MECHANICAL ENGINEERING
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Impedance Control of the Knee Mechanism on a Transfemoral Prosthetic for Level Walking

Namita Anil Kumar, Woolim Hong, and Pilwon Hur, Ph.D.
namita.anilkumar@tamu.edu, ulim8819@tamu.edu, pilwonhur@tamu.edu

vASB2020 Virtual 44th Meeting of the American Society of Biomechanics, August 4-7, 2020

IMPEDANCE CONTOL

- Impedance control allows the user to interact with the prosthetic $\Longrightarrow$ improves user comfort.
- Models the motorized joint as a spring damper system. At instant t in the gait cycle, the torque is modeled as follows.

$$\tau(t) = \underbrace{K(t)}_{\text{Stiffness}} \left(\theta(t) - \underbrace{\theta_e(t)}_{\text{Equilibrium angle}}\right) + \underbrace{D(t)}_{\text{Damping}}\dot{\theta}(t)$$

- Generally, the gait cycle is split up into 4-6 phases. The impedance parameters vary from among phases.

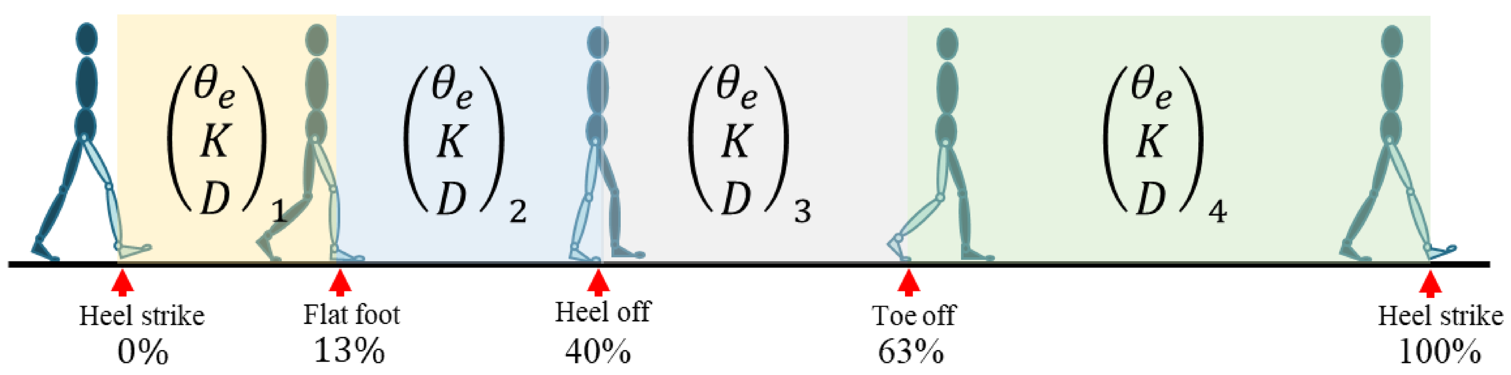

Fig. 1 An example of impedance control frameworks

- Sup et al. [1] had a set of constant parameters (K, D, θ_e) for each phase of the gait cycle.
- Fey et al. [2] varied $K(t)$ linearly with $\theta(t)$ during stance and $\theta_e(t)$ linearly with shank force during late stance.

- The above studies do not ensure continuity in $K(t)$ and $D(t)$ between phases $\Longrightarrow$ issues in robustness [3].
- Anil Kumar et al. [4] proposed 4th order polynomials for $K(t)$ and $D(t)$ of a prosthetic ankle's controller. Constraints ensured continuity of $K(t)$ and $D(t)$ across phases. In addition to having continuous $K(t)$ and $D(t)$, this controller has fewer tuning parameters and does not mandate a load cell.

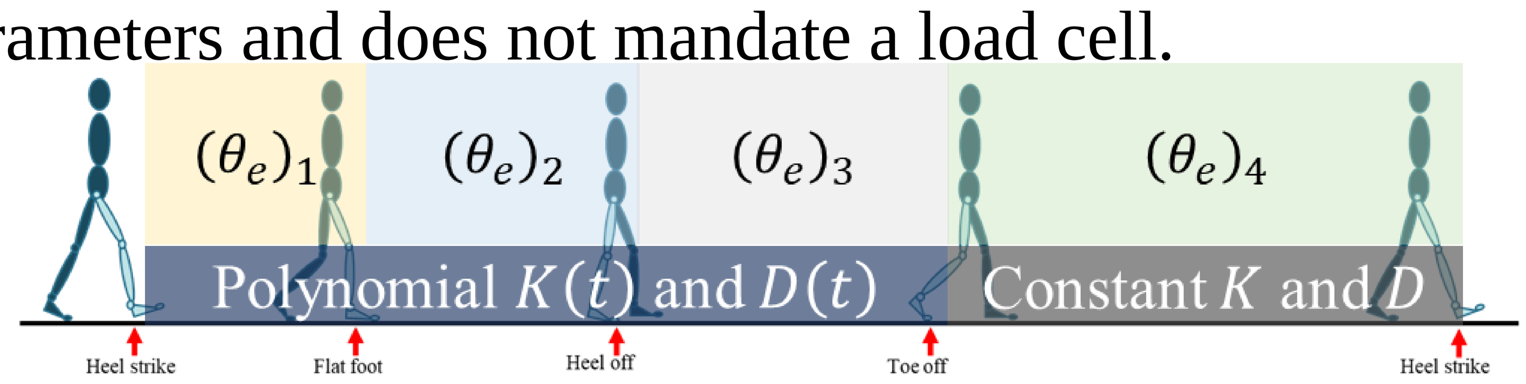

Fig. 2 Impedance control framework for a prosthetic ankle from Anil Kumar et al. [4]

OBJECTIVE

- To extend the work from Anil Kumar et al. [4] to the knee.
- This work features a hybrid of impedance control and trajectory tracking (like Lawson et al. [5]).
- Low gain PD during terminal swing facilitates terrain adaptation.

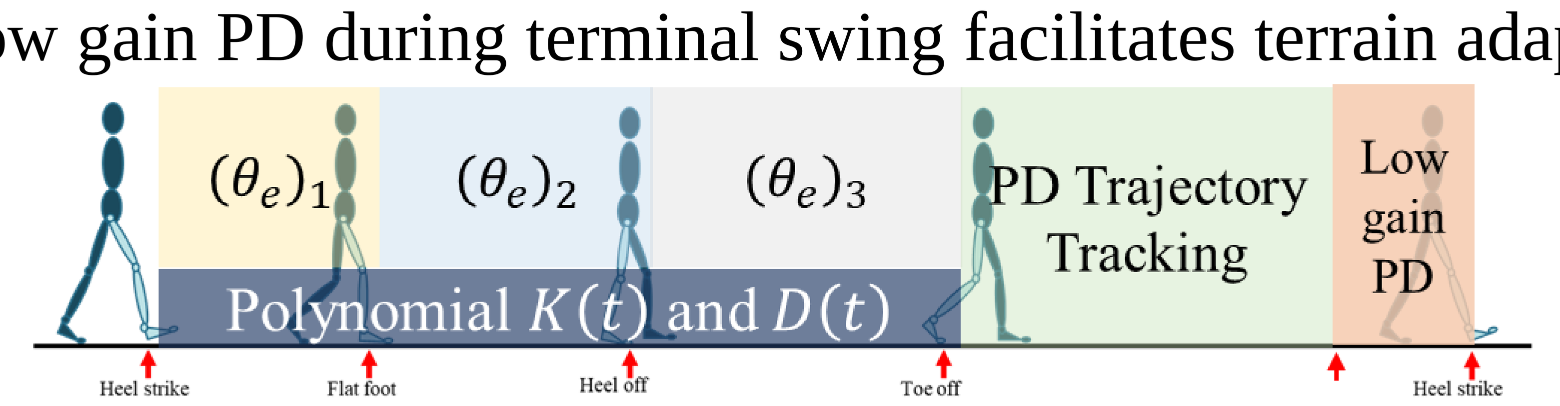

Fig. 3 Proposed hybrid control framework for the knee. The sectioning of the gait cycle is based on Anil Kumar et al. [4]

METHOD

- We estimated the knee impedance parameters for the stance phase of the gait cycle through a least squares optimization.
- The controller was tested on level ground with a transfermoral prosthesis–AMPRO II. An able-bodied, 30-year-old male subject walked at a self-selected speed with an emulator.

$$\min_{\theta_e,\, K(t),\, D(t)} \left\| \tau_{Healthy\ data} - \tau_{Contol} \right\|$$

Subject to:
- $K(t)$, $D(t)$ are nonnegative
- $K(t), D(t)$ are continuous at:
  - 0% and 100% of the gait cycle
  - stance to swing transition
- Bounds on θ_e and $D(t)$

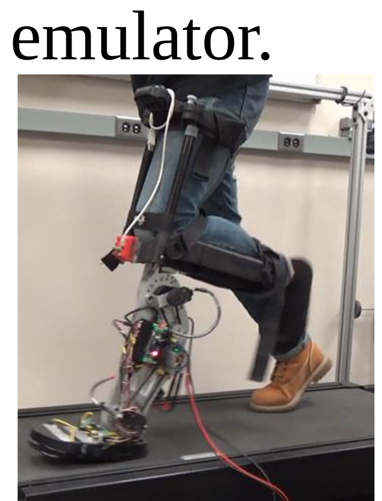

Fig. 4 Subject with AMPRO II while wearing an emulator

RESULTS

- Estimated $K(t)$ and $D(t)$ have been depicted in Fig. 5. Further, $(\theta_e)_1$=7.69°, $(\theta_e)_2$ = 5.21°, $(\theta_e)_3$ = 15.97°.

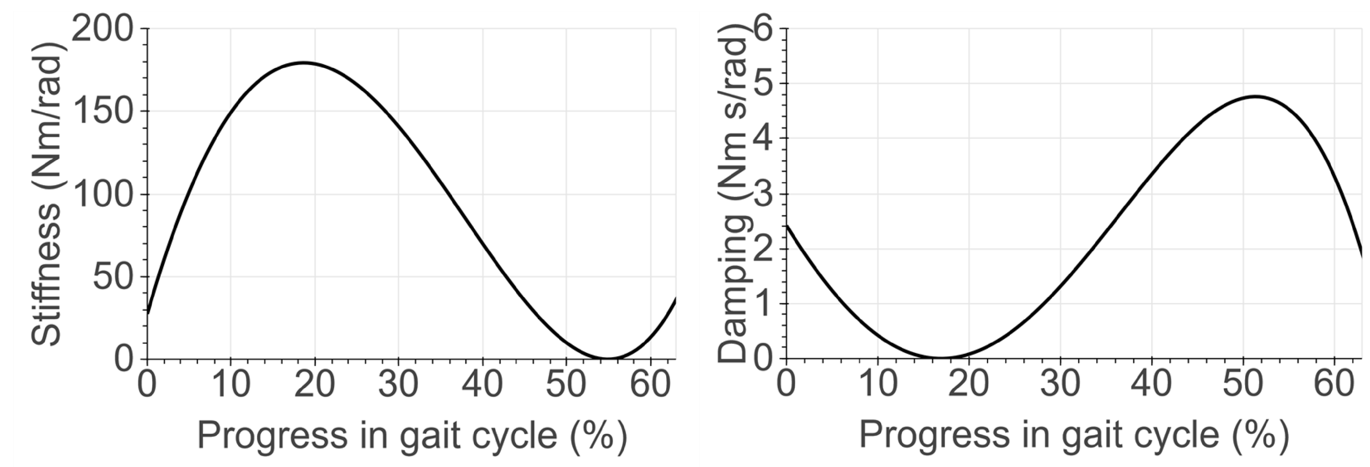

Fig. 5 Estimated impedance curves for the stance phase.
Left: Estimated knee stiffness; Right: Estimated knee damping

EXPERIMENT RESULTS (Fig. 6)

- Both ankle and knee kinematics resembled able-bodied walking. Further tuning can counter the lessened ankle dorsiflexion during mid-stance.
- Though the ankle torque followed a human-like trend, peak torque was limited due to actuator's torque limitations.
- Knee torque deviated from healthy trends (highlighted with red boxes in Fig. 6). The first is attributed to the controller's high damping parameters (requiring further tuning). The second discrepancy is due to the low gain PD controller.

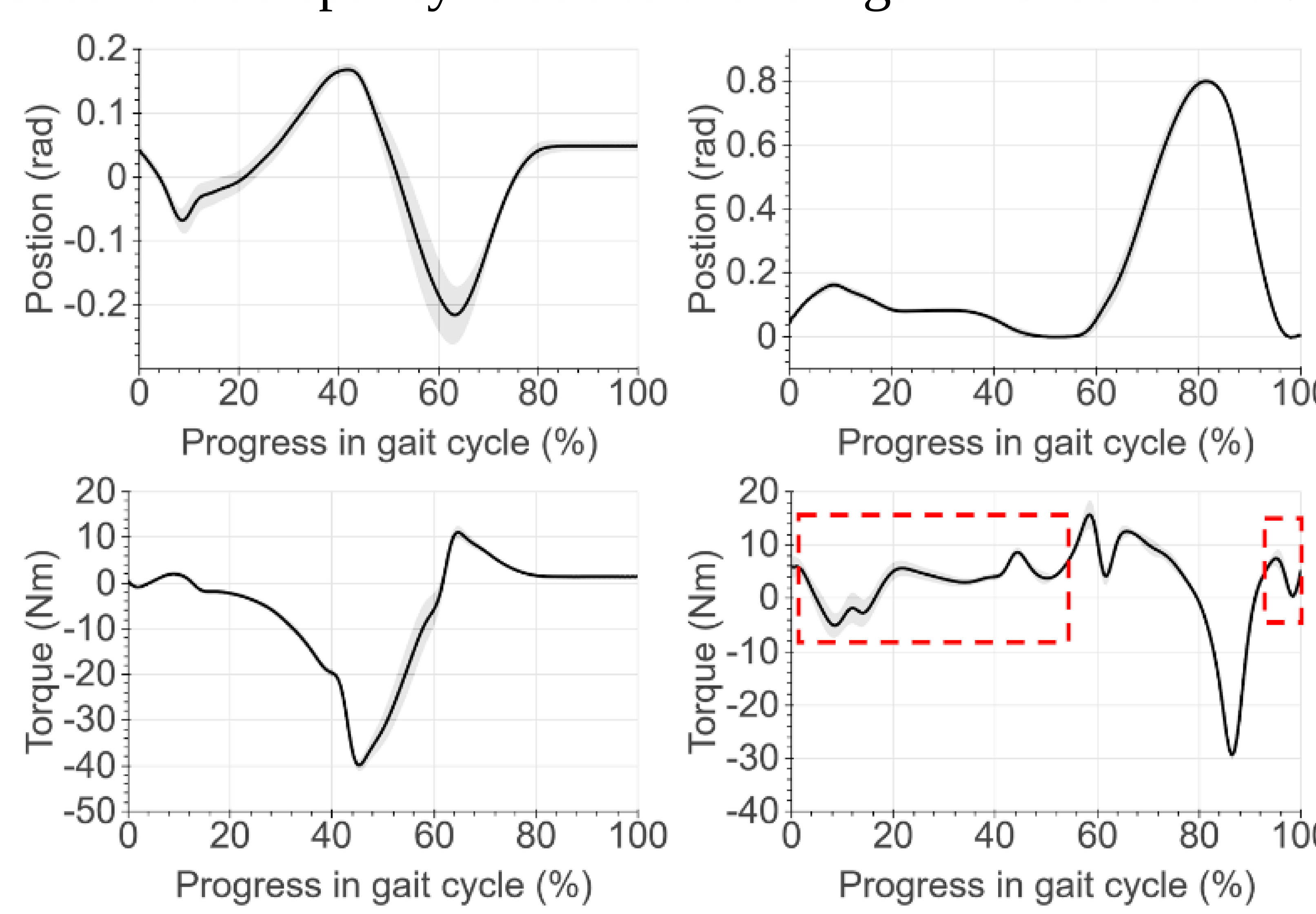

Fig. 6 Top left: Ankle position, Top right: Knee position,
Bottom left: Ankle torque, Bottom right: Knee torque

CONCLUSION

- The proposed controller generated human-like gait.
- The proposed controller requires lesser tuning owing to few tuning parameters.
- A well-defined rule base enables simple and intuitive tuning procedures. (Anil Kumar et al. [4])

FUTURE WORK

- To estimate continuous reference curves for equilibria angles.
- Extend of the proposed controller for sloped walking.
- Eliminate the tuning process via auto-tuning methods such as fuzzy-logic.

REFERENCES

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