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 prostheses 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 [1]. (Figure 2)
- A powered 2-DOF ankle-foot prosthesis will be used in this study

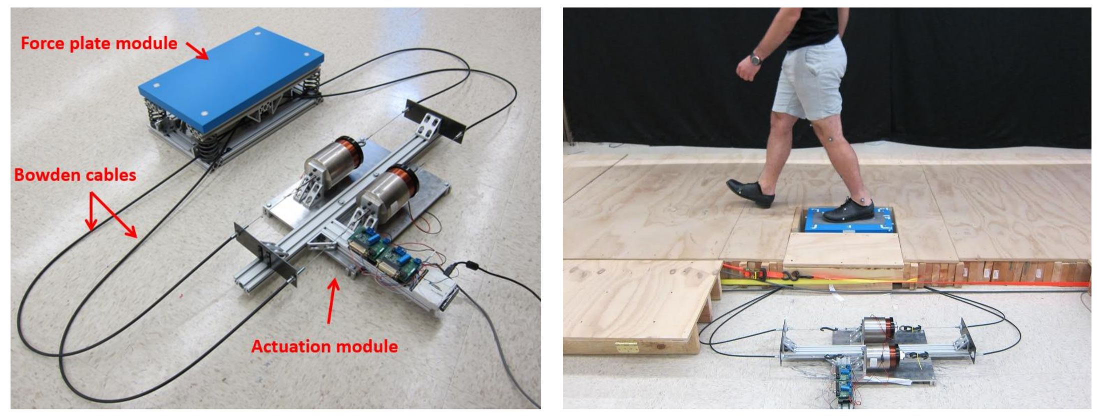


Figure 1. A vibrating platform installed in an instrumented walkway. The platform is used for estimation of the ankle impedance in two DOF.

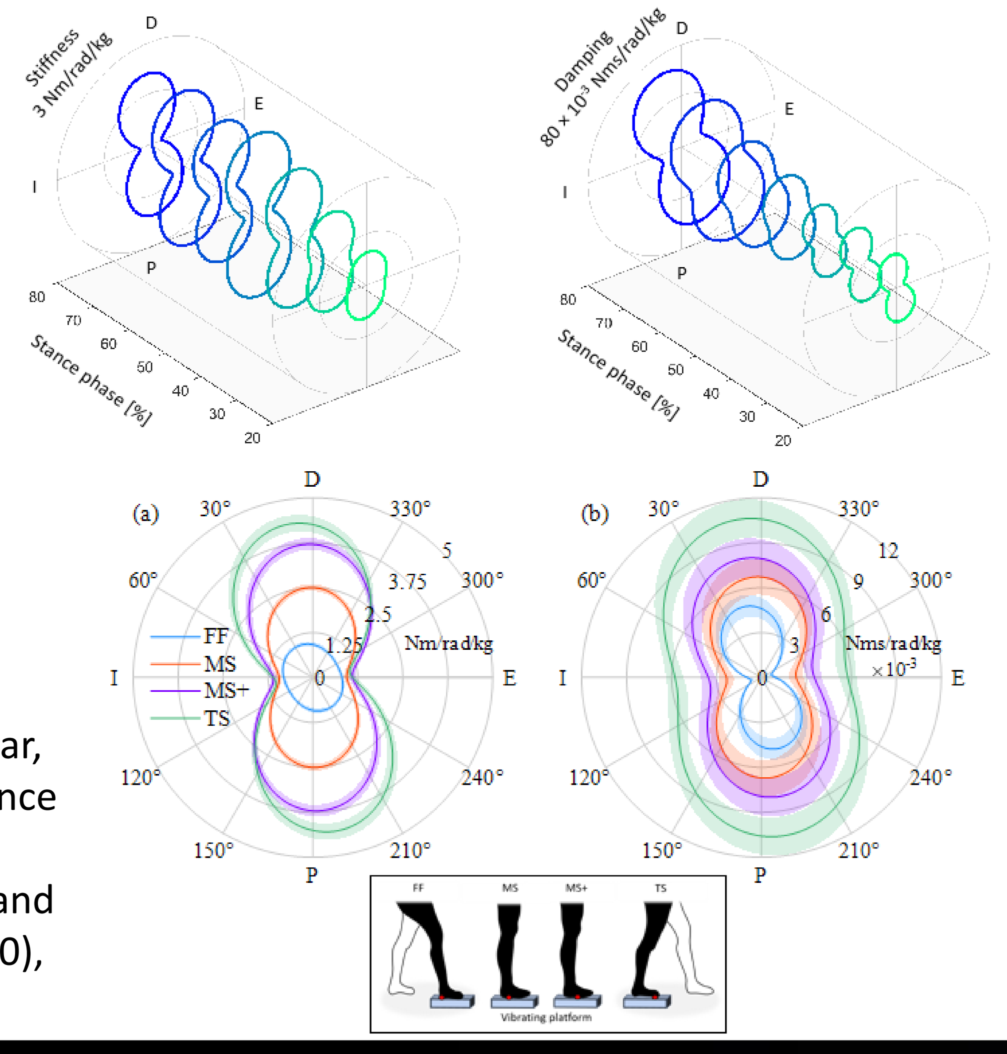


Figure 2. The magnitude and profile of 2-DOF stiffness (left) and damping (right) of ankle during stance phases of straight step.

[1] G. Ribeiro, L. Knop, M. Rastgaar, "Multi-Directional Ankle Impedance During Standing Postures", IEEE Transactions on Neural Systems and Rehabilitation Engineering, 28 (10), 2224-2235, 2020.

Thrust 2

- To match the impedance of the biological ankle joint, a variable stiffness soft system that utilize multi-material composite is designed that deforms in response to fluid pressurization.
- 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 is shown in Figure 4.

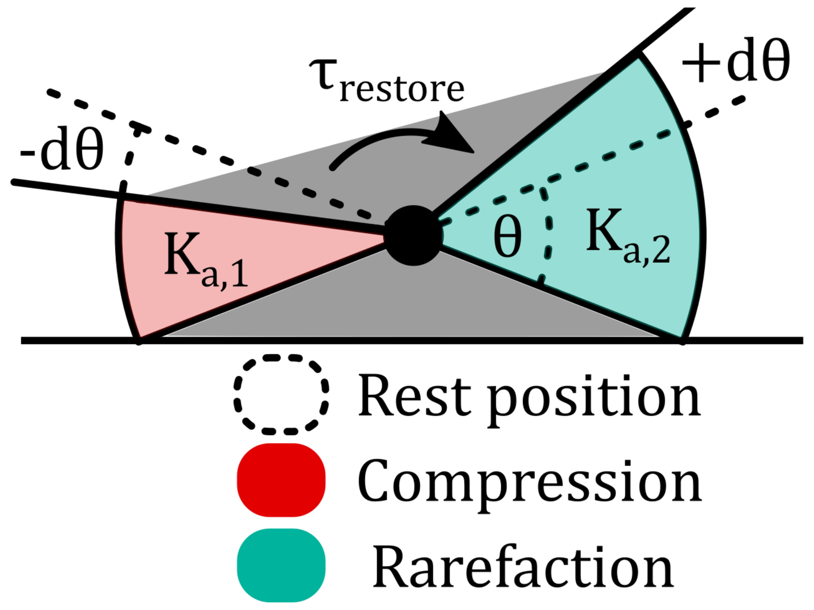
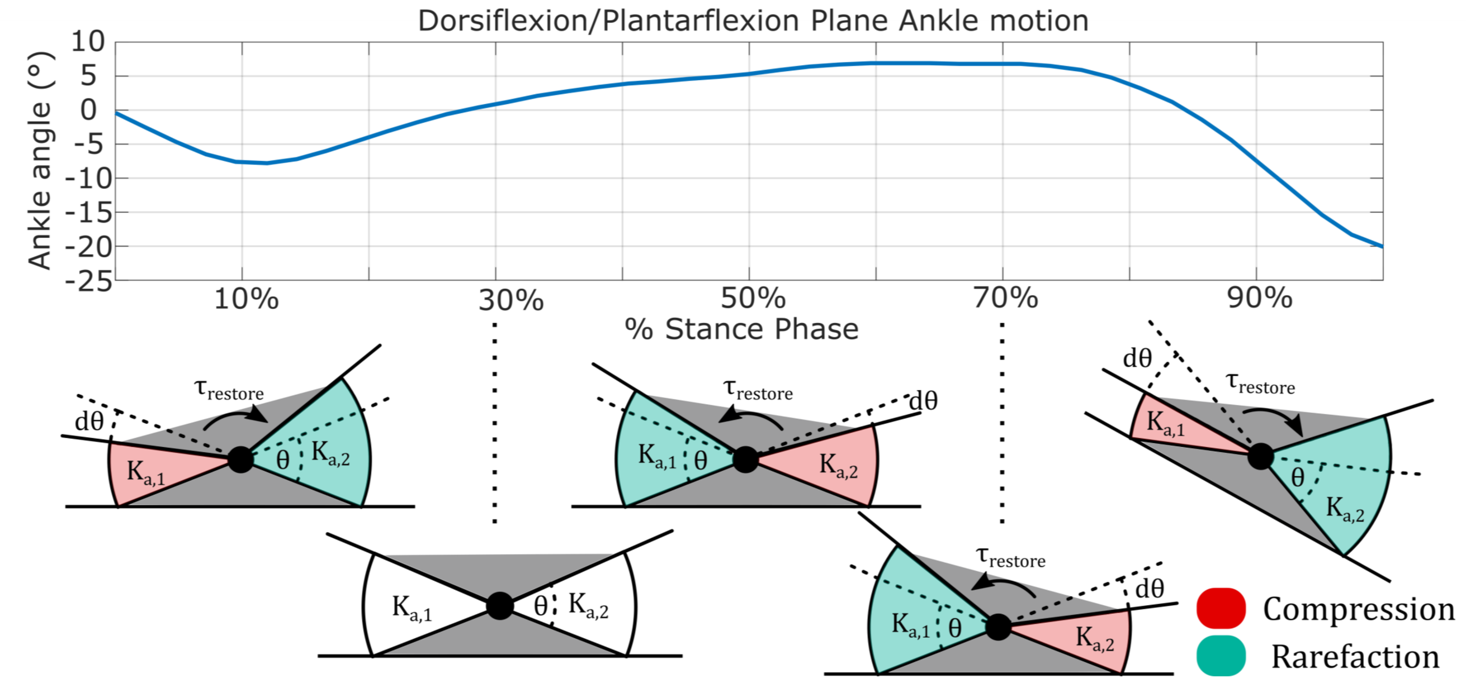


Figure 3 (left). Pair of antagonistic actuator concept being able to deliver torques in either directions.

Figure 4 (bottom). Dorsiflexion/Plantarflexion plan ankle motion using the pair of antagonistic actuators.



[2] 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.
- Simulate those environments using a unique experimental platform, the Variable Stiffness Treadmill (VST), which can simulate a wide variety of dynamic and compliant walking surfaces (Figure 5).

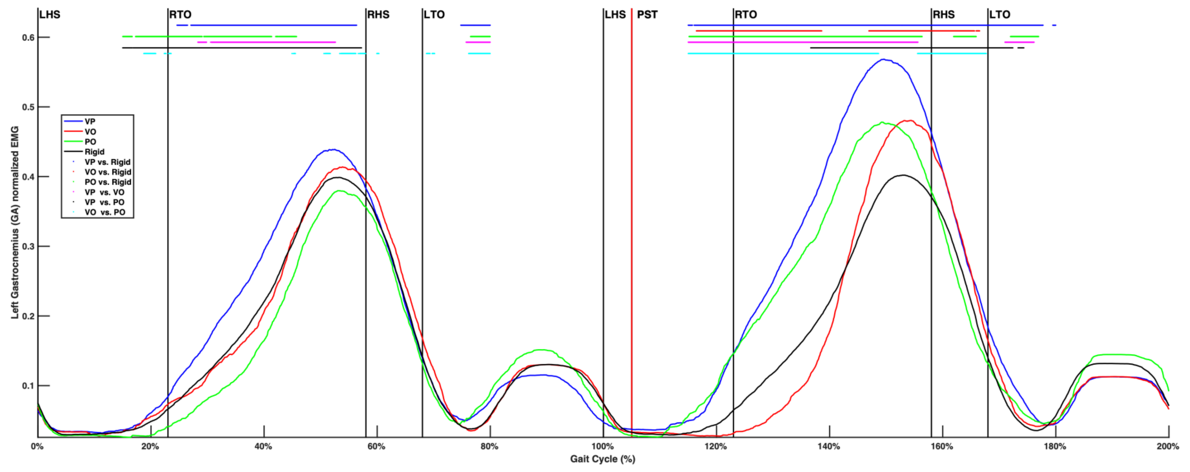


Figure 5. The VST and Oculus Rift experimental platform (left). Mean normalized activation for the GA muscle in the studied conditions: Visual and Physical (VP), Visual Only (VO) and Physical Only (PO) perturbations. (bottom)

- We have been studying the effect of visual anticipation (using Virtual Reality) of floor compliance changes on human gait, and quantifying those effects with changes on the EMG activity before stepping on the compliant surface.
- 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 [3].

[3] 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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