Lazarus: Passive Lower-Limb Exoskeleton

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Overview

- Passive lower-limb exoskeleton for walking gait restoration
- No battery/motor/controller
- Lightweight, cheap, no recharge, no cool-down
- Pneumatic energy, high torque output, high efficiency
- This will be successful if muscle activation is lowered during testing

Theory

1. Torque in Ankle Actuator:

$$M_a = R_a * [P_1 * (A_{piston} - A_{rod}) - P_2 * (A_{piston})]$$

2. Torque in Hip Actuator:

$$M_h = R_h * [P_1 * (A_{piston} - A_{rod}) - P_2 * (A_{piston})]$$

3. Residual Torque of Wearer:

$$R_i = [Human\ Ankle\ Torque, Human\ Hip\ Torque] - [M_a, M_h]$$

4. Average Moment (Torque) Cost of Wearer:

$$C_{mom} = \left(\frac{1}{6 * T}\right) * \sum_{i=1}^{6} \int_0^T |R_i(t)| * dt$$

Inputs

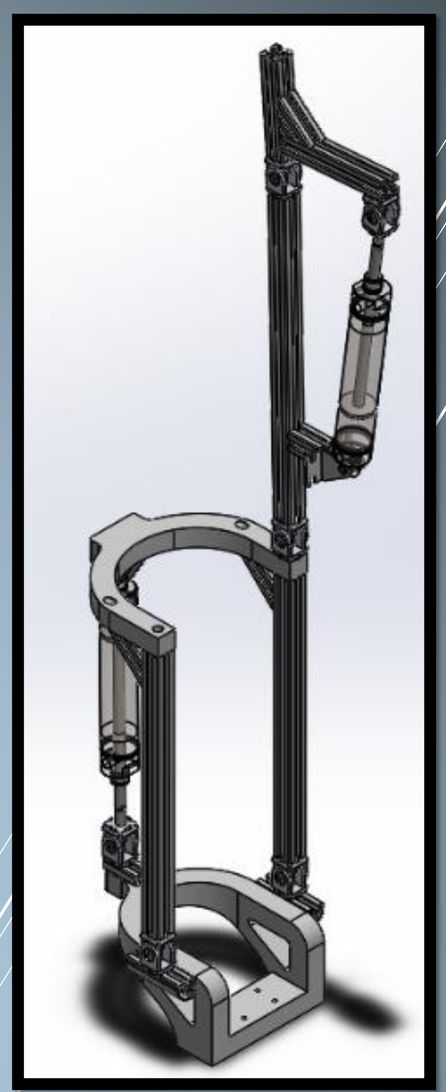
- 10 Human Subjects @ 3 Walking Speeds[1]:
  - 0.8, 1.2, and 1.6 m/s
- Collected in Real Time:
  - Hip Torque
  - Ankle Torque
  - Hip Angles
  - Ankle Angles

- [1] Moore et al., PeerJ 2015

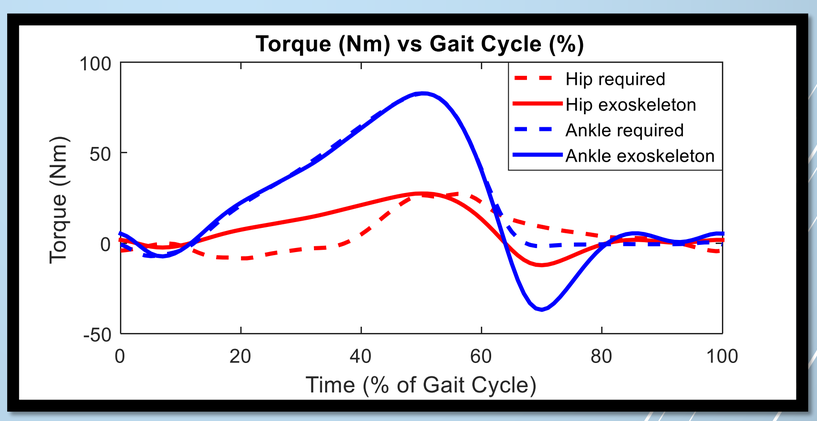
Design Optimization

Outputs

- Minimized Moment Cost ("C_{mom}")
- Optimal Moment Arm (cm) (x2)
- Optimal Piston Position (ml) (x2)
- Optimal Initial Pressure (Mpa) (x2)
- Optimal Tube Volume (ml) (x2)



Optimal Design Parameters			
Walking Speed (m/s)	0.8	1.2	1.6
Moment Cost (Nm)	7.0352	7.4821	8.7679
Ankle Moment Arm (cm)	15.2800	10.6600	15.4900
Hip Moment Arm (cm)	4.9000	5.0700	9.8100
Initial Ankle Piston Position (ml)	53.9300	31.3824	44.1386
Initial Hip Piston Position (ml)	41.1400	17.0267	22.4600
Initial Pressure, Side 1 of System (Mpa)	0.4218	0.4304	0.2159
Initial Pressure, Side 2 of System (Mpa)	0.2805	0.2412	0.1302
Tube Volume, Side 1 of System (ml)	22.4344	22.1500	22.0074
Tube Volume, Side 2 of System (ml)	73.0320	98.7922	75.0720

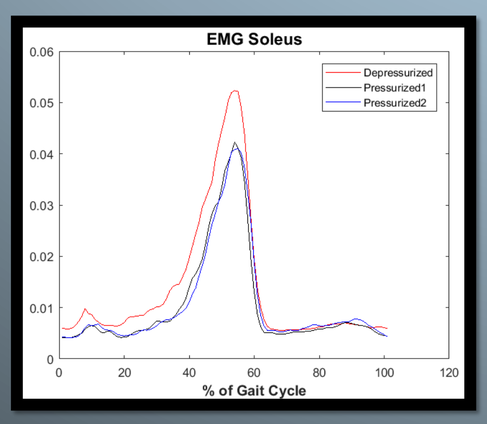


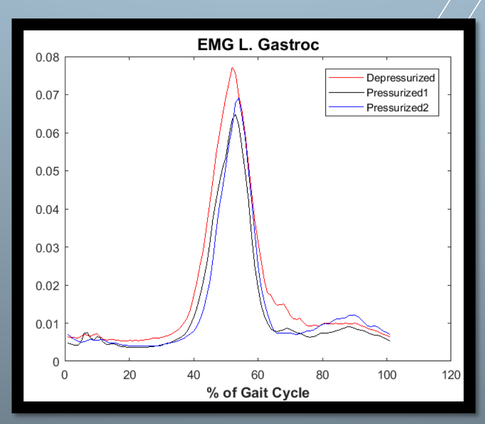
Prototyping

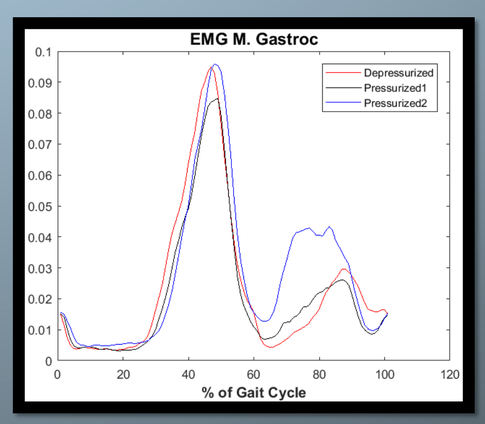
- Build Materials: 80/20 Extruded Aluminum, 6061 Aluminum
- Manufacturing Processes: Welding, 3D Printing, Lathes, Milling, Grinding

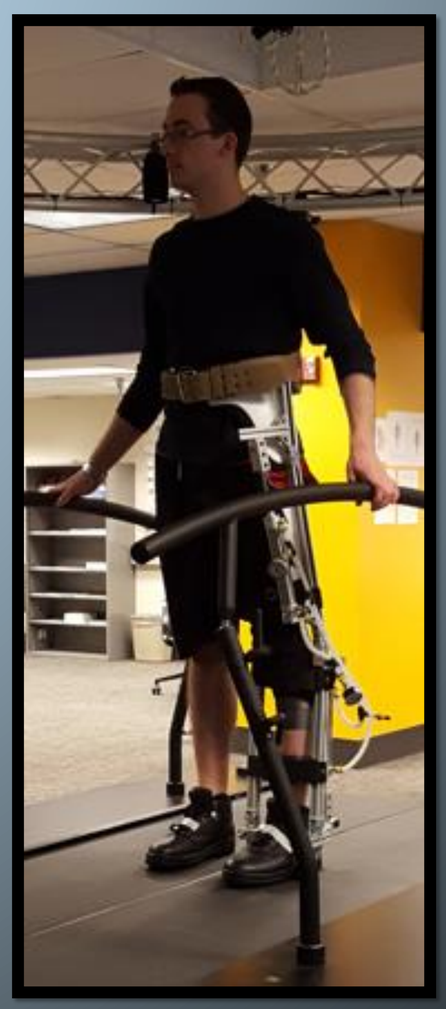
Testing

- Human Motion & Control Laboratory at CSU
- Electromyography (EMG) Sensors on Soleus, Lateral Gastrocnemius, and Medial Gastrocnemius measure muscle activation
- Pressure Sensors measure change in pressure on both sides of each actuator
- Real-time data collection via D-Flow software for Data Acquisition and Analytics









Results

- One test subject for two trials
- Several hundred walking gaits averaged together
- 5 of 6 total EMG Signals showed a decrease in Muscle Activity
- Pressure sensors showed peak pressure at 50-60% of the gait cycle
  - Consistent with Design Optimization results

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