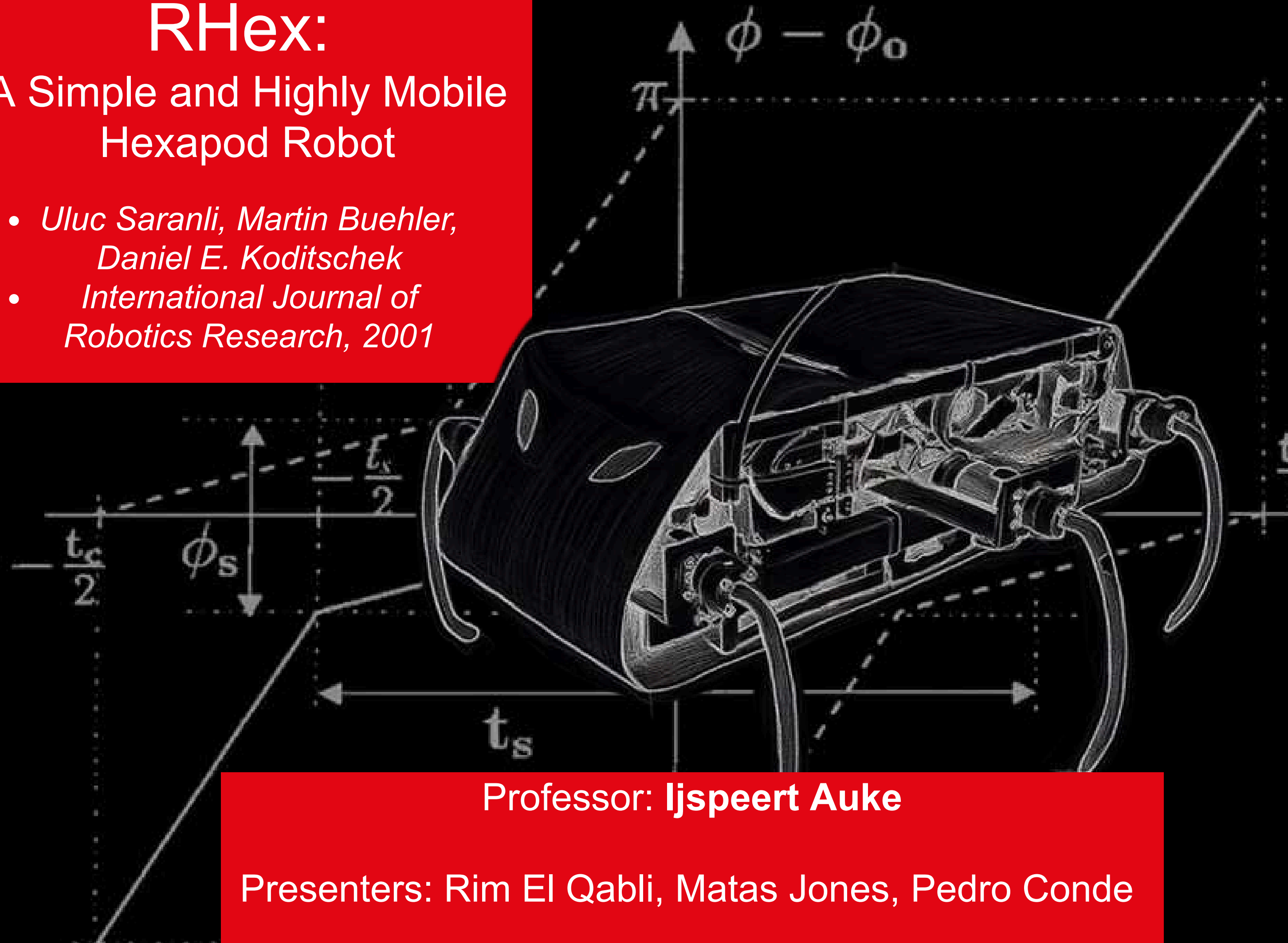


RHex:

A Simple and Highly Mobile Hexapod Robot

- *Uluc Saranli, Martin Buehler, Daniel E. Koditschek*
- *International Journal of Robotics Research, 2001*



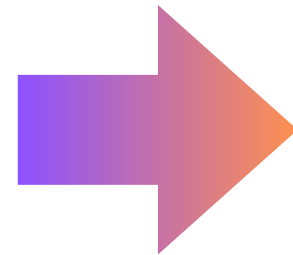
Professor: **Ijspeert Auke**

Presenters: Rim El Qabli, Matas Jones, Pedro Conde



Problem

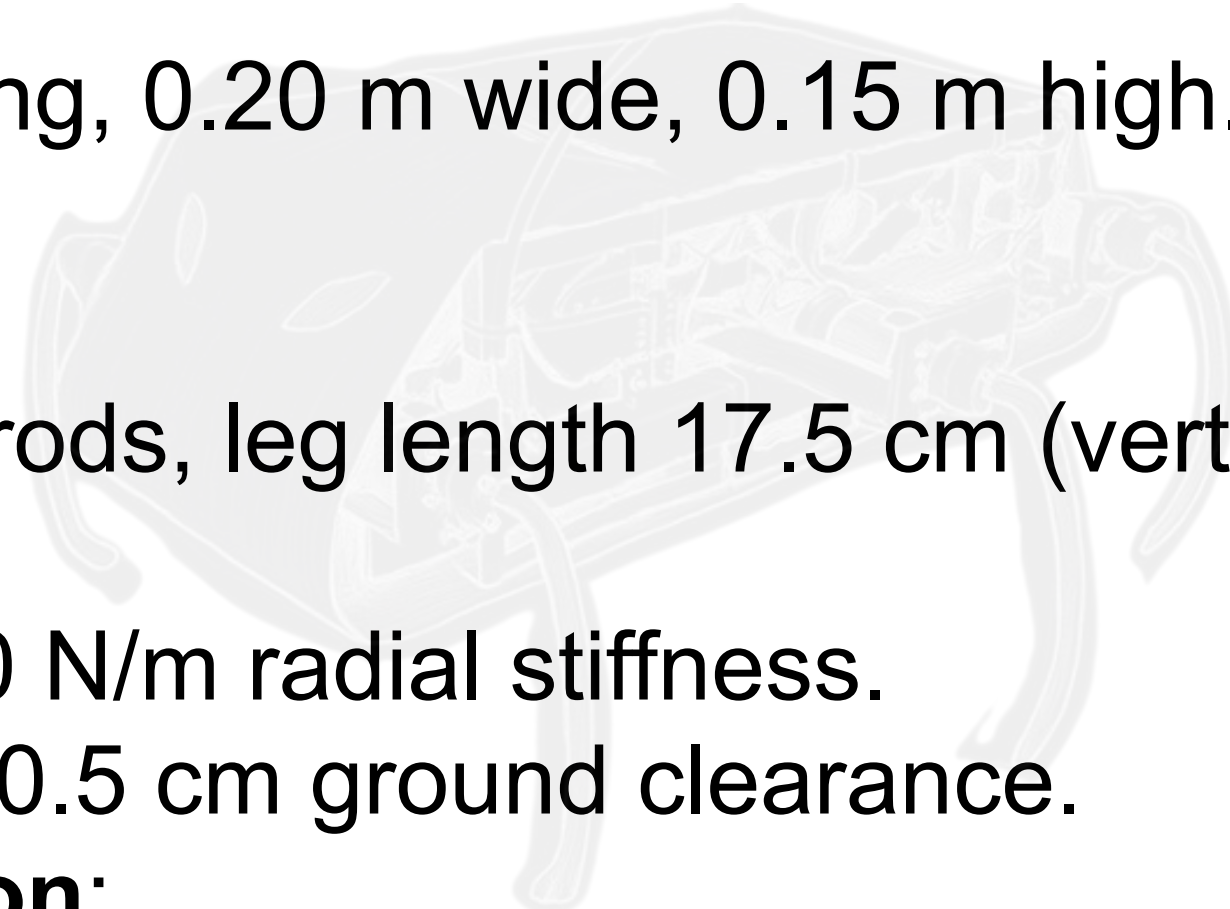
- Robots must handle **rough, uneven terrain** (rocks, steps, gaps).
- Wheeled robots struggle: earlier hexapods were **complex, heavy, often tethered**.
- As a result, they usually had to move **slowly** to stay stable.



What this paper shows

- **RHex**: simple, power-autonomous **hexapod** with **6 motorised legs**.
- Uses a **fixed tripod stepping rhythm** (clock-driven, no terrain sensing).
- Still runs at about **1 body length/s** and climbs obstacles **higher than its body clearance**.

Robot - Hardware

- **Type:** hexapod, compliant legs, one DOF per leg (revolute hip joint).
 - **Size & mass:**
 - Body \approx 0.53 m long, 0.20 m wide, 0.15 m high.
 - Mass \approx 7 kg.
 - **Legs:**
 - C-shaped Delrin rods, leg length 17.5 cm (vertical distance from ground to hip).
 - Compliant: \sim 4500 N/m radial stiffness.
 - **Body clearance:** \approx 10.5 cm ground clearance.
 - **Power & computation:**
 - Power-autonomous.
 - Onboard PC/104 controlling everything.
- 

Control - Gait - Performance

- **Control type:**
 - **Clock-driven, open-loop** in task space.
 - At each hip: **local PD control** tracks a periodic reference angle trajectory.
- **Gait type:**
 - **Alternating tripod gait:** 3 legs on the ground, 3 in the air, tripods 180° out of phase.
 - Legs rotate full circle with **slow retraction** (stance) and **fast protraction** (swing), reducing toe stubbing.
- **Design method:**
 - Inspired by **biology** (cockroach running) and **simple modeling**, parameters tuned empirically through simulation and experiments, not via formal optimization or proof.
- **Sensors:**
 - Only **joint encoders** for leg angles, **no terrain sensing**, no IMU.
- **Performance snapshot:**
 - Speed up to **0.55 m/s \approx 1.04 body lengths/s**.
 - Sustained locomotion at max speed >15–18 min on battery.

Simple and robust design

- **Hexapod** 6 legs
- **One hip motor per leg**
- **Compliant C-shaped legs** flexible mechanism
- **Legs capable of full rotation** avoids toe stubbing problem
- **No exteroception sensors** as of 2002
- Only **proprioception sensors** encoders for trajectory tracking

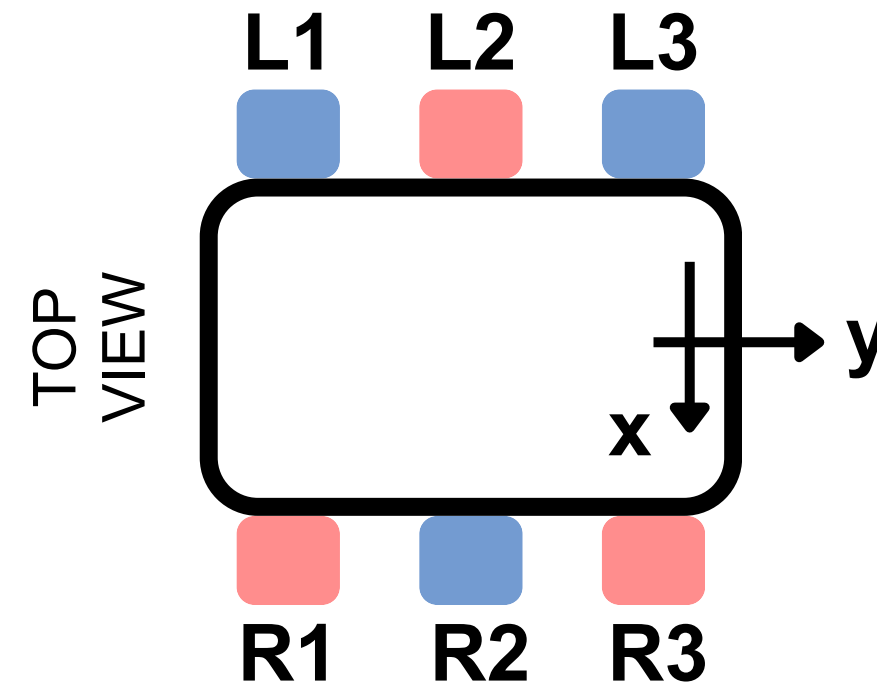


It's not a question of cost or lack of technology

Researchers wanted to prove that a **mechanically stable**, well designed robot, could traverse complex terrain **without exteroception or environment feedback control**

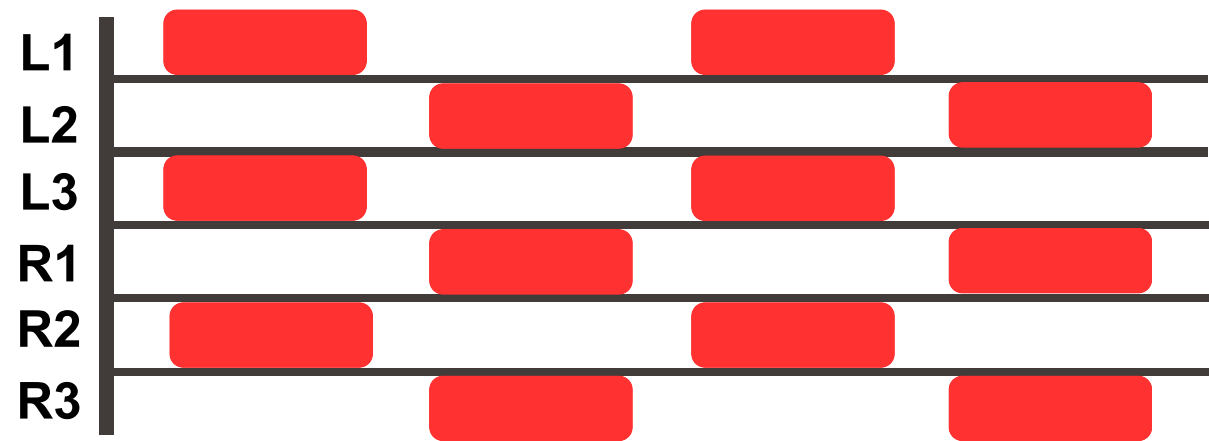
Alternating Tripod Gait

- Always at least 3 legs touching the ground at all times
- Identical **upside-down** operation
- No restrictions on **forward directionality**

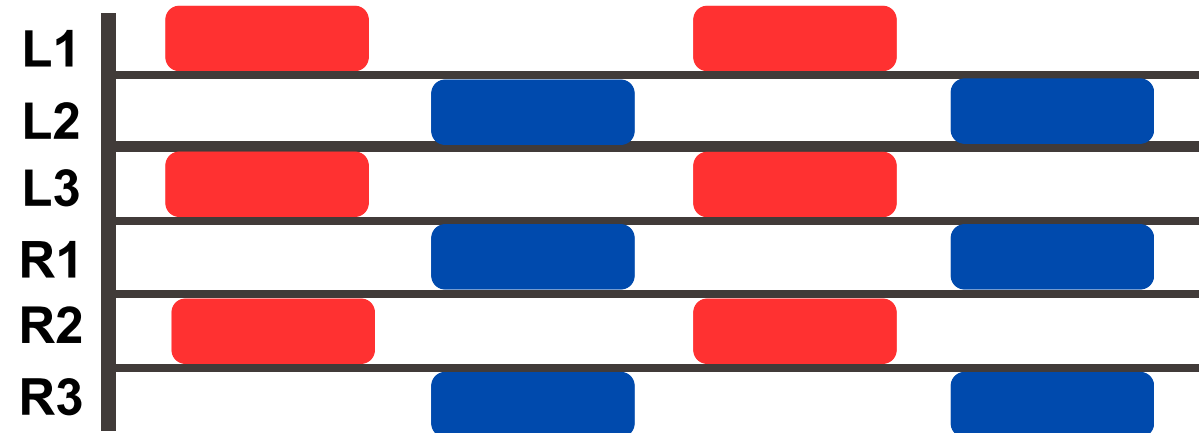


Dual Tripod Footfall Patterns

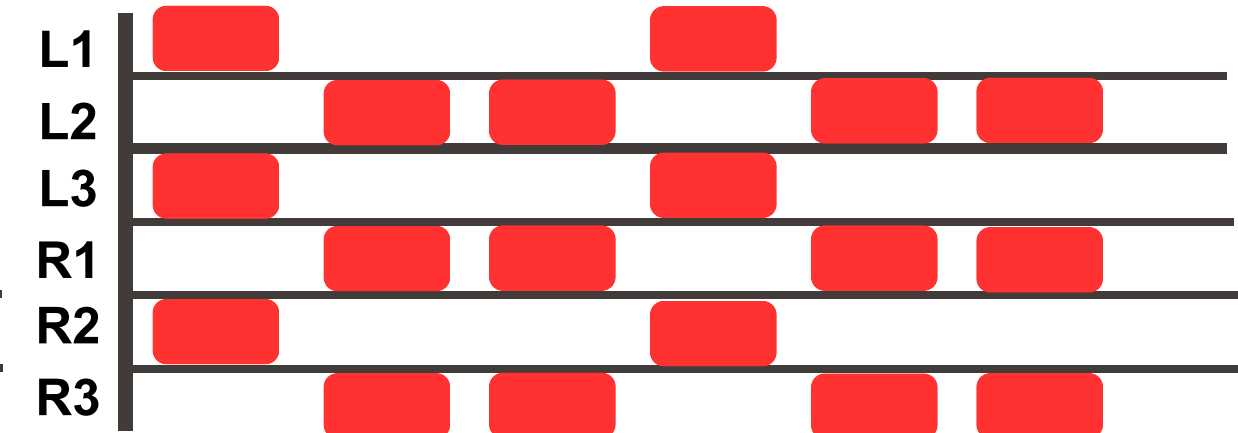
Forward



Right Rotation



Forward + Left Rotation

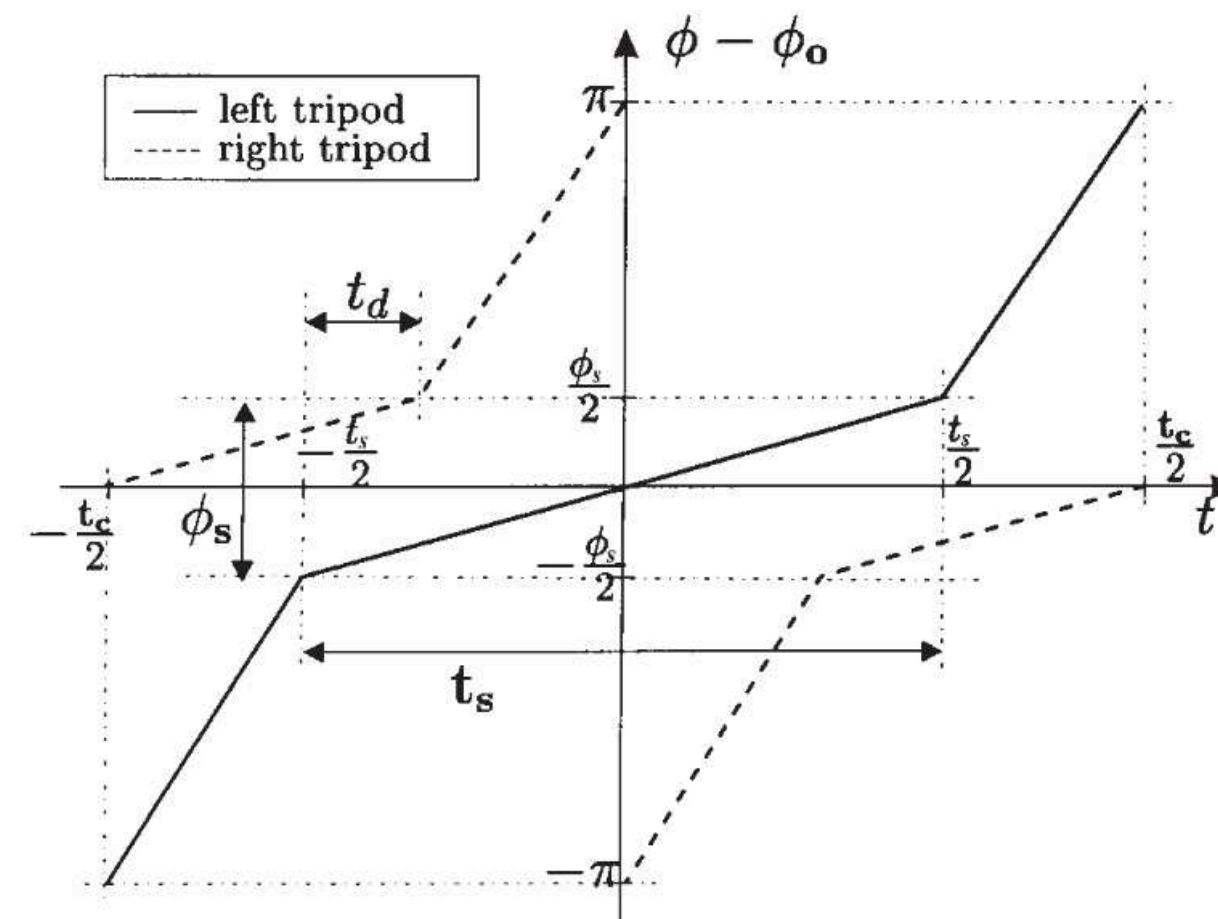


- **Slow retraction** phase (contact phase)
- **Fast protraction** phase (no contact phase)

- Motor Direction that propels RHex forward
- Motor Direction that propels RHex backward

Controllers

- Each hip is controlled by a **local controller**
- Closed-loop PD hip position tracking of an open-loop periodic reference trajectory, hand tuned coefficients
- ! Open loop task controller, closed loop hip control
- Each leg of a tripod is **actuated simultaneously**



Tripod Angle Trajectories

Equations

Each leg is assumed massless and is described in spherical coordinates $[\theta_i, \phi_i, \rho_i]^T$

Individual leg force and torque is generated by the compliant leg contacting the ground

Total force and torque on body is the sum of the 6 individual leg contributions

Individual Leg

$$\mathbf{F}_i = \begin{bmatrix} -\cos \theta_i \sin \phi_i & \sin \theta_i \sin \phi_i & -\cos \phi_i \\ \sin \theta_i & \cos \theta_i & 0 \\ \cos \theta_i \cos \phi_i & -\sin \theta_i \cos \phi_i & -\sin \phi_i \end{bmatrix} \cdot \begin{bmatrix} F_{r_i} \\ \tau_{\theta_i} / \rho_i \\ \tau_{\phi_i} / (\rho_i \cos \theta_i) \end{bmatrix}$$

$$\boldsymbol{\tau}_i = (\bar{\mathbf{v}}_i + \mathbf{a}_i) \times \mathbf{F}_i$$

Body

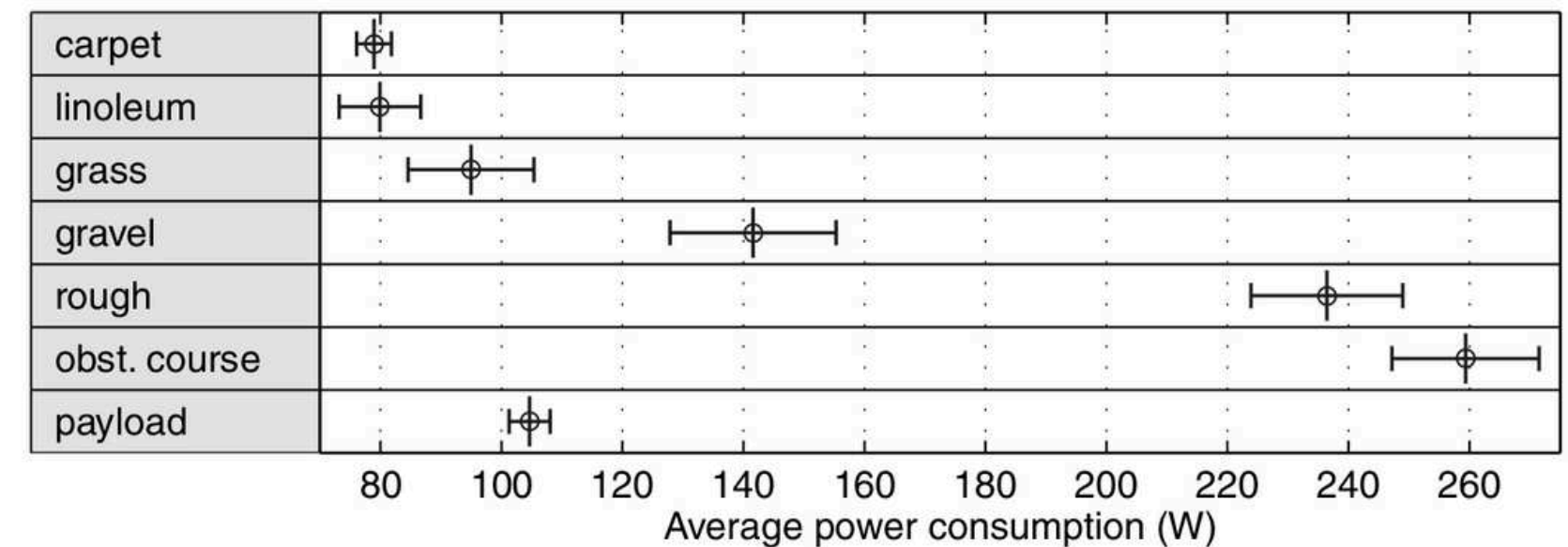
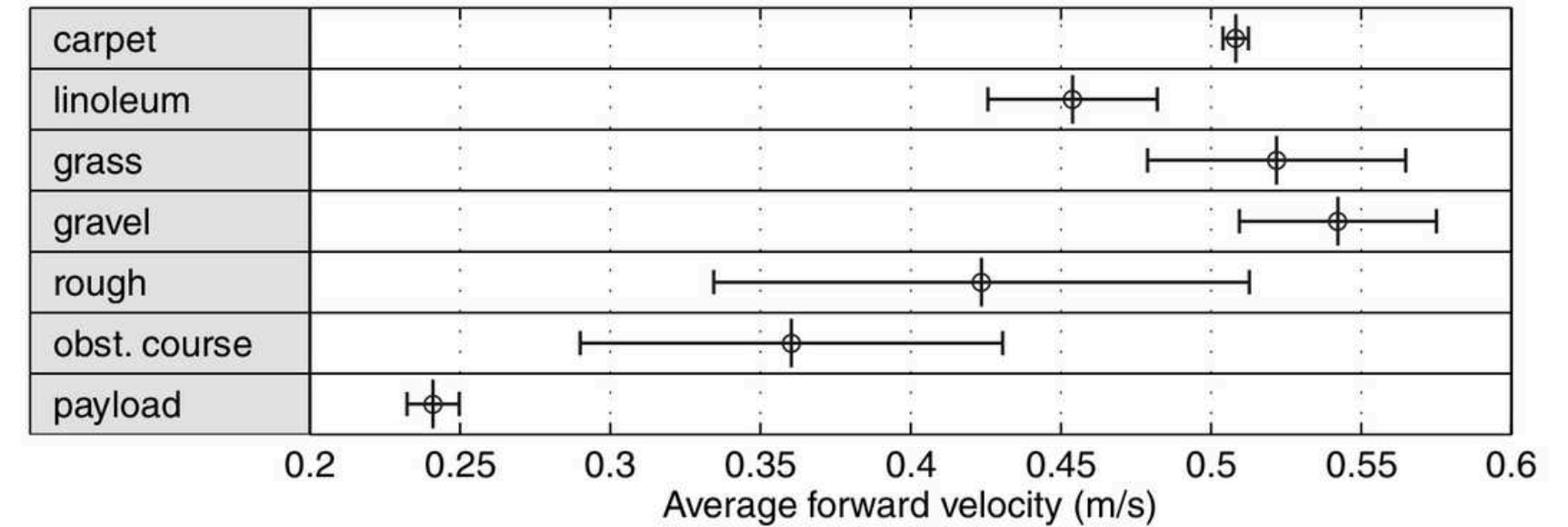
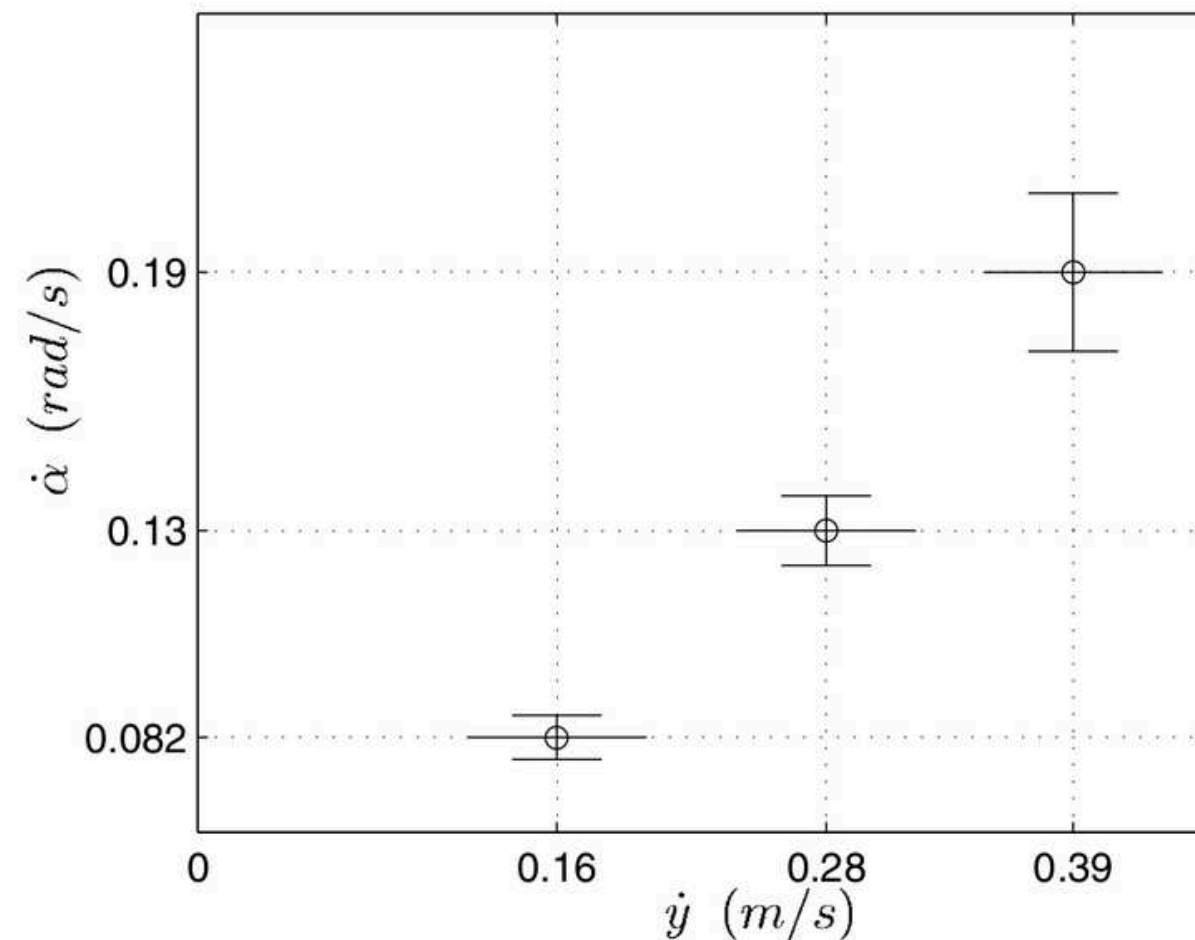
$$\mathbf{F}_T = [0 \ 0 \ -mg]^T + \mathbf{R}_b \sum_{i=1}^6 leg_i \mathbf{F}_i$$

$$\boldsymbol{\tau}_T = \mathbf{R}_b \sum_{i=1}^6 leg_i \boldsymbol{\tau}_i$$

F_{r_i} : Radial leg spring force
 τ_{θ_i} : Bend torque in θ_i -direction
 τ_{ϕ_i} : Hip torque in ϕ_i -direction
 \mathbf{a}_i : body leg attachment point
 \mathbf{v}_i : leg state in Cartesian coordinates
 \mathbf{R}_b : body orientation in space
 leg_i : leg contact state

Forward Locomotion

- **Stable** forward speed of ~ 0.5 m/s across surfaces
- Terrain affects traction and speed **variability**
- Energy **efficiency** varies significantly with surface type

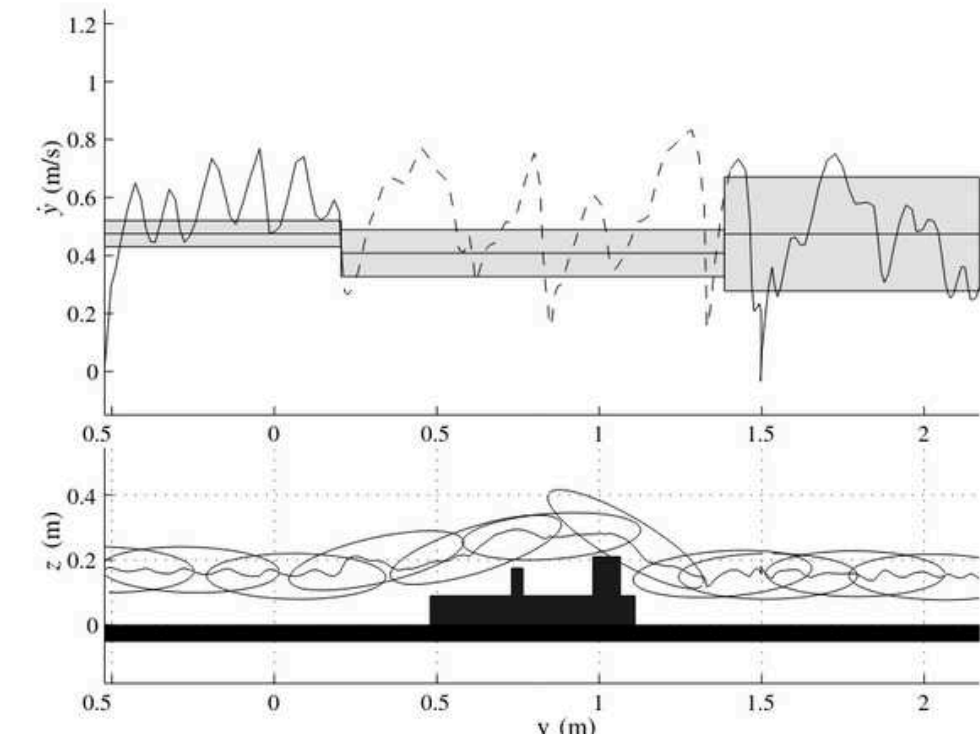


Turning Locomotion

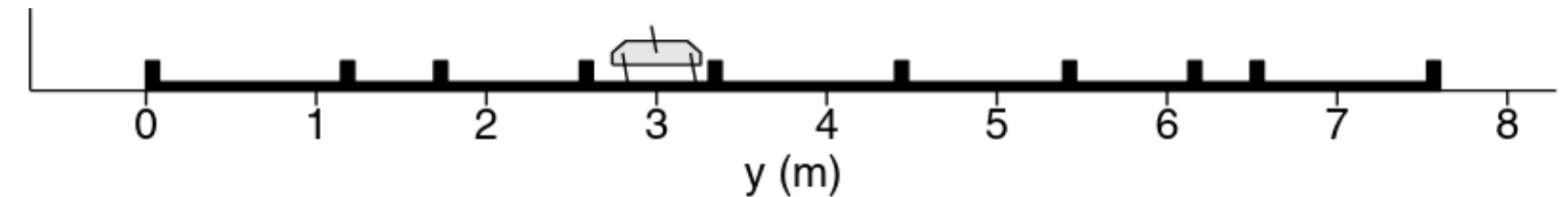
- Turning modes include arcing turns and in-place rotation
- Yaw rate increases almost **linearly** with speed

Obstacle crossing

- Clears **15–22 cm** obstacles using unchanged **open-loop controller**.
- Only **modest speed loss**; variability from unpredictable leg contact and landing.



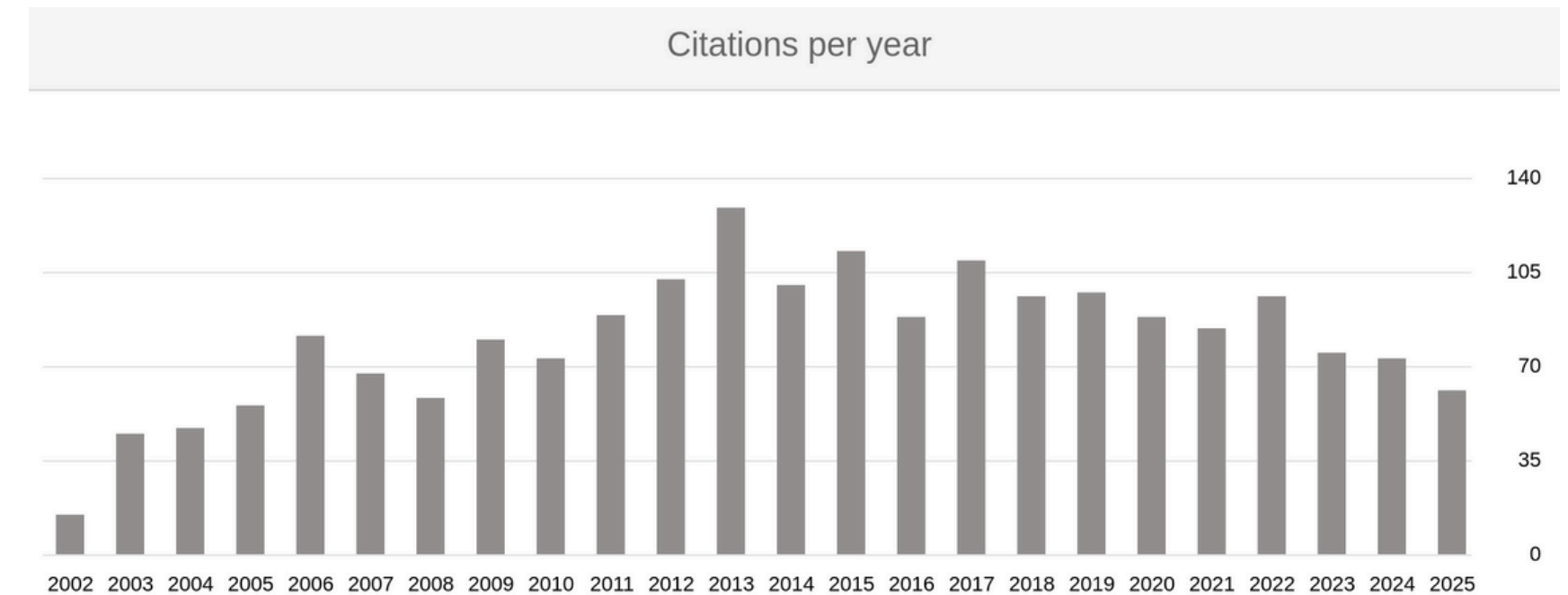
Obstacle course & rough terrain



- <50% successful runs: 10-obstacle, 8 m course with ~ 0.4 m/s speeds.
- **High mechanical load and power consumption**: broken legs, 3xWatts of walking on carpet



- 1932 citations accros different domains
- Established the RHex-class hexapod template
- X-RHex, T-RHex, and field-ready variants (stronger frames, sensing, modular payloads).

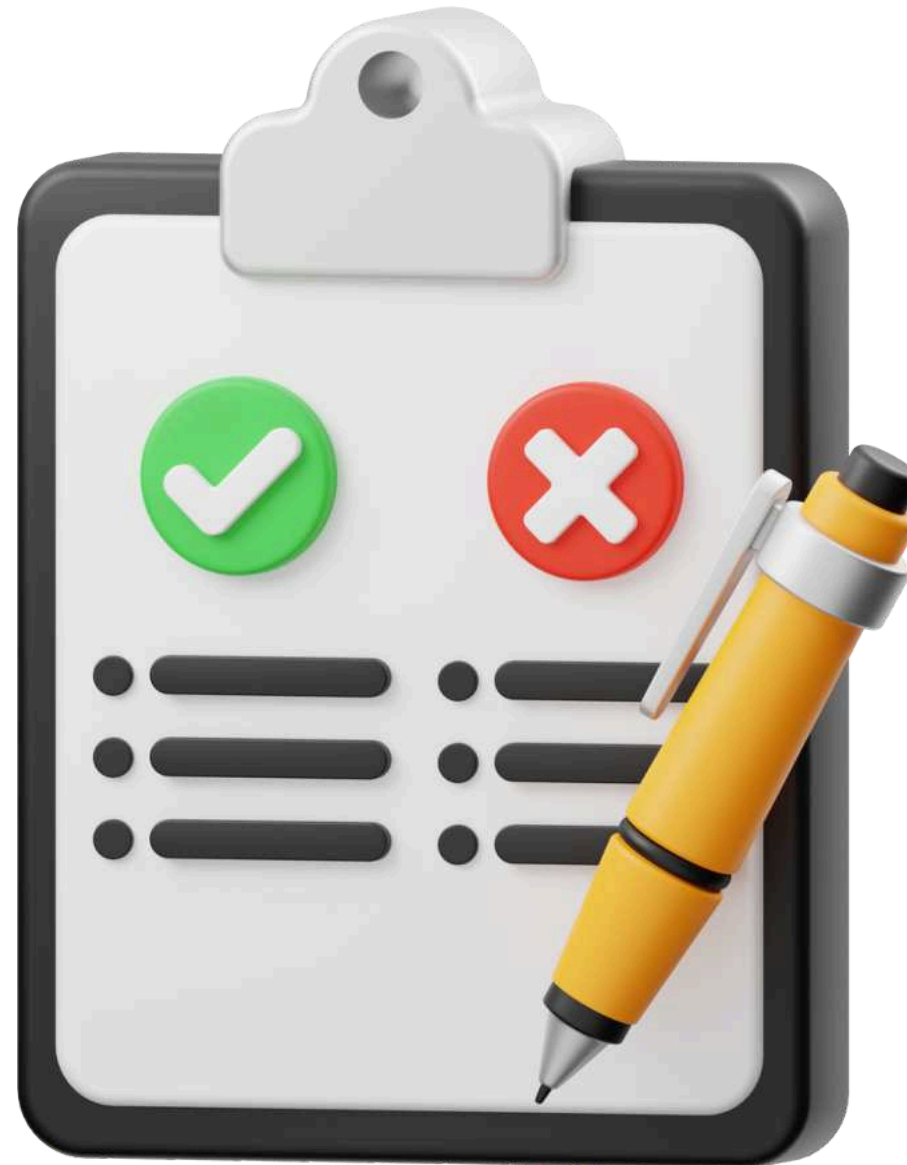


[Google Scholar - Citations per year](#)

- Develops a benchmarking framework featuring controlled experiments, precise performance measurements, and fully reproducible gait and control settings.

Pros

- Demonstrates exceptional rough-terrain mobility with a minimalist design
- Provided a rigorous experimental framework



Cons

- Reliance on open-loop control limits robustness
- Exhibits energetic inefficiency and hardware fragility