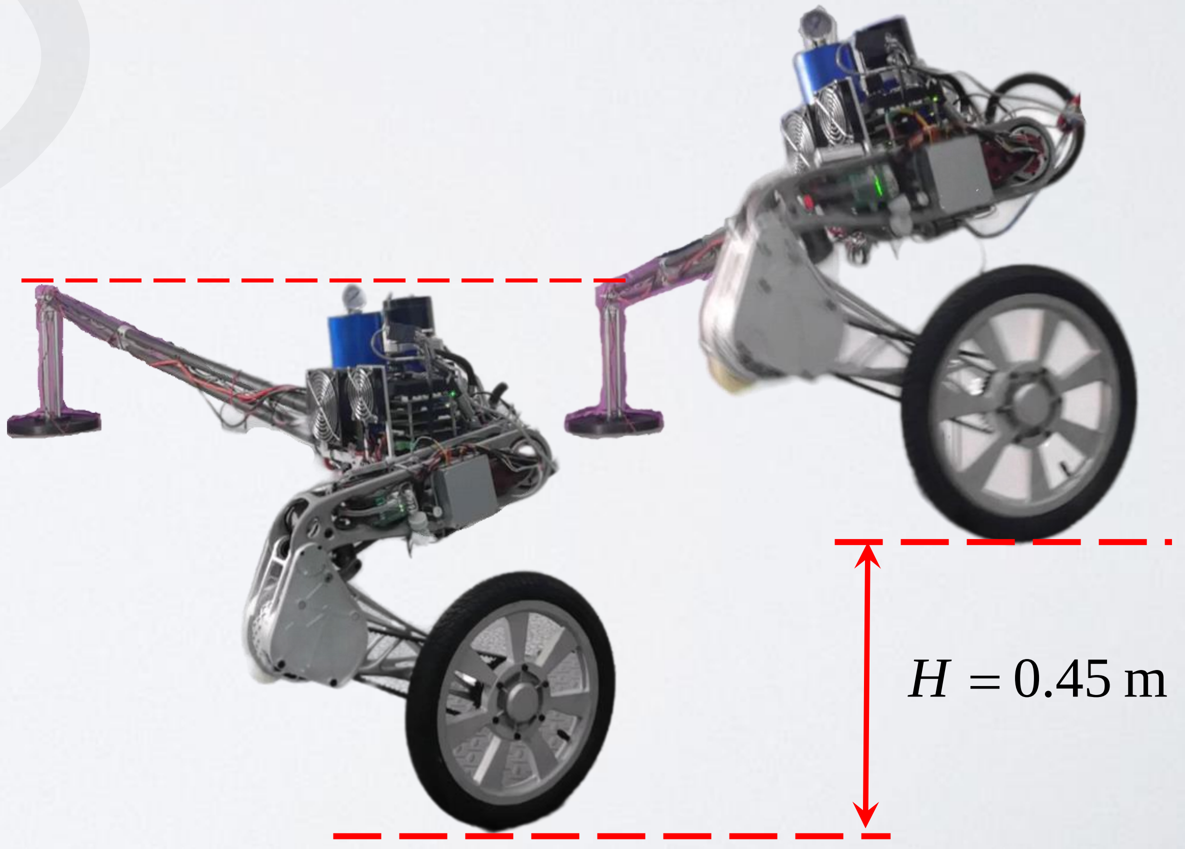
Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)

Cite this as: Xu LI, Haoyang YU, Huaizhi ZONG, Haibo FENG, Yili FU, 2024. Light weight design and integrated method for manufacturing hydraulic wheel-legged robots. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 25(9):701-715. https://doi.org/10.1631/jzus.A2300343

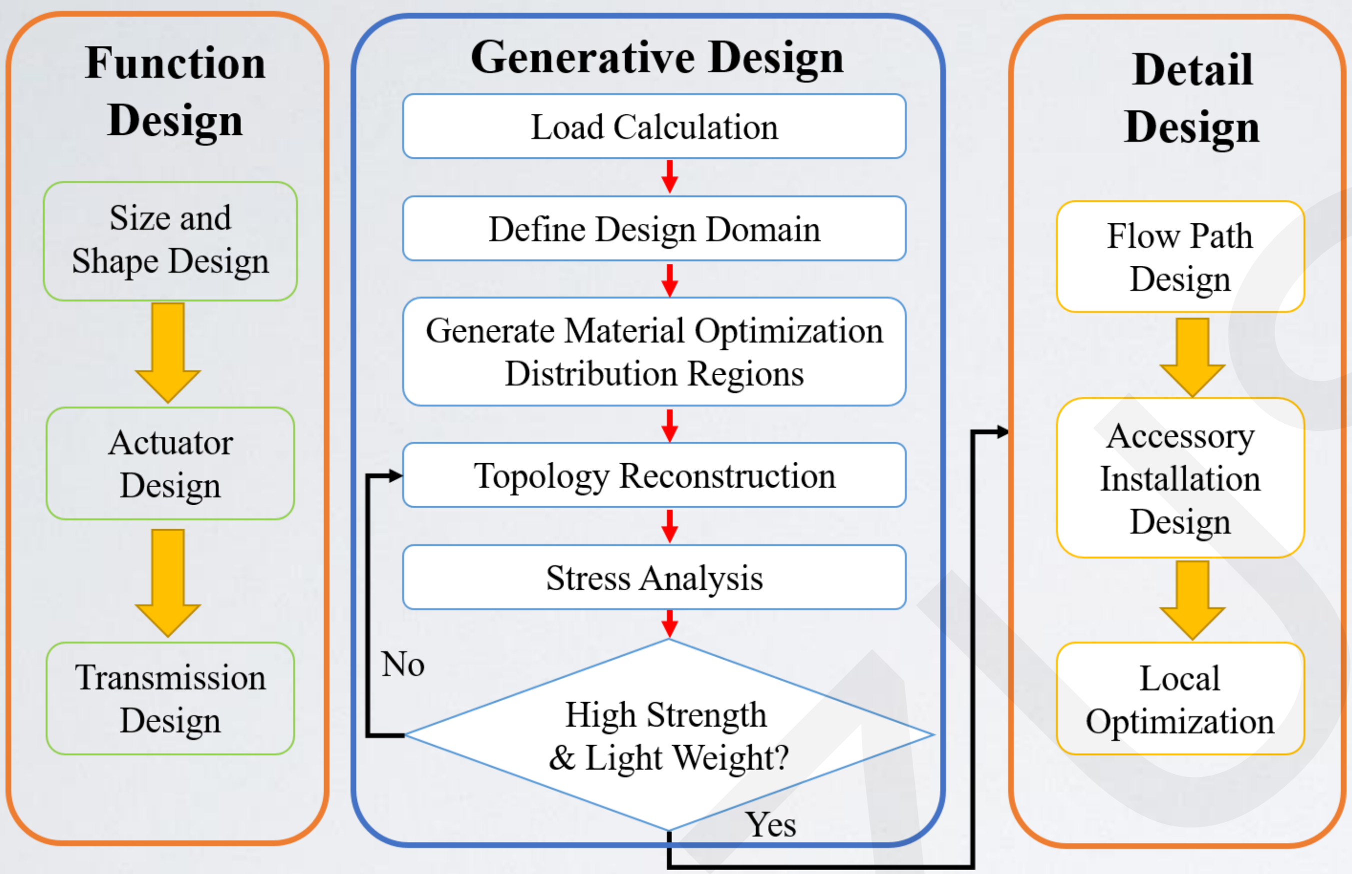
Light weight design and integrated method for manufacturing hydraulic wheel-legged robots

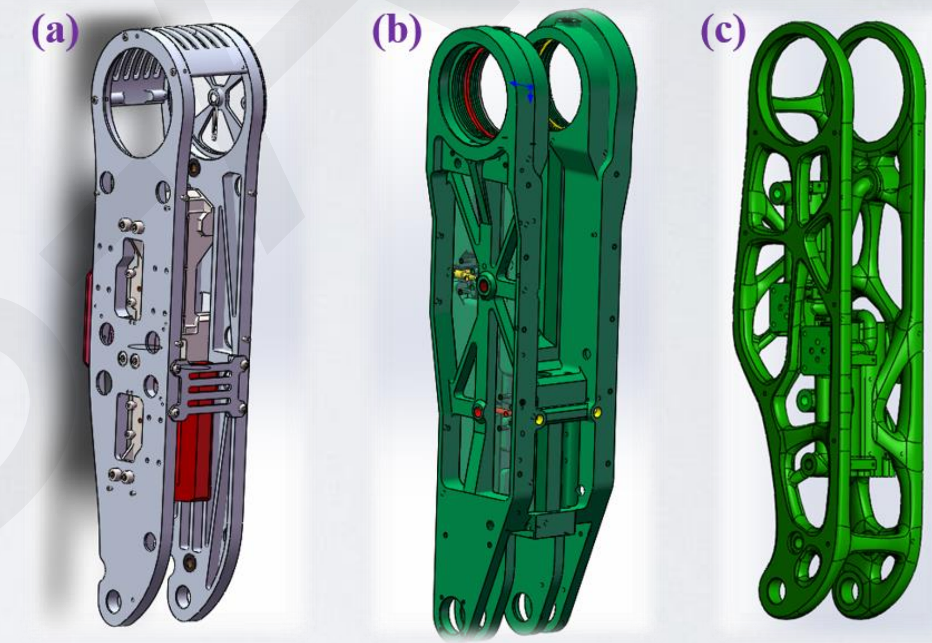
Key words:
Wheel-legged robot,
Hydraulic driven,
Topology optimization,
Additive manufacturing,
Jump control



Lightweight Design Method

Proposed a reliable and efficient lightweight **design** and **processing** technology for hydraulic robot part design.





Assembled Thigh Weight: 3.7kg

Integrated Thigh by SM Weight: 3.55kg

Integrated Thigh by LD&IM Weight: 1.75kg

52.7% reduced weight of thigh components

- Function design: Design of fundamental **mounting and functional dimensions** according to robot actuation and transmission requirements.
- Generative design: Generation of topology structures based on **finite element analysis** and **topology optimization** according to loads and design domains.
- Detail design: Optimize flow channels to reduce flow resistance.

Integrated Manufacturing

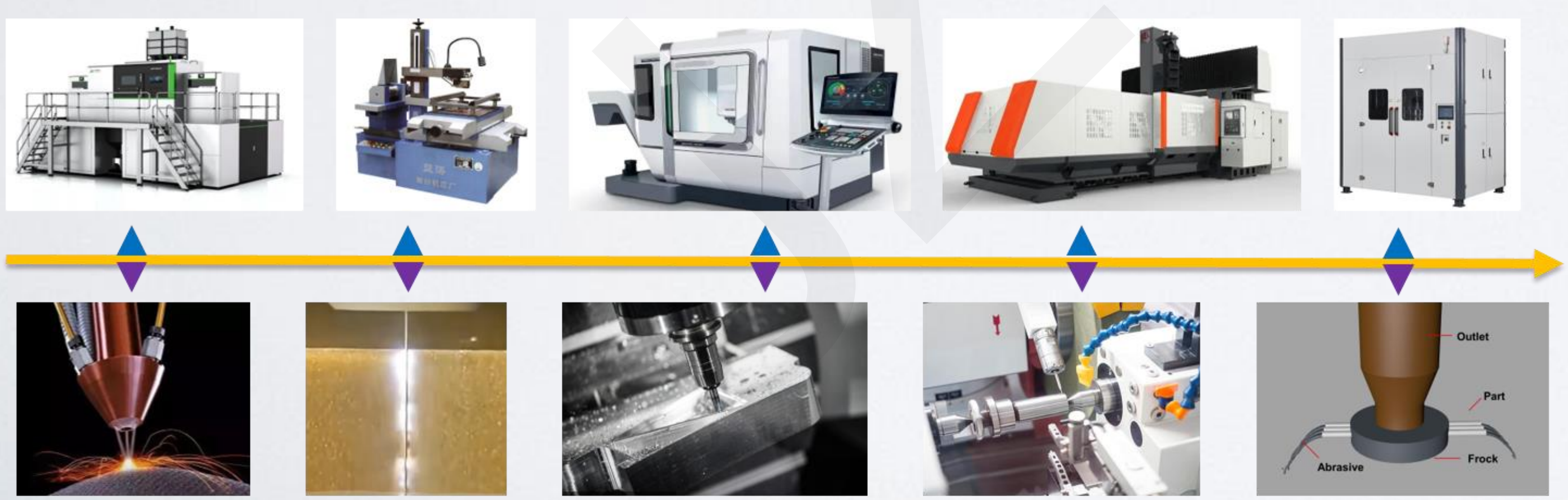
Proposed a set of complex and reasonable manufacturing methods to **bridge the gap between the conceptual model and practical parts.**

Model Processing
- Printing Direction
- Process Allowance
- Add Support
- Slice
- Print Simulation

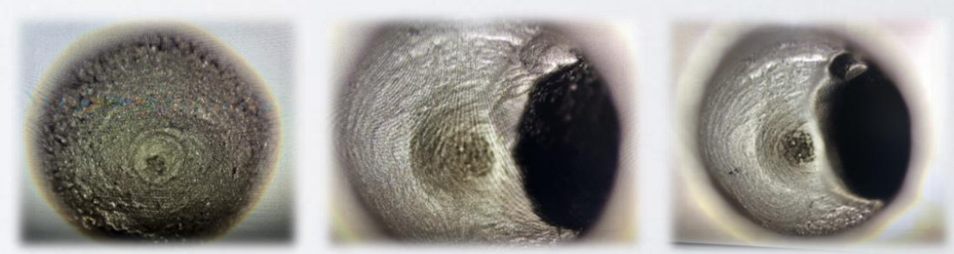
Laser Forming & Post Process
- Printing
- Cleaning Powder
- Heat Treatment
- Remove Support
- Polishing

Subtractive Manufacturing
- Alignment Benchmark
- Turning, Milling, Grinding, Clamp
- Pipeline Polishing
- Surface Treatment
- Cleaning & Detection

- ➢ model processing: Plan the printing orientation and supporting materials.
- ➢ laser forming : SLM 3D metal printing, heat treatment, remove the supporting and polish.
- ➢ Substractive manufacturing: Assembled surface and hole precision machining, flow channel polishing.



SLM 3D Printing | Wire Cutting | CNC Machining | Precision Machining | Pipeline Polishing

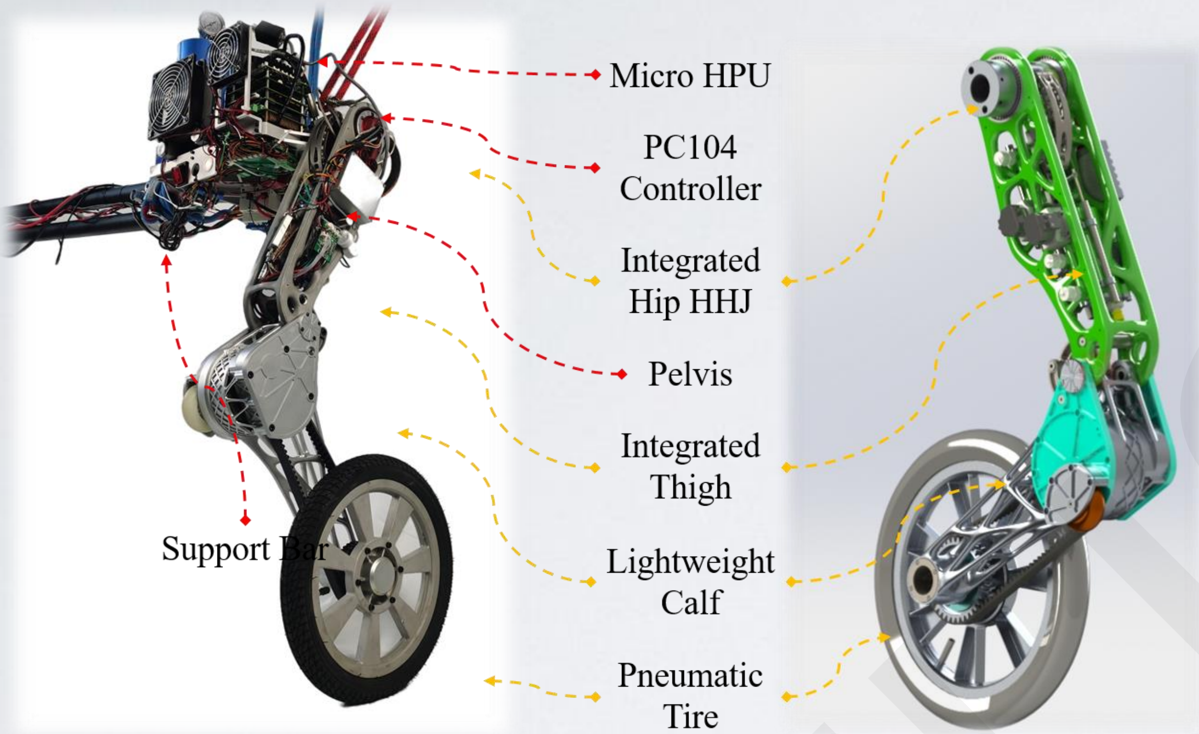


Before Polishing | After Rough Polishing | After Fine Polishing

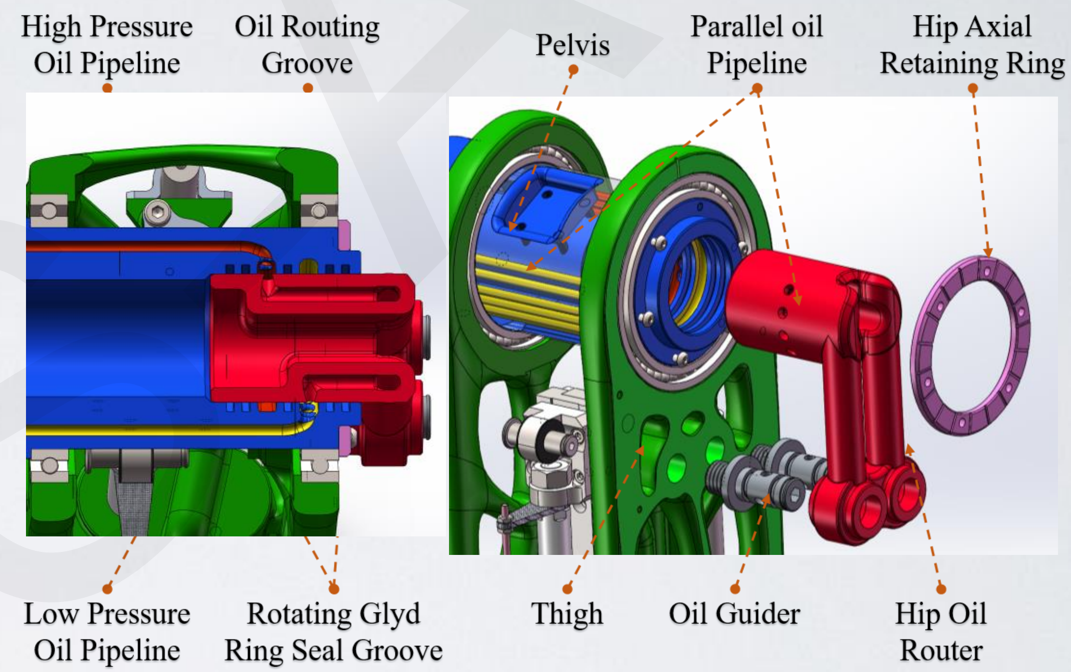
Abrasive flow technology to obtain smooth flow channels

Hardware of WLR-IV single-legged robot

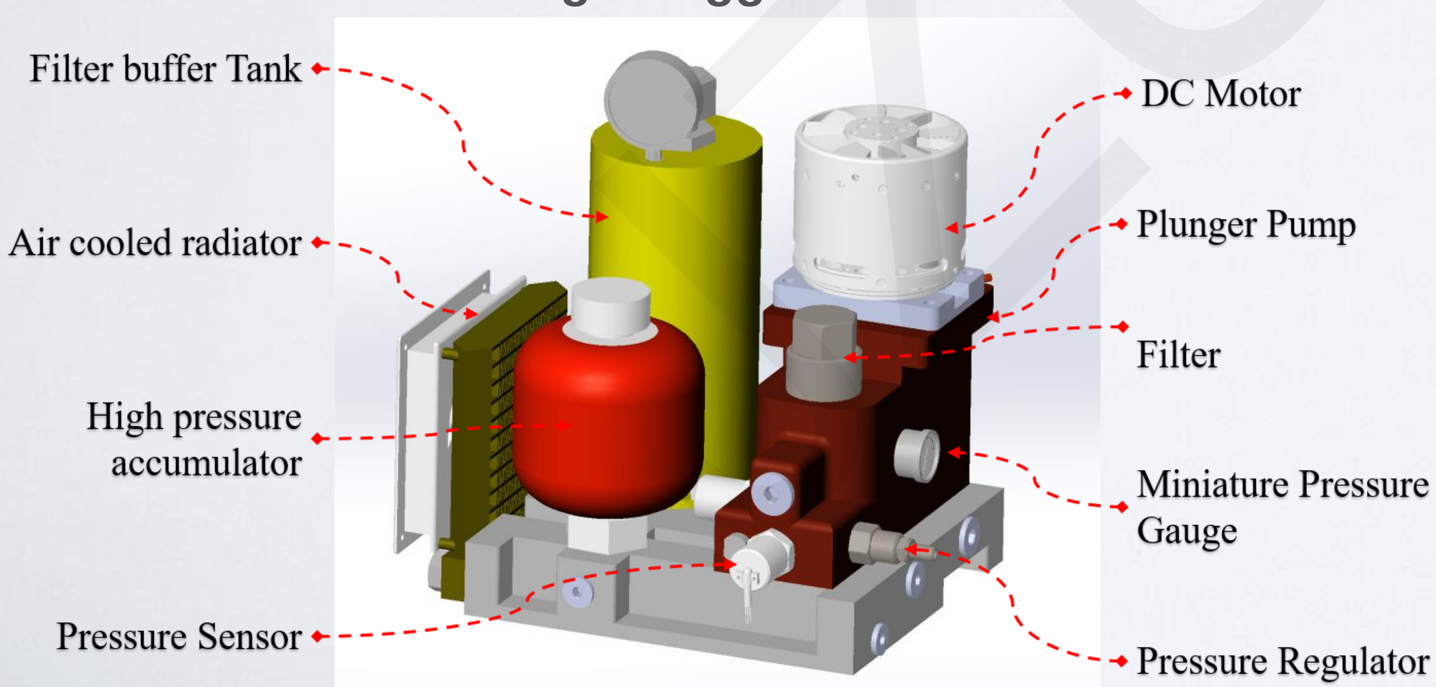
Design and manufacture the WLRIV single–legged robot using the method proposed in this work.



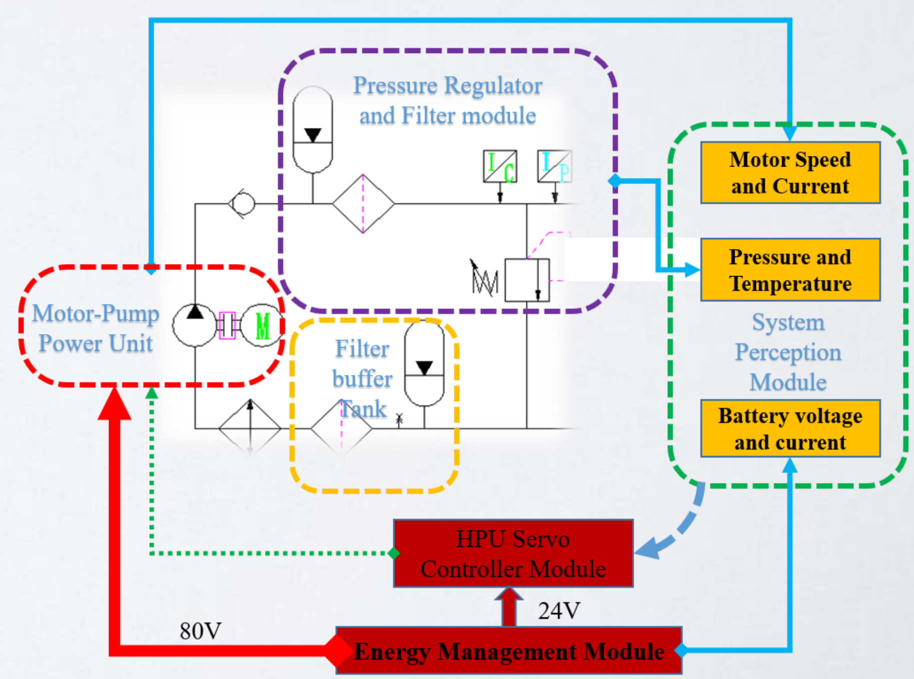
WLRIV single–legged robot



Hip hydraulic hole-less joint (HHJ)



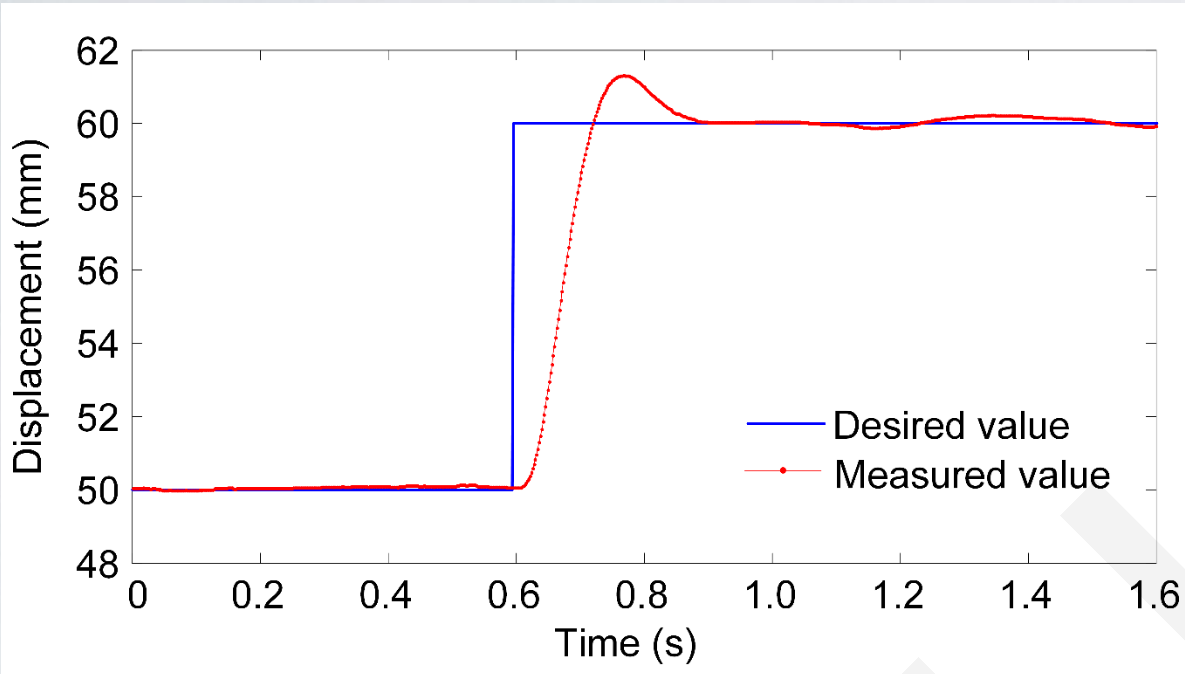
Hydraulic power unit (HPU)



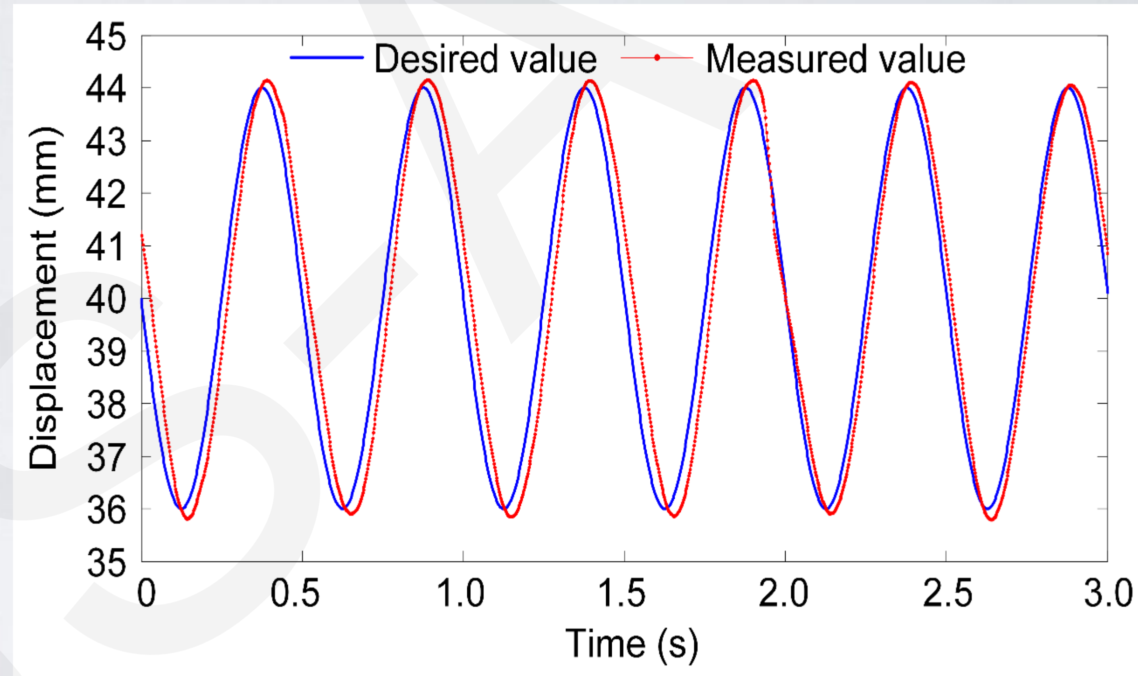
Hydraulic schematic diagram of HPU

HDU Performance Experiments

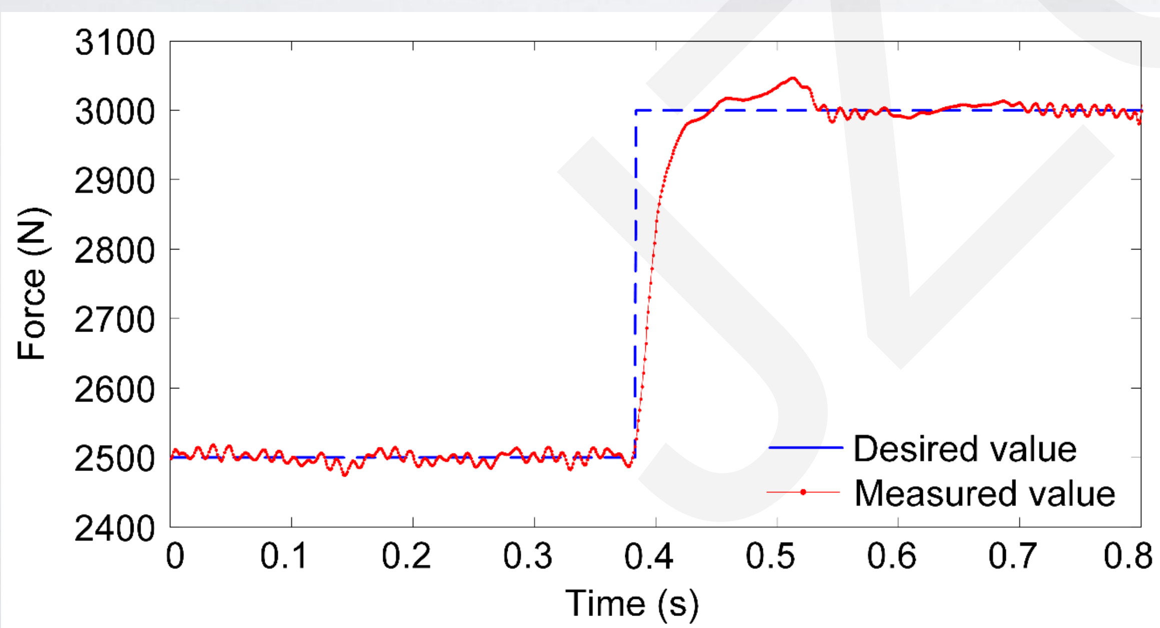
Joint servo experiments to verify the performance of hydraulic components designed using the method proposed in this work.



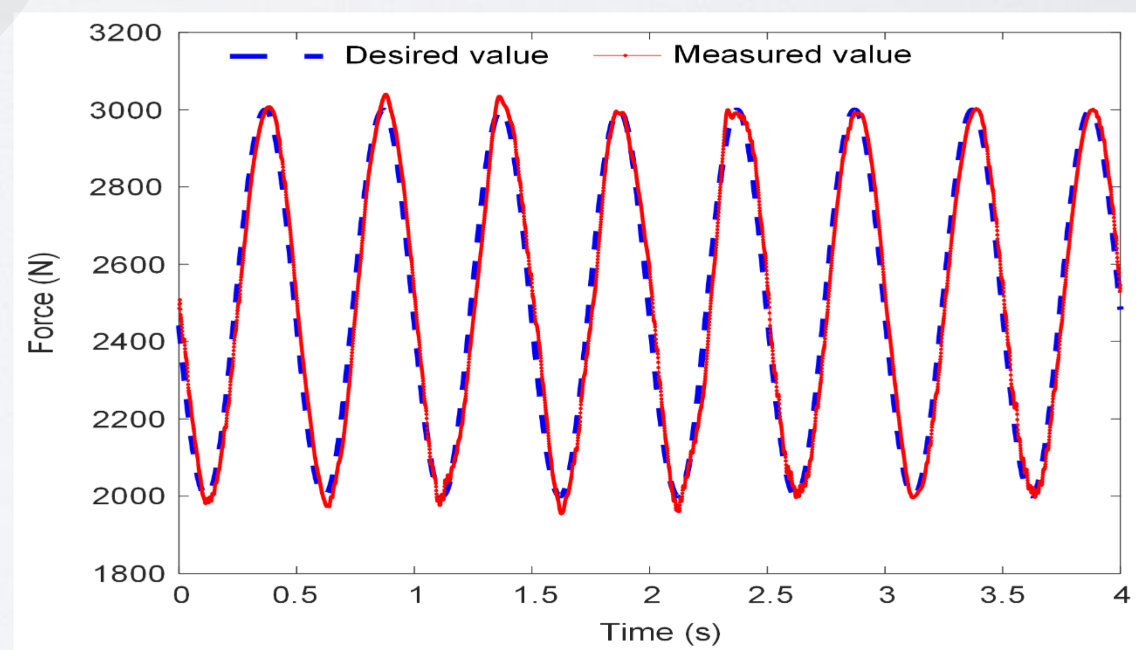
Knee HDU displacement step-up tracking performance



Knee HDU displacement sinusoidal signal tracking performance



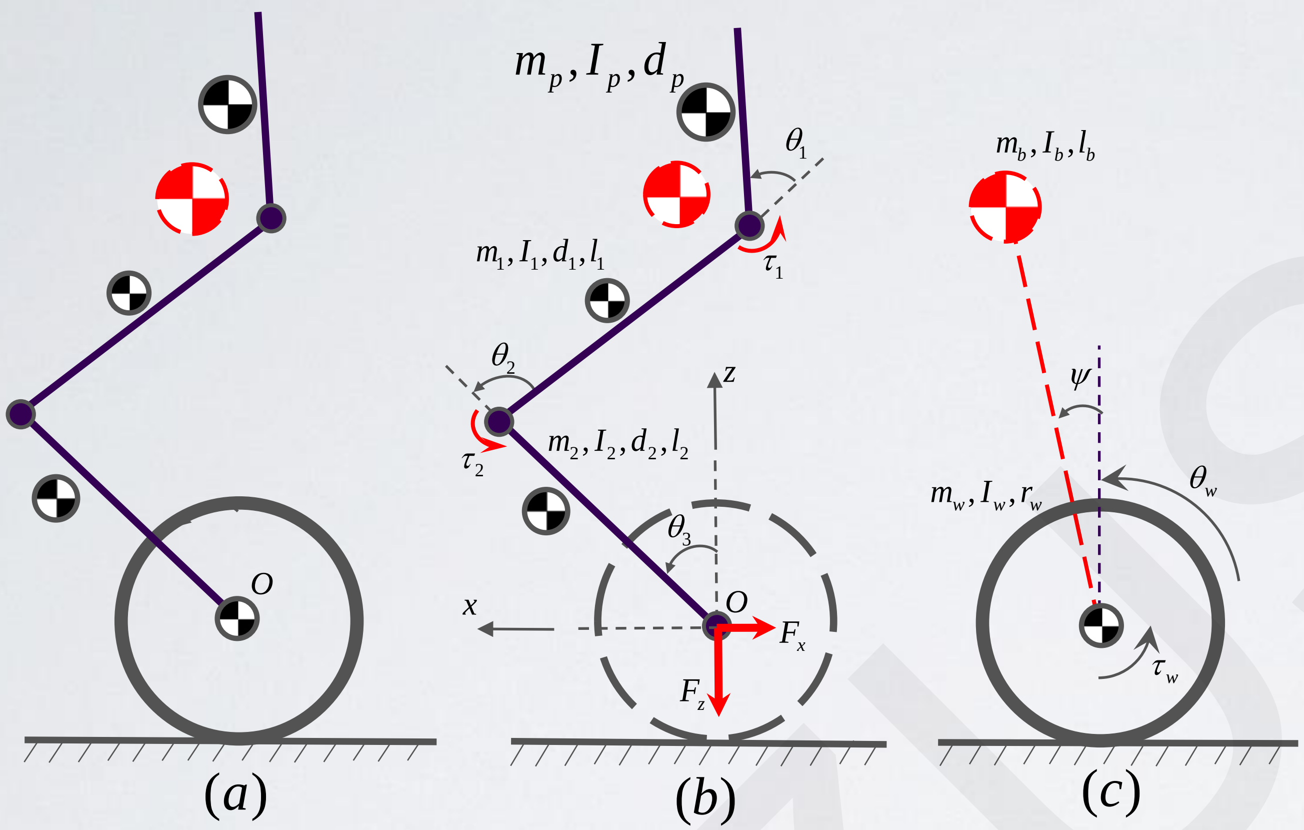
Knee HDU force step-up tracking performance



Knee HDU force sinusoidal signal tracking performance

Jump control

A jump controller was designed to achieve vertical jump and verify the hardware performance of the robot.



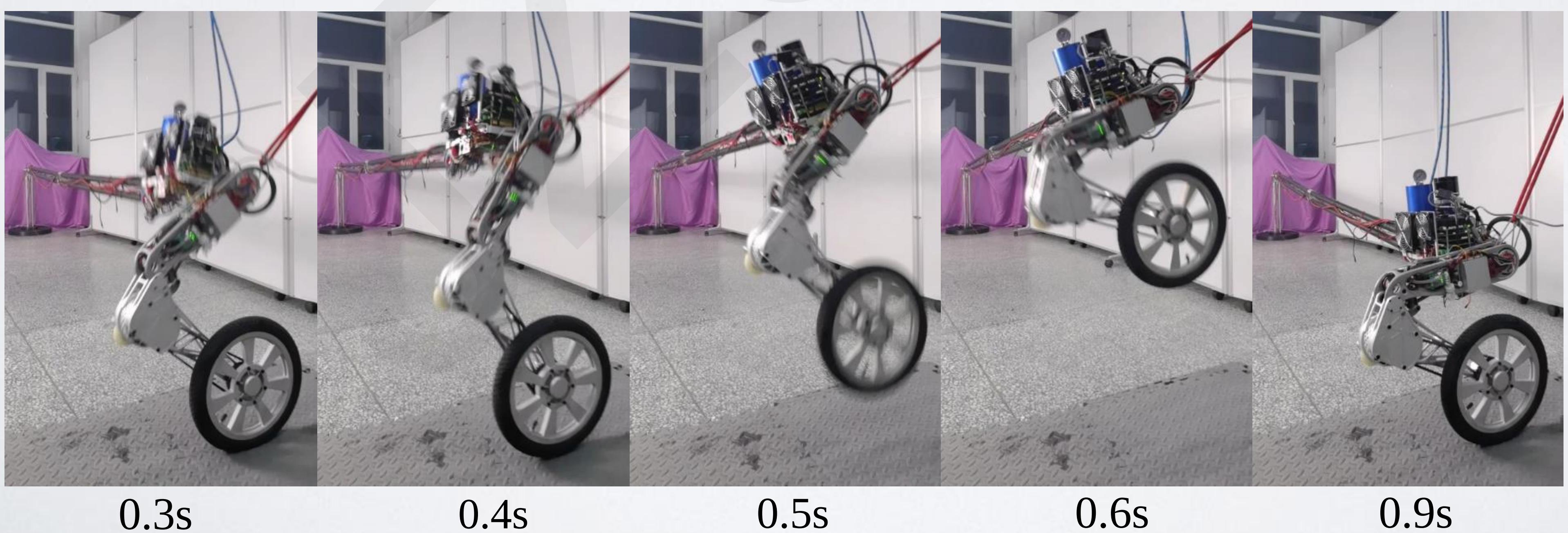
Decouple the robot into a WIP and a three-link model

Balance Controller

- $\dot{x}_W = Ax_W + B\tau_W$ — WIP Dynamic
- $J = \int_0^\infty \left[x_W^T Q x_W + R\tau_W^2\right]$ — Cost Function
- $\tau_W = -K(l_b) \cdot x_W$ — Feedback Policy

Jump Control Strategy

- $\dot{x} = \begin{bmatrix} \dot{\theta} \\ -M^{-1}(C+G) \end{bmatrix} + \begin{bmatrix} 0 \\ M^{-1}B \end{bmatrix}\tau$ — Dynamic
- $y = \begin{bmatrix} h_1(x,t) \\ h_2(x,t) \end{bmatrix} = \begin{bmatrix} x_{com}(t) - 0 \\ \theta_2(t) - \theta_{2d}(t) \end{bmatrix}$ — CoM Costraint
- $\tau = -\frac{1}{L_g L_f h}\left[L_f^2 h + K_p \tilde{x} + K_d \dot{\tilde{x}}\right]$ — Controller



WLRIV single legged robot achieve a jump height of 0.45m