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

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Goal: To consolidate the impedance control of robotic ankle-foot prosthesis to a mechanical module comprised of programmable material.

- **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 with programmable material,
- **Thrust 3:** Evaluate the prosthesis' performance with human users in a comprehensive simulated environment and outdoors.

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.
- A 2-DOF vibrating platform was designed and fabricated for estimation of the time-varying ankle impedance. (Figure 1)
- An estimation method provides ankle impedance in 2DOF during the stance phase of gait. (Figure 2)

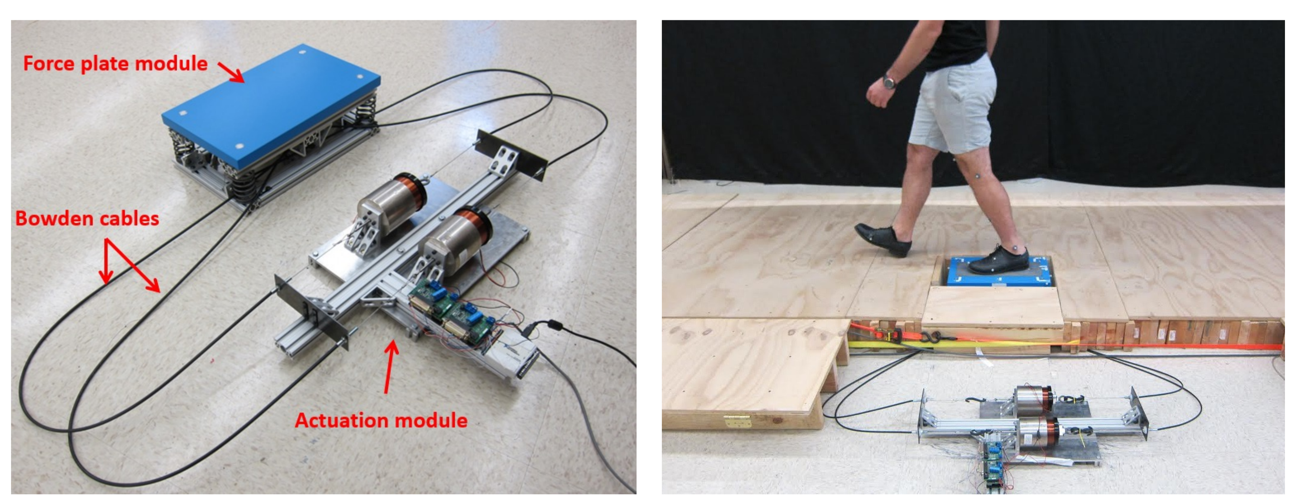

Figure 1. A vibrating platform installed in an instrumented walkway. The platform is used for estimation of the ankle impedance in two DOF.

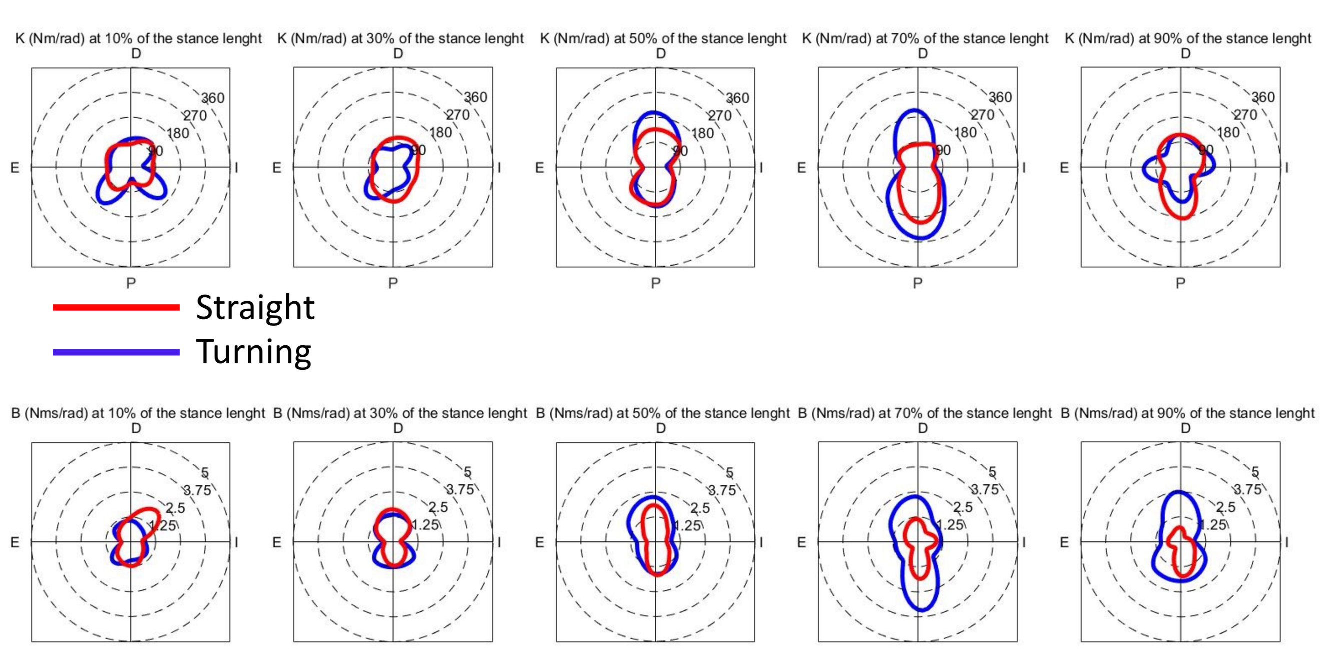

Figure 2. The magnitude and profile of 2-DOF stiffness (top) and damping (bottom) during stance phases of straight step and step turn (averaged over 5 subjects).

Thrust 2

- To match the impedance of the biological ankle joint, a variable stiffness soft system that utilize multi-material composite is designed
- Antagonistic pairs of unfolding textile based inflatable actuators for each DOF to provide tunable impedance are developed (Figure 3).
- Experimentally found mechanically programmed torque response.

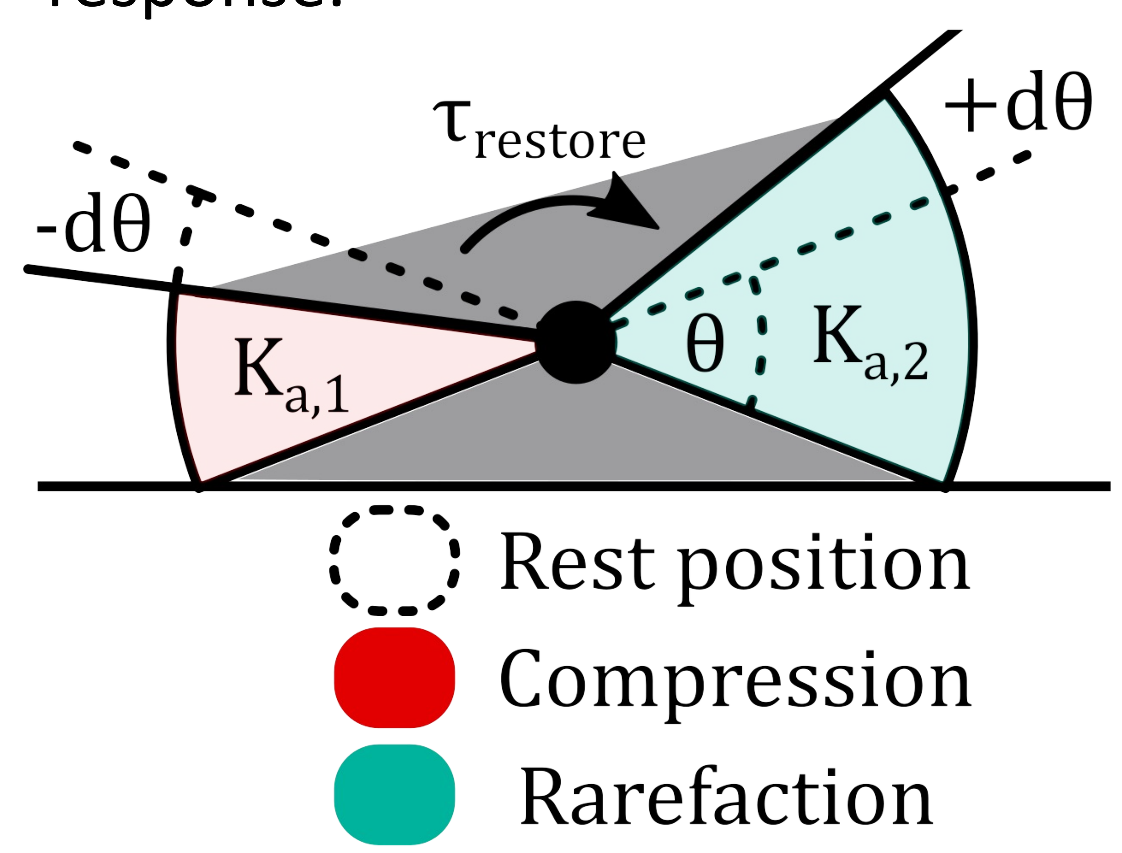

Figure 3 Pair of antagonistic actuator concept being able to deliver torques in either directions.

[1] Unfolding Textile-Based Pneumatic Actuators for Wearable Applications, O'Neill et al, Soft Robotics, 2021

Thrust 3

- Understand and quantify stability improvements from the proposed system to the performance of the ankle-foot prosthesis in real-world dynamic environments.

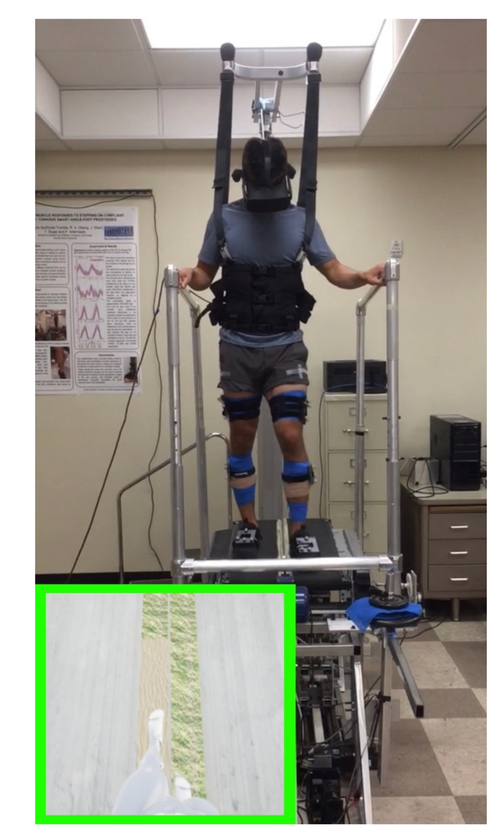

Figure 4. The VST and Oculus Rift experimental platform (left). Mean normalized activation for the GA muscle in the studied conditions: Visual and Physical (VP), Visual Only (VO) and Physical Only (PO) perturbations. (bottom)

- Results show that there are predictable and repeatable muscle activation patterns both before and after surface stiffness changes, and these patterns are affected by the perceived visual and proprioceptive feedback [2].

[2] Michael Drolet, Emiliano Quinones Yumbla, Bradley Hobbs and Panagiotis Artemiadis, "On the Effects of Visual Anticipation of Floor Compliance Changes on Human Gait: Towards Model-based Robot-Assisted Rehabilitation," In the Proc. of the 2020 IEEE International Conference on Robotics and Automation (ICRA), pp. 9072-9078, 2020.

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