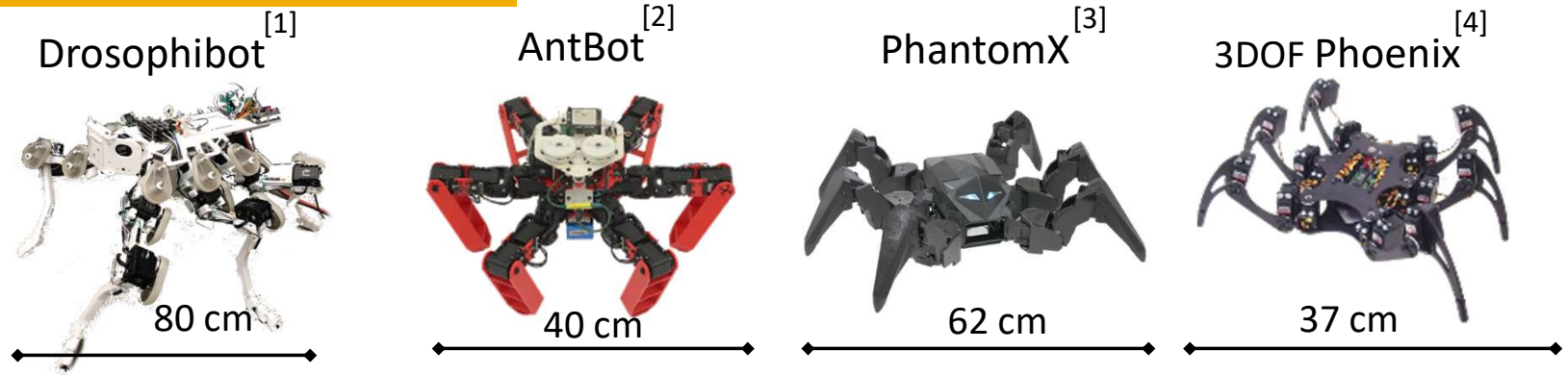
V. A. Tucker, American Scientist, 1975.



State of the art of hexapod robots

P. Manoonpong, L. Patane, X. Xiong, I. Brodoline, J. Dupeyroux, S. Viollet, P. Arena and J. R. Serres, *Sensors*, 2021. <https://doi.org/10.3390/s21227609>

State of the art of hexapod robots mimicking insects



Mass [kg]	1 kg	2.3 kg	2 kg	1.3 kg
Autonomy (approx.)	30 min	15 min	20 min	20 min
Actuators' angular speed	59 rpm	90 rpm	106 rpm	50 rpm
Maximum load	700 g	700 g	700 g	700 g
Price	1 k€	2 k€	3.3 k€	1 k€
Year	2019	2019	2020	2015

[1] C. Goldsmith, N. Szczecinski and R. Quinn, *Living Machines*, 2019.

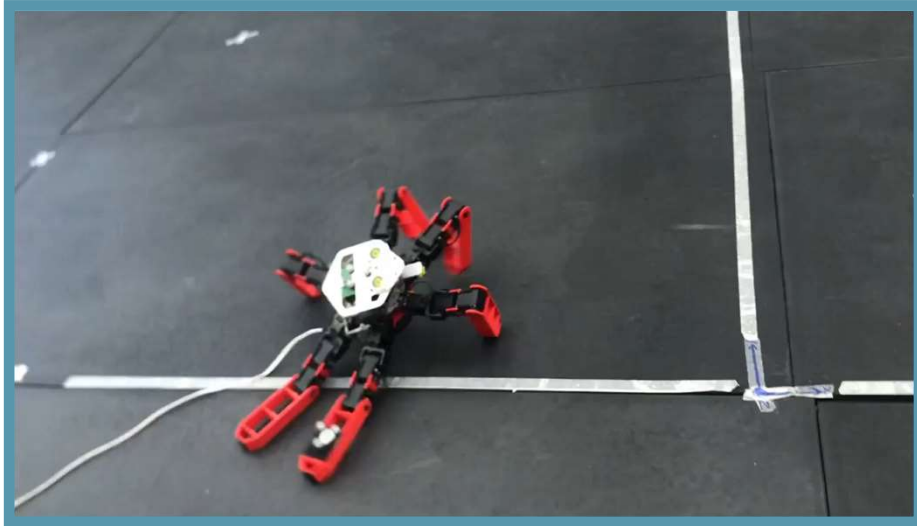
[2] J. Dupeyroux, J.R. Serres, S. Viollet, *Science Robotics*, 2019.

[3] PhantomX Metal Hexapod MK-III Kit, Ref. KIT-MKIV-XL-S, 2020.

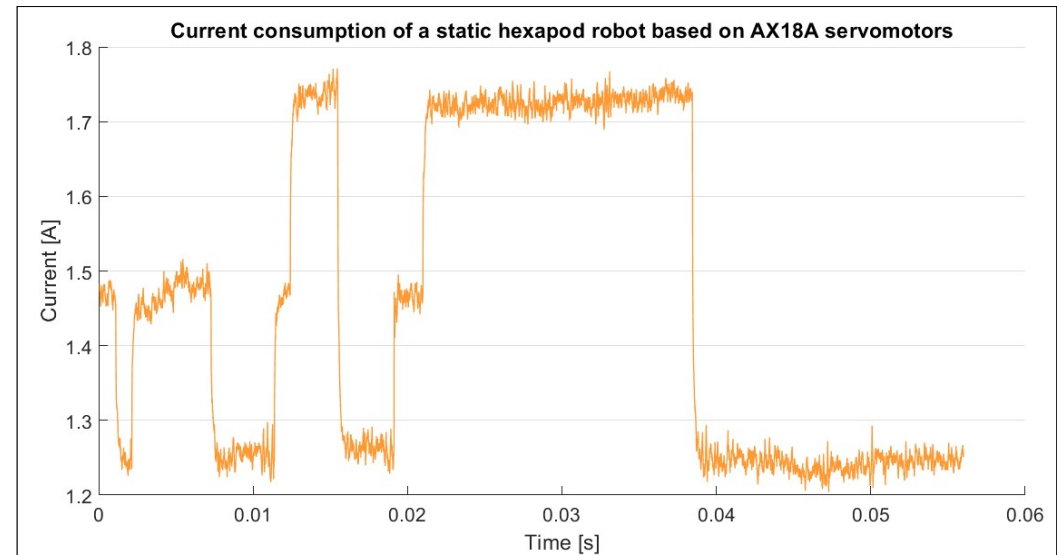
[4] J. H. Barron-Zambrano, C. Torres-Huitzil, B. Girau, *Neurocomputing*, Volume 170, 2015.

Design and manufacture of a bio-inspired hexapod

The shortcomings of today's robots



I. Brodoline et al, Workshop GDR 2088 BIOMIM 1st Annual Meeting, Nice, France, 2020.



Advantages:

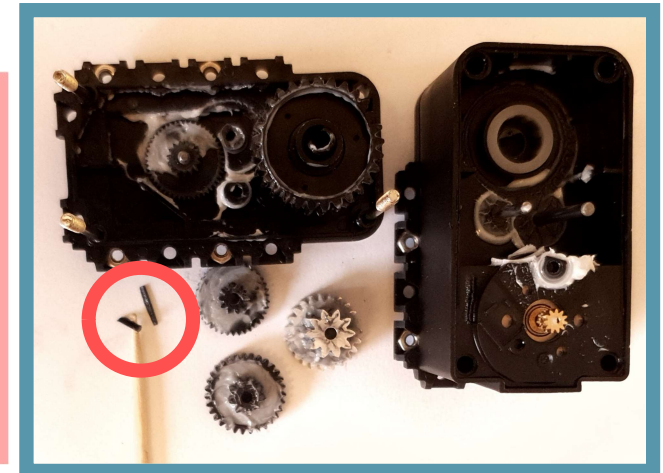
+

- Compact
- Simple to implement
- Easy to control (speed, position)
- Numerous models available

Disadvantages:

-

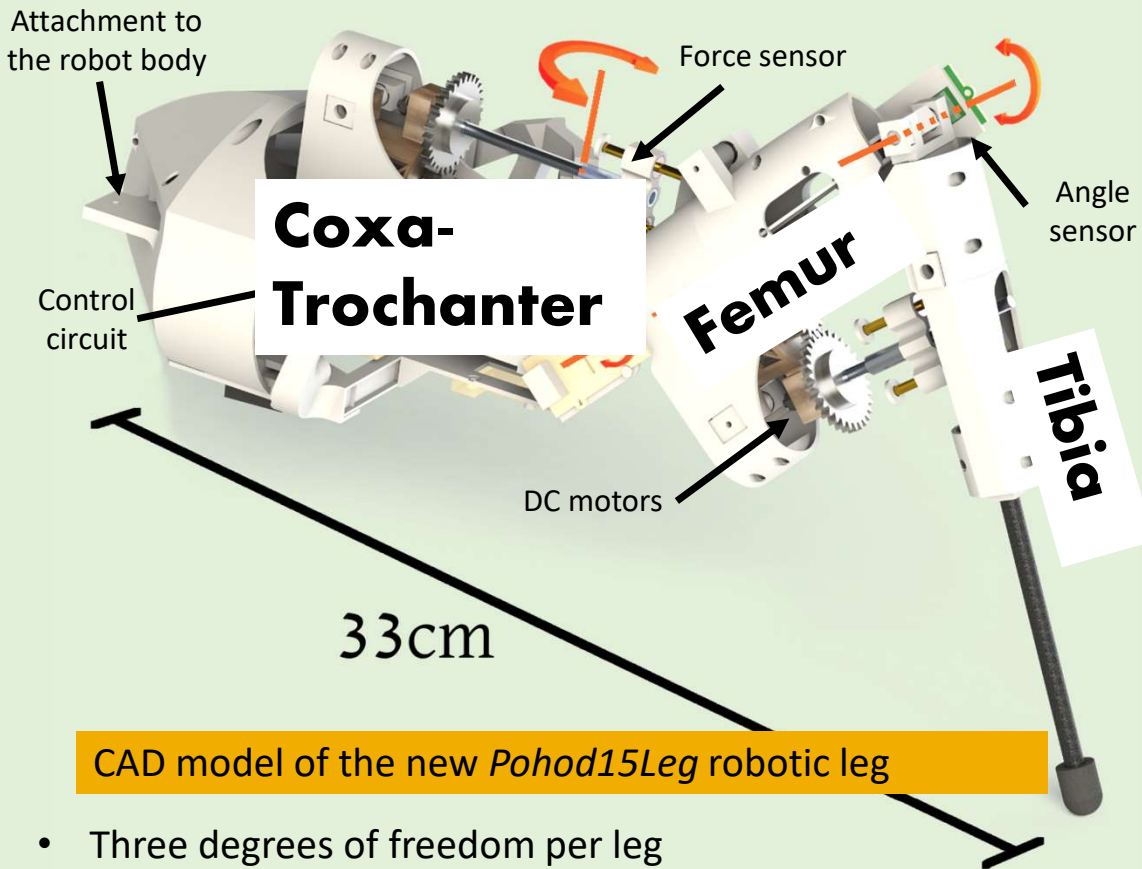
- Continuous energy consumption
- Overheating
- Fragile gears
- High price



Servomotor with broken teeth

Design and manufacture of a bio-inspired hexapod

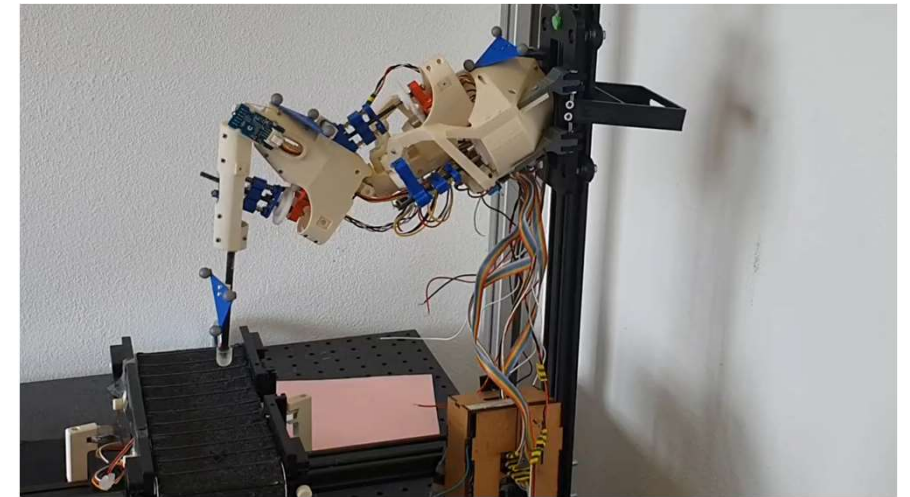
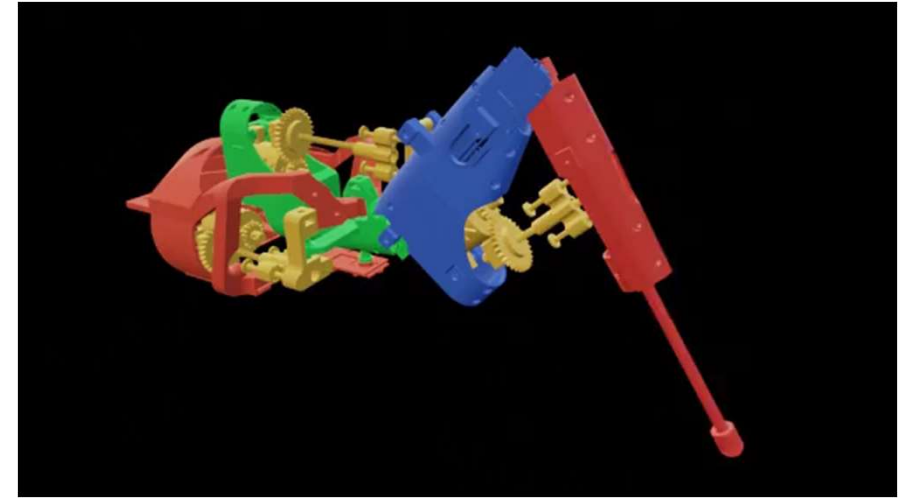
Technological choices for the *Pohod15Leg* leg



CAD model of the new *Pohod15Leg* robotic leg

- Three degrees of freedom per leg
- Angular and force sensors
- Dimensions consistent with the ant *Cataglyphis fortis* (1:30)
- Fully 3D printed structure (420g)

Demonstration of the degrees of freedom of the *Pohod15Leg* leg

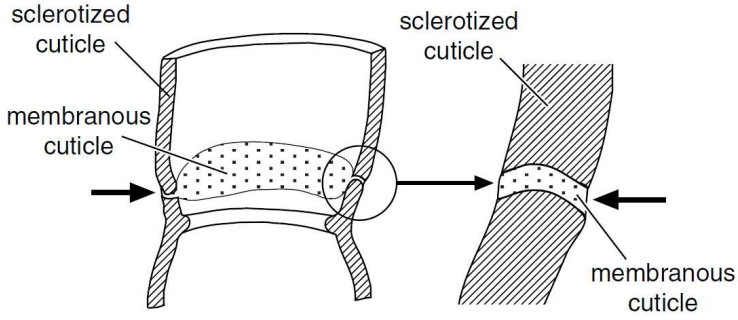


Video of *Pohod15* walking on a treadmill.

Design and manufacture of a bio-inspired hexapod

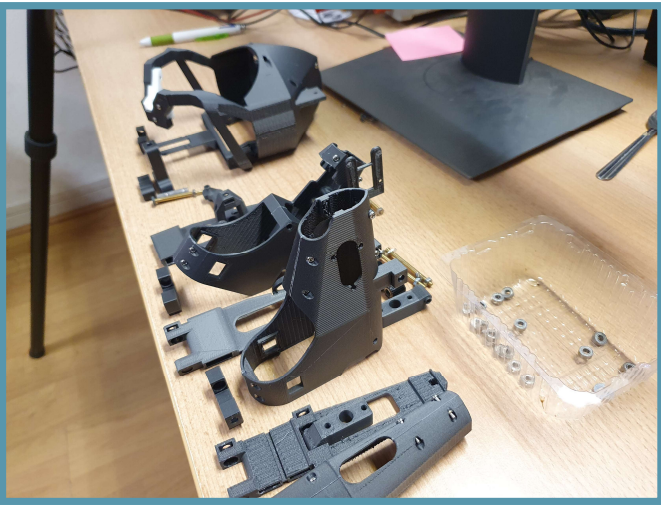
The leg actuator

Resistance & Overheating

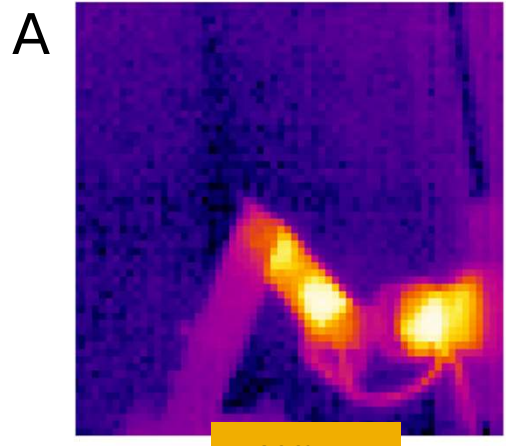


Cross-sectional diagram of an insect leg joint

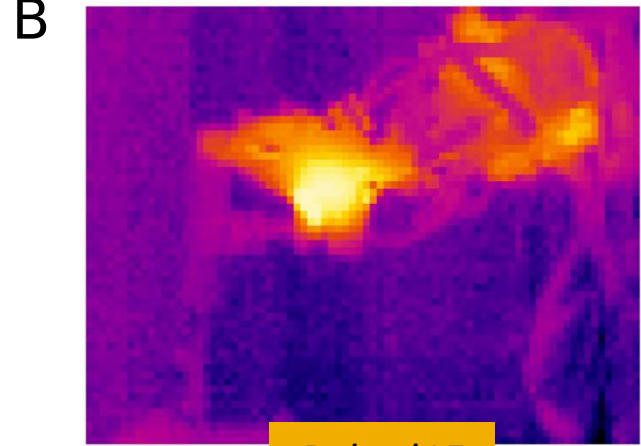
R. F. Chapman et al, The Insects Structure and Function, 2012.



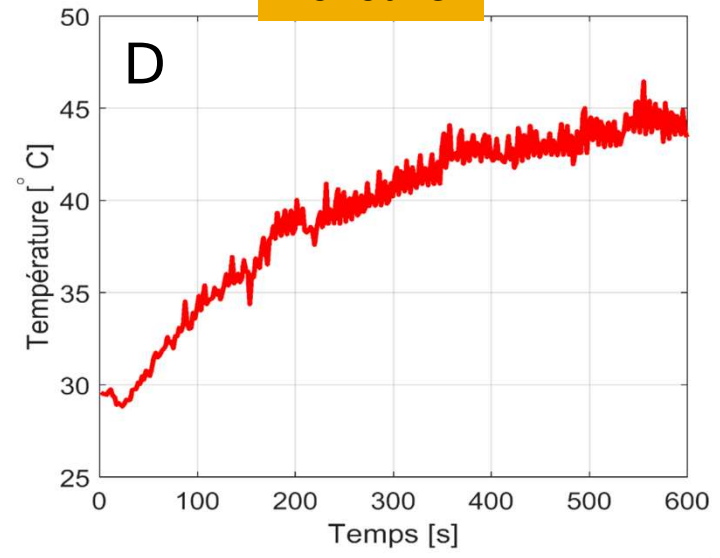
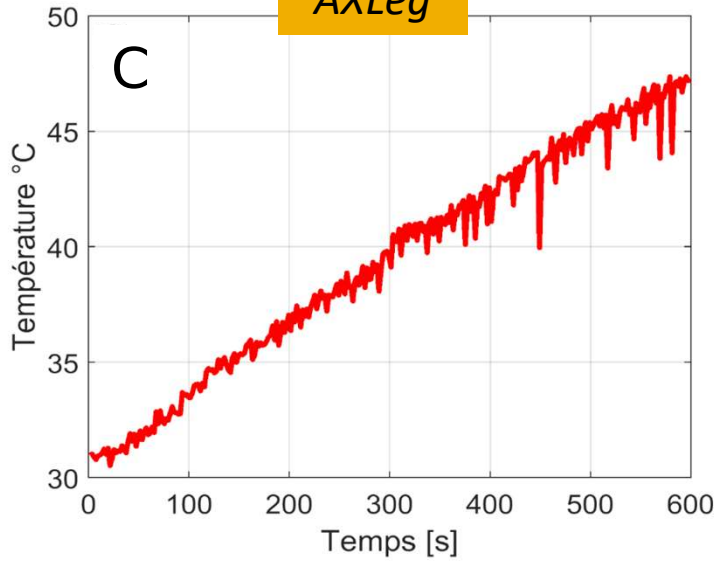
Evolution of the average temperature of a hexapod leg after 10min of walking



AXLeg

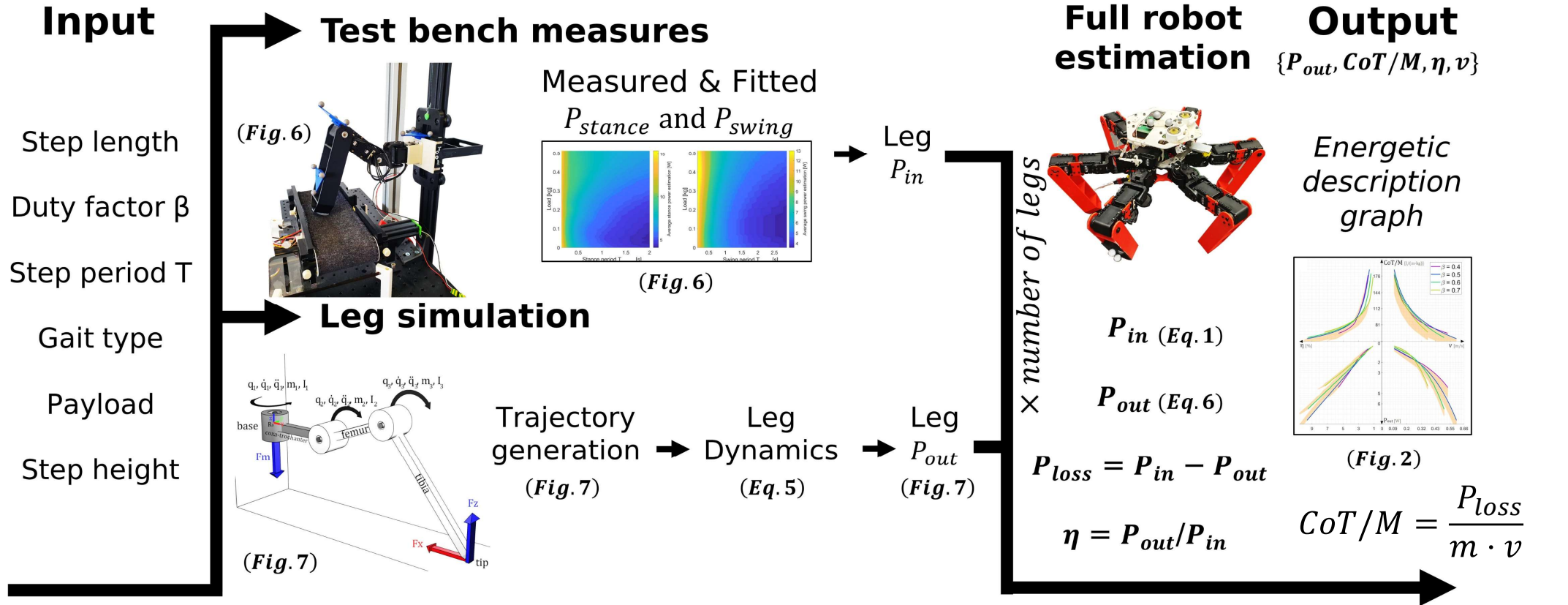


Pohod15



Performance evaluation of a hexapod robot

Estimating the energy profile



Thermodynamics of animal locomotion
E. Herbert et al, Physical Review Letters, 2020.

Thermodynamics of metabolic energy conversion under muscle load
C. Goupil et al, New Journal of Physics, 2019.

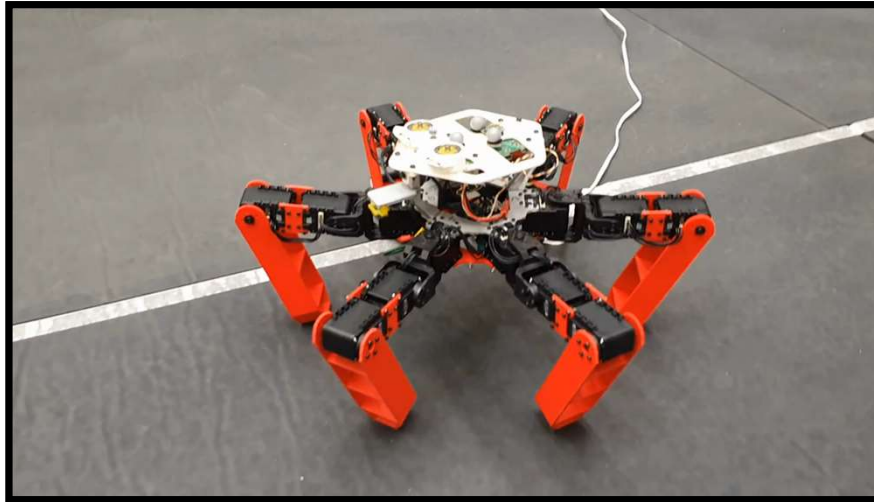
Four energy descriptors : $\{P_{out}, \eta, CoT/M, v\}$

Ilya Brodoline, Emilie Sauvageot, Stéphane Viollet, and Julien R Serres. (2024). Shaping the energy curves of a servomotor-based hexapod robot. *Scientific Reports*, 14(1), 11675. <https://doi.org/10.1038/s41598-024-62184-y>

Performance evaluation of a hexapod robot

Measuring the cost of transport

AntBot experiment in the Mediterranean flight arena

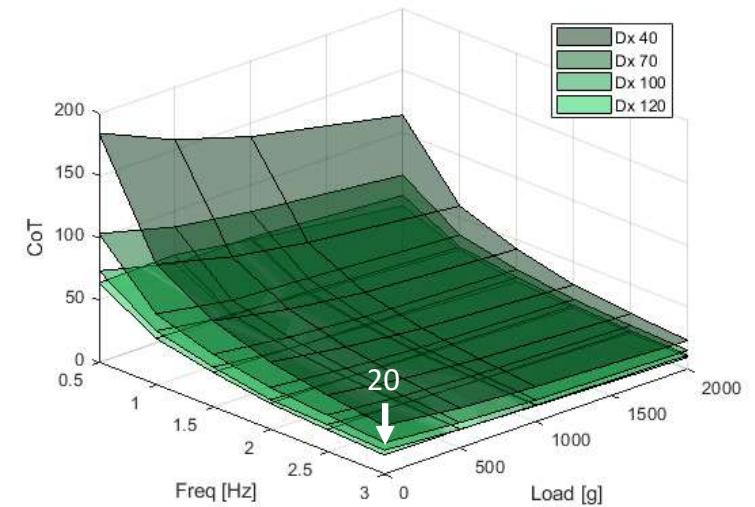
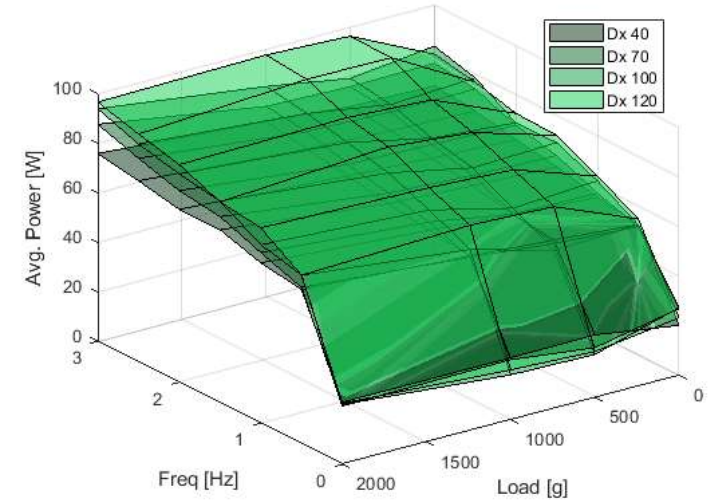


Specific resistance

$$\varepsilon [\emptyset] = \frac{P_{in}}{m \cdot g \cdot v}$$

P_{in} : power used to move [W]
 m : mass set in motion [kg]
 g : acceleration of gravity [m/s²]
 v : speed [m/s]

Average power consumed by AntBot



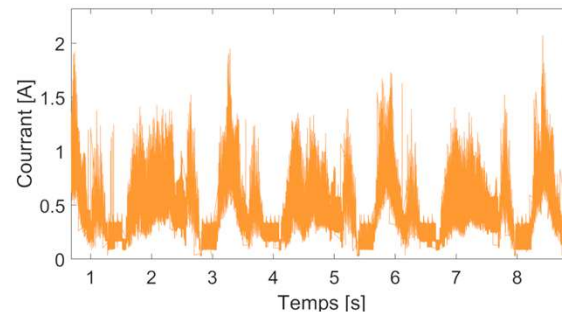
CoT measured for AntBot

Performance evaluation of a hexapod robot

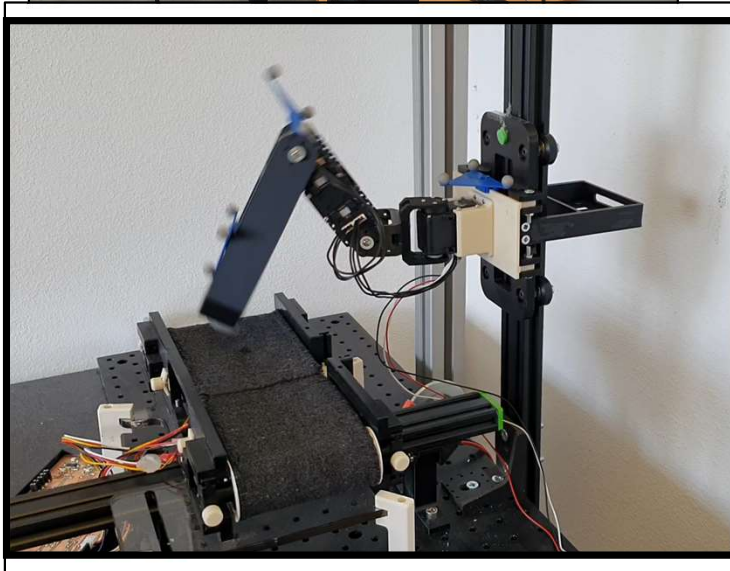
The MiMiC-Ant test bench



MiMiC-Ant test bench, with Pohod15 installed.



MiMiC-Ant test bench, with AXLeg installed.



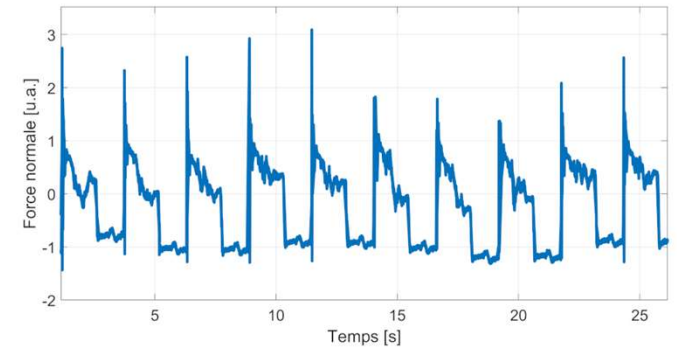
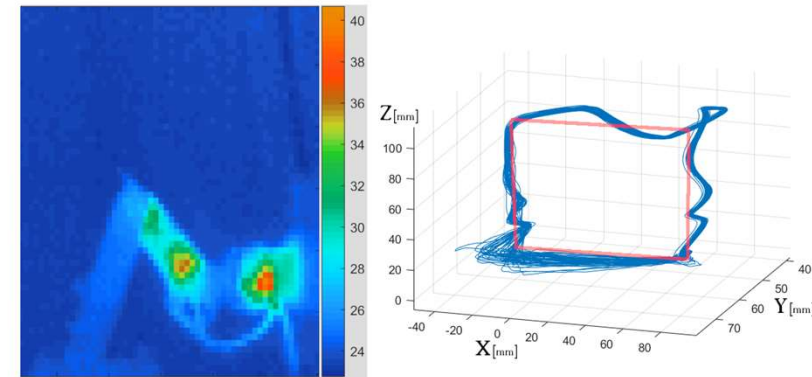
I. Brodoline, P. Moretto, S. Viollet, V. Fourcassié, and J. R. Serres, *IEEE Instrumentation & Measurement Magazine*, 2022.

J.R. Serres, V. Fourcassié, I. Brodoline, P. Moretto, S. Viollet, *Projet MiMiC-ANT, PEPS INSIS* 2020.



Define a standardised procedure for identifying the energy profile of a hexapod robot

Example of test bench measurements

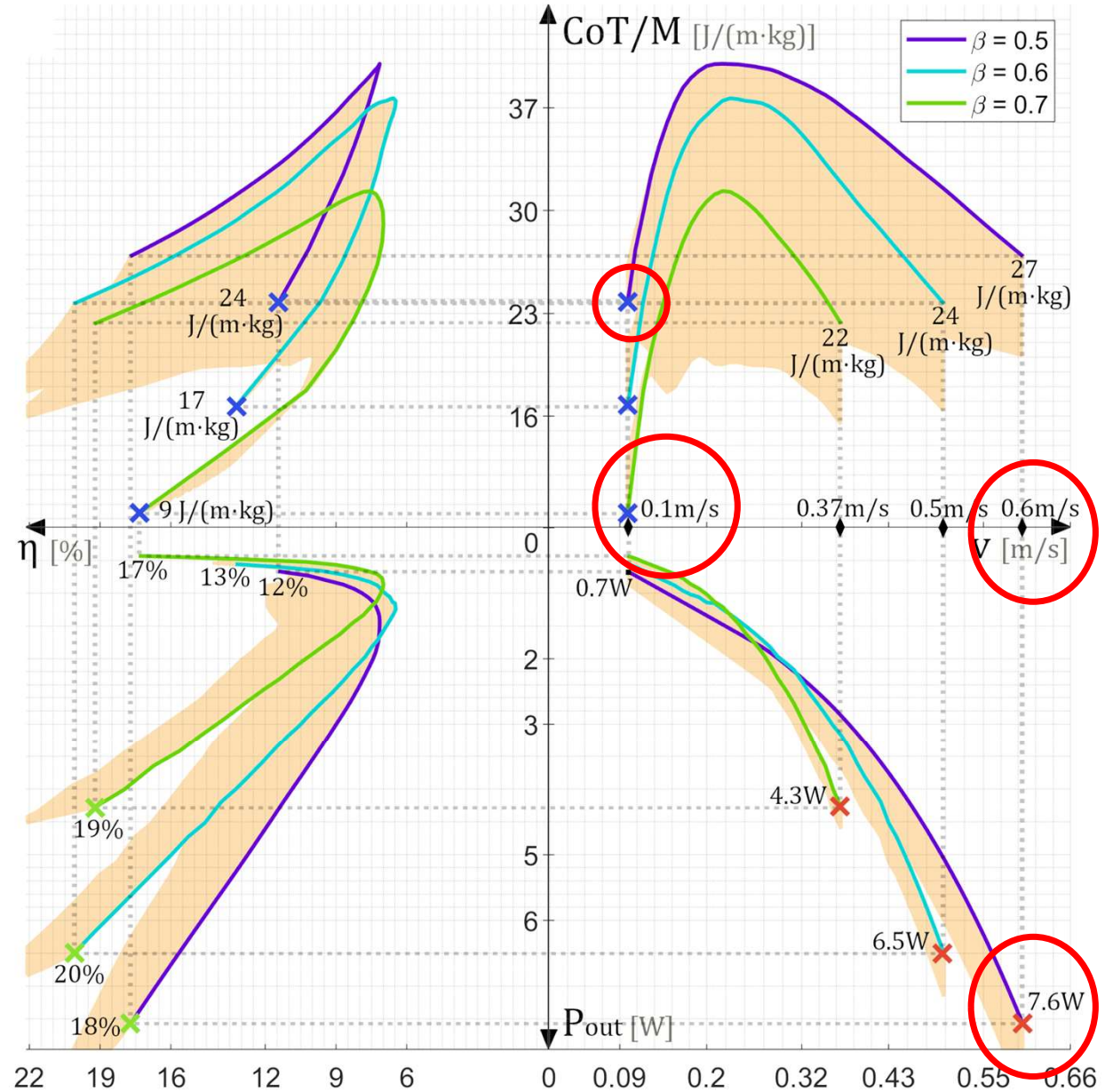


Measuring the performance of a hexapod robot

The optimal energy profile

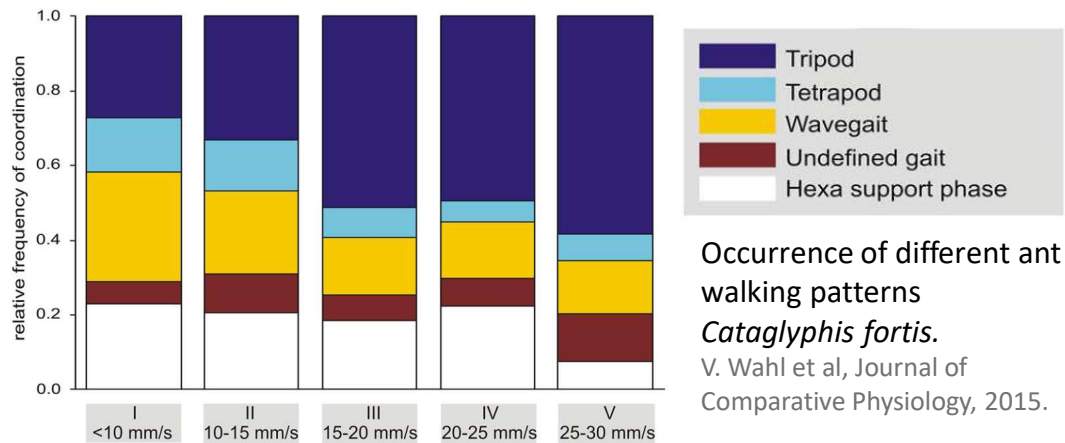
Optimized energy description of the hexapod if it has several operating points. This is achieved by reducing the P_{in} power consumption by 36W.

- X CoT/M minimum
- X Maximum energy efficiency
- X Maximum mechanical output power



Comparison of two leg-based hexapods *AXLeg & Pohod15Leg*

Indicateur de performance	AXLeg	Pohod15Leg
Masse [kg]	1,9 kg	2,5 kg
Fréquence [Hz]	0,37	0,31
Longueur des pas [mm]	106	115
Vitesse [cm/s]	7,8	7,1
Précision des pas [mm]	±3	±1
Propulsion inefficace	5 %	9 %
Puissance moy. [W]	28	81
Puissance moy. statique [W]	9	0
Résistance spécifique ϵ	19	47
Degré d'élévation de température (DET)	3,2°C/min	2,1°C/min



Conclusion

Outcomes

- Identification of structural shortcomings in bio-inspired hexapods.
A single optimum operating point
New actuators ?
- Proposal for a new bio-inspired *Pohod15Leg* open source leg design.
Open science project
Hexapod cost < 3000 €
- Definition of a new method for estimating and optimizing the performance of a hexapod robot using a single leg.
Hexapod evaluation method
Reduction in the number of prototyping iterations

