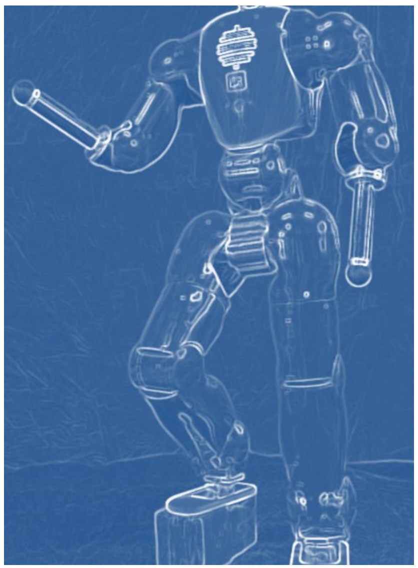
Design Specifications and Compliant Actuation Concepts of WALK-MAN Humanoid



Nikos Tsagarakis

& Human Centered Mechatronics Group @ IIT-ADVR

& UNIPI (Manolo Garabini, Manuel Catalano, Antonio Bicchi)

iit istituto italiano di tecnologia

Workshop on the Mechatronic Design of Humanoid Robots: Current and Future Trends

Humanoids 2014, 18-20th November, Madrid, Spain

Special credits


Francesca Negrello


Manolo Garabini

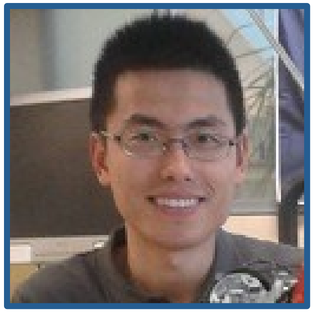

Jerryll Noorden


Gia Vo Loc


Wooseok Choi


Manuel Catalano


Houman Dallali


Zhibin Li


Wesley Roozing


Enrcico Mingo


Alessio Rocchi

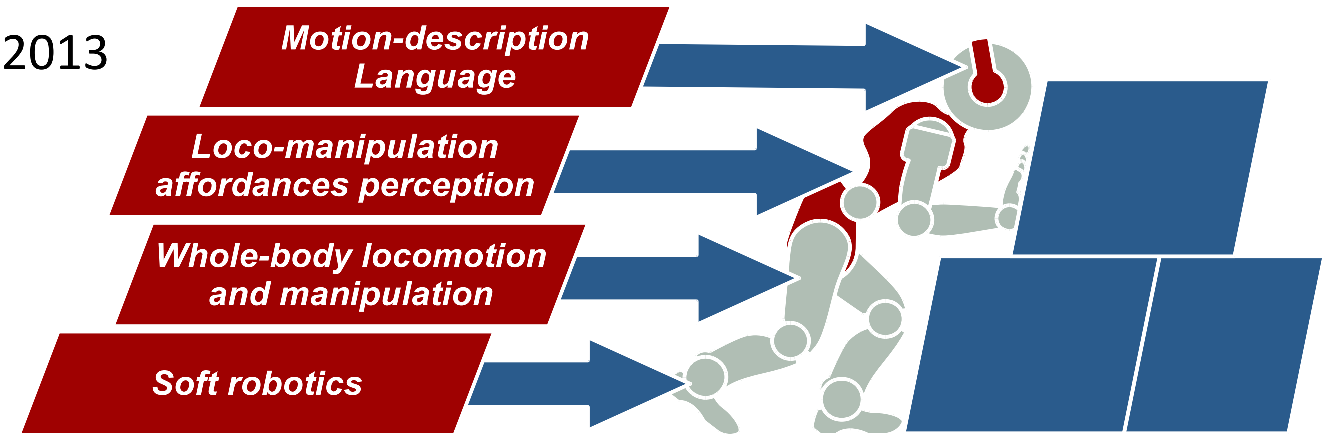
WALK-MAN EC Project

Whole Body Adaptive Locomotion and MANipulation

- Integrated Project (IP), 5 partners
- Coordinator: IIT
- Duration: 48M
- Started: Sept 2013

SEVENTH FRAMEWORK PROGRAMME

WALK-MAN key enabling technologies



www.walk-man.eu

IIT-ADVR + iCub Facility

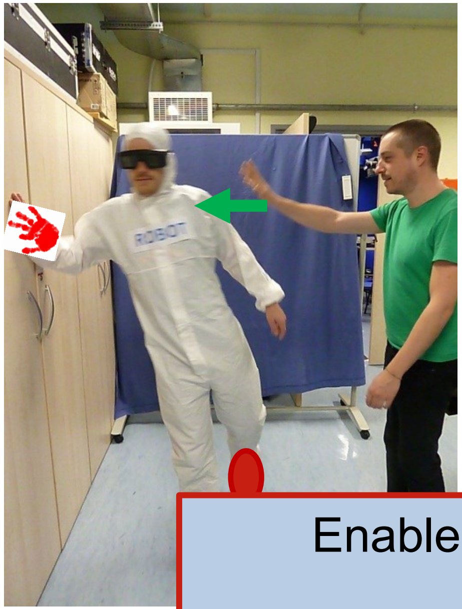
istituto italiano di tecnologia

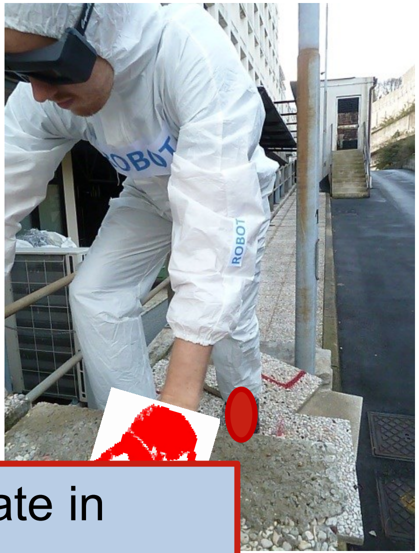
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Karlsruher Institut für Technologie

UCL Université catholique de Louvain

Humanoids with Human Level Performance



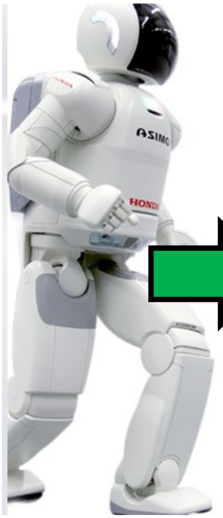
Enable robots to demonstrate similar skills and operate in unstructured spaces designed for humans



Robotic actuation

Main trends

Electrical



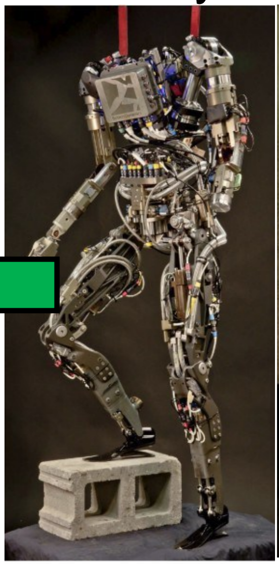
- robustness
- low power density
- efficiency

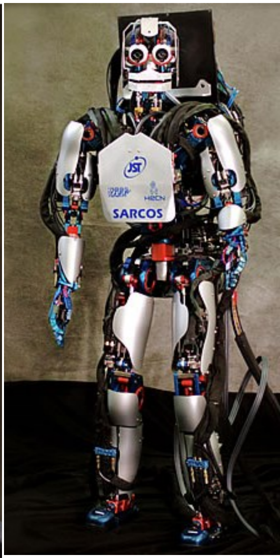
Intrinsically stiff actuation
+
Active impedance regulation

Intrinsic compliant actuation
+
Control to satisfy performance indexes

1. **lower impact forces, improves robustness**
2. **passive adaptability to interaction**
3. **peak power generation**
4. **energy efficiency**

Hydraulic

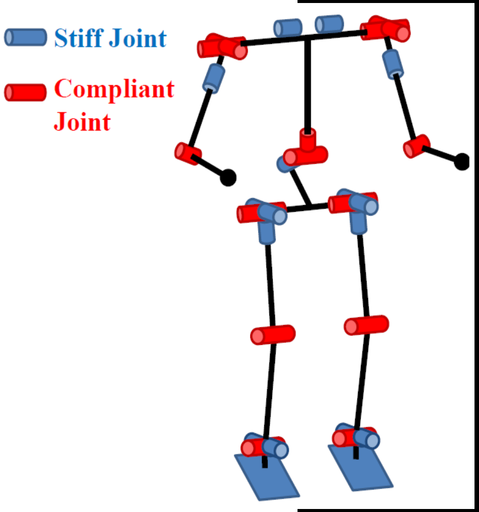


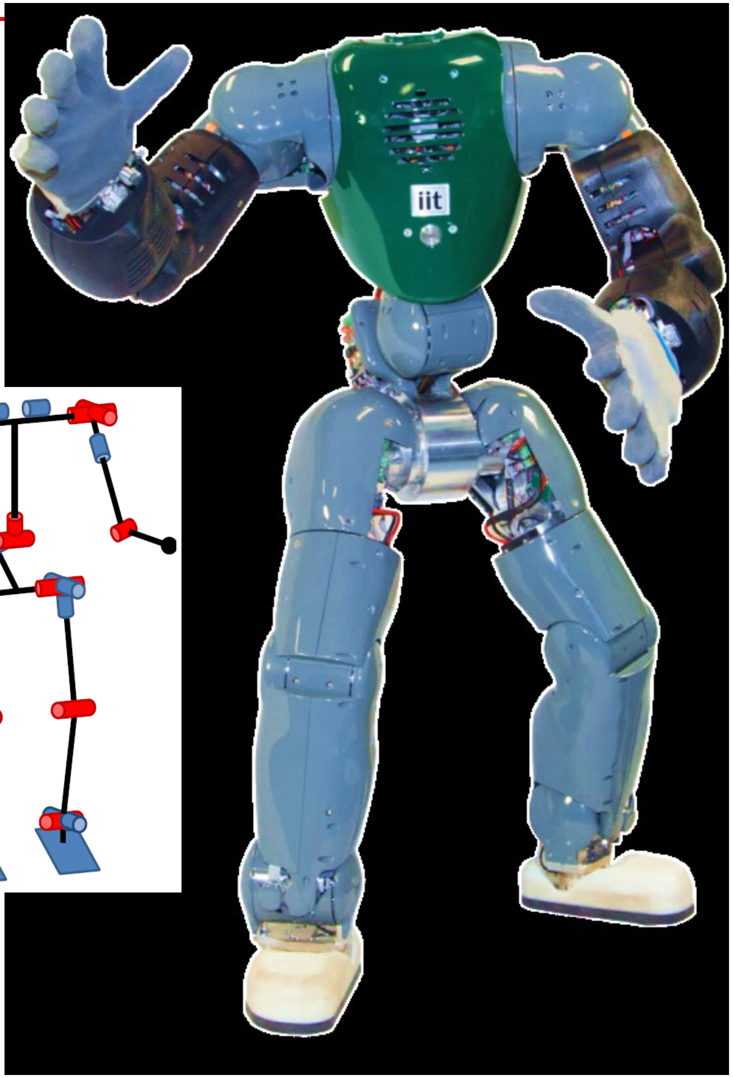


- efficiency
- safety

COMAN overview

- **31 DOFs + 2DOF for hands**
- **Actuation**
  - moderate to high power
  - passive series compliance
    - legs (ankle/knee and hip sagittal joints)
    - torso (pitch and yaw)
    - arms: (shoulder and elbow
- **Sensing**
  - joint torque sensing
  - 2 x 6 DOF F/T sensors
  - IMU
- **Power autonomy**
  - battery
  - power management system
- **On board computation power**
  - 2 x PC104 (1 inside the torso and one in the head)
- **Weights 31Kg**



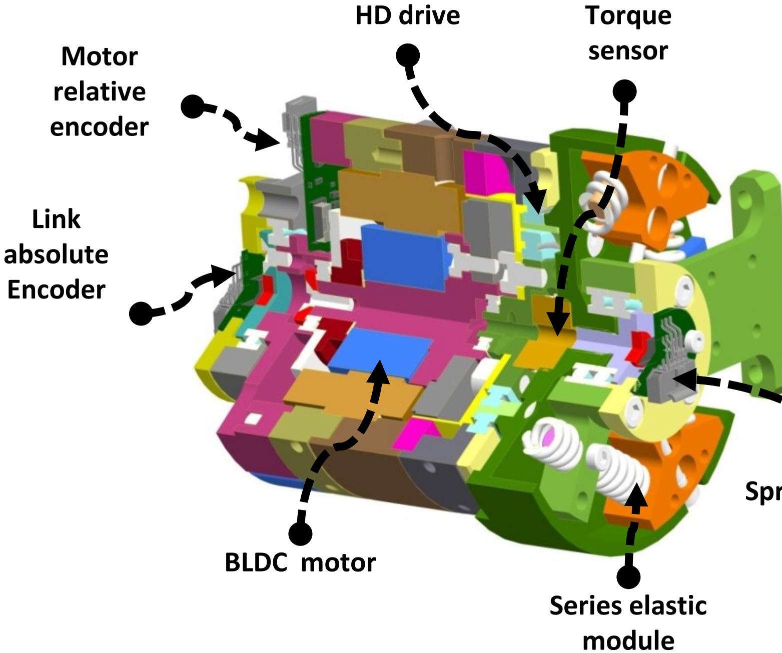


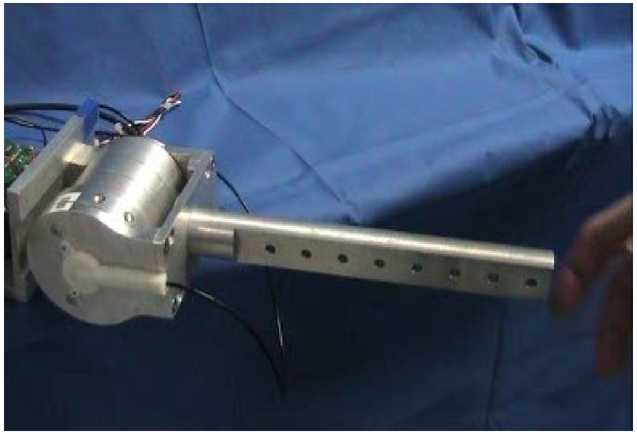
COMAN Actuation

Three key design features

- F1: moderate to high power capacity actuation
- F2: intrinsic joint elasticity for physical robustness
- F3: joint torque sensing and active compliance regulation

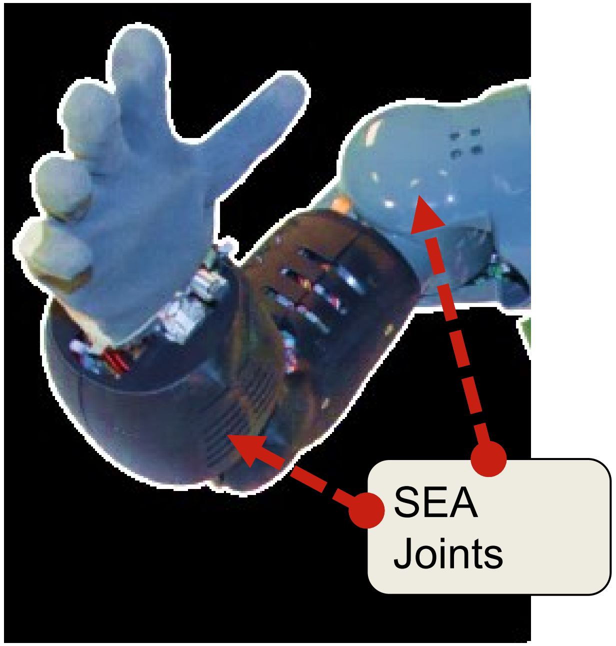
Diameter	70mm
Length	80mm
Peak Torque	55Nm
Max rotary passive deflection	+/-0.2rad
Weight	0.7Kg

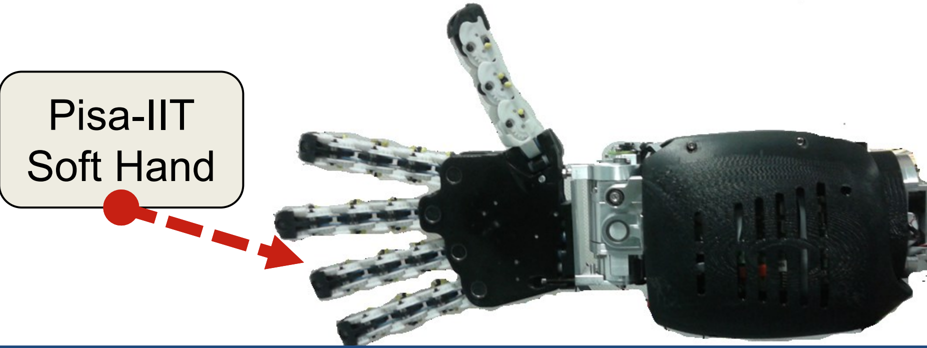


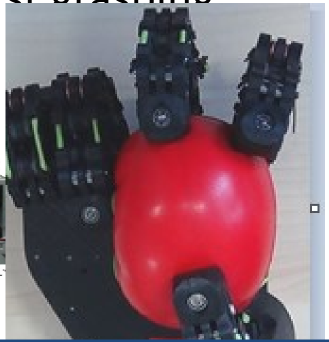


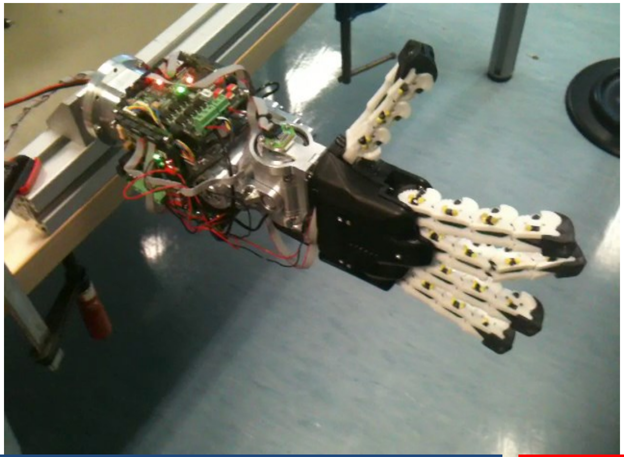
Arm/hand modules

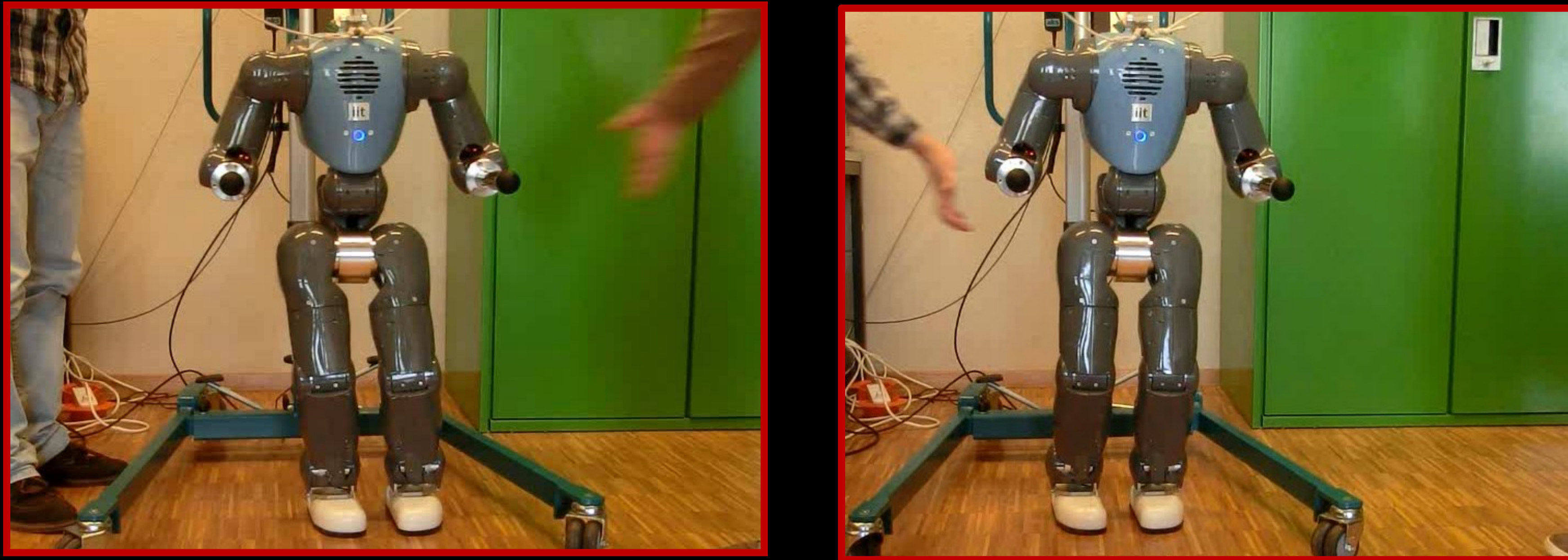
- 7DOF Arm
  - Torque controlled
  - 6 DOF F/T sensor
  - passive compliance
    - shoulder (flex/ext and abd/add) motions
    - elbow flex/ext
- Hand
  - Developed originally in Pisa (**Catalano & Bicchi et al, Humanoids 2012**)
  - adapted now for IIT-COMAN
  - fully articulated, 5 fingers hand
  - under-actuated, driven by a single motor with the







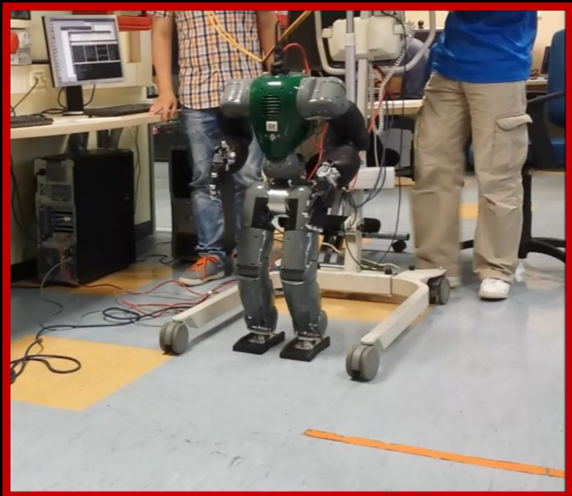


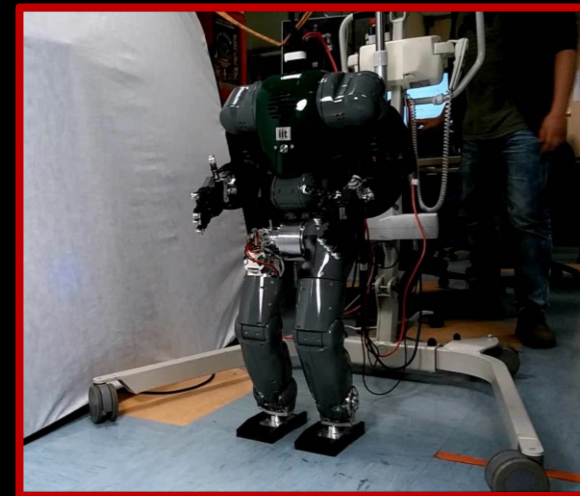


Zhibin Li et al, Humanoids 2012

iit ADVR
ISTITUTO ITALIANO
DI TECNOLOGIA

Perrin et al, IROS 2013



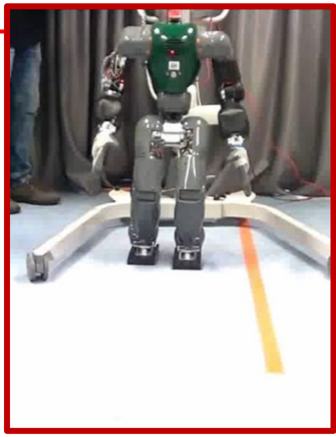


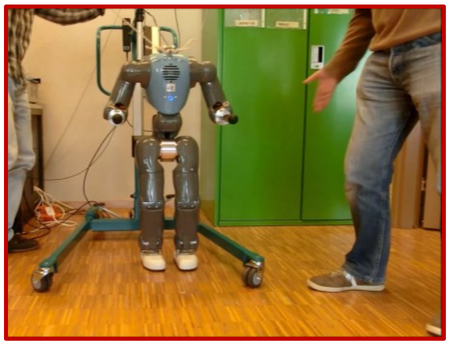
Zhibin Li, Xin Wang, et al

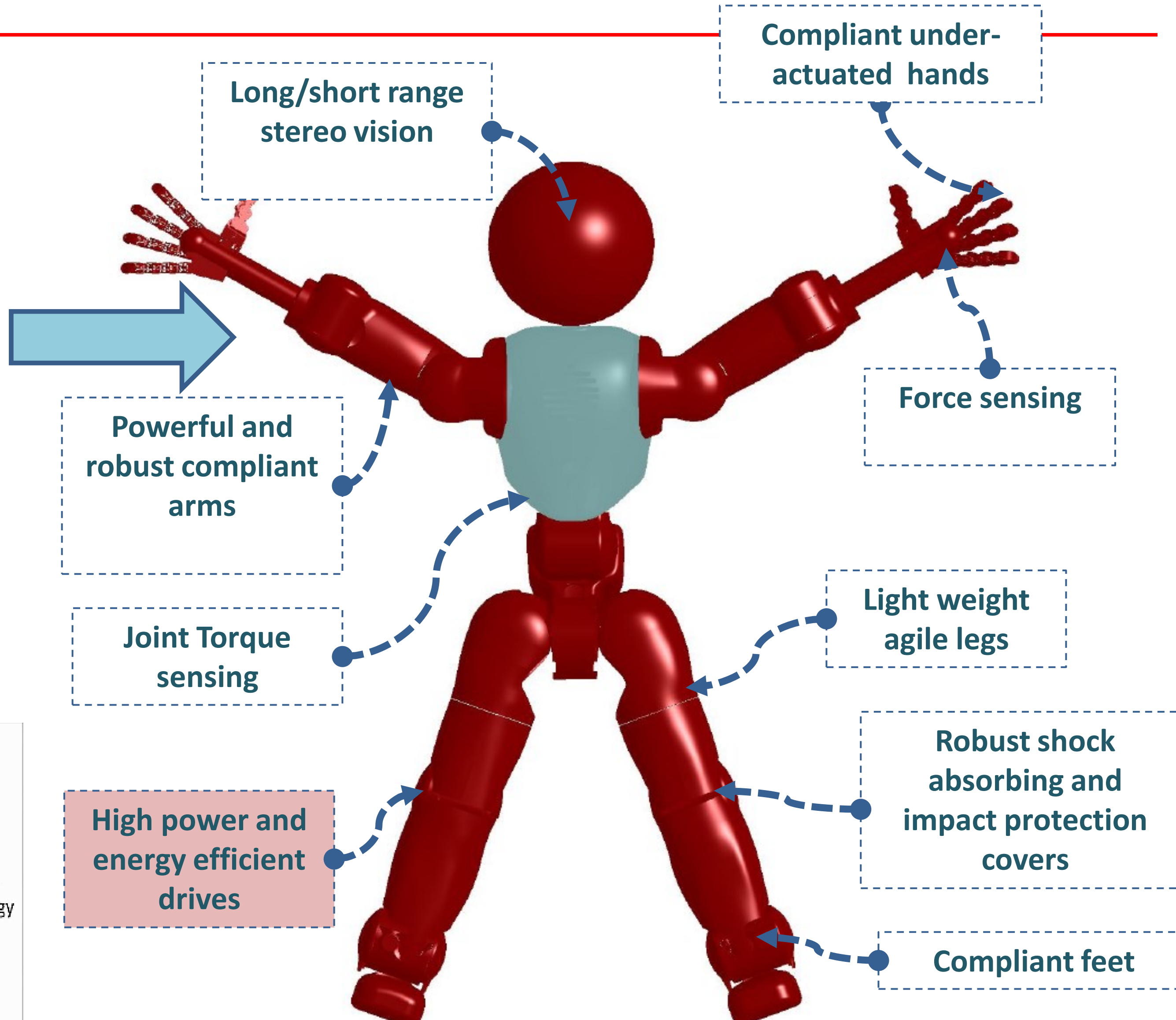
Ajoudani , Lee et all Humanoids 2014

Rocchi, Mingo et all ICRA 2015 (submitted)

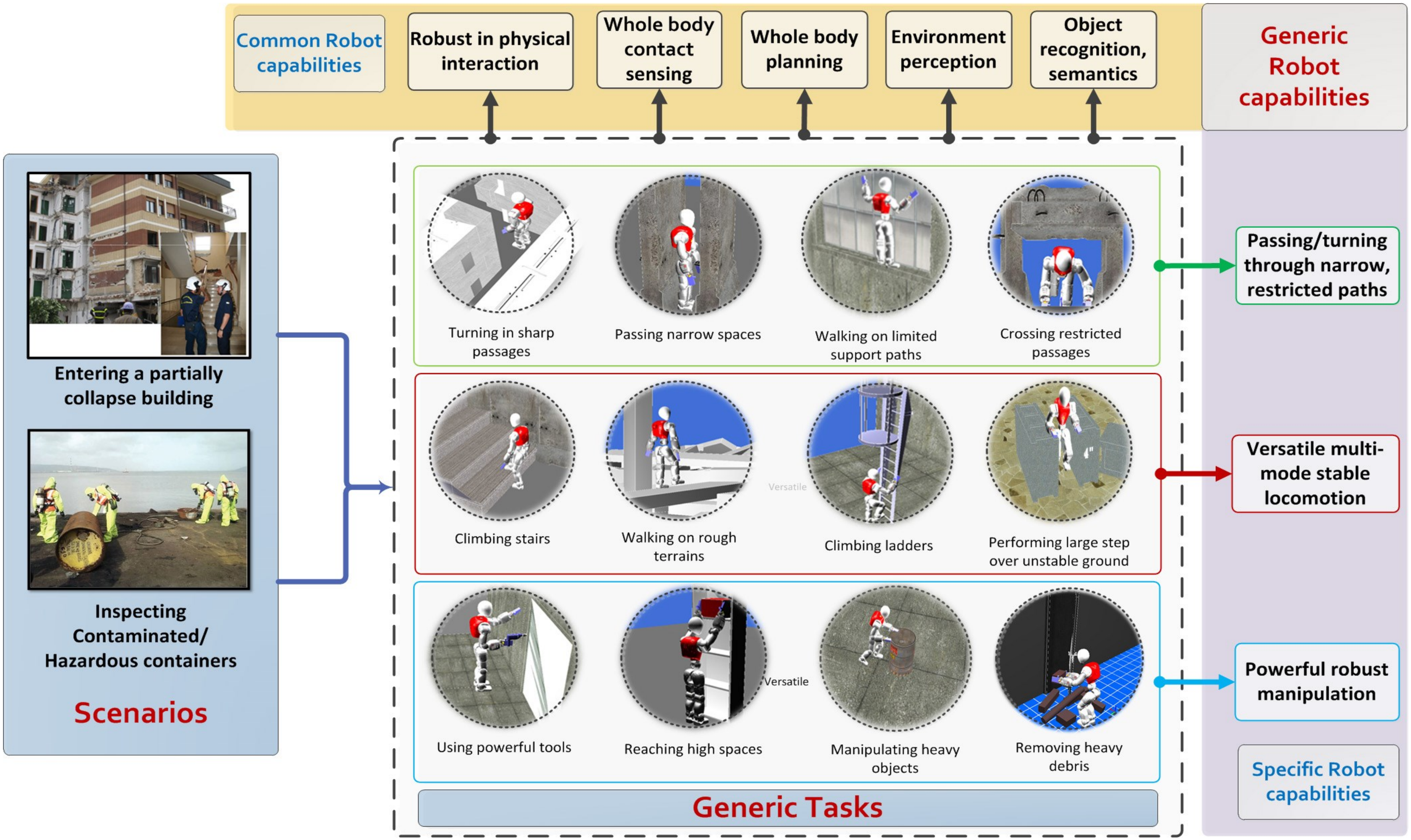
WALK-MAN Humanoid





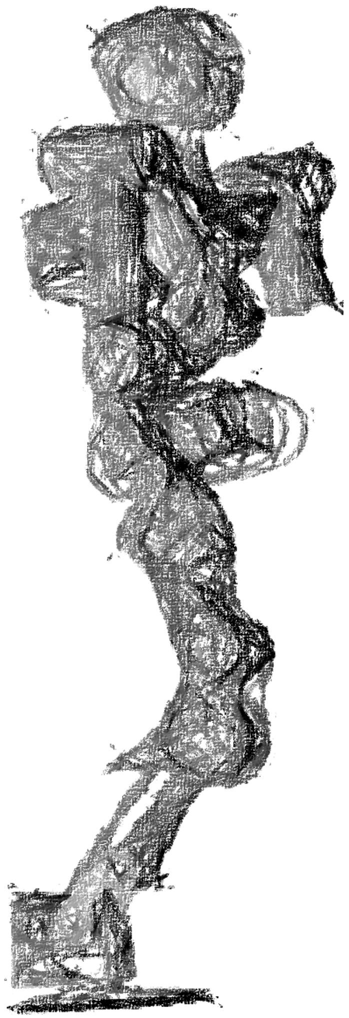


Generic subtasks/interaction scenarios of the robot deployment



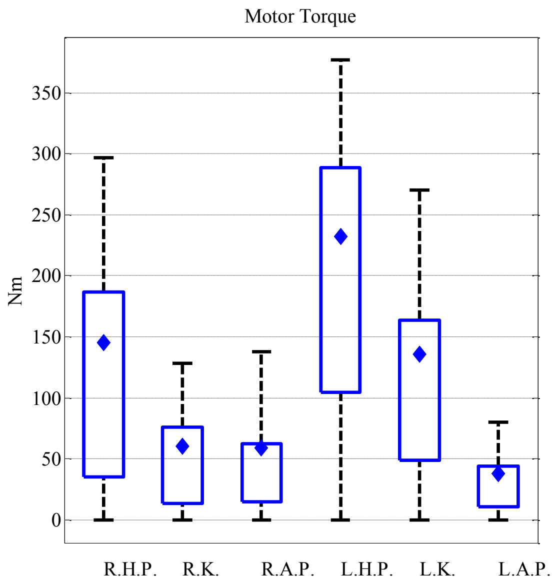
WALK-MAN robot specifications

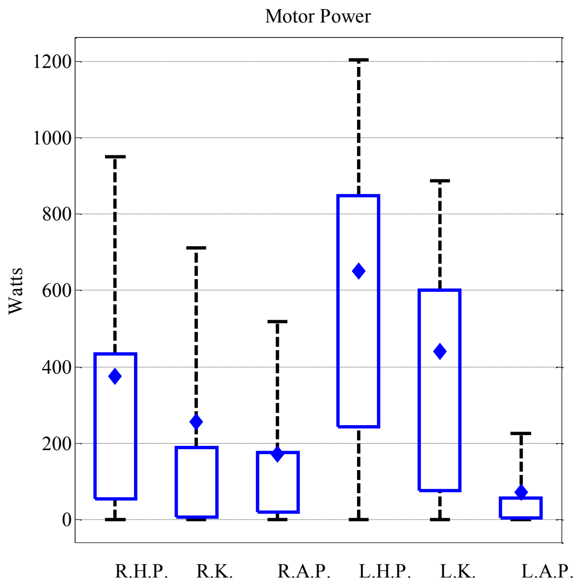
- Robot Size and Kinematics.
- Joint Range of motion
- Joint strength requirements
- Design features for Robust Physical Interaction
  - **Actuation specifications and design approach**
  - End effectors
- Perception system
- Power Autonomy
- Computation and Control Requirements
- Command and Control Interface

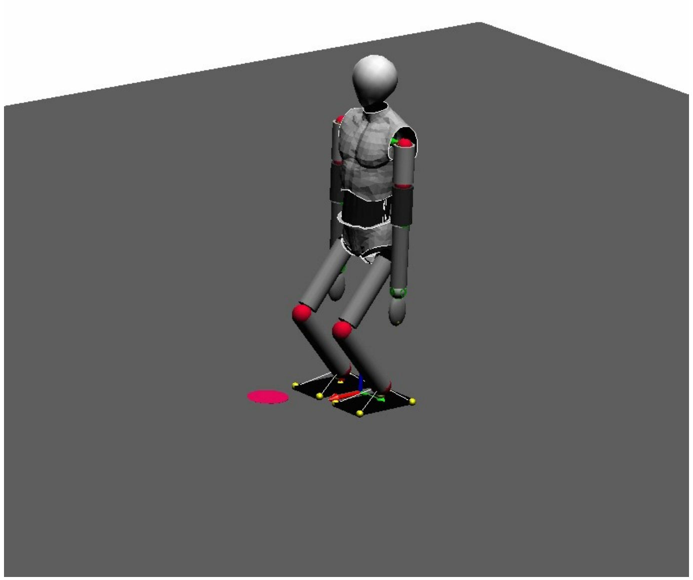


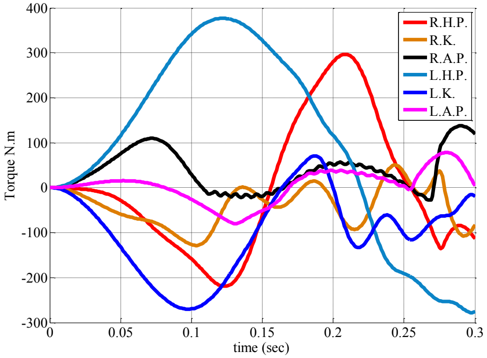
Primitive High Strength/Power (HSP) Tasks

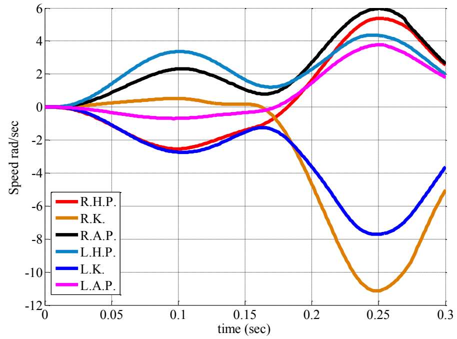
HSP Task 10: Front Fast Stepping (0.3sec) to recover balance

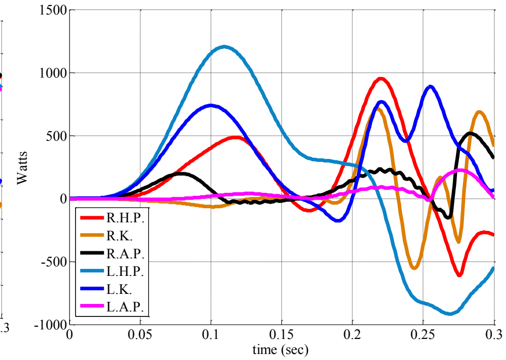


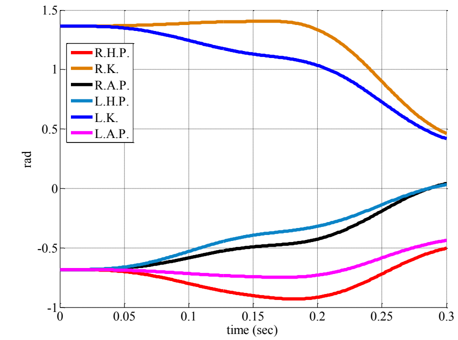






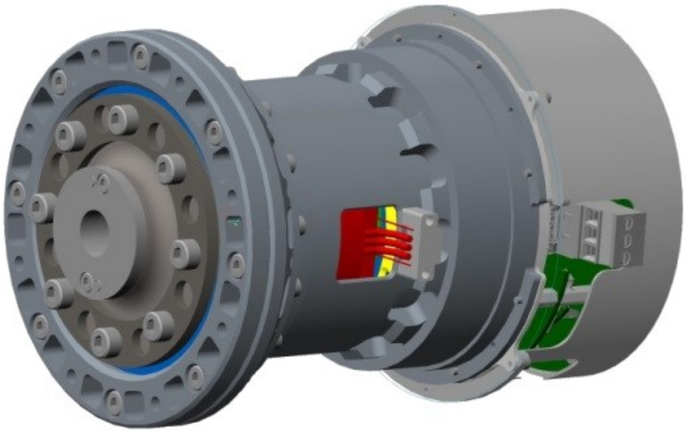


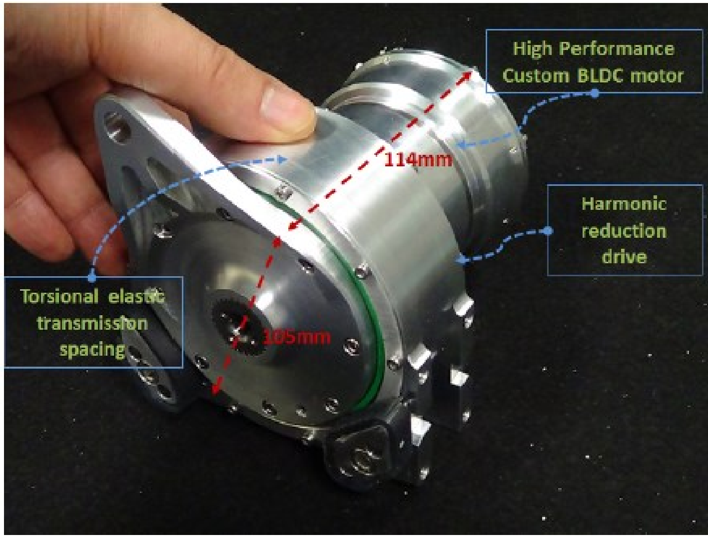




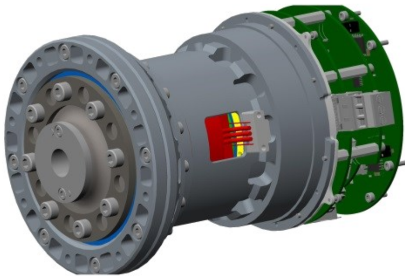
Power branch (PB)

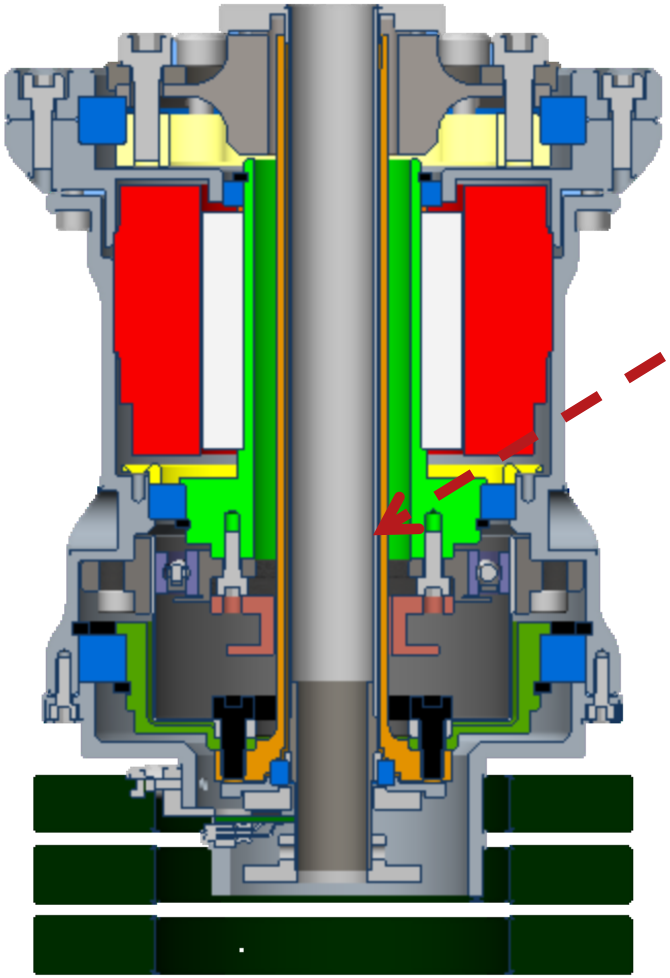
- Custom high performance frameless BLDC motor
  - improved strength and resistivity at high temperatures
  - 800W continuous power at 100°C rise, nominal peak power: 2.9KW
- Gearing : 80/1
- Joint torque/speed
  - Static Peak torque 270Nm
  - Dynamic Peak torque 220Nm
  - speed at dynamic peak torque 11-12rad/sec (at 48V)
- Full feedback
  - High resolution absolute encoders (19bit)
  - Torque encoder sensing
    - Resolution: 25mNm
    - Max offset: 0.5Nm



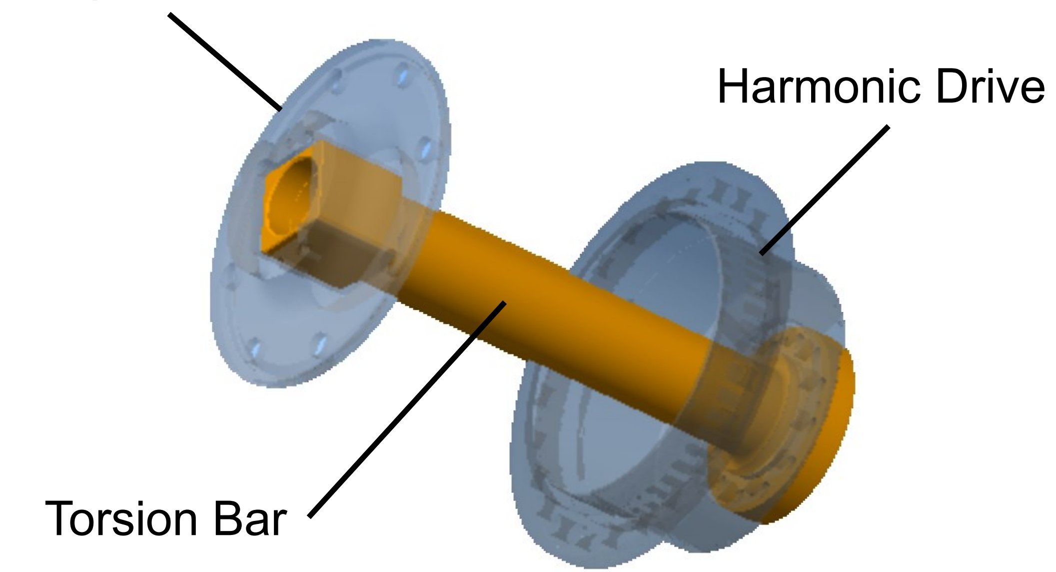


WALK-MAN Actuation Principles
Power Branch (PB)



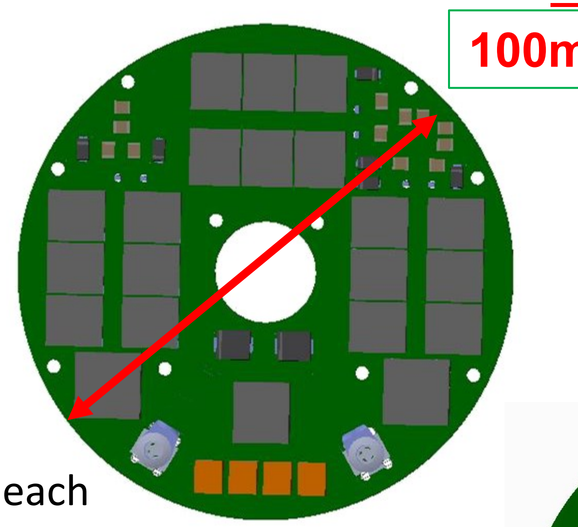


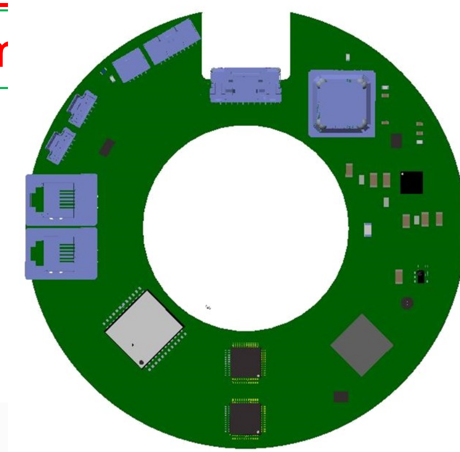
- **Elastic Element:**
  - Torsion Bar
    - Material: Titanium
    - Dimension:
      - 200 Nm > De 19 mm, Di 16 mm, L 97 mm
      - 140 Nm > De 15.6 , Di 12.6 mm, L 77 mm
      - Safety Factor: 2

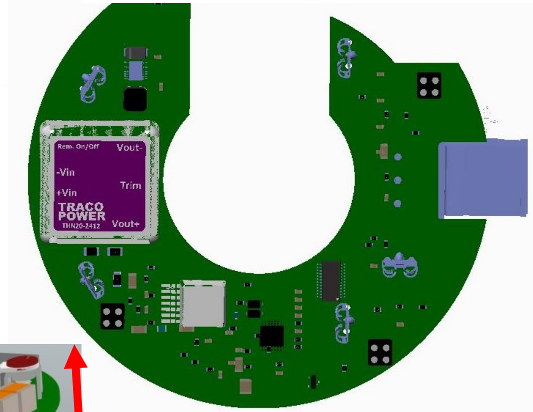


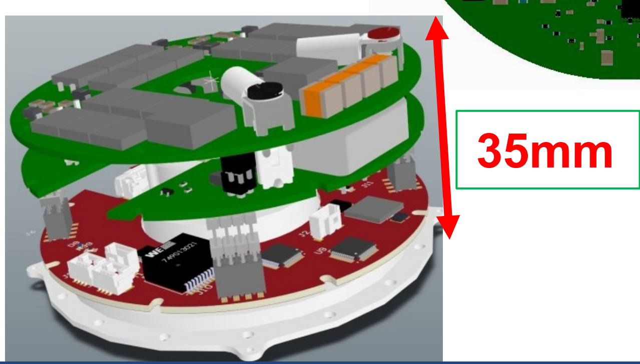
WALK-MAN Actuation Principles
Custom driver Electronics

- Hard real time Communication interface (EtherCAT)
- A single DSP for each motor
  - TMS320F28335 (32bit, 150MHz)
- Control
  - 20KHz Current loop
  - 5KHz Torque loop
  - 2KHz Impedance loop
  - Accurate current measurement for each motor phase.
- Several Analogue & Digital I/O ports
- Power inverter
  - Power bus: up to 140V
  - Local power up/down control through EtherCAT
  - High current (120A continuous, 300A peak)
  - Regenerative energy capability
- Fully integrated in the motor assembly







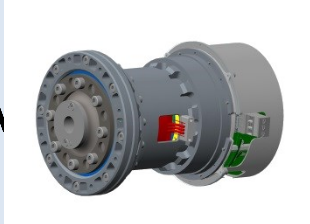


WALK-MAN Actuation Principles

Power Branch (PB)

One common design

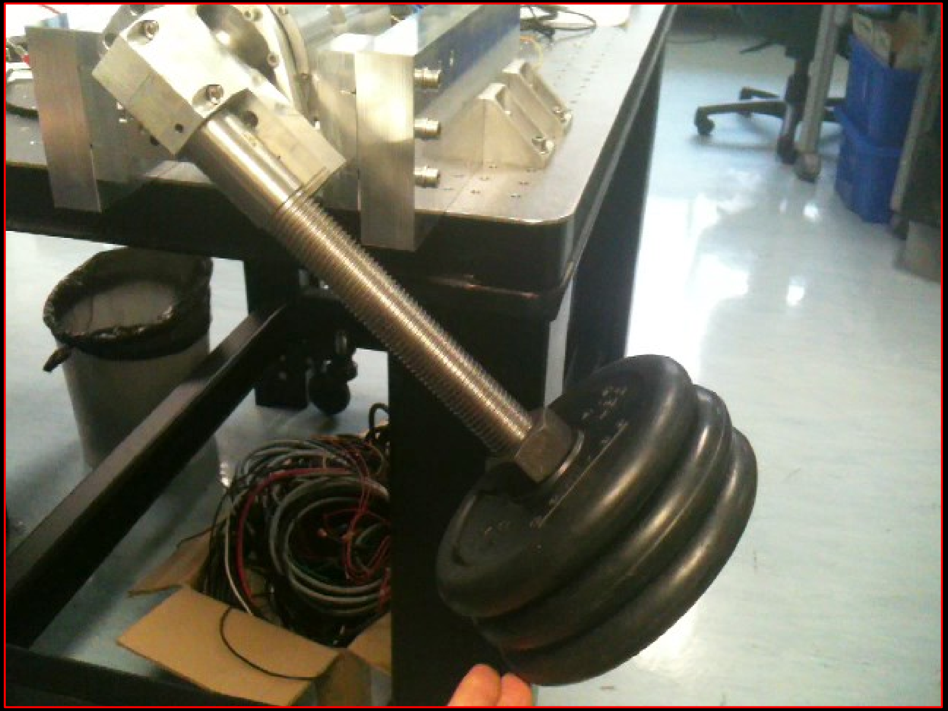
Three sizes with three different torque, power and stiffness ranges

Specification	A 	B 	
Continues Power (W) @ 120C rise	900	500	222
Intermediate Mechanical Power operating point (G=80:1, eff=70%)	112Nm@11.7rad/s 1300W	89Nm@11.7rad/s 1040W	30Nm@10.2rad/s 305W
Dynamic Peak Mechanical Power operating point, (G=80:1, eff=70%)	220Nm (10.4rad/sec) 2280W	140Nm (11.2rad/sec) 1560W	40 Nm(9.3rad/s) 370W
Static Peak Torque (Nm), (G=80:1, eff=90%)	270Nm	180Nm	52Nm
No load speed (rpm)	14rad/s	16.7rad/s	11.3rad/s
Weight (kg)	2.0	1.5	0.7
Stiffness (Nm/rad)	2600	2000	1500
Overall dimensions DxL (mm)	110x150	100x140	(60x100)

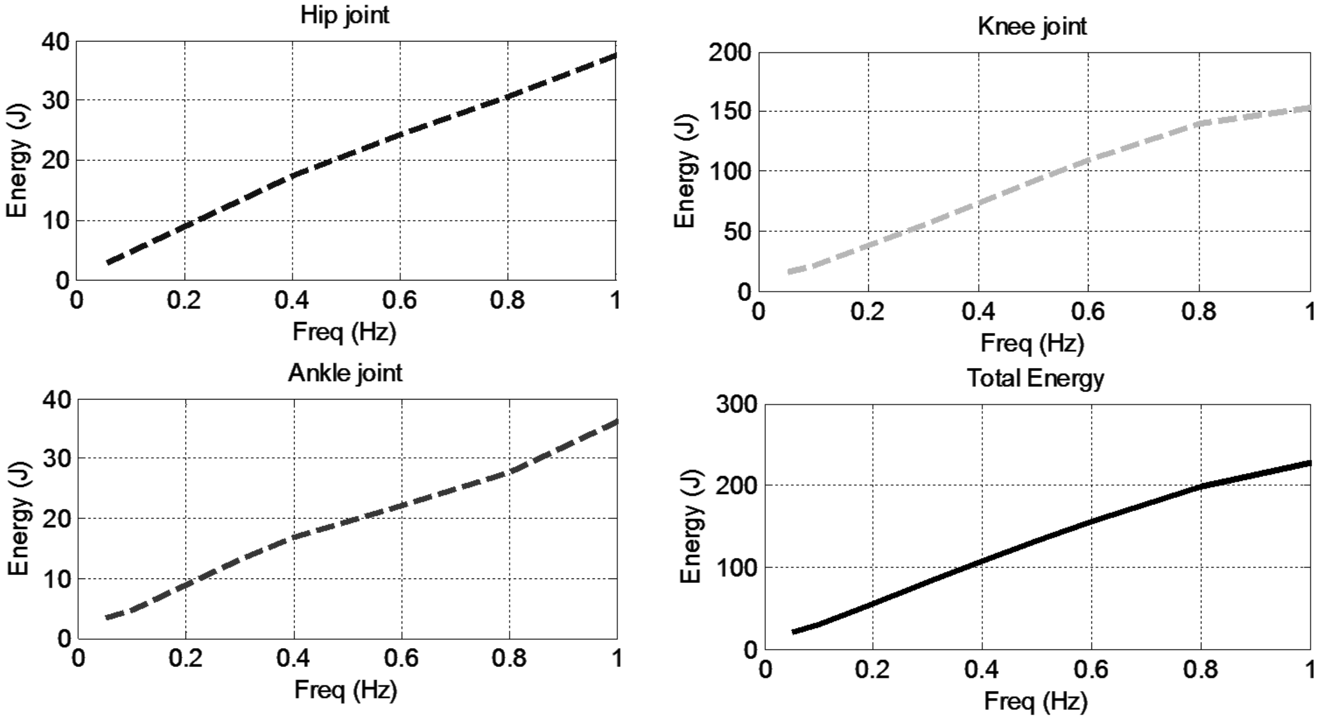
In collaboration with University of Pisa

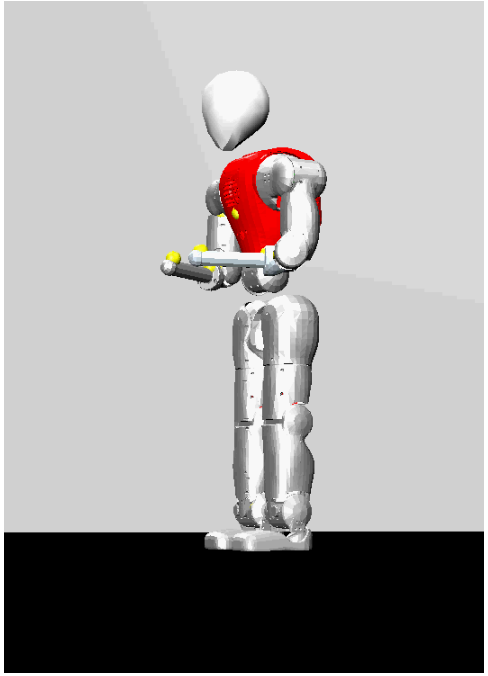
WALK-MAN Actuation Principles

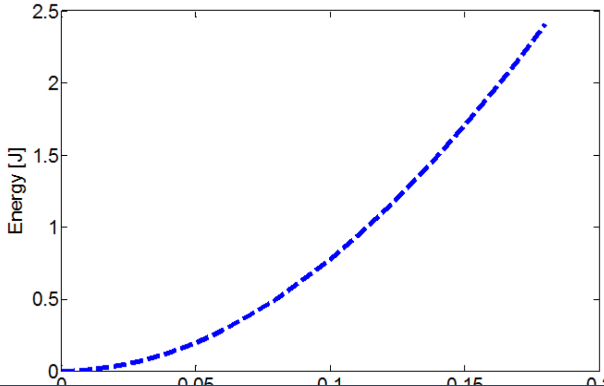
Power Branch (PB)



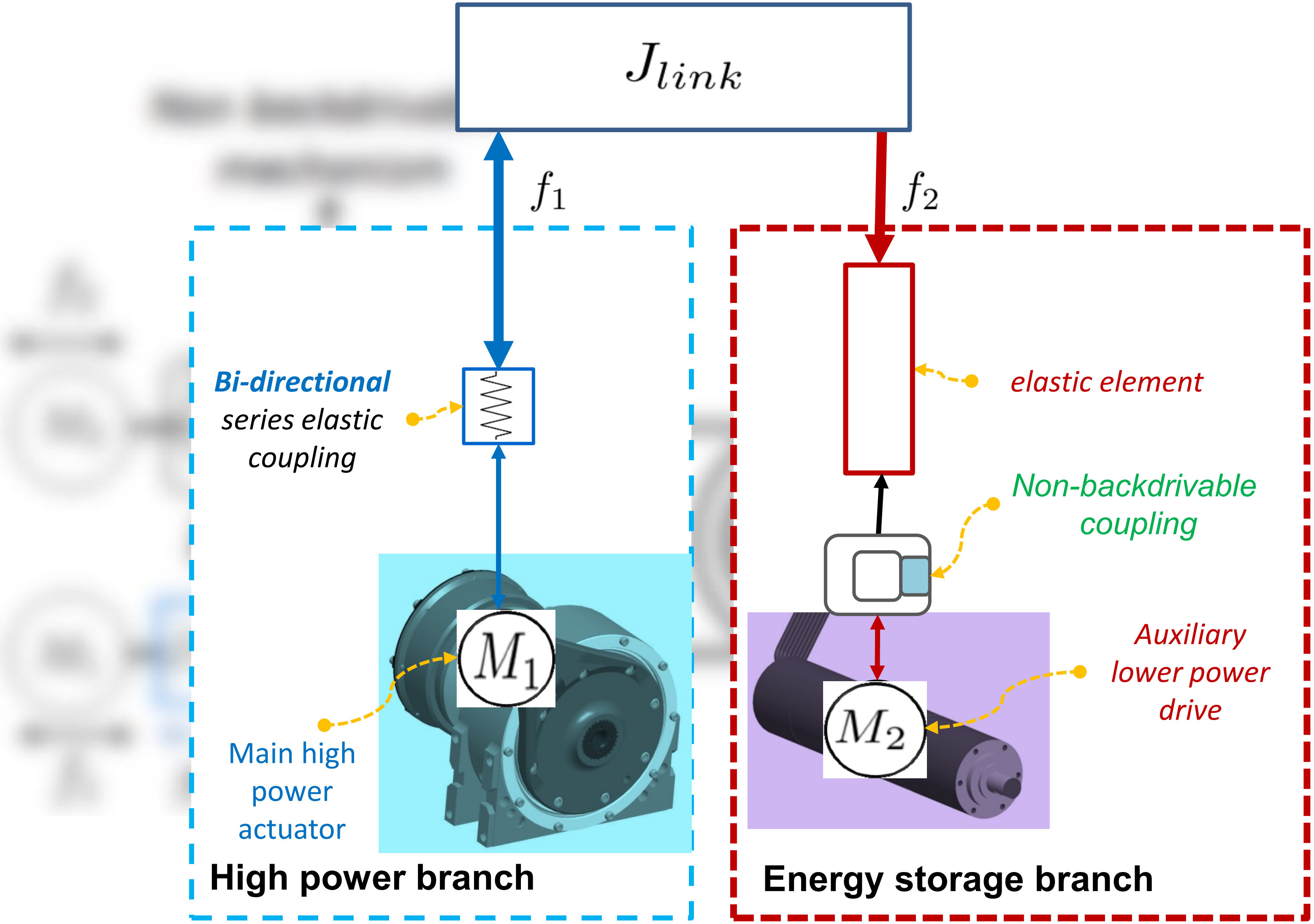
COMAN squatting energy example





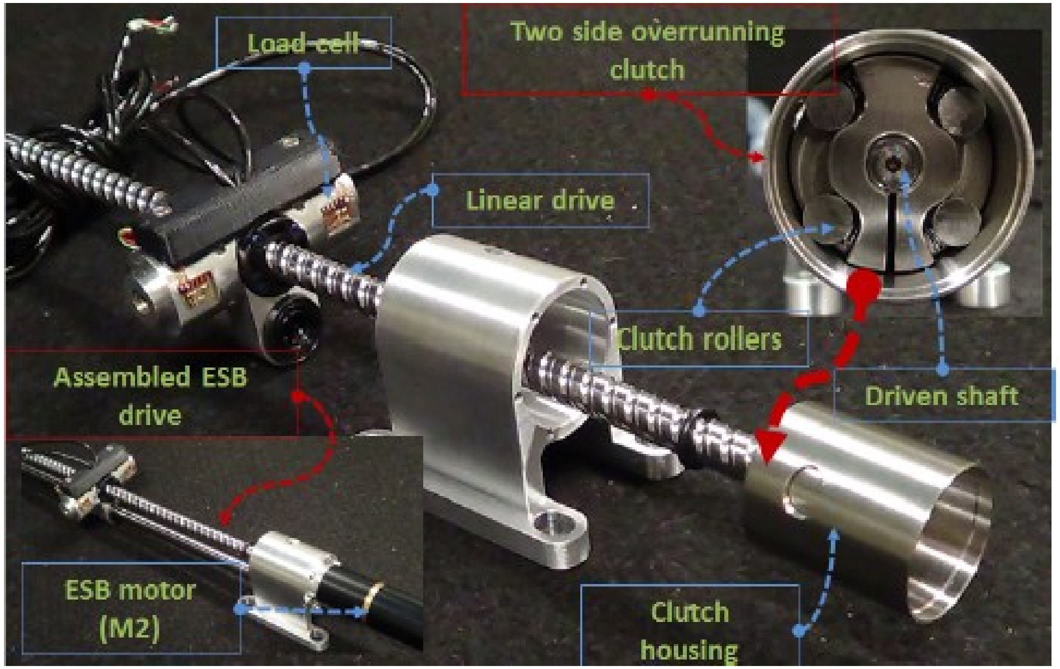


Asymmetric compliant antagonistic joint



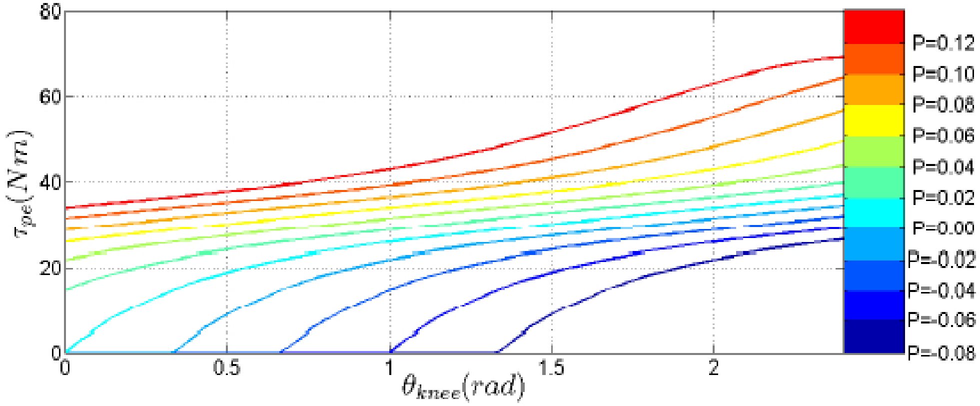
Energy storage branch (ESB)

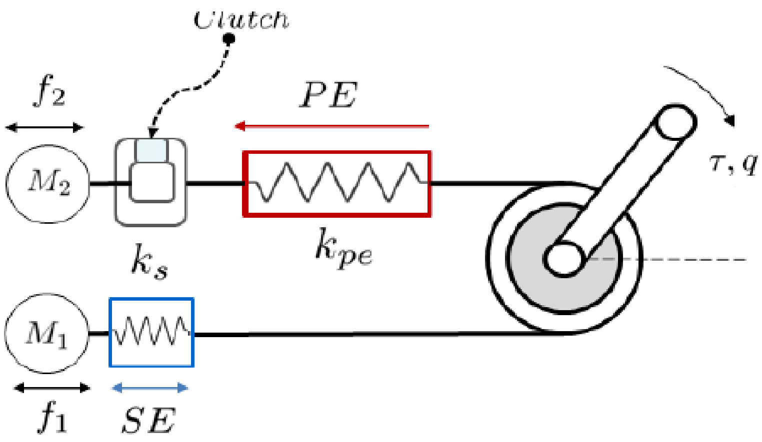
- Energy storage capacity in the ESB is maximized
  - use an elastic band similar to shock cords instead of mechanical metal springs.
- Ability to regulate the pre-tension of the elastic element
  - brushless DC servomotor (100W)
  - coupled to a low gear ratio planetary gearhead in series with a highly back-drivable ball screw transmission
  - Efficient maintenance of pretension with the use of a two-way overrunning clutch module.
- The force of the elastic band is monitored with a load cell

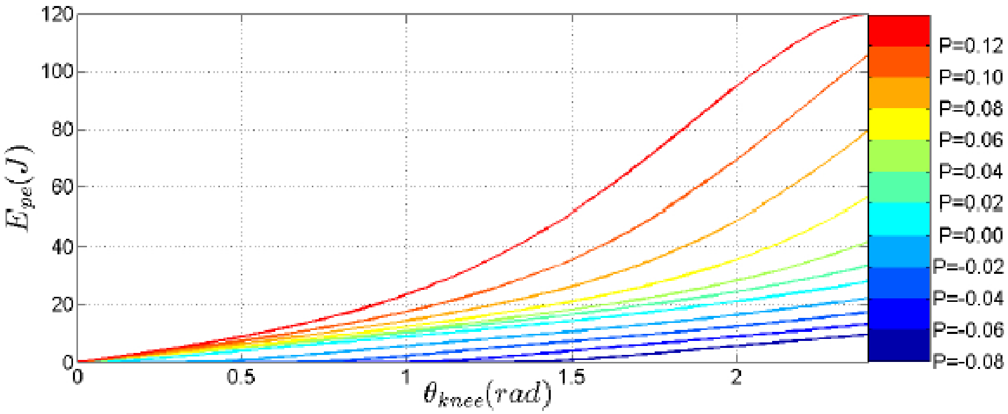


Energy storage branch (ESB)

- large energy storage capacity
- controllable energy storage and release
- Expected benefit
  - efficient operation in cyclic motions
  - zero energy static load compensation

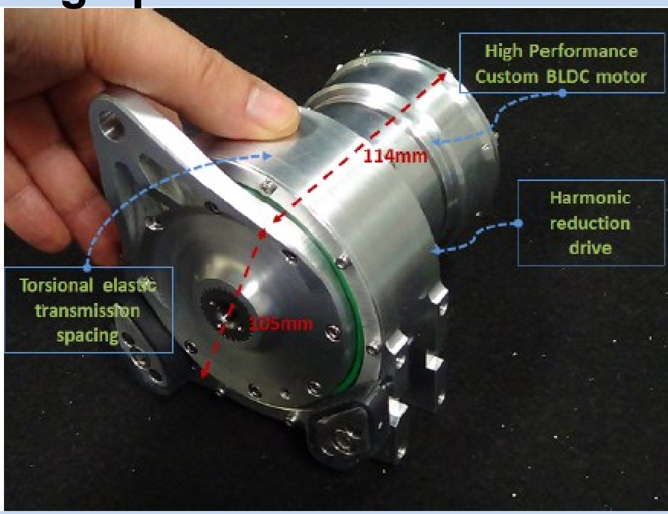




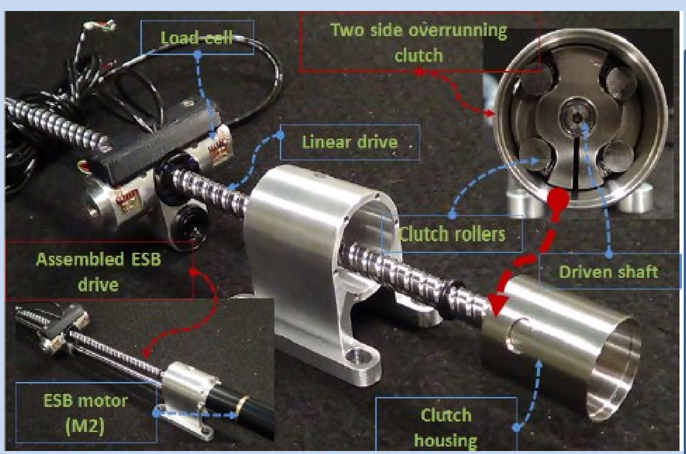


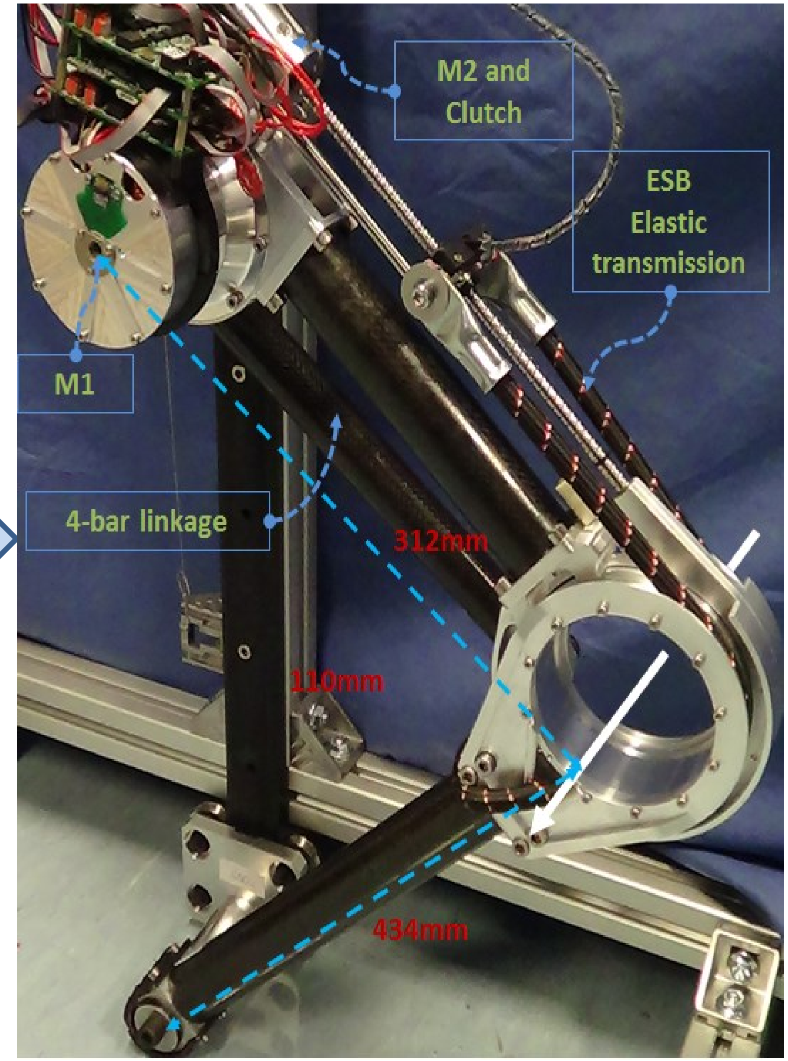
Knee joint prototype

High power branch

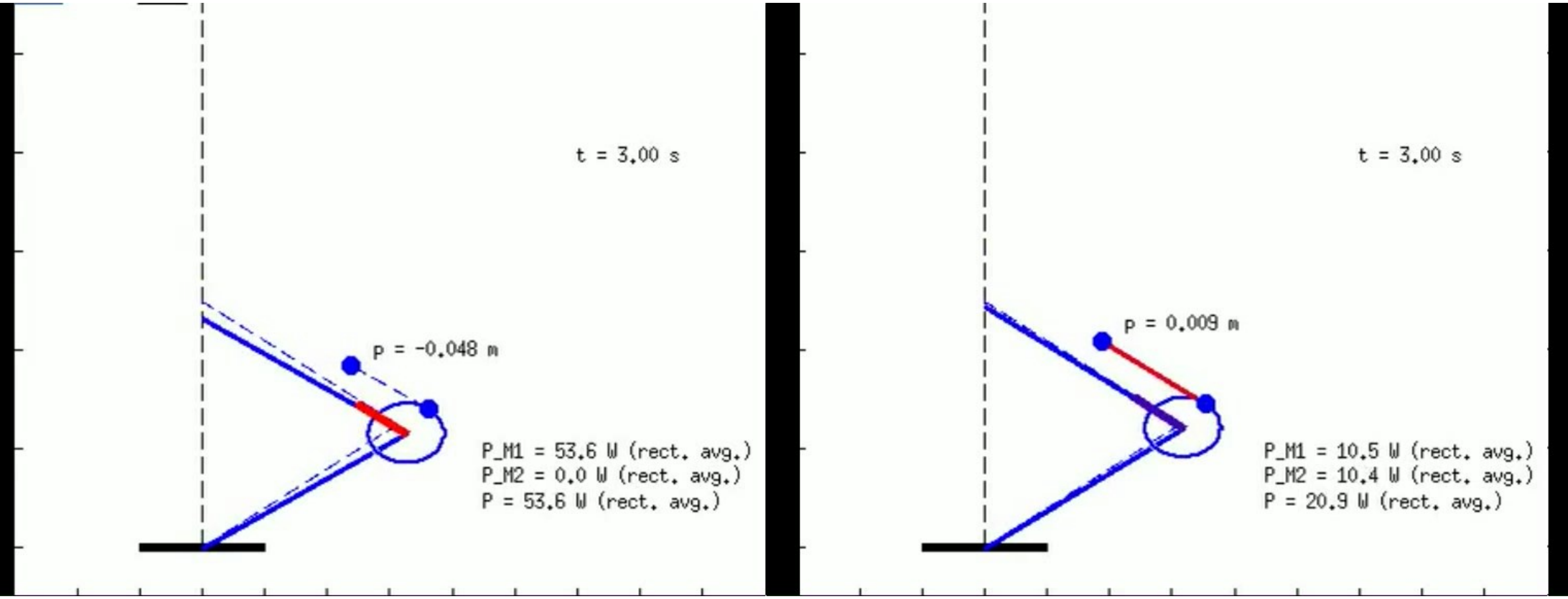


Energy storage branch

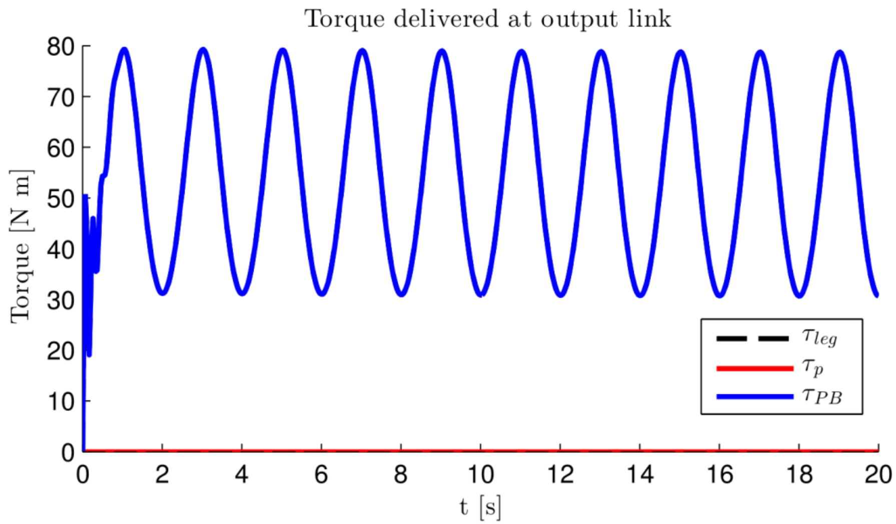


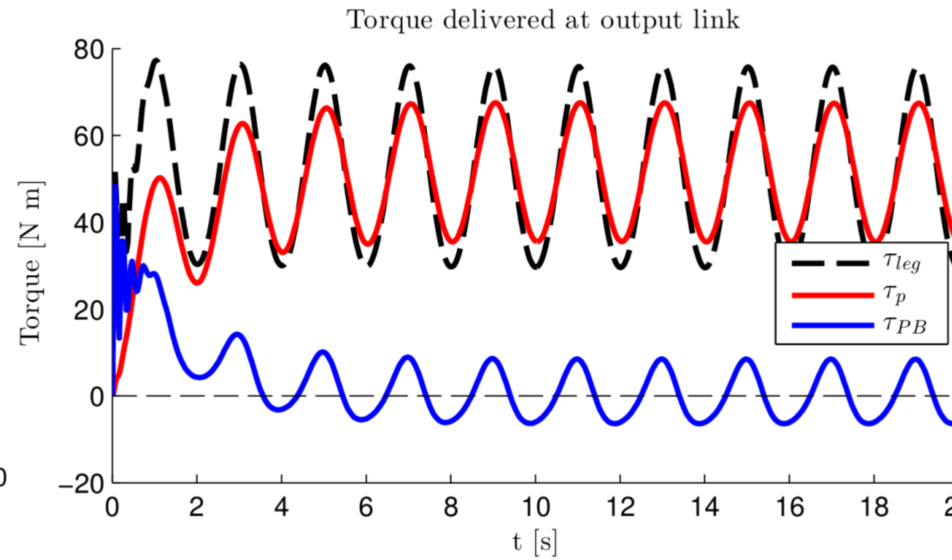


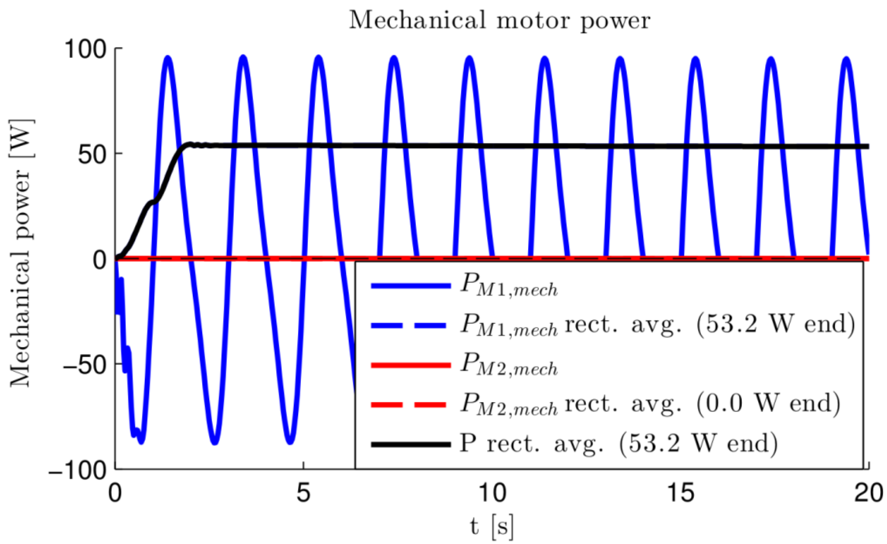
0.5Hz squatting with q=0.8..1.8rad
Without and with ESB

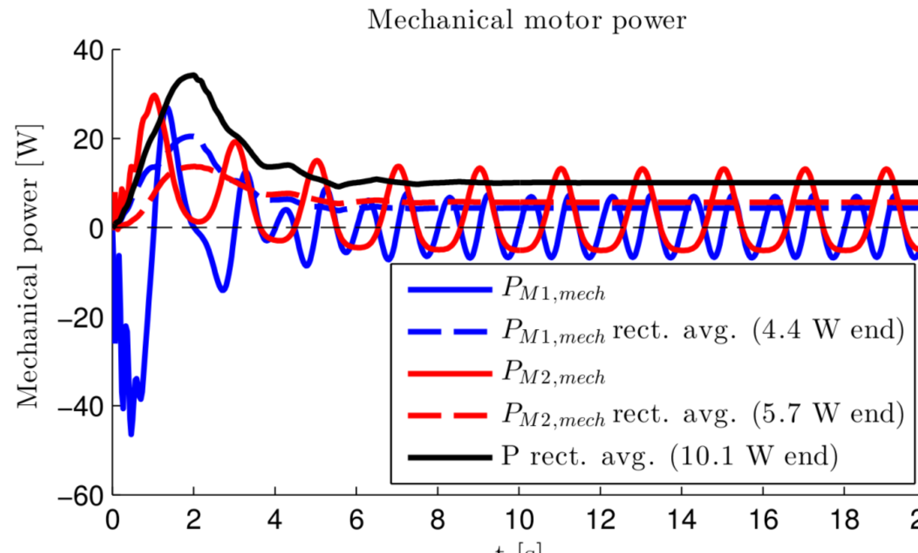


0.5Hz squatting with q=0.8..1.8rad
Without and with ESB: Power/Torque comparison







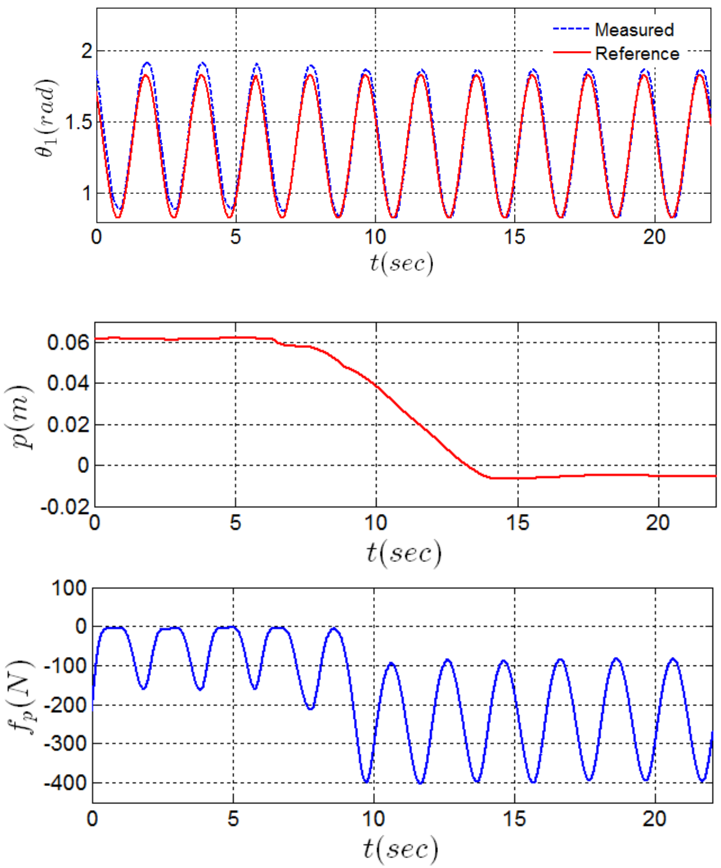


Squatting motion

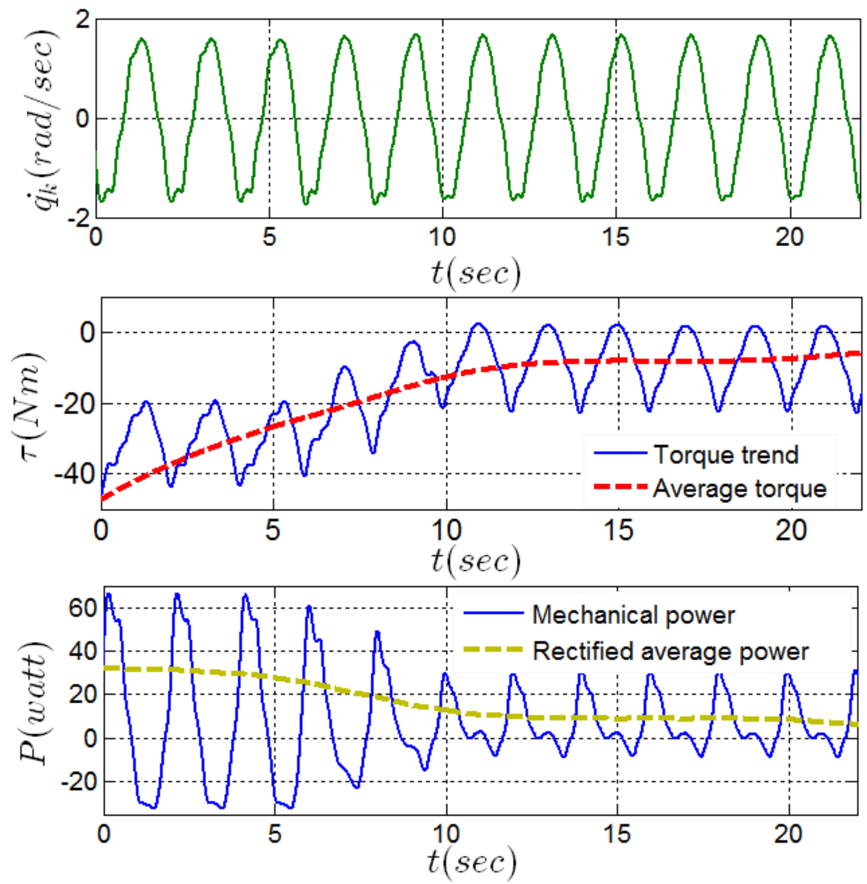
Squatting motion data

Improved efficiency

Power and energy storage branch actuation trajectories



Effect on power and torque requirements



Many thanks for your attention