PAL ROBOTICS RESEARCH

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Whole-Body Kinematics Modeling in presence of Closed-Linkages

Application to the Kangaroo Biped Robot

Enrico Mingo Hoffman | Sai Kishor Kothakota | Adrià Roig Moreno | Andrea Curti | Narcís Miguel | Luca Marchionni

Motivation

Kangaroo is a new humanoid bipedal robot designed by PAL Robotics for research on **agile and dynamic locomotion.**

Kangaroo design exploits **linear electric actuation** and **non-linear transmissions** based on closed, parallel and differential kinematic chains.

Closed linkages have multiple advantages w.r.t. open-kinematic chains:

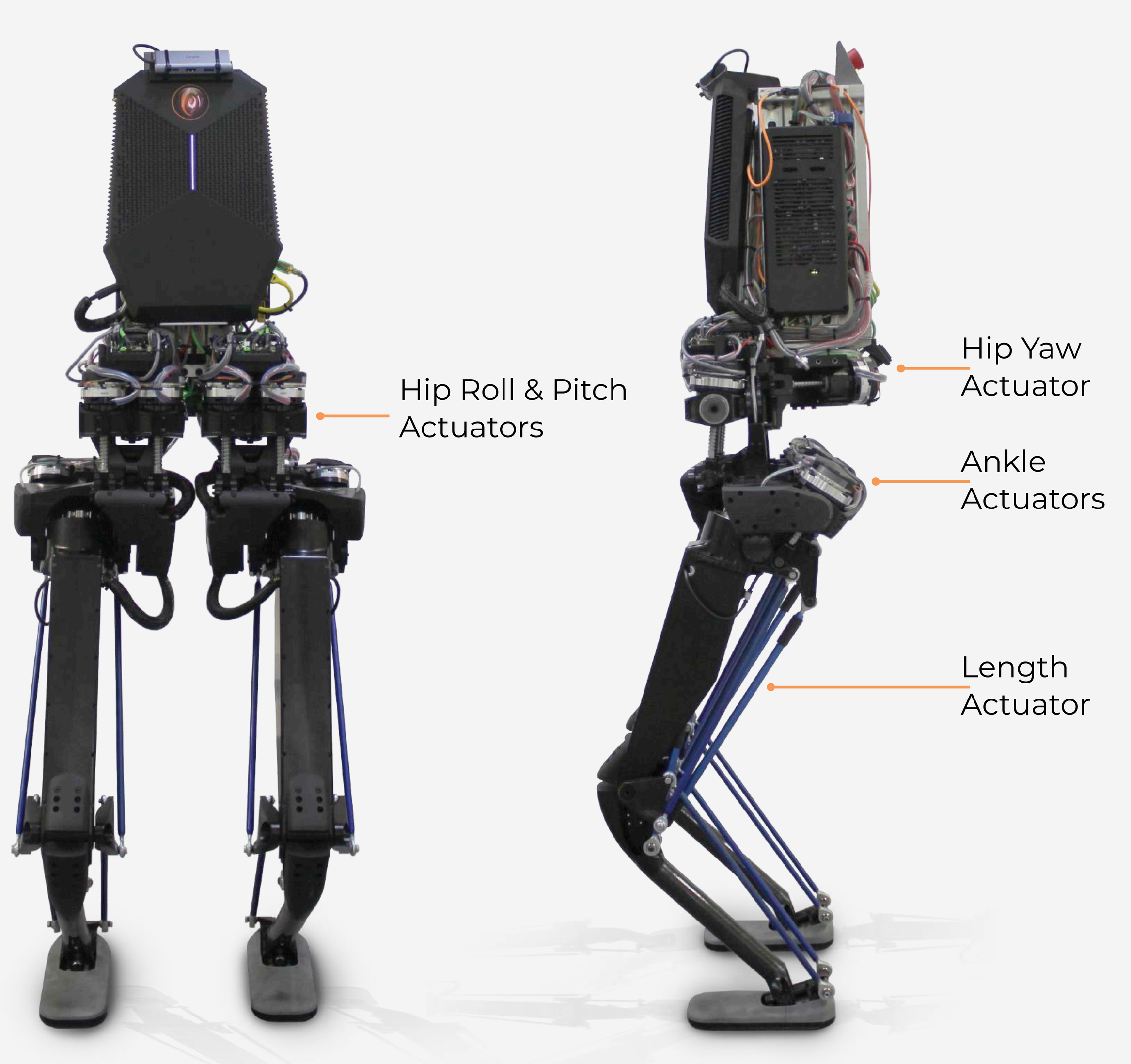
- Actuator relocation to achieve better mass and inertia distribution.
- Superior stiffness.
- High payload-to-weight ratio.

KANGAROO

Model

76 Degrees of Freedoms (DoFs)

12 actuated DoFs | 64 passive DoFs



NON-LINEAR ACTUATION

Extension/retraction of the **leg length actuator** does not change feet orientation w.r.t. hip

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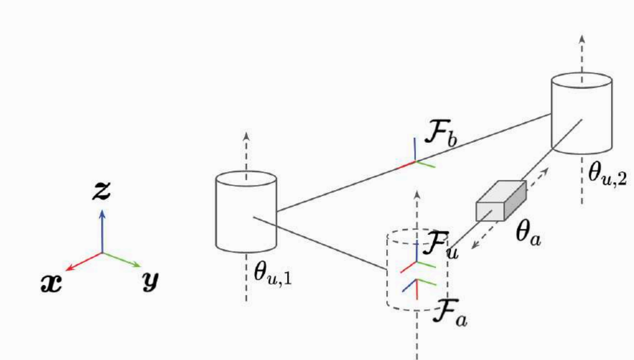
New frontiers of Parallel Robotics

Scan the QR code to check the videos

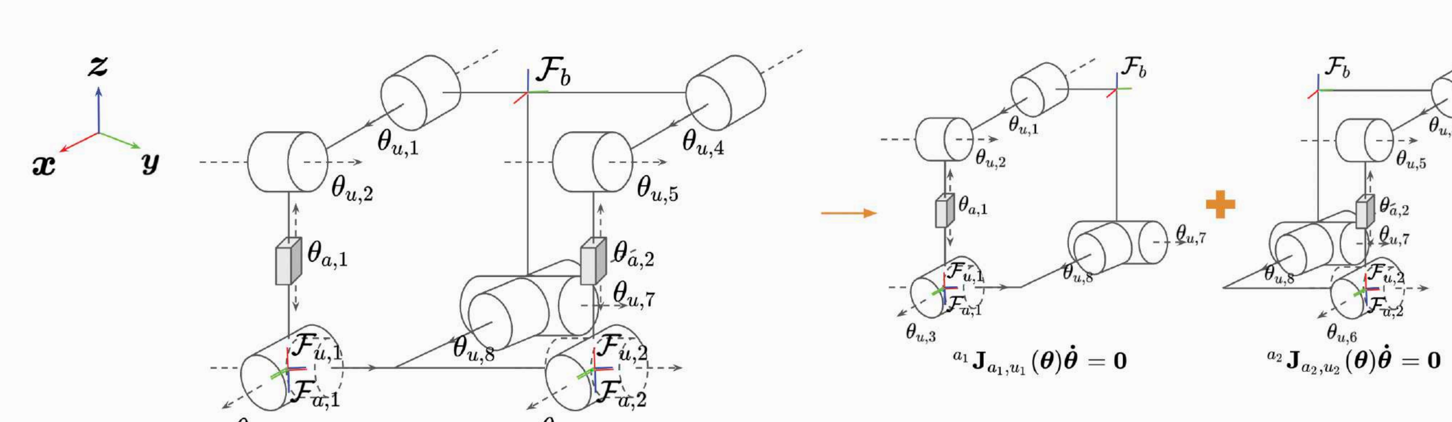
Modeling of closed linkages

- Constraint-based formulation: the closed linkage is opened at one joint and a constraint is added



$$\boldsymbol{\theta} = \begin{bmatrix}\boldsymbol{\theta}_u \\ \boldsymbol{\theta}_a\end{bmatrix} \rightarrow {}^a\mathbf{p}_{a,u}(\boldsymbol{\theta}) = \mathbf{0} \xrightarrow{\frac{\partial}{\partial t}} {}^a\mathbf{J}_{a,u}(\boldsymbol{\theta})\dot{\boldsymbol{\theta}} = \mathbf{0}$$

- Complex linkages (e.g. differential) can be obtained stacking Jacobians:



$$= \begin{bmatrix}{}^{a_1}\mathbf{J}_{a_1,u_1}(\boldsymbol{\theta}) \\ {}^{a_2}\mathbf{J}_{a_2,u_2}(\boldsymbol{\theta})\end{bmatrix}$$

Closed linkage constrained whole-body control

PRIORITY

$$\begin{aligned} \min_{\boldsymbol{\nu}} \ & \|\mathbf{J}_c(\mathbf{q})\boldsymbol{\nu} - \mathbf{K}_c\mathbf{e}_c(\mathbf{q})\| + \epsilon\|\boldsymbol{\nu}\| \\ \text{s.t.} \ & {}^a\mathbf{J}_{a,u}(\mathbf{q})\boldsymbol{\nu} = \lambda\, {}^a\mathbf{e}_u(\mathbf{q}) \\ & \frac{\boldsymbol{\theta}_m - \boldsymbol{\theta}}{dt} \leq \dot{\boldsymbol{\theta}} \leq \frac{\boldsymbol{\theta}_M - \boldsymbol{\theta}}{dt} \\ & \dot{\boldsymbol{\theta}}_{a,m} \leq \dot{\boldsymbol{\theta}}_a \leq \dot{\boldsymbol{\theta}}_{a,M} \end{aligned}$$

$$\downarrow$$

$$\begin{aligned} \min_{\boldsymbol{\nu}} \ & \|\boldsymbol{F}_{CoM}(\mathbf{q})\|_{\mathbf{w}_1} + \|\boldsymbol{F}_{fb}(\mathbf{q})\|_{\mathbf{w}_2} + \epsilon\|\boldsymbol{\nu}\| \\ \text{s.t.} \ & {}^a\mathbf{J}_{a,u}(\mathbf{q})\boldsymbol{\nu} = \lambda\, {}^a\mathbf{e}_u(\mathbf{q}) \\ & \frac{\boldsymbol{\theta}_m - \boldsymbol{\theta}}{dt} \leq \dot{\boldsymbol{\theta}} \leq \frac{\boldsymbol{\theta}_M - \boldsymbol{\theta}}{dt} \\ & \dot{\boldsymbol{\theta}}_{a,m} \leq \dot{\boldsymbol{\theta}}_a \leq \dot{\boldsymbol{\theta}}_{a,M} \\ & \mathbf{J}_c(\mathbf{q})\boldsymbol{\nu} = \mathbf{J}_c(\mathbf{q})\boldsymbol{\nu}_0 \end{aligned}$$