A Human Knee Impedance Model for Lower-Limb Exoskeleton Control

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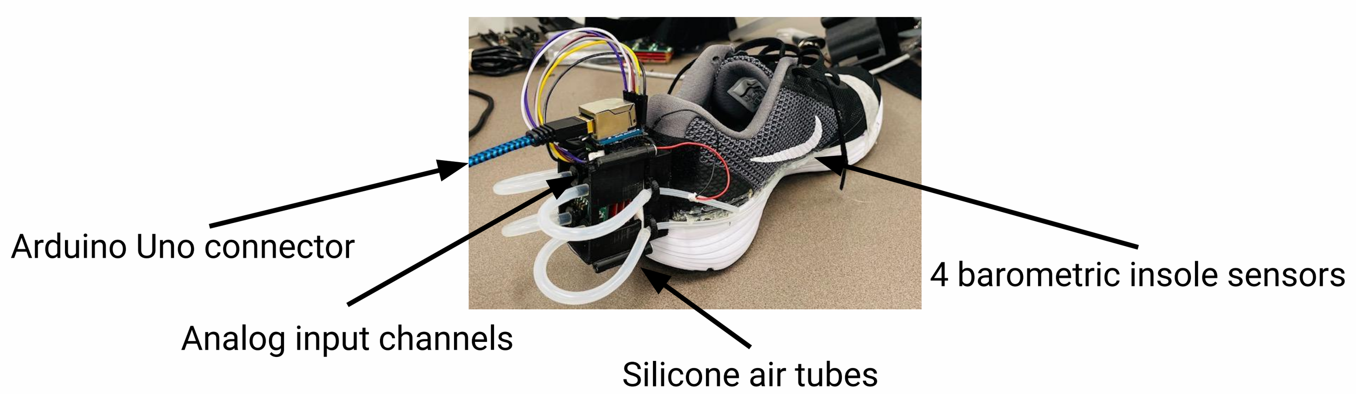
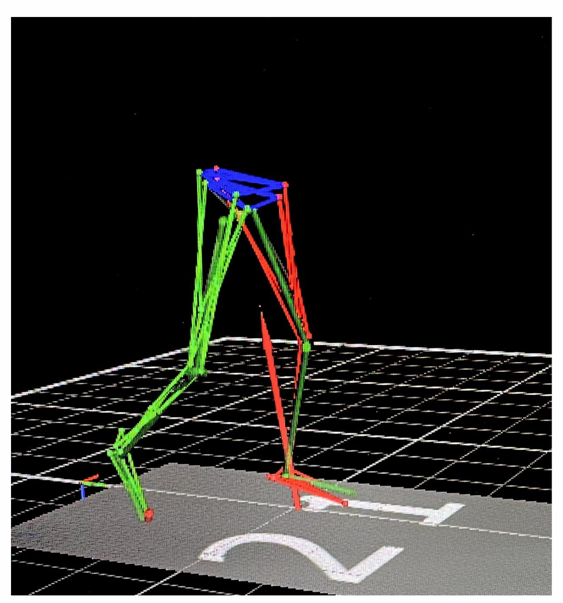
Introduction

Gait rehabilitation and the recovery of lower-limb functions are essential to improve the quality of life of patients affected by musculoskeletal damage, aging, and disease. As conventional treatments are often too expensive, labor-intensive, and restricted to hospitals, wearable sensors and robotics have shown the potential to meet these issues. This research seeks to use Smart Shoes to identify specific phases of gait and to combine this data with motion capture data to create a human knee impedance model that can be integrated into a lower-limb exoskeleton control system.

Kinematic Data Collection



Participants wore 16 motion capture markers and smart shoes. The 12 infrared cameras and Vicon motion capture software registers lower body angles, forces, and torques in the x, y, and z planes. The Smart Shoes' embedded pressure sensors allow for the detection of 4 gait cycle phases (heel strike, mid-stance, toe-off, and swing) and are synchronized with the motion capture system.



Human Knee Impedance Model

A spring-damper model is considered for modeling human knee torque and is defined as:

$$T_h(t) = k \cdot (\theta_h(t) - \theta_0) + b \cdot \dot{\theta}_h(t),$$

where $T_h(t)$, $\theta_h(t)$, and $\dot{\theta}_h(t)$ represent knee torque, angle, and angular velocity, respectively. The knee angular velocity is calculated using MATLAB, while the knee angle is captured by the Vicon gait plugin software. k, b, and θ_0 represent knee stiffness, damping, and setpoint, respectively. The final goal of this model is to identify k, b, and θ_0 for each of the 4 gait cycle phases using a least square method with $T_h(t)$ as the output and knee angle and angular velocity as inputs.

Experimental Design

Smart Shoe Building → **Data Collection** → **Data Synchronization** / **Impedance Model Framework** / **Gait Phase Detection**

Smart Shoe Building
- Implement Arduino (C++) code that reads sensor values and calculates time between heel strikes
- Build and integrate Smart Shoes with the exoskeleton hardware and software

Data Collection
- Code the Smart Shoe to sync with motion capture recording
- Simultaneously record the time, ground reaction forces, Smart Shoe data, and kinematic data for 1 minute

Data Synchronization
- Align sampling frequencies
- Match camera and sensor data timing

Impedance Model Framework
- Use MATLAB to run a least square calculation

Gait Phase Detection
- Use MATLAB to define setpoints for each of the 4 gait phases

Future Work

Future work will continue to develop the human knee impedance model and integrate it into the control structure of a lower-limb exoskeleton:
- Verify the validity of the impedance model for subjects with mobility impairments.
- Seek to expand the model to more complex tasks, including walking in an outdoor environment, where factors such as uneven terrain, changing gait speeds, and more will complicate the model.
- Embed the impedance model into an exoskeleton control system, which will be based on Dynamic Movement Primitives, a method for trajectory control and planning.

References

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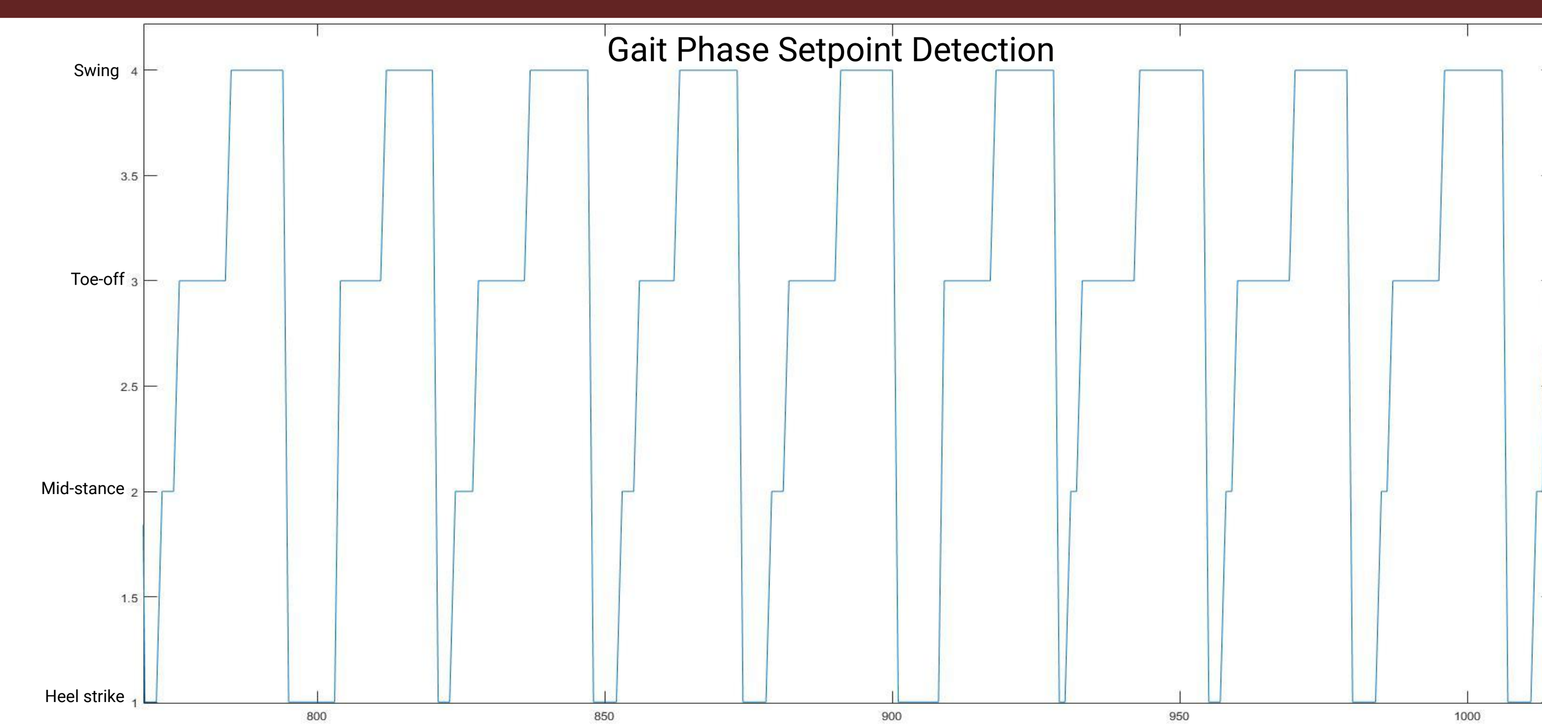
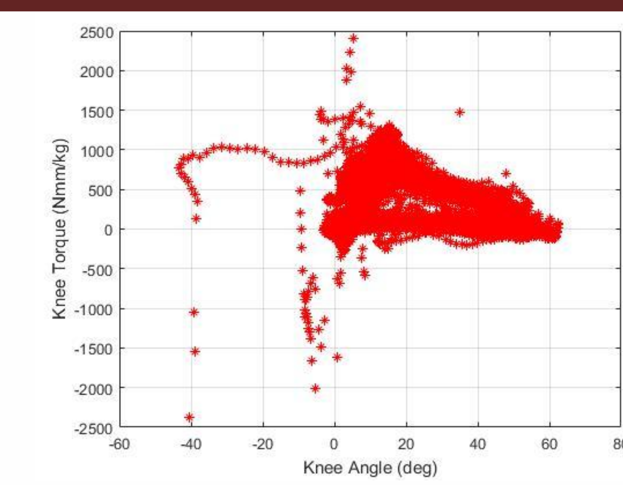
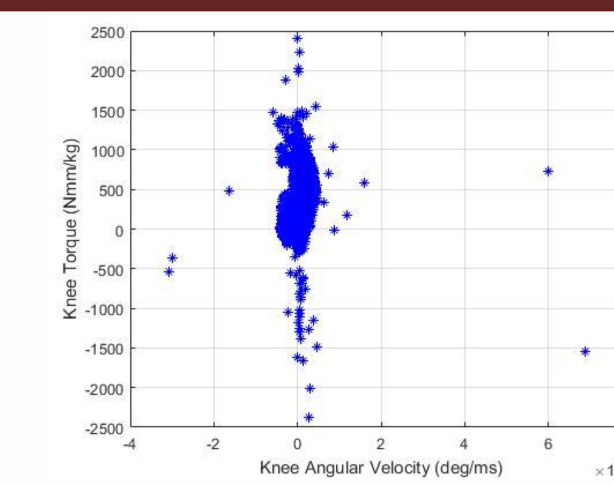
Results and Conclusions







Conclusions:

- A Smart Shoe was able to be built and integrated with a lower-limb exoskeleton. The Smart Shoe code was also updated to export sensor values to a spreadsheet and calculate the time between consecutive heel strikes.
- A gait phase detection algorithm was successfully implemented and precisely aligned with the kinematic data obtained from the motion capture system.
- Human knee impedance was successfully modeled, and stiffness, damping, and setpoint were found for each of the 4 gait phases using a least squares calculation.

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