ATLAS: A Multi-Axis Ankle-Foot Prosthetic With Adaptive Tendon Stiffness for Locomotor Assistance and Stability

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Ankle-foot prosthetics aim to recreate the biological motion of the ankle and restore natural gait to transtibial amputees. Achieving this requires motion in three dimensions and a variable-stiffness shock absorber mimicking the adaptive behavior of the Achilles tendon. Prior research has not met this goal, as most devices augment only plantarflexion/dorsiflexion and rely on fixed-stiffness springs that cannot adjust energy return in a fixed travel range across gait speeds. This project presents ATLAS, a three-degree-of-freedom ankle-foot prosthesis with a variable-stiffness artificial Achilles tendon designed to replicate multi-plane ankle mechanics and adaptive energy storage. ATLAS uses a parallel J-hook linkage driven by brushless motors and 100:1 harmonic gearboxes to guide the heel in a natural arc about the tibia. This configuration produces high torque with low backlash while preserving multi-plane motion. A two-stage artificial Achilles tendon provides adaptive stiffness: an outer spring remains constantly engaged, while an inner spring engages under compression, with servo-actuated supplemental springs enabling spring rate shifts from 67 N/mm to 200 N/mm. Results reveal normalized gait at 0.45 and 0.9 m/s with peak plantarflexion torque of 140 Nm. Engaging one supplemental tendon servo increased peak plantarflexion torque by 5 Nm with only 1 mm additional compression. Additionally, all three degrees of freedom were achieved and verified during bench trials. These findings demonstrate that multi-plane actuation combined with adaptive stiffness can better replicate biological ankle mechanics and improve propulsion in transtibial prostheses. Future work will reduce system weight and refine adaptive control algorithms.

Awards Won:

Second Award of $2,400