Design and Evaluation of a Mobile Ankle Exoskeleton with Switchable Actuation Configuration

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Background

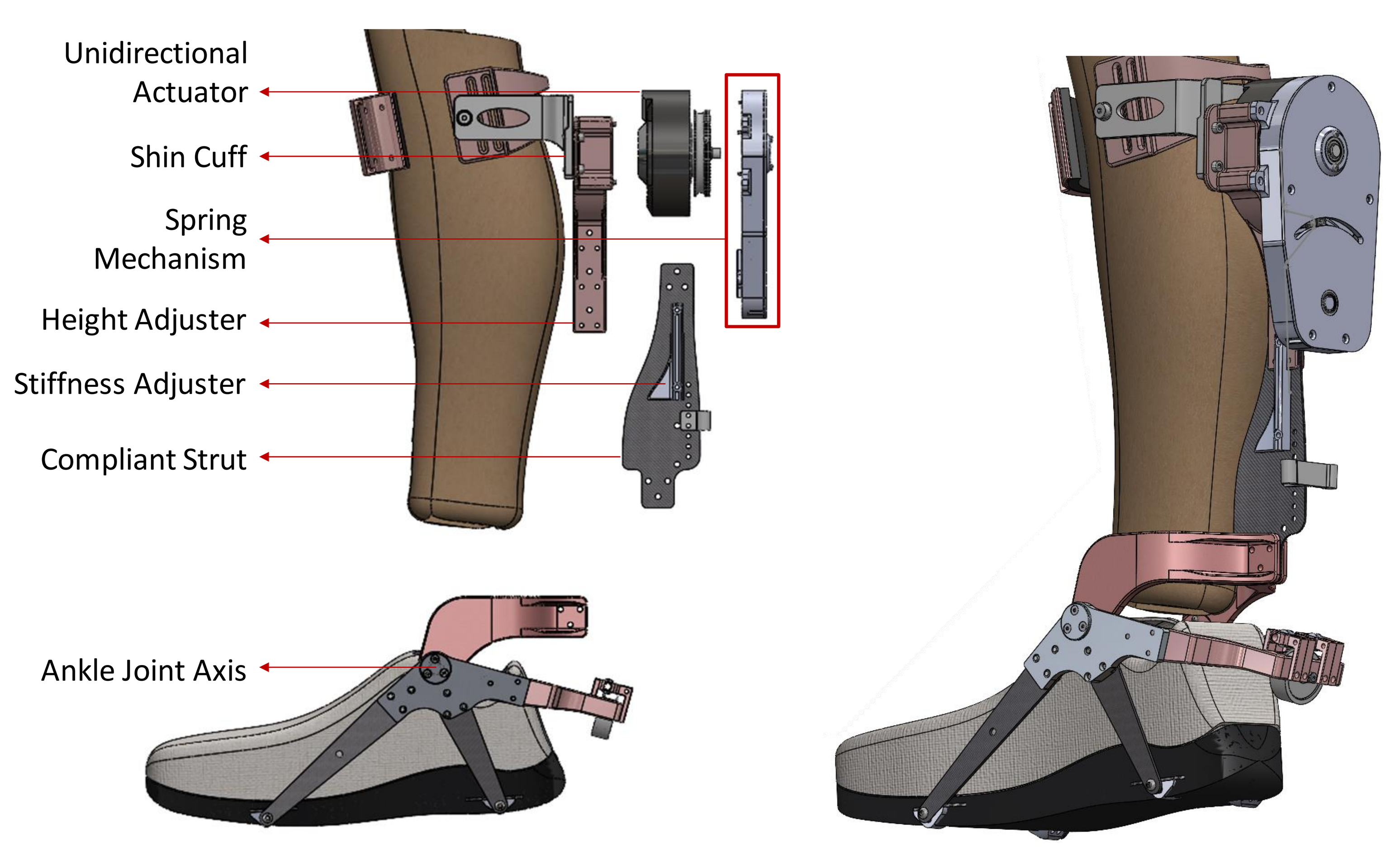
Powered Ankle Exoskeletons have proven to improve walking energetics, carrying heavy loads and improving speed, however their design limit them to lab settings

Design Challenges:

- Restricts ankle joint to plantarflexion / dorsiflexion which limits exoskeletons for walking / running tasks
- Unidirectional actuators allows back drivability but lacks quick and smooth transitioning from Swing to Stance phase

Design

Leveraging mechanical compliance to allow Eversion / Inversion and Internal / External Rotation while assisting plantarflexion



- Peak assistive plantarflexion torque: 50Nm
- Weight: 950 gm

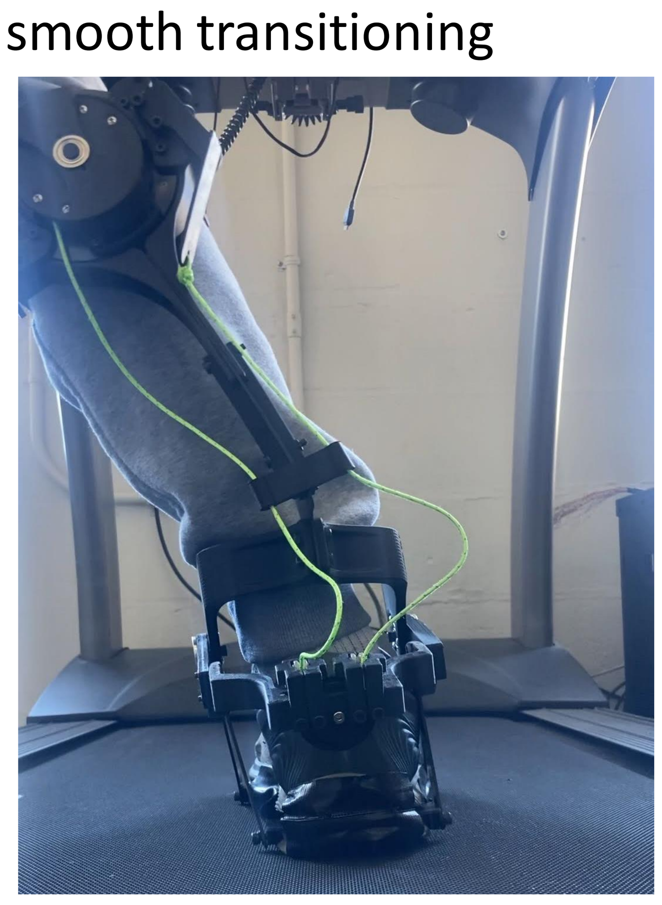
Prototype

Hardware:

- Fabrication: Carbon Fiber Sheets and 3D Printed
- Actuator: Dephy Actpack 4.1, 9:1 Gear Ratio
- Sensors: IMU, Absolute Rotary Encoder
- Microcomputer: RaspberryPi 4

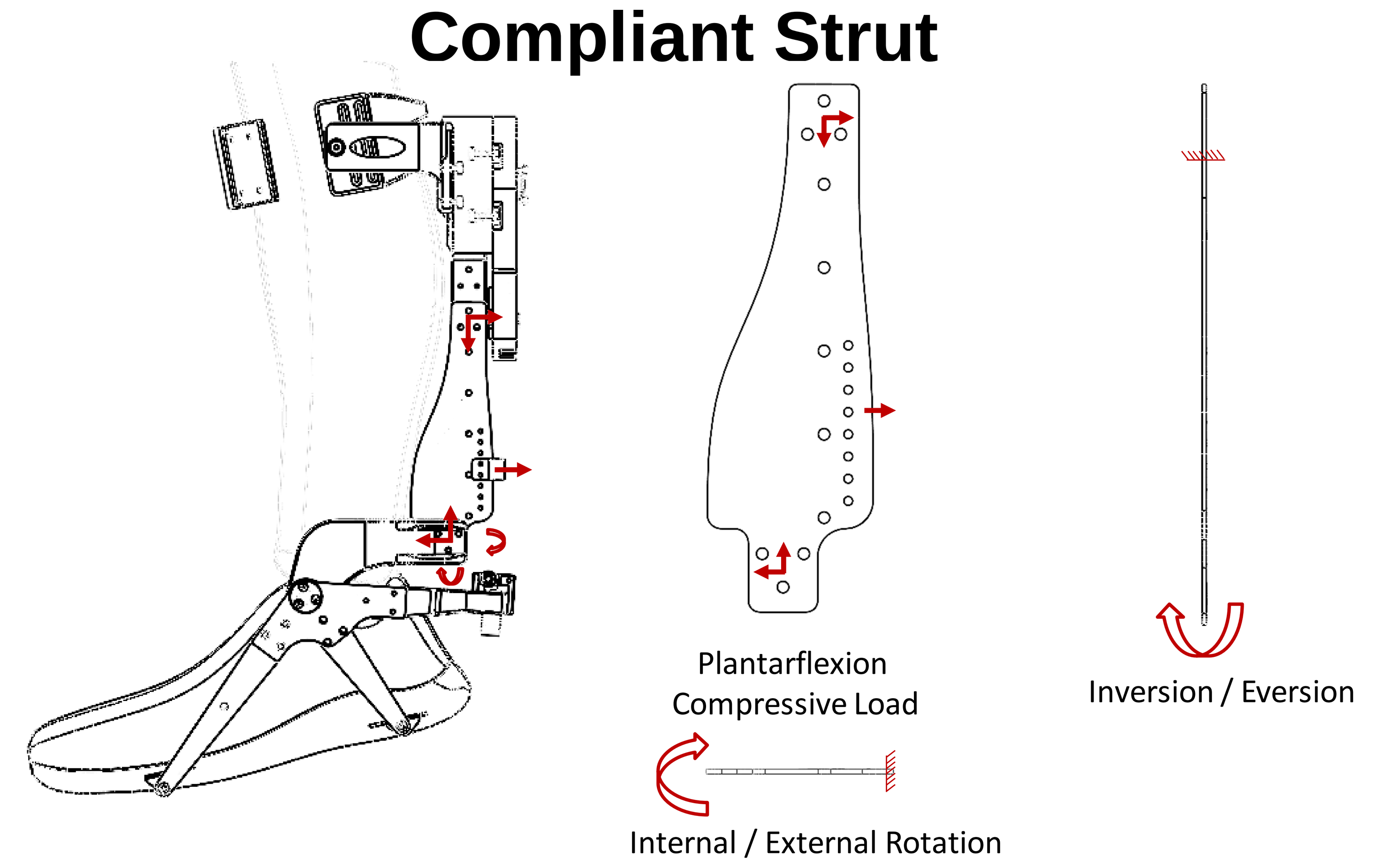
Result:

- Compliant Sturt enables comfortable Eversion/Inversion and Internal/External Rotation
- Adding series elasticity enables smooth transitioning



*Previous iteration of Exoskeleton with beam spring for series elasticity instead of Spring Mechanism

Compliant Strut



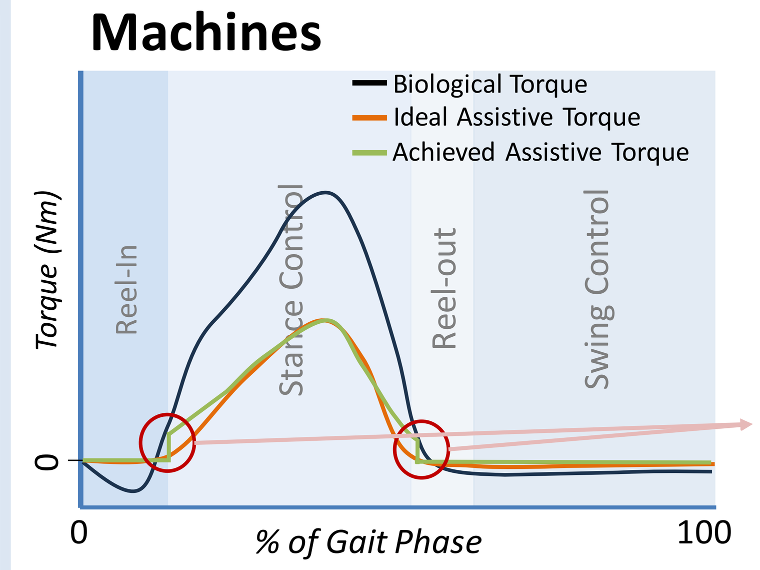
Forces and Moments on Compliant Strut supporting Inversion/Eversion and Internal/External Rotation of Ankle Joint

Gait Phase-based Controller

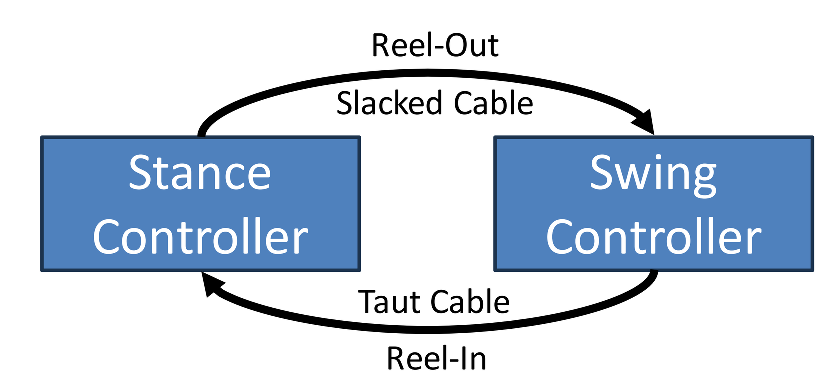
Time based Gait Phase Estimator

$$\%\ Phase = \frac{(t - t_{Last\ HeelStrike})}{T_{Avg.of\ last\ 3\ Steps}}$$

Gait Phase-based State Machines

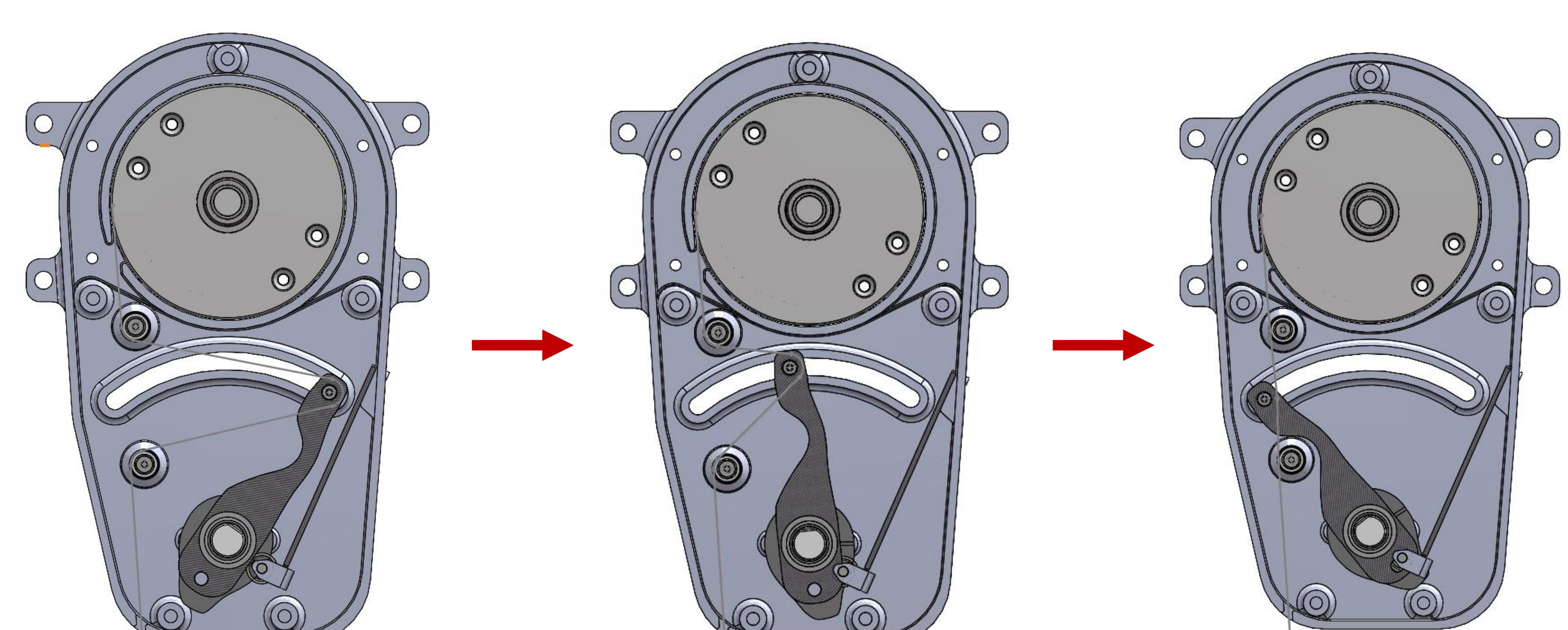


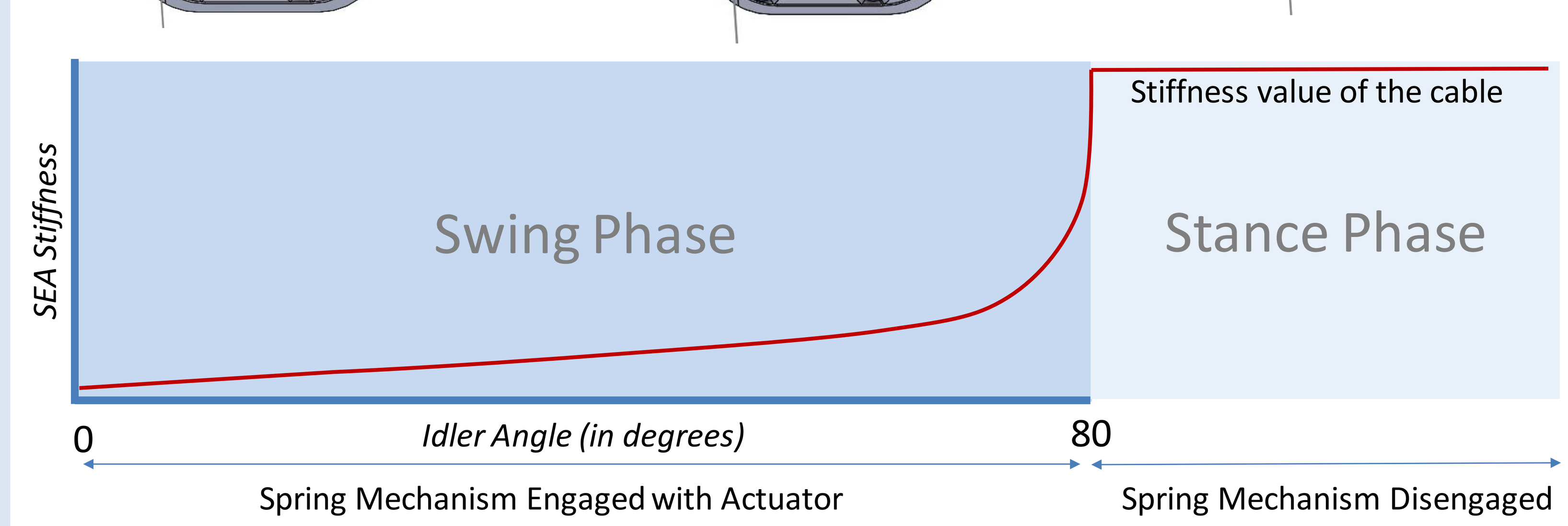
In cable driven system, we can achieve competing requirements of high-torque in Stance and zero-torque in Swing



However, to make this transition smooth we need series elasticity with:
- Low Stiffness during Swing
- High Stiffness during Stance

Spring Mechanism





- Kinematic arrangement of the cable around idler enables engagement and disengagement of spring with actuator
- The stiffness during transition behavior between engagement and disengagement is governed by the CAM profile pushing on Beam Spring

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