ANIMAL ROBOTS

BirdBot achieves energy-efficient gait with minimal control using avian-inspired leg clutching

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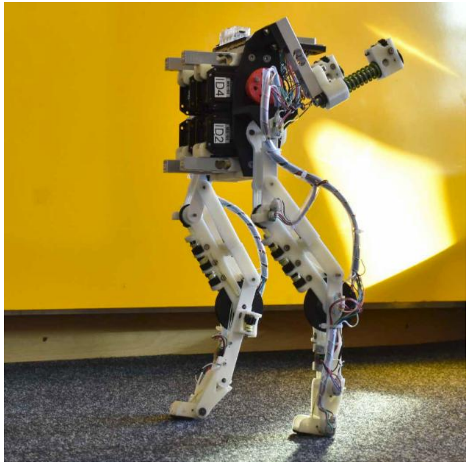
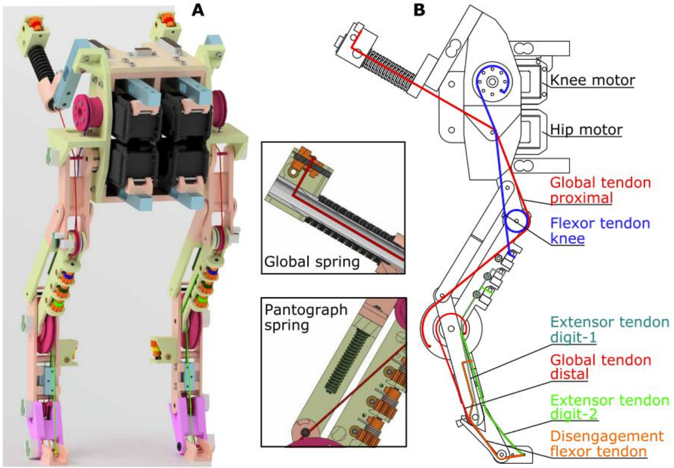
Presentation by: Aurélien Genin, Christopher Xu, Dalia Somekh





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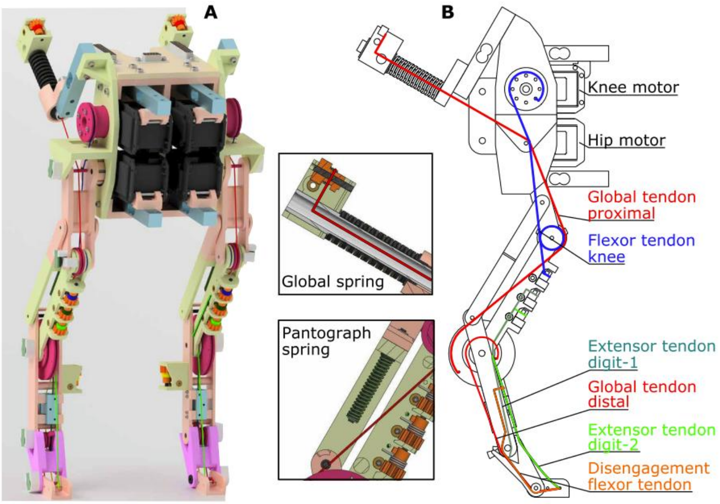
Summary of the article

Mechanical design of a biped robot-> Fast bipedal running robots

Network of tendon and springs with a bistable joint to create a mechanically energy-efficient leg that switches configuration for swing and stance phases



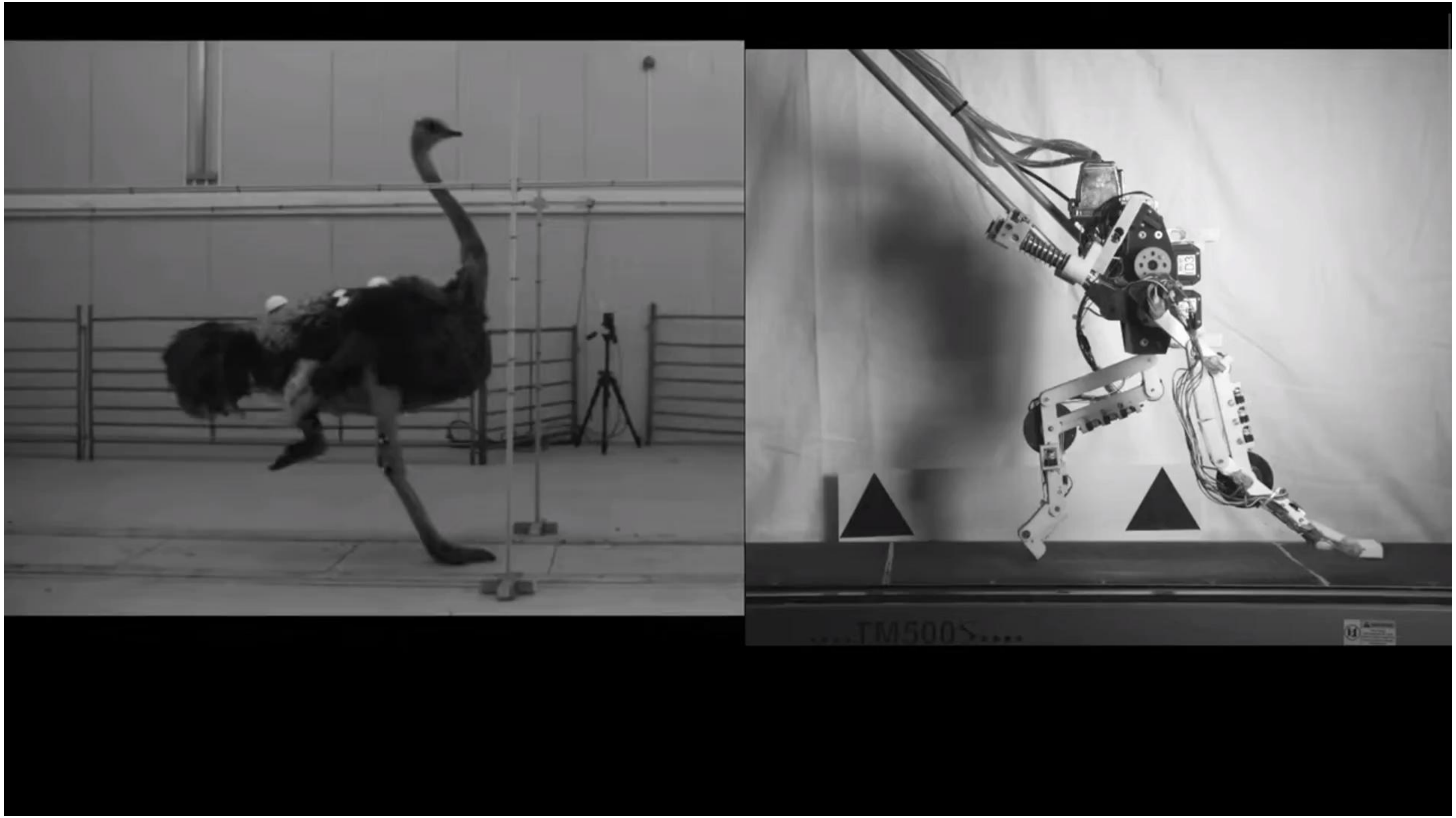
Contact-triggered mechanism

Feedforward control, without rapid feedback => CPG

Only 2 actuators per leg

Very scalable

Inspired by ostriches



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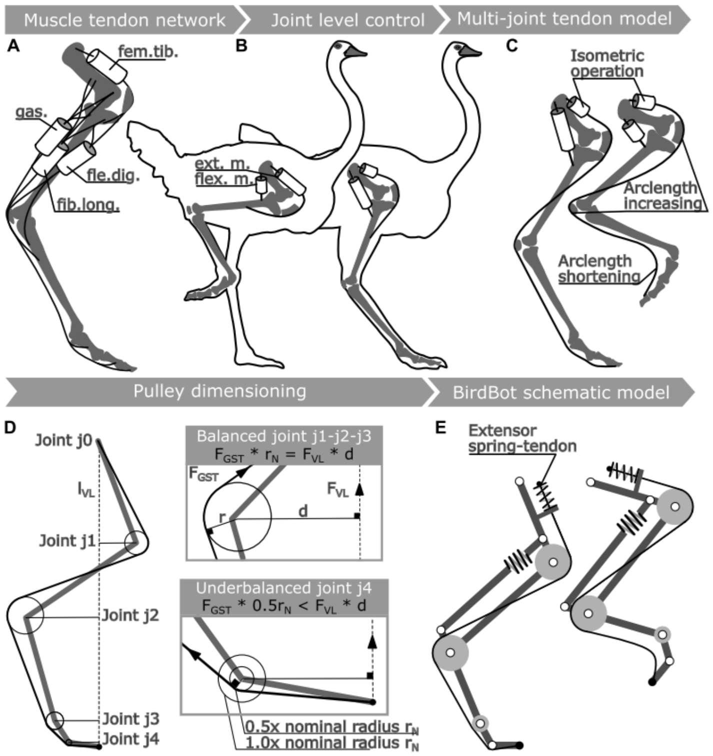
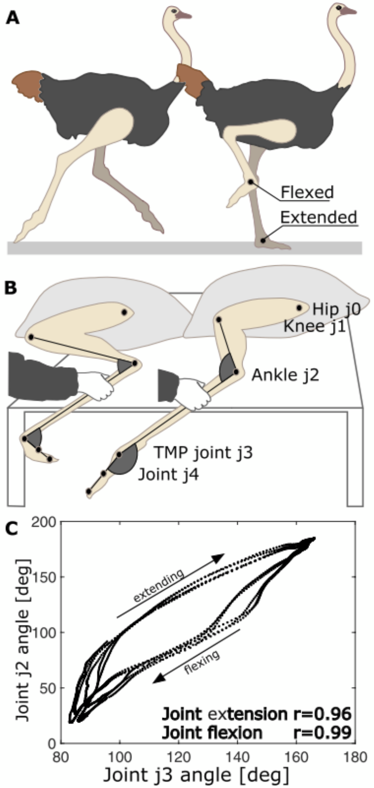




Mechanical coupling between ankle and tarsometatarso-phalangeal (TMP) joints

Multi-joint tendons allow for only two muscles to fully extend and flex the leg

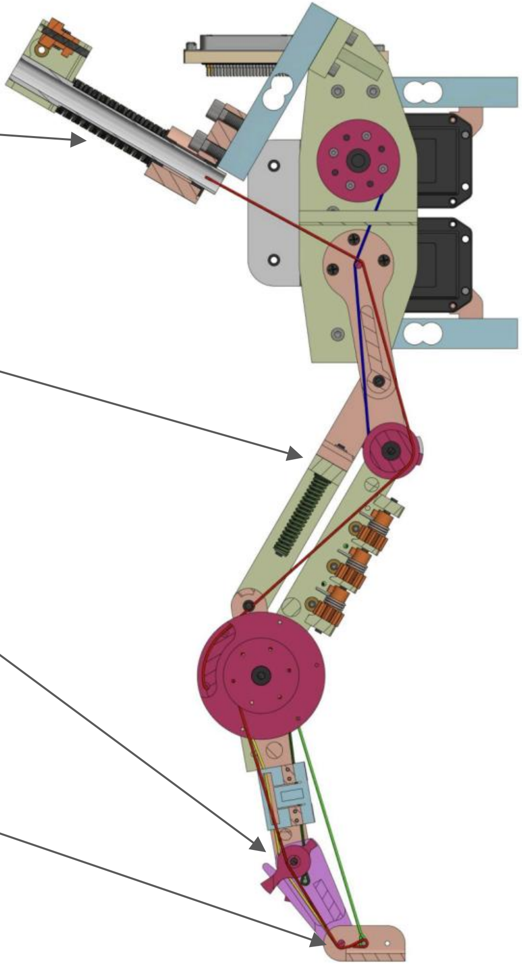
Main design components

Gravity compensating spring

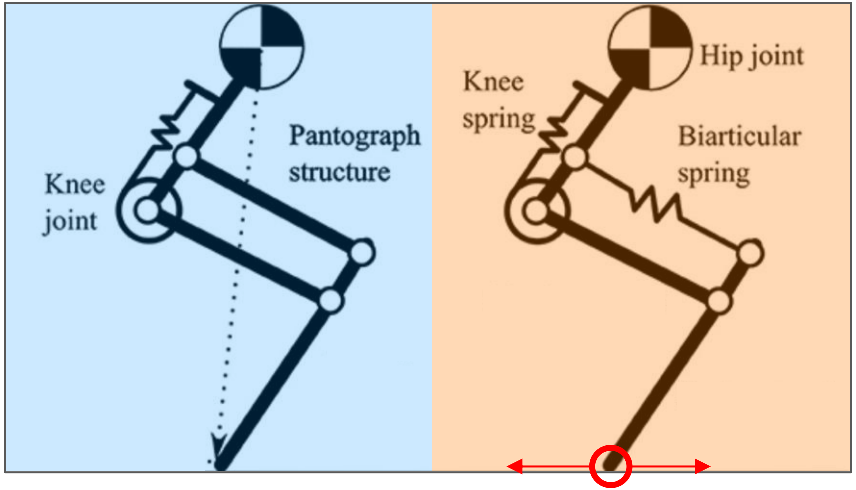
Biarticular spring pantograph

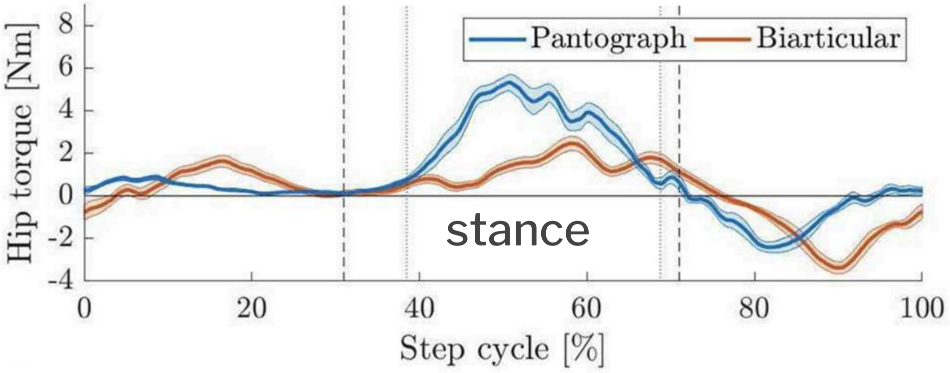
Toe-controlled tendon clutch

Pulley imbalance for compliant toe



Biarticular spring reduces hip power





Biarticular spring creates elasticity on leg angle during stance

Hip joint is an oscillating motion, so a spring recycles energy

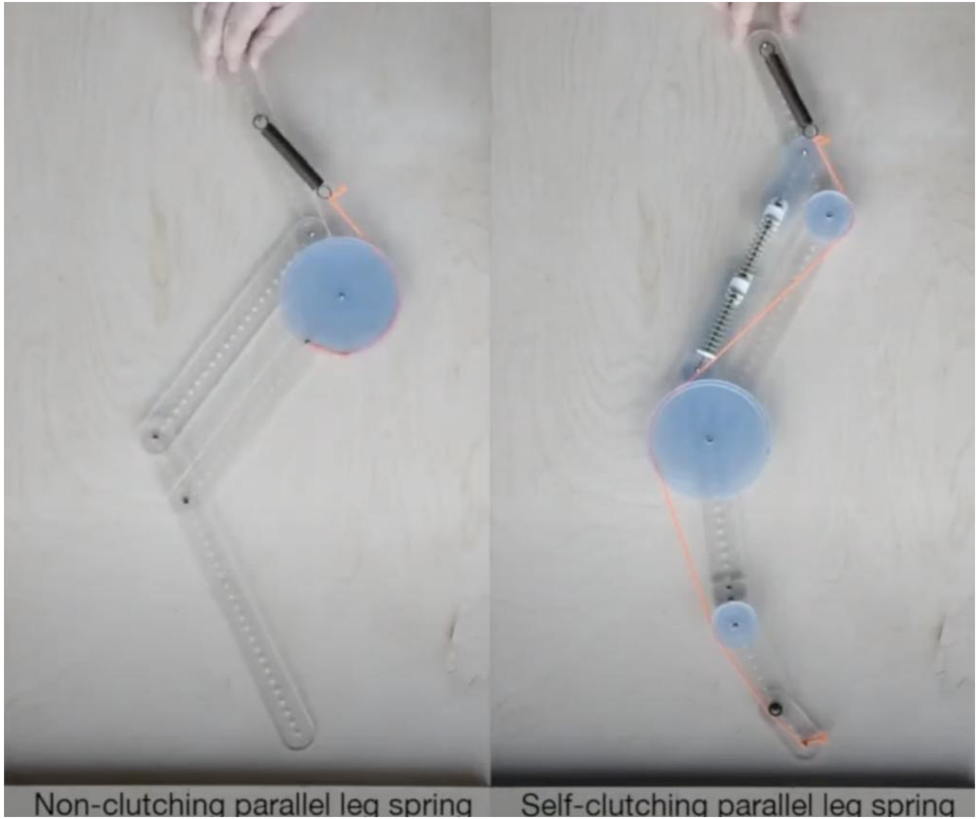
F. Ruppert, A. Badri-Spröwitz, Series elastic behavior of biarticular muscle-tendon structure in a robotic leg. *Front. Neurorobot.* 13, 64 (2019).

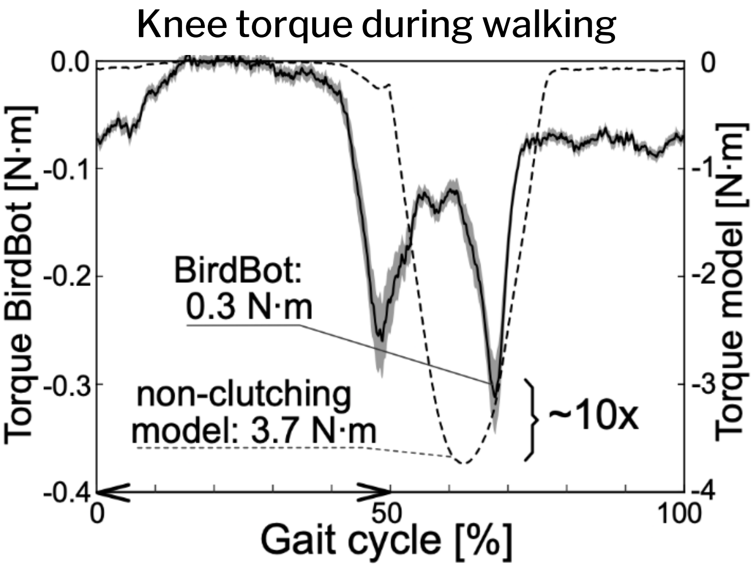
Clutching spring reduces knee power

BirdBot achieves energy-efficient gait with minimal control using avian-inspired leg clutching

Movie S7: Design comparison, 3 panels

Spring clutch reduces knee power

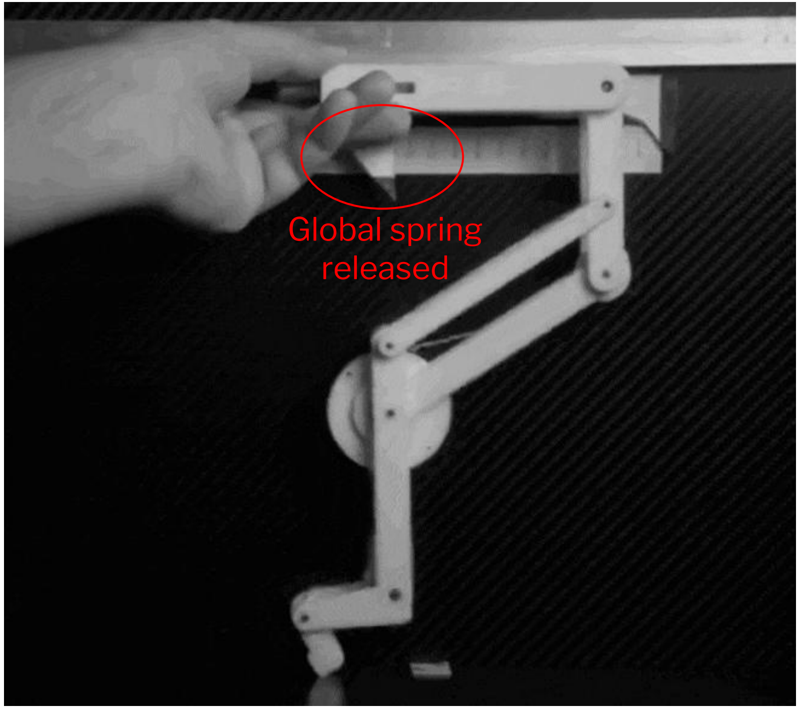


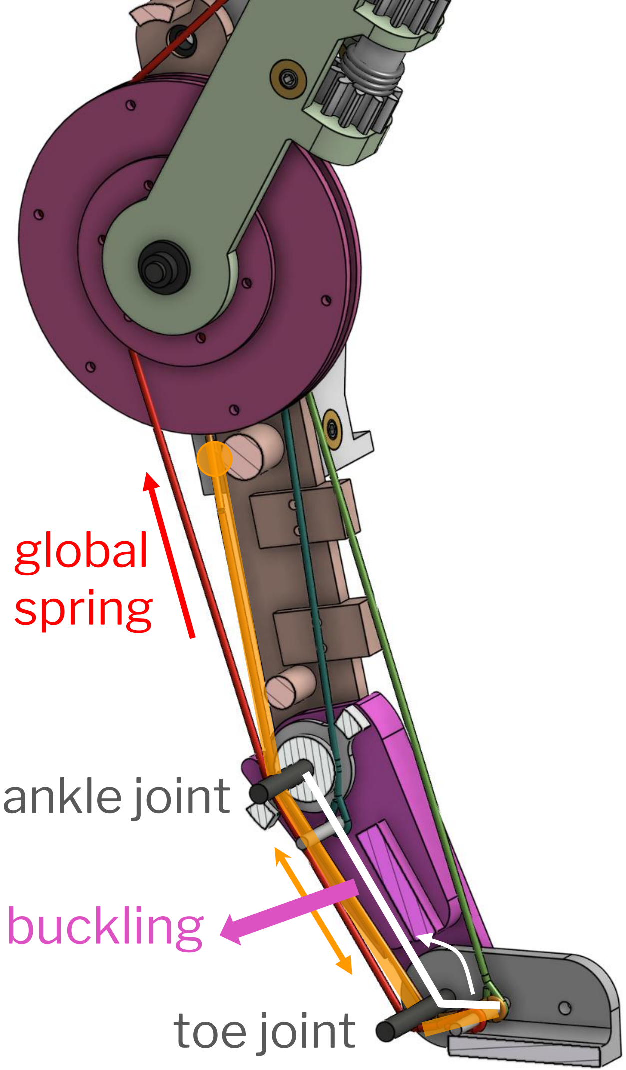


- Knee is hard to lift   If toes are off the ground, knee is easy to lift

Disengagement tendon

Ankle joint buckles due to coupling with toe joint

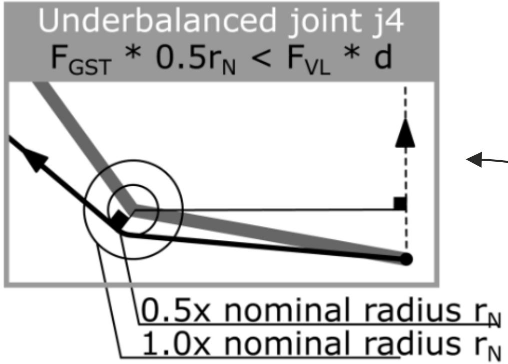


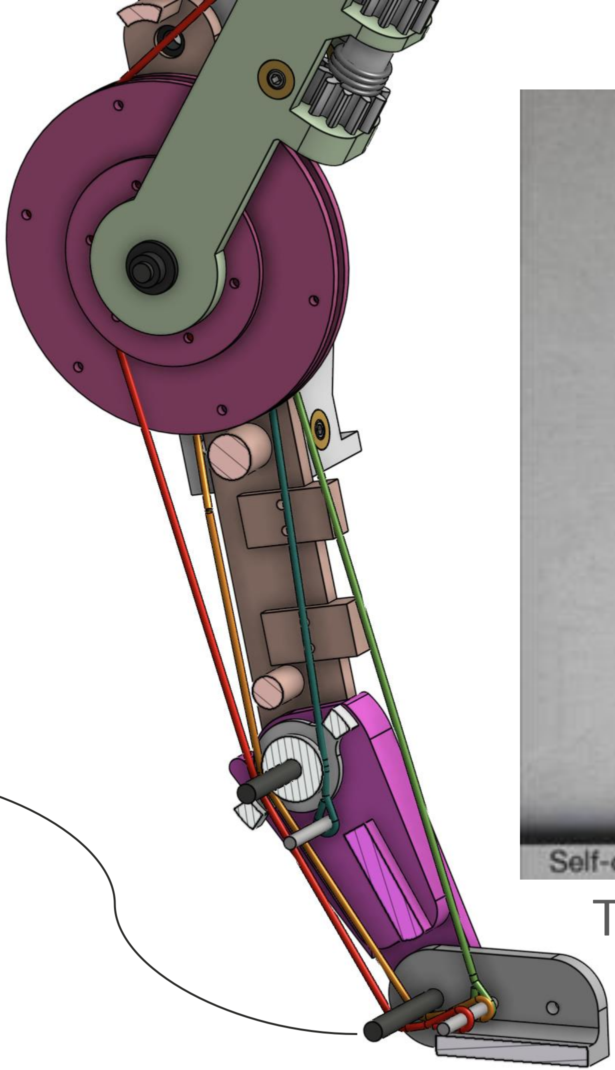


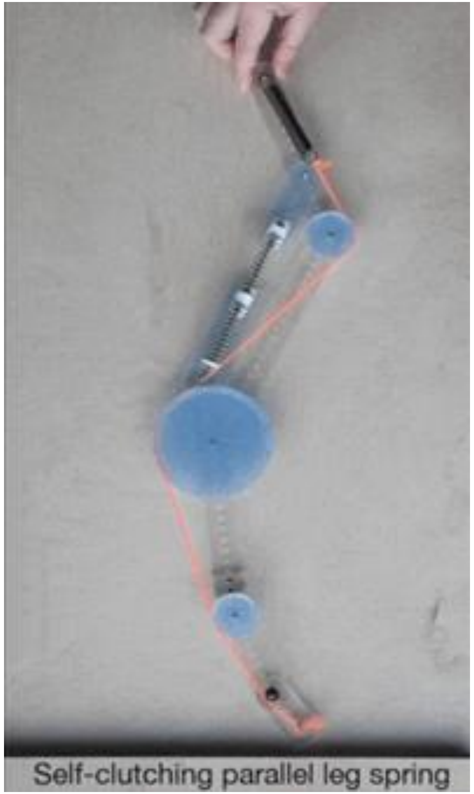
- Knee becomes easy to lift at certain leg

Pulley imbalance

Small toe pulley creates a very compliant toe, making the global spring active for any ground contact







Toe bends first!

Open-loop position control with CPG

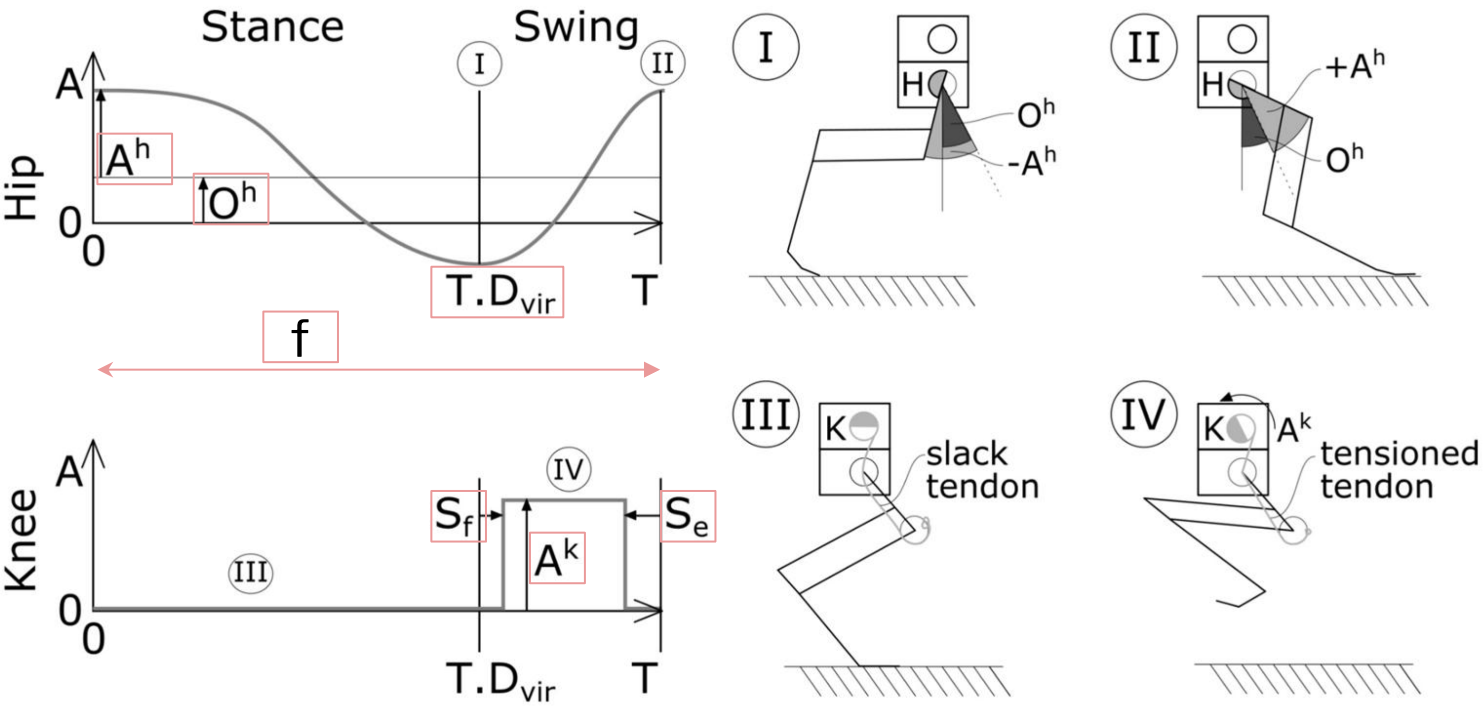
Simple control without sensors, only a few tuning parameters

$$\dot{\phi}_i = 2\pi f + \sum_{i \neq j} c_{ij} \sin(\phi_j - \phi_i - \varphi_{ij})$$

$$\dot{a}_i^h = \boxed{\alpha}(A_i^h - a_i^h)$$

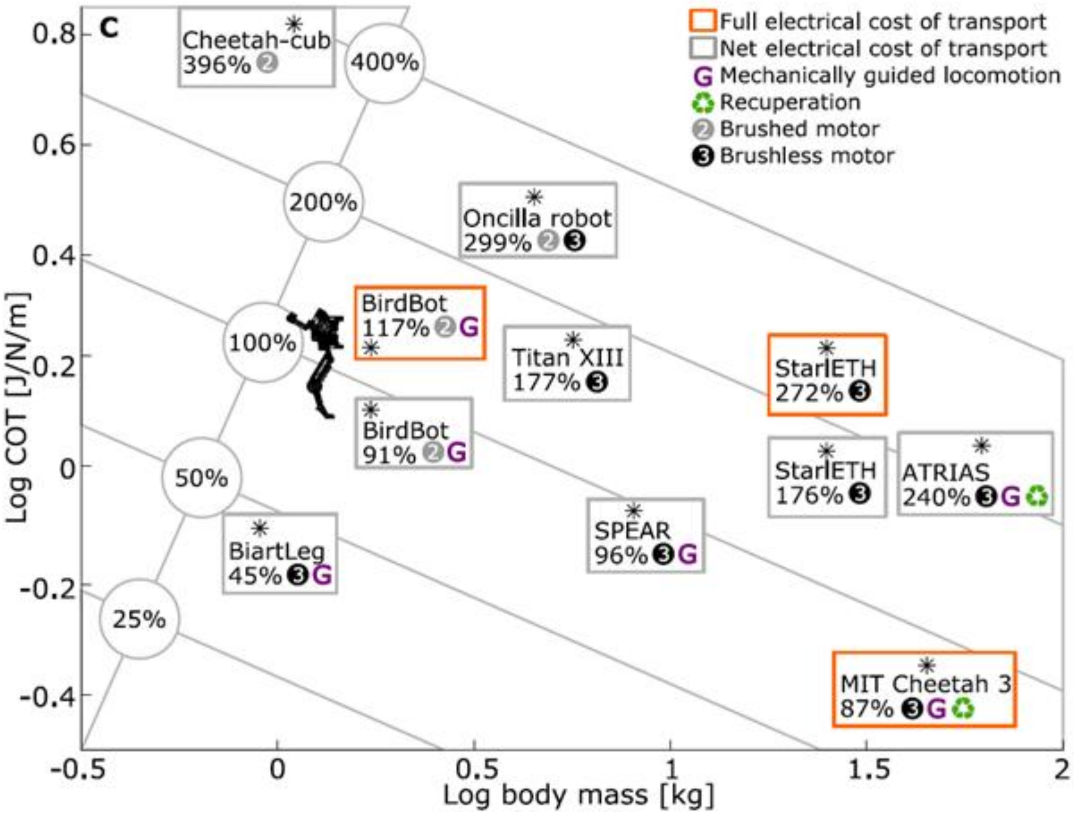
$$\dot{o}_i^h = \alpha(O_i^h - o_i^h)$$

8 hand-tuned parameters



Cost Of Transport (COT)

- BirdBot's relative net COT of 91%, comparable to running animal with similar body mass.
- BirdBot's COT is roughly ¼ of that of Cheeta-cub.



Electrical COT of selected legged robots relative to body mass on a logarithmic scale.

Pros and Cons

Pros:

- No actuation needed for standing upright.
- Rapid automatic stance-swing transition.
- Simple control.
- Possibility of scalability.
- Energy efficiency.

Cons:

- Complex mechanical structure.
- Limited speed range.

Citations

10 citations and more than 15’000 downloads according to Science Robotics.

“Parallel-elastic joints can improve the efficiency and strength of robots by assisting the actuators with additional torques.”

Filip Bjelonic, Joonho Lee, Philip Arm, Dhionis Sako, Davide Tateo, Jan Peters, Marco Hutter, Learning-Based Design and Control for Quadrupedal Robots With Parallel-Elastic Actuators, IEEE Robotics and Automation Letters, 8, 3, (1611-1618), (2023).

Possible exam questions

1. **Briefly explain BirdBot's clutching leg mechanism.**
   BirdBot uses a passive clutching mechanism inspired by bird anatomy. The leg's spring tendon network automatically switches between stance phase and swing phase. During stance, the leg engages a spring structure that supports the body's weight and stores elastic energy. At the end of the stance phase, the system disengages allowing the leg to flex easily. This approach enables smooth transitions between walking phases without requiring sensors or complex control systems.

2. **What are the main results in terms of Cost of Transport?**
   BirdBot shows economical locomotion with relative net COT of 91%, slightly lower than that of a running animal with similar body mass. The clutch leg design allows to reduce the knee-flexing torque to 1/10 of that of non-clutching leg design similar to Cheeta-cub. As a result, BirdBot's COT is roughly ¼ of that of Cheeta-cub and within the range of an animal of equal weight.