HIRoLab
Human Interactive Robotics Laboratory

ASU BIO-INSPIRED MECHATRONICS LAB
Arizona State University

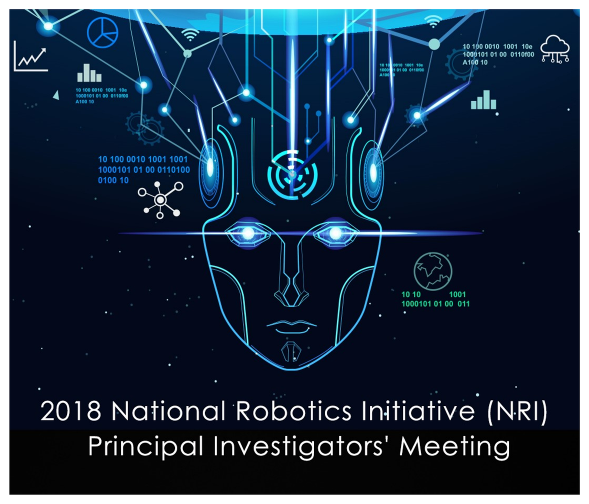
Human Oriented Robotics and Control Lab

NRI: INT: COLLAB: Anthropomorphic Robotic Ankle Prosthesis with Programmable Materials

Mo Rastgaar[1], Panagiotis Polygerinos[2], Panagiotis Artemiadis[2]

1830460, Michigan Technological University[1]

1830256, Arizona State University[2]



Goal

To consolidate the impedance control of a powered 2-DOF ankle-foot prosthesis to a mechanical module comprised of programmable material to follow 2-D impedance of ankle.

Thrusts

- **Thrust 1:** Estimate 2-DOF ankle impedance during the stance phase in different gait scenarios and implement in the design and control of a 2-DOF prosthesis,
- **Thrust 2:** Equip an existing 2-D ankle-foot prosthesis with a controllable ankle impedance module built out of programmable material,
- **Thrust 3:** Evaluate the prosthesis' performance with human users.

Thrust 1

- Impedance control of the 2-DOF prosthesis would require quantitative knowledge of the time-varying impedance of ankle during the stance phase of gait. An information that is currently unavailable
- A 2-DOF vibrating platform was designed and fabricated for estimation of the time-varying ankle impedance in 2-DOF. (Figure 1)
- It applies motion perturbations to the ankle in 2-DOF, and measure the ankle torques and kinematics. An estimation method provides ankle impedance in 2-DOF during the stance phase. (Figure 2)

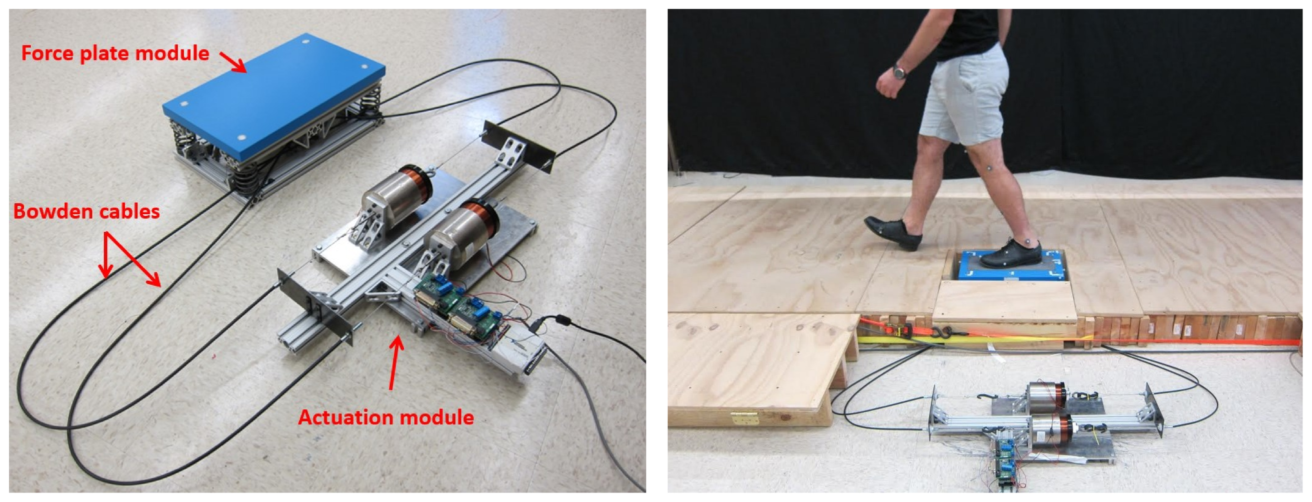


Figure 1. A vibrating platform installed in an instrumented walkway. The platform is used for estimation of the ankle impedance in two DOF.

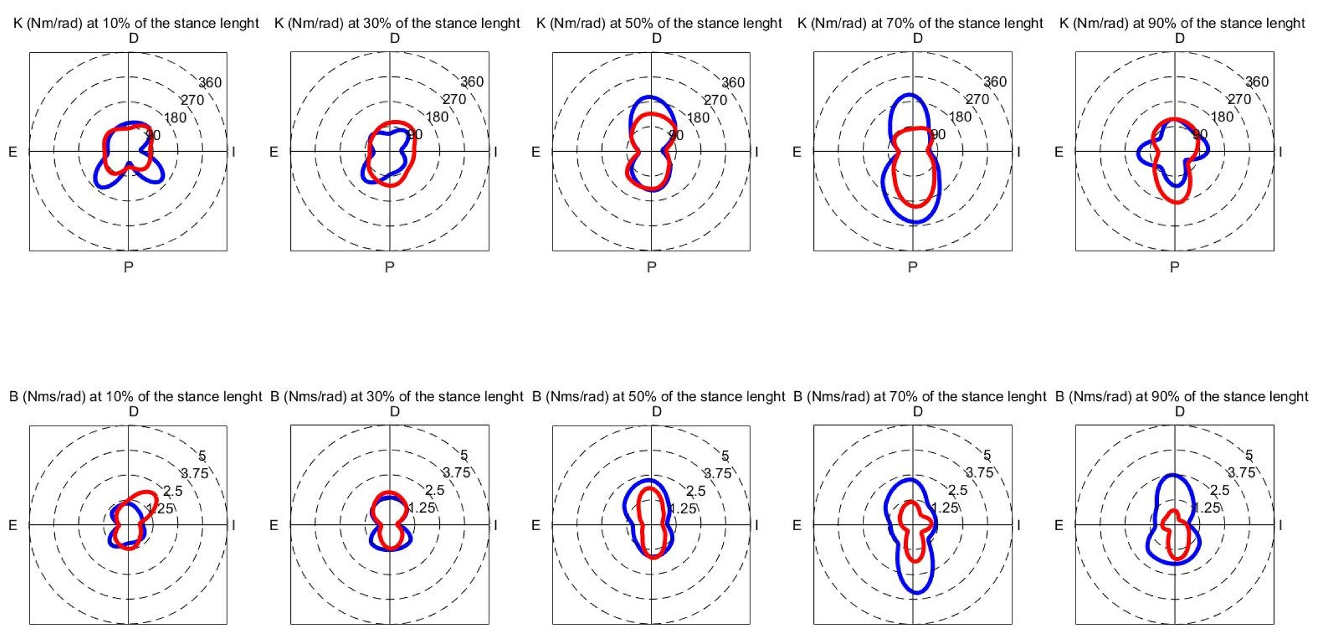


Figure 2. The 2-DOF stiffness and damping in straight step and step turn. The magnitudes of the multi-directional stiffness (top) and damping (bottom) of the ankle at different instances of the stance phase of gait are shown (averaged over 5 subjects).

- A powered 2-DOF ankle-foot prosthesis will be used in this study. (Figure 3)

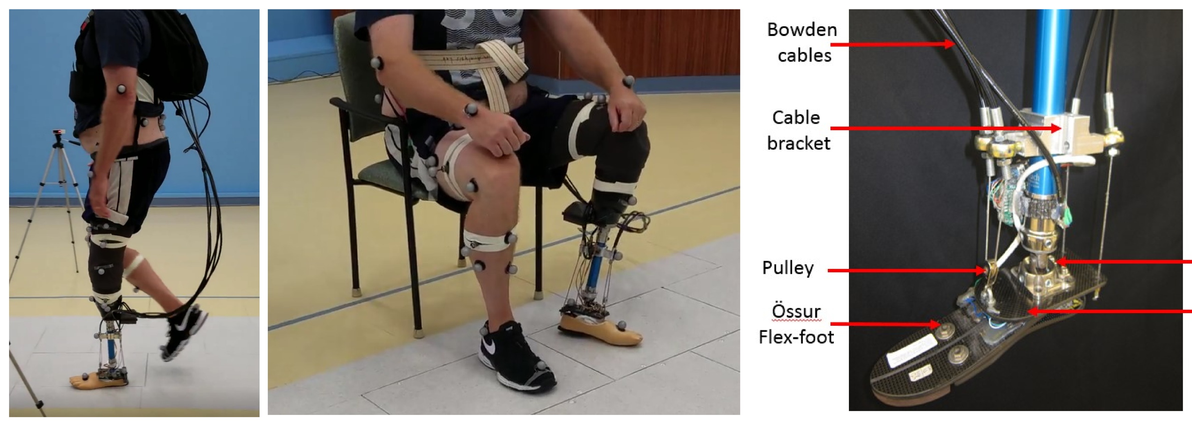


Figure 3. Main components of the 2-DOF ankle-foot prosthesis.

Thrust 2

- To match the impedance of the biological ankle joint, a variable stiffness soft system that utilize multi-material composite will be designed that deforms in response to fluid pressurization.
- The principle of mechanical programming will be utilized through optimization of geometrical paraments of the soft system. (Figure 4)
- The soft module when integrated to the universal joint of the prosthesis will aim to provide stiffness similar to the biological ankle joint. Four independently controlled soft structures will provide support during the 2-DOF motion of the prosthesis. (Figure 5)
- The impedance modulation unit model will be evaluated while improving fabrication techniques with a custom high-fidelity Soft Robotics Evaluation Platform. (Figure 6)
- The integration of the soft impedance modulation unit made from programmable materials with the prosthesis will be optimized prior to fabrication/integration using computational methods.(Figure 7)

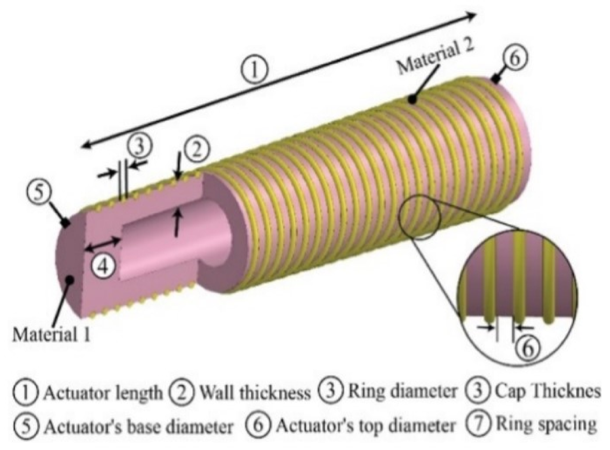


Figure 4. Mechanically programmed soft ring-reinforced actuator with geometric and design parameters that alter its behavior / impedance

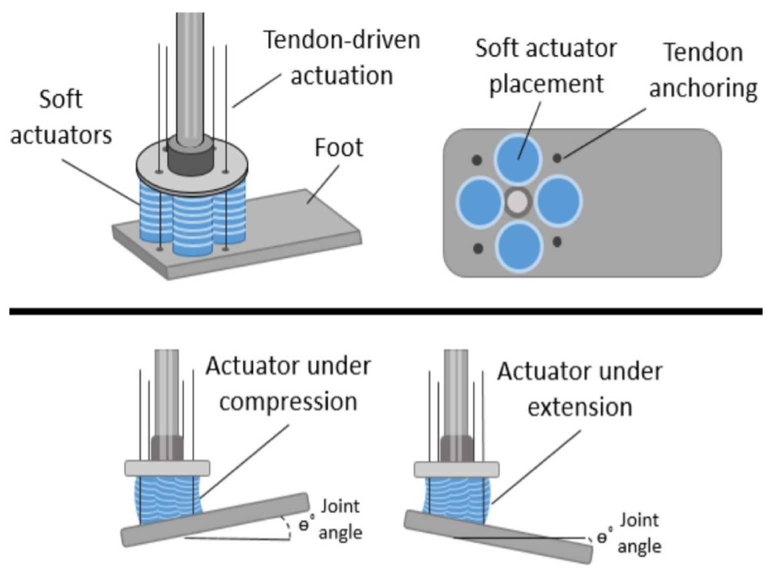


Figure 5. Illustrations of the novel prosthetic foot mechanism: Top, the placement of the programmable soft impedance modulation units. Lower, example of ankle impedance matching in dorsiflexion and plantarflexion.

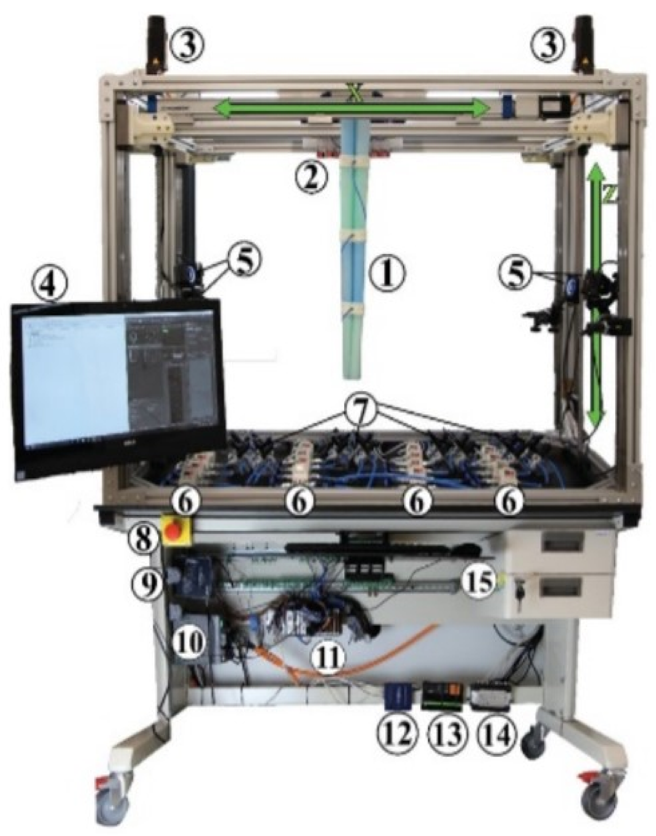


Figure 6. Soft robotics evaluation platform with electro-pneumatic equipment that enables mechanical characterization of soft actuators/robots

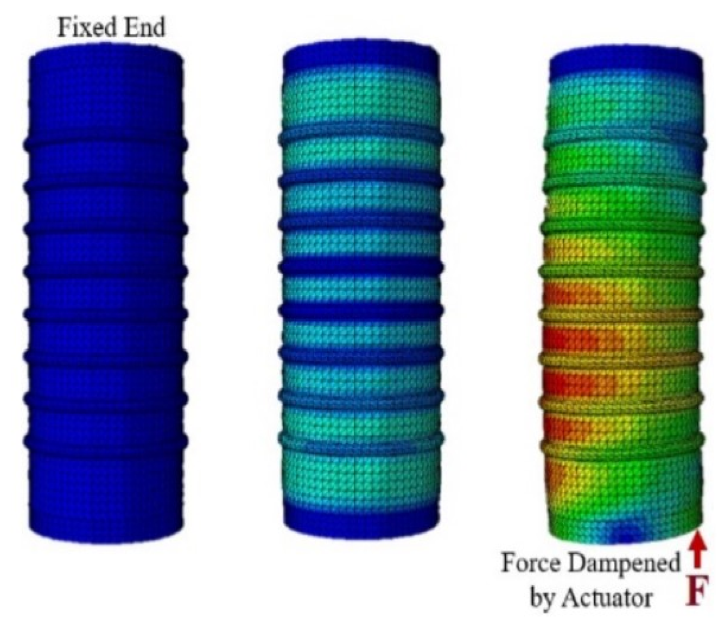


Figure 7. Computational (Finite Element Methods) simulation of programmable soft actuator. Left: unpressurized actuator with high compliance/flexibility. Middle: Pressurized actuator with increased impedance. Right: Force/Torque dampened by pressurized soft actuator.

Thrust 3

- Understand the effect of the proposed system on the performance of the ankle-foot prosthesis in real-world challenging and dynamic environments
- Simulate those environments using a unique experimental platform, the ASU Variable Stiffness Treadmill (VST), which can simulate a wide variety of dynamic and compliant walking surfaces (Figure 8)

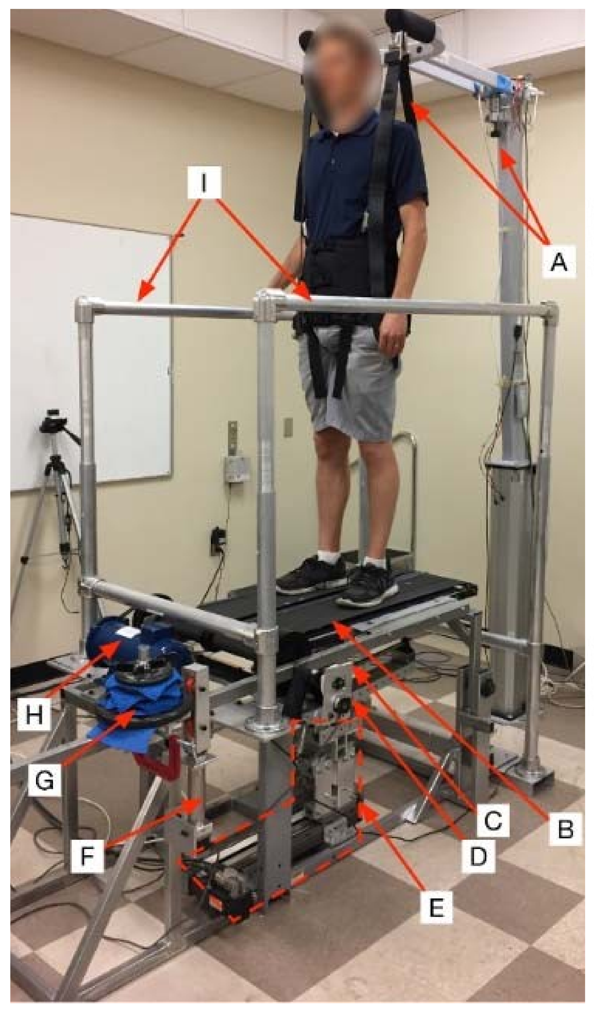


Figure 8. The ASU VST platform

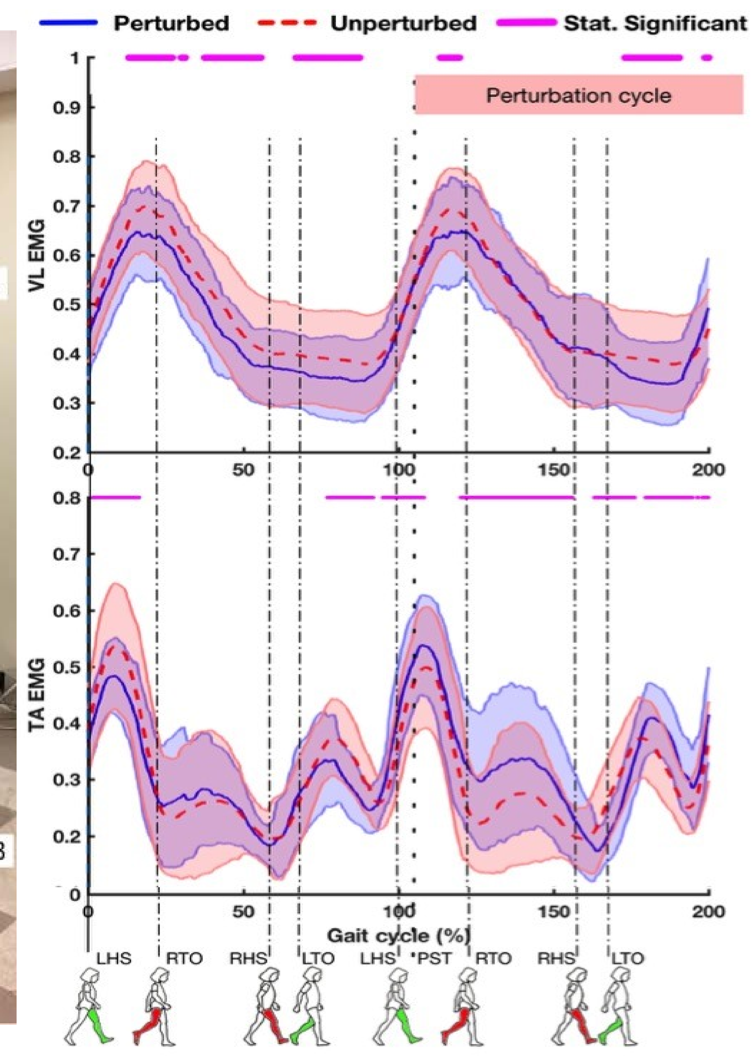


Figure 9. Muscle activation differentiation before stepping on compliant surface (Perturbation Cycle) from the TA and VL muscles

- We have been focusing on the mechanisms involved during human locomotion, while transitioning from rigid to compliant surfaces such as from pavement to sand, grass or granular media.
- 4 subjects stepped on a compliant surface simulated by the VST. EMG and kinematics of both legs were measured.
- The analysis of muscular activation during the transition from rigid to compliant surfaces reveals specific **anticipatory muscle activation that precedes** stepping on the compliant surface. [1]
- The anticipatory muscle responses will be used for the control of the prosthesis
- Future experiments will combine virtual reality and stiffness perturbations via the VST to understand differences in EMG activations between expected vs unexpected changes of walking surface characteristics

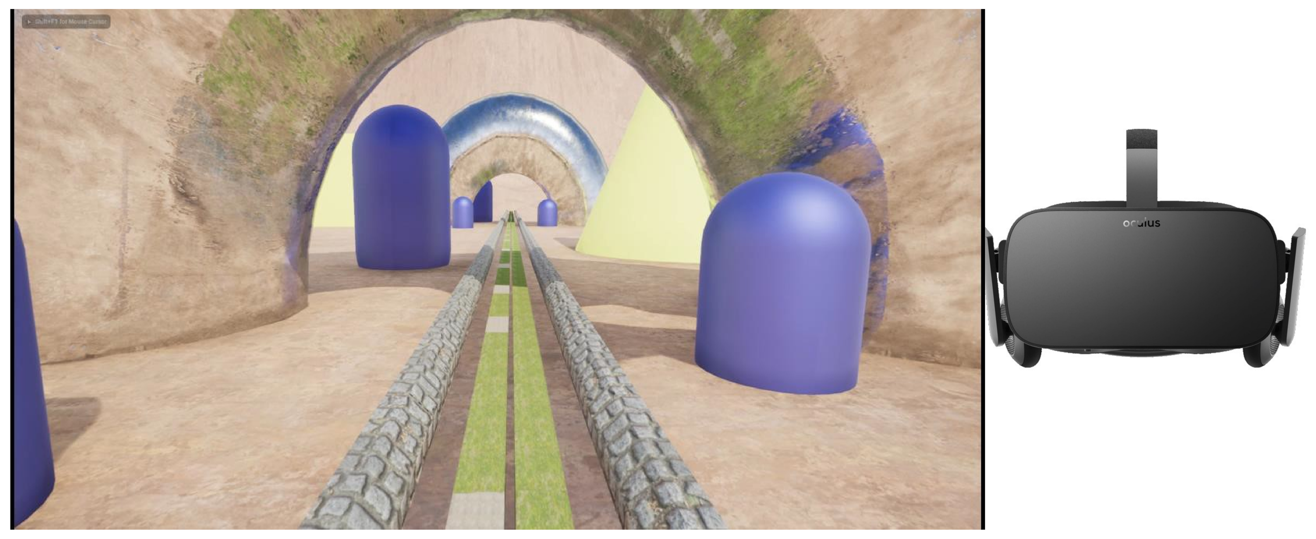


Figure 10. Virtual reality interface for addressing expected and unexpected surface transitions

References:

[1] Emiliano Quinones Yumbla, Ruby Afriyie Obeng, Jeffrey Ward, Thomas Sugar and Panagiotis Artemiadis, "Anticipatory muscle responses in transitions from rigid to compliant surfaces: towards smart ankle-foot prostheses," ICRA 2019, (under review)