Co-evolution of Morphology and Control of a Wearable Robot for Human Locomotion Assistance exploiting Variable Impedance Actuators

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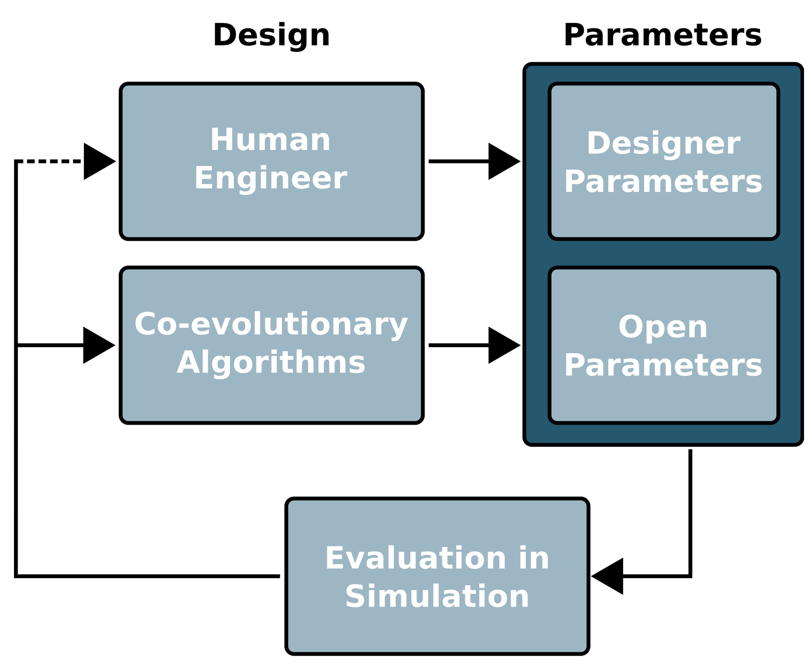
Objectives

- Design of **Wearable Robot** for the **lower limbs**
- Optimizing **dynamics** of the **WR and the human body** wearing it
- Co-evolution of **mechanical structure** and **control system**

Methodology

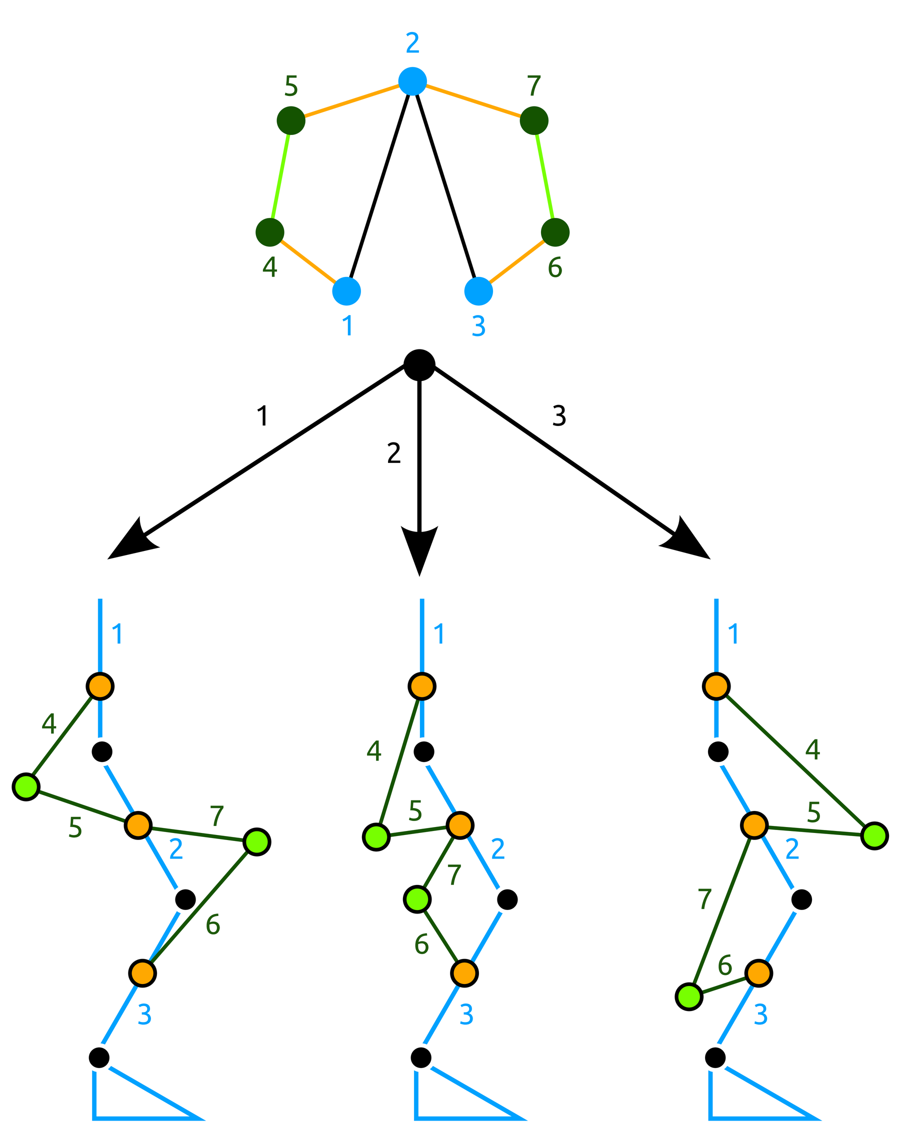


- Parameters set by **Engineer** and those open for **optimization**
- Physics based dynamical simulation of mechanical system
- Optimization (PSO) of open parameters to restore **Physiological Gait** and optimize **Dynamical Interaction**

Mechanical Structure

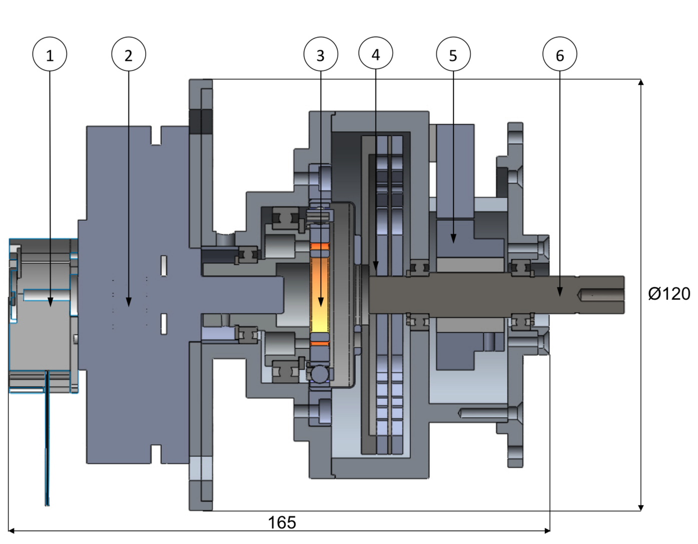
- Basic **human model** (in blue)
- **Attachment joints** on the three human segments (in orange)
- Additional **WR joints** (in green)

- Actuation of human **Hip** and **Knee** DOFs (3 human segments) using 4 additional WR segments
- **Topologies** (at the top) generated using HR-isomorphism and HR-degeneracy tests [1]
- Transpose kinematic structure (top) into actual mechanical structure (bottom)



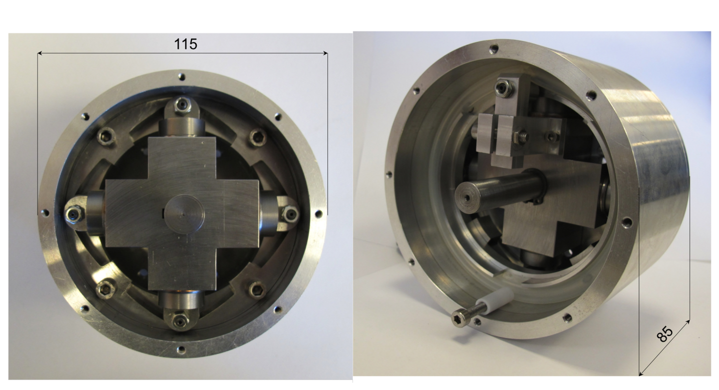
WR Joint Actuation

Compliant elements exploited to provide **Assistance As Needed** [2].



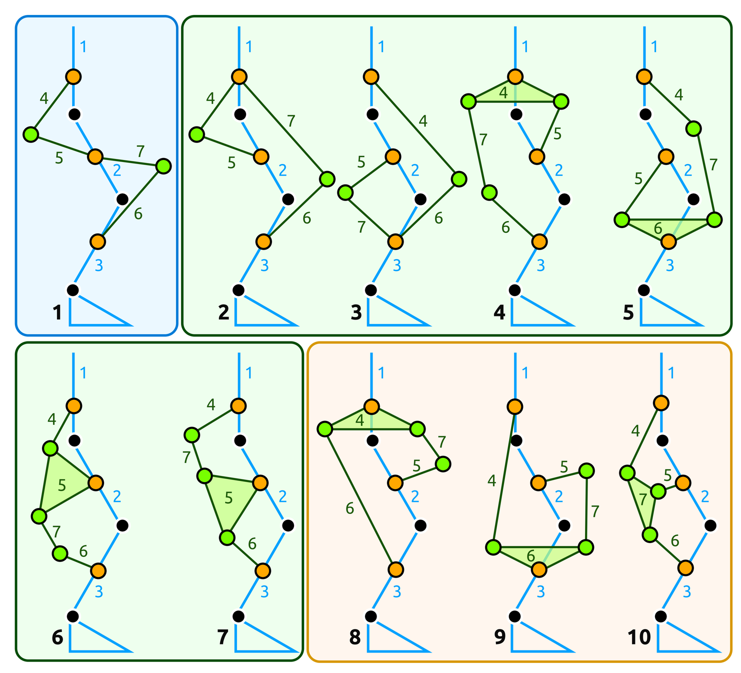
- Series Elastic Actuator
- EC-flat 90W Maxon motor
- Harmonic Drive reduction gear (100:1)
- Maximum output torque of 30 Nm
- Maximum peak velocity of 5.2 rad/s

- Visoelastic Passive Joint
- (a) Torsional stiffness module, 4 linear springs on CAM profile
- (b) Torsional damping module, roller compresses tube filled with viscous fluid



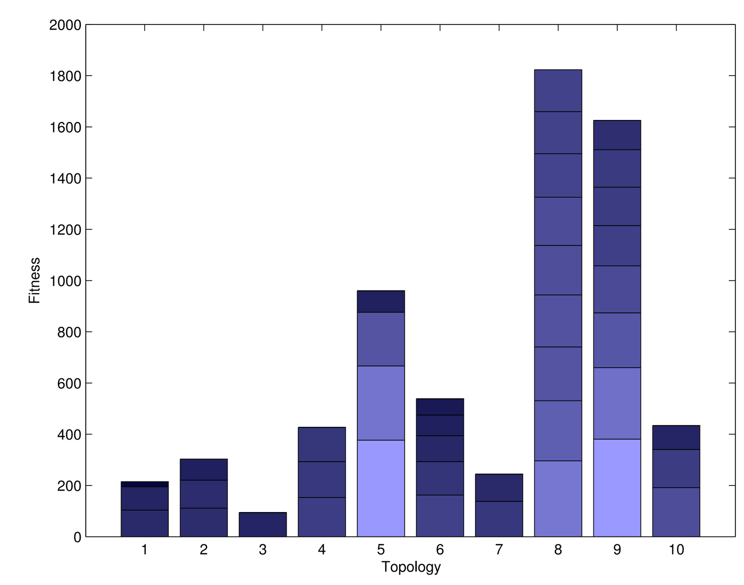
(a) (b)

Experiments

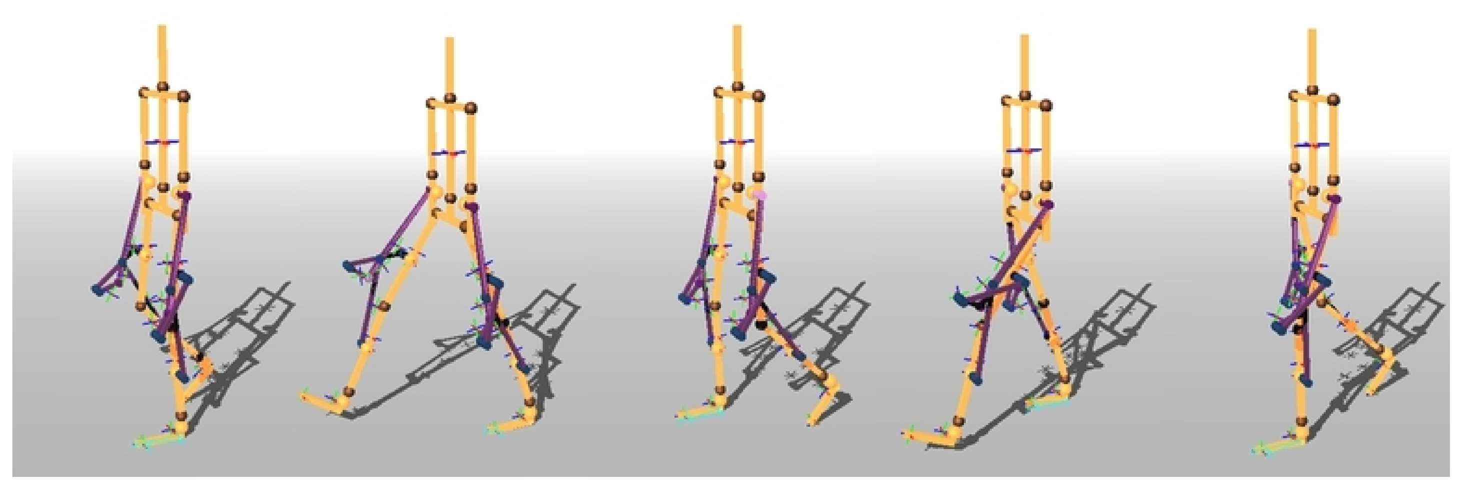


- Selection of **10 topologies** x 10 experiments, evaluated on 88 core cluster
- Optimization of:
  - WR **segment lengths**
  - WR actuator **joint placement** (*active* vs *passive*)
  - WR **mass distribution**
- Evaluated on:
  - Maximize restoration of **human physiological gait**
  - Minimization of **required WR torques**

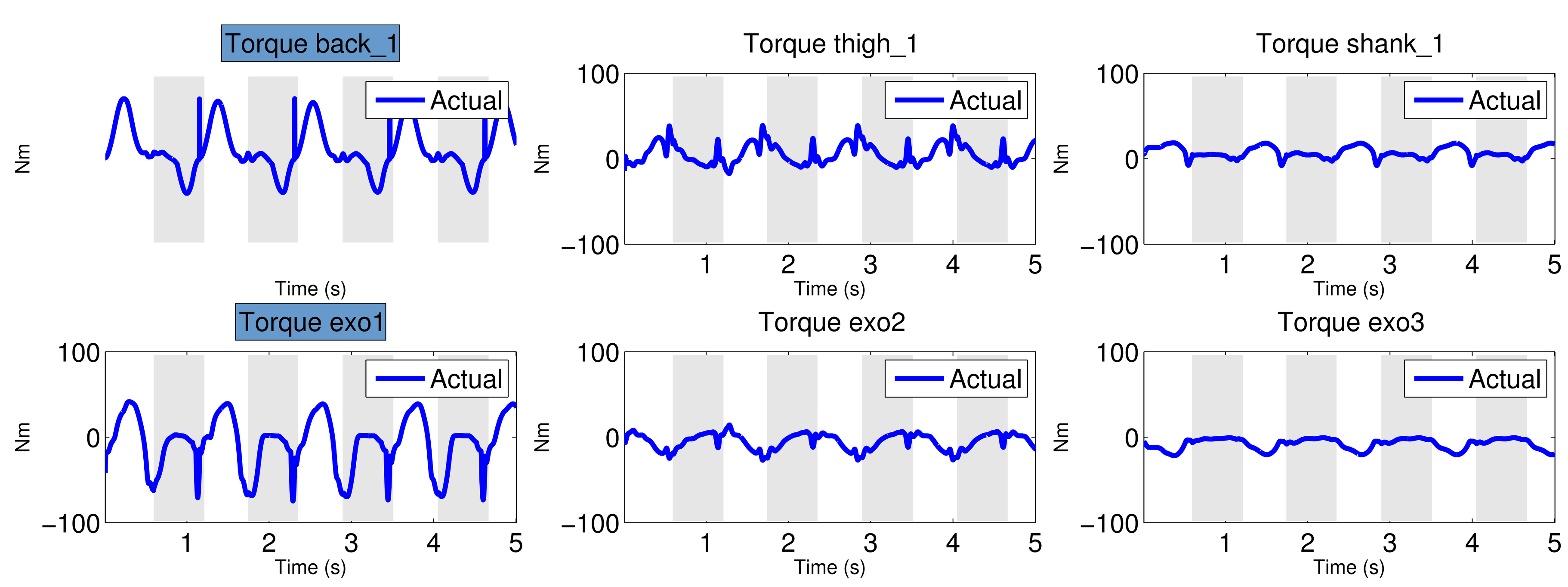
Results



- Over **300 (locally) optimal solutions** found
- Pruning of solutions based on requirements (maximum link length, gait restoration, mass, maximum joint velocities), reduced solutions to ~ 40
- Topologies 5, 8 and 9 are most performant (on the left)
- Final solution ranked based on *Pareto Optimality* results in **8 final solutions**



One of the best solutions for topology 8 featuring a small WR construction with relatively low active torque requirements. The WR is situated close to the body and a large portion of the torques are being generated by the passive elements.



Active (blue label) and passive torques of the six WR joints during the gait cycle of the solution depicted above. Stance phase is indicated in the gray shaded areas.

Acknowledgments

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References

[1] F. Sergi, D. Accoto, N. Tagliamonte, G. Carpino, and E. Guglielmelli. A systematic graph-based method for the kinematic synthesis of non-anthropomorphic wearable robots for the lower limbs. *Frontiers of Mechanical Engineering*, 6:61–70, 2011. 10.1007/s11465-011-0206-2.

[2] H. Vallery, J. Veneman, E. Van Asseldonk, R. Ekkelenkamp, M. Buss, and H. Van Der Kooij. Compliant actuation of rehabilitation robots. *Robotics & Automation Magazine, IEEE*, 15(3):60–69, 2008.

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