

Mode-Unified Strategy for Continuous Control of Knee-ankle Prostheses



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Collaborated with

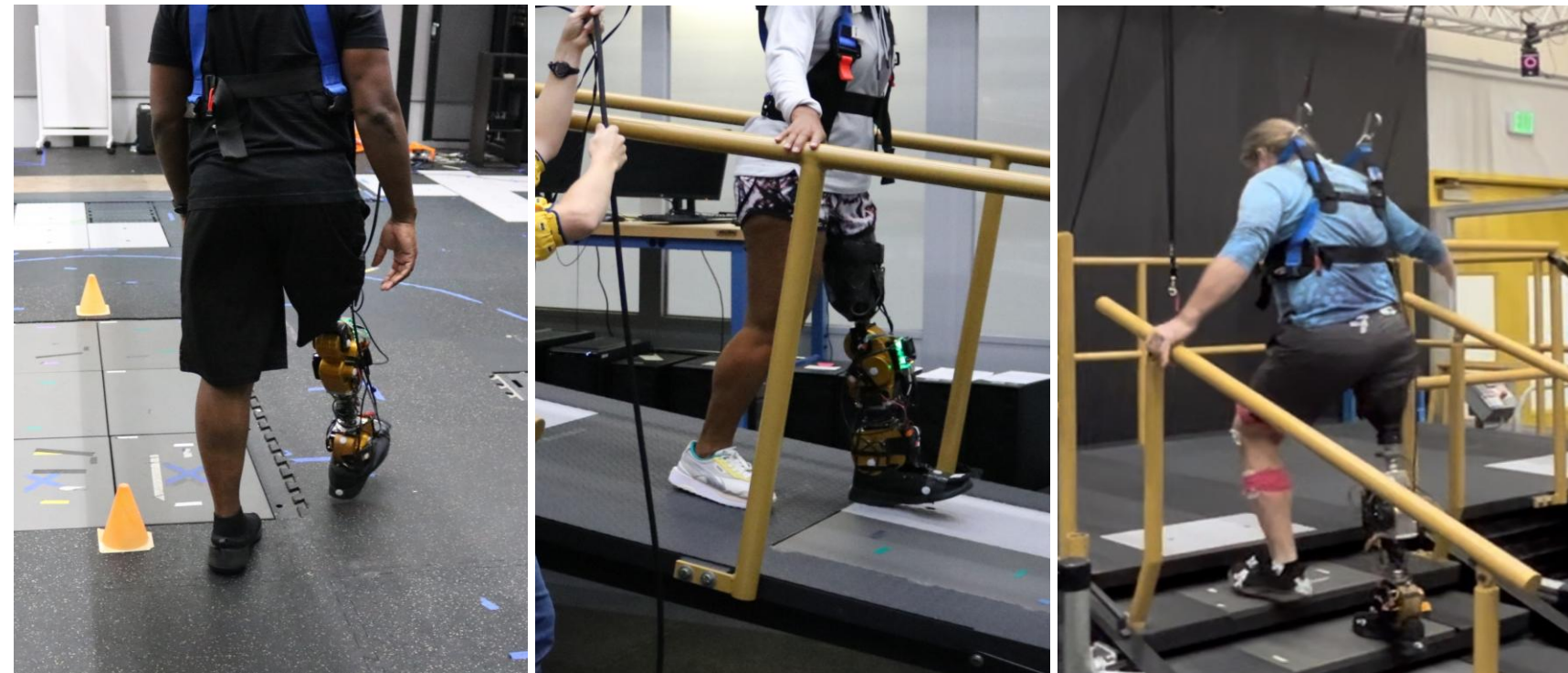


Funded by



Vision for this work

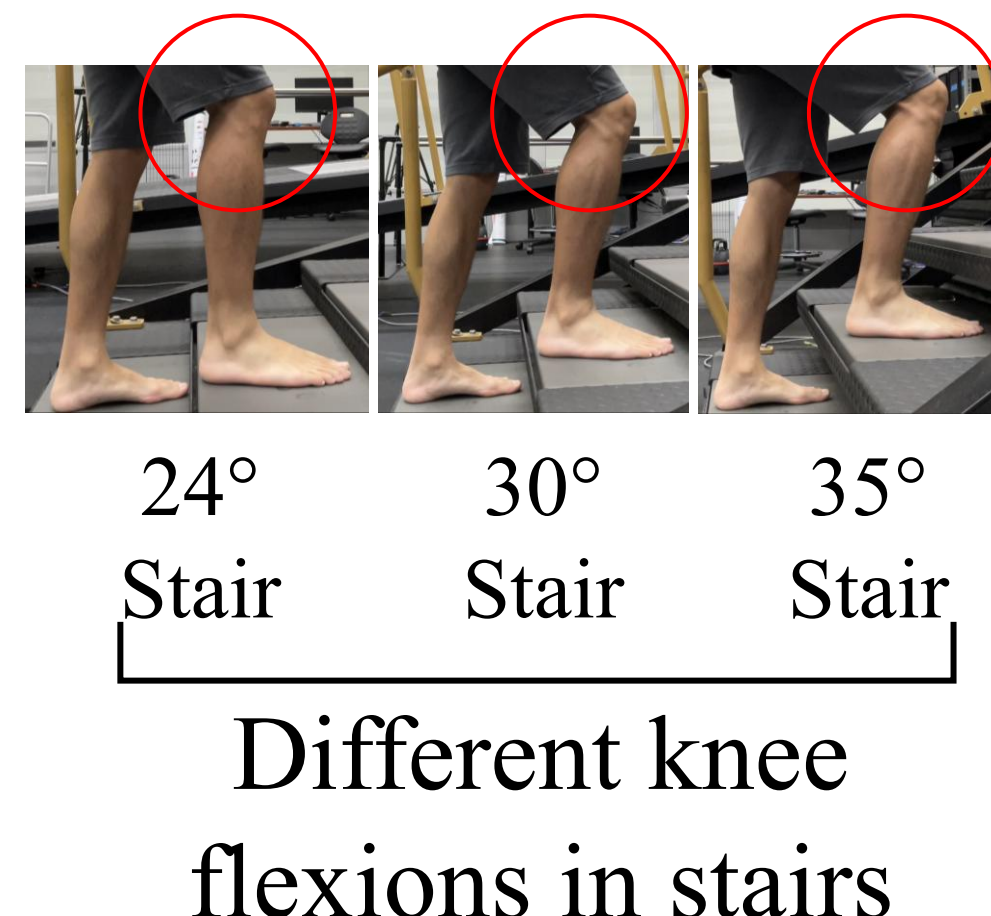
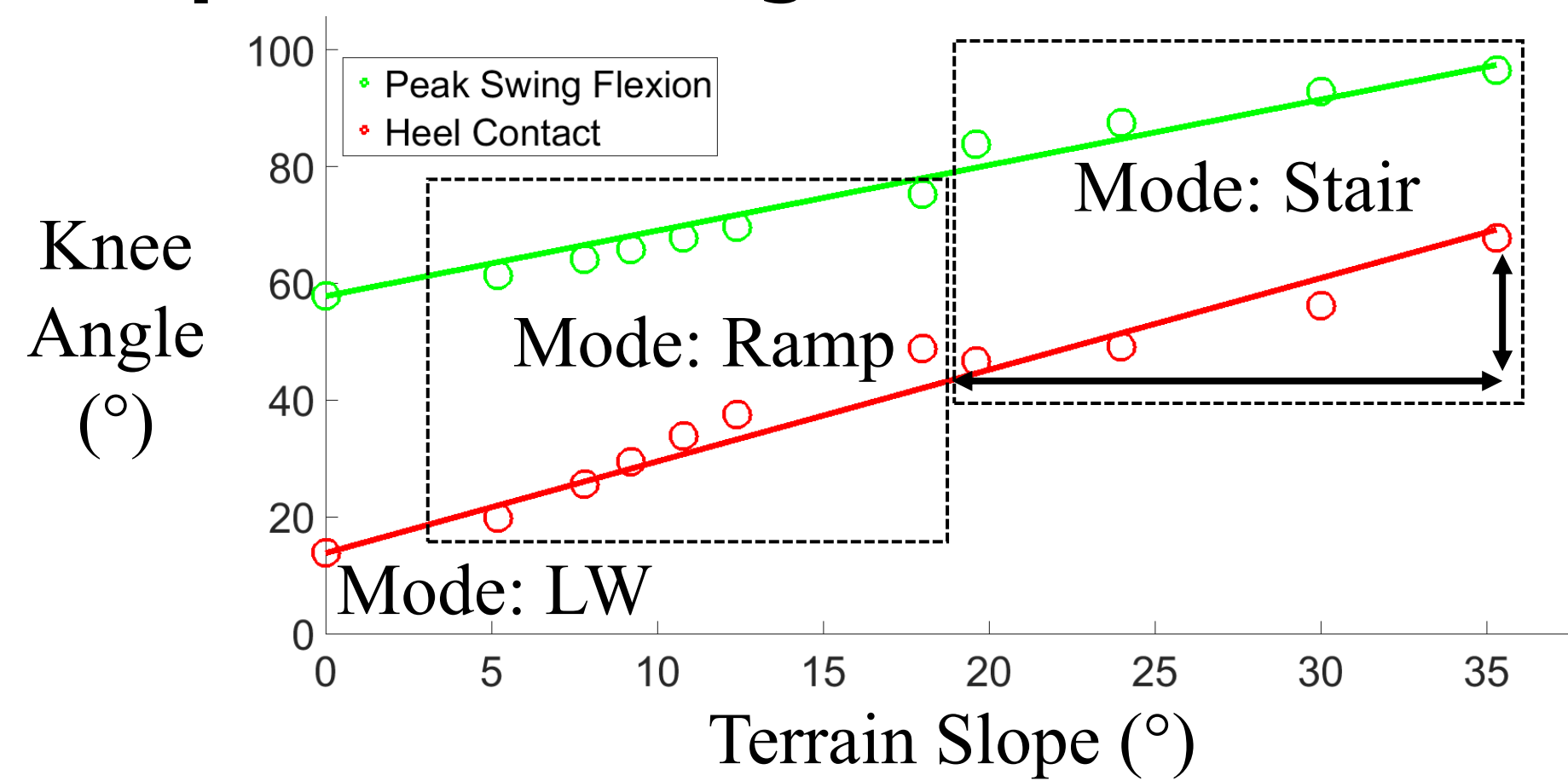
- Discrete controller → Continuous



0° Level-Ground 7.8°~12.4° Ramp 10.2cm~17.8cm Stair

$-35.3^\circ \sim 35.3^\circ$
Continuous Terrain Slope

- Replicate scaling human biomechanics



24° Stair 30° Stair 35° Stair
Different knee flexions in stairs

- Lower tuning efforts: Nominal solution w/o personalizing

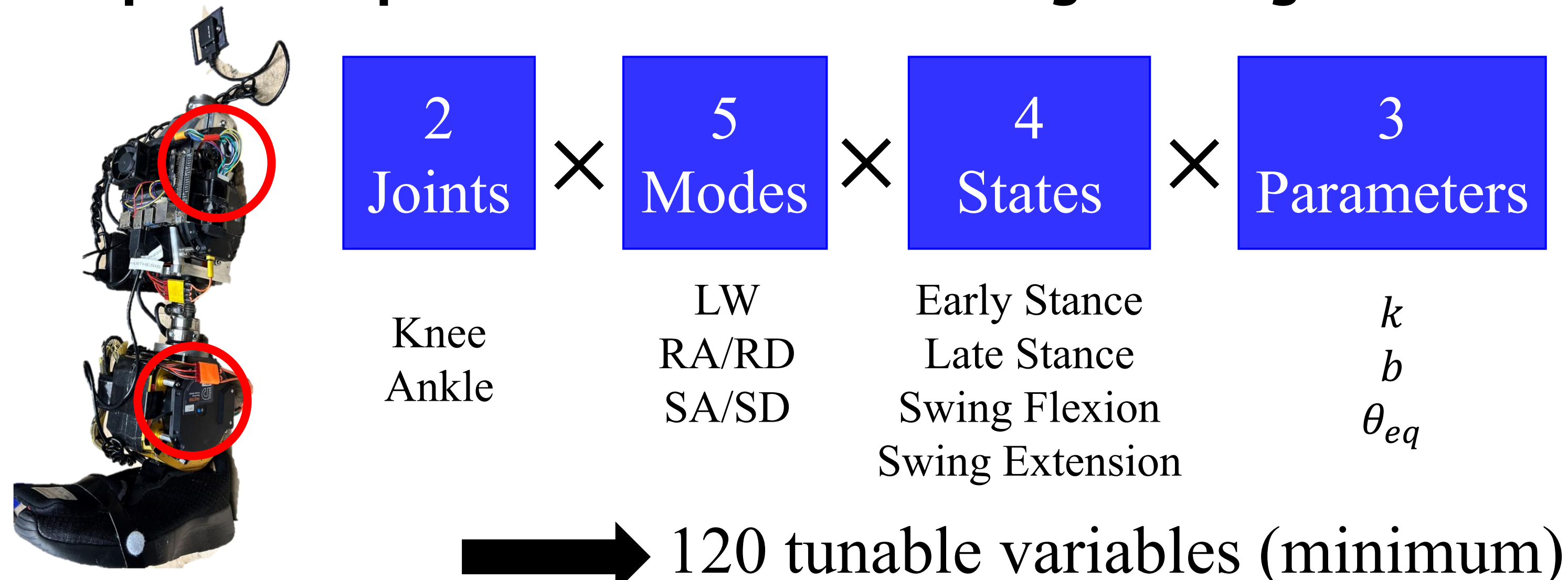
Hypothesis: The mode-unified continuous strategy will render human lower limb movement accurately than the traditional discrete-based strategy.

Motivation

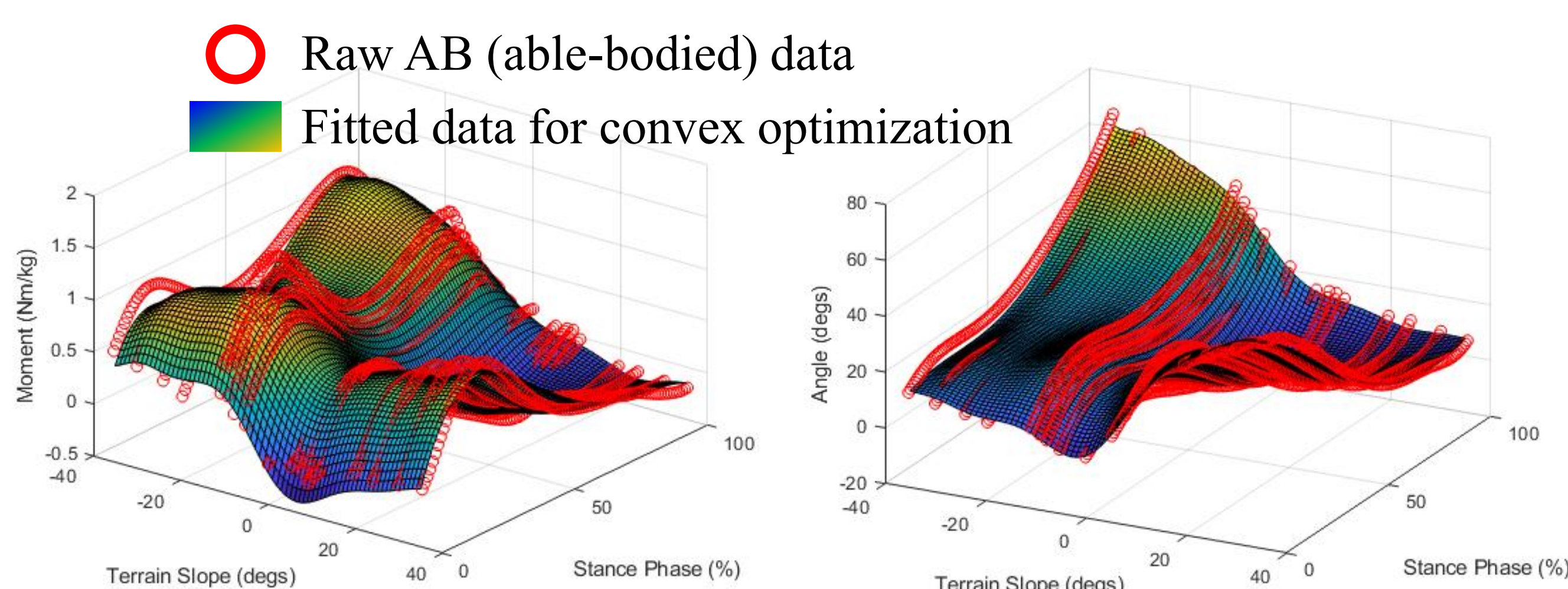
- Mode-specific control strategy: Dynamic mismatch

- Between-mode error → **potential fall** (Level vs stairs)
- Within-mode error → **non-scaling** (5° vs 11° ramps)

- Separate impedance controllers → High tuning efforts



Approach: Data-driven modelling[1, 2] using AB (able-bodied) locomotion data [3] across various conditions



Goal: Biomimetic impedance controller

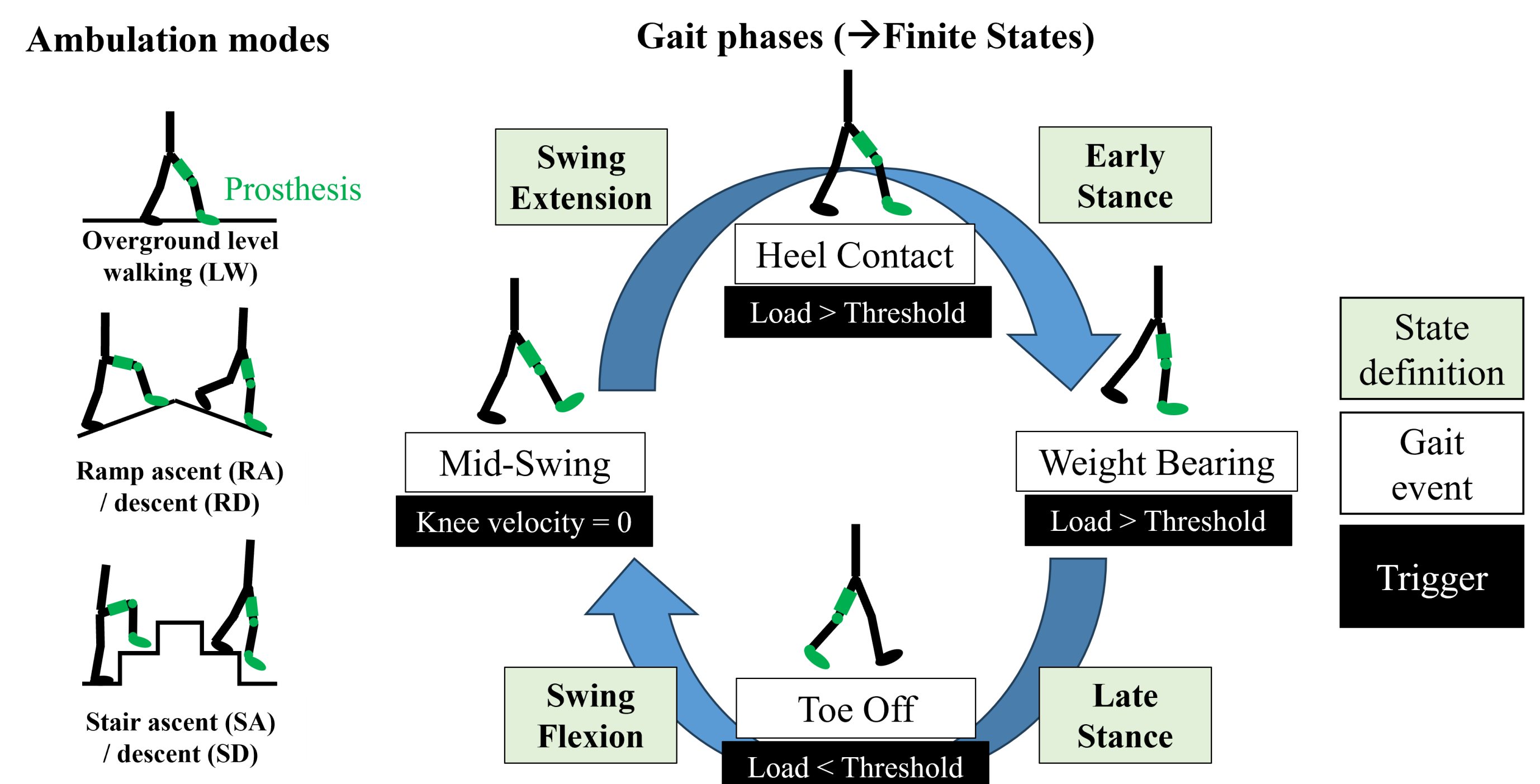
$$\tau = K(\theta_{eq} - \theta) - B\dot{\theta}$$

Given (AB)

Methods

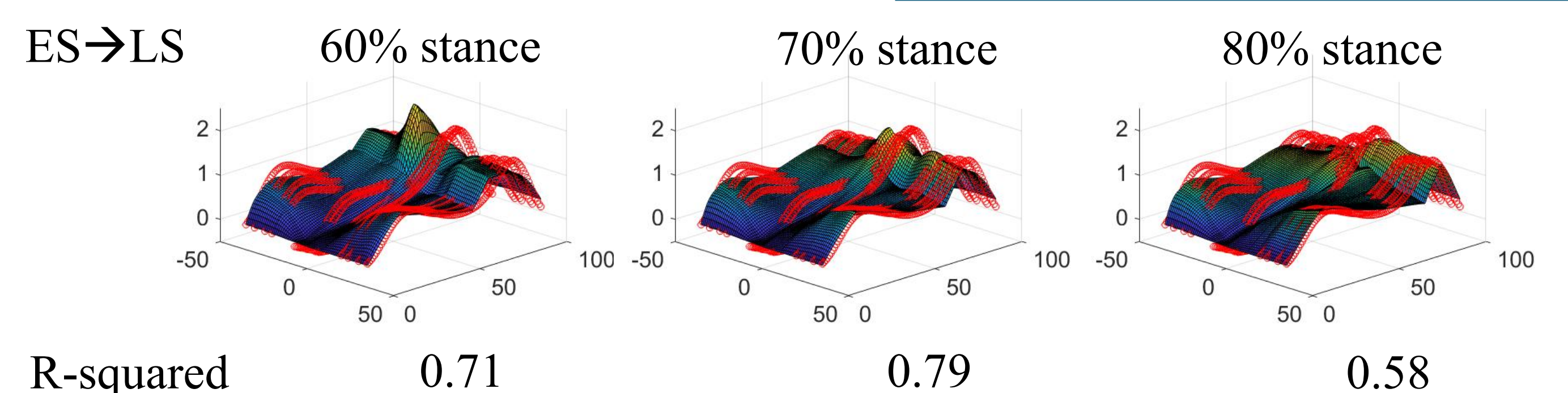
- FSM-based Impedance parameter optimization

- Stance phase: Kinetics (joint torque)
 - * Varied early → late stance timings: 60, 70, 80%
- Swing phase: Kinematics (joint angle)
 - * Knee: peak flexion → heel contact angle
 - * Ankle: peak plantarflexion → heel contact angle

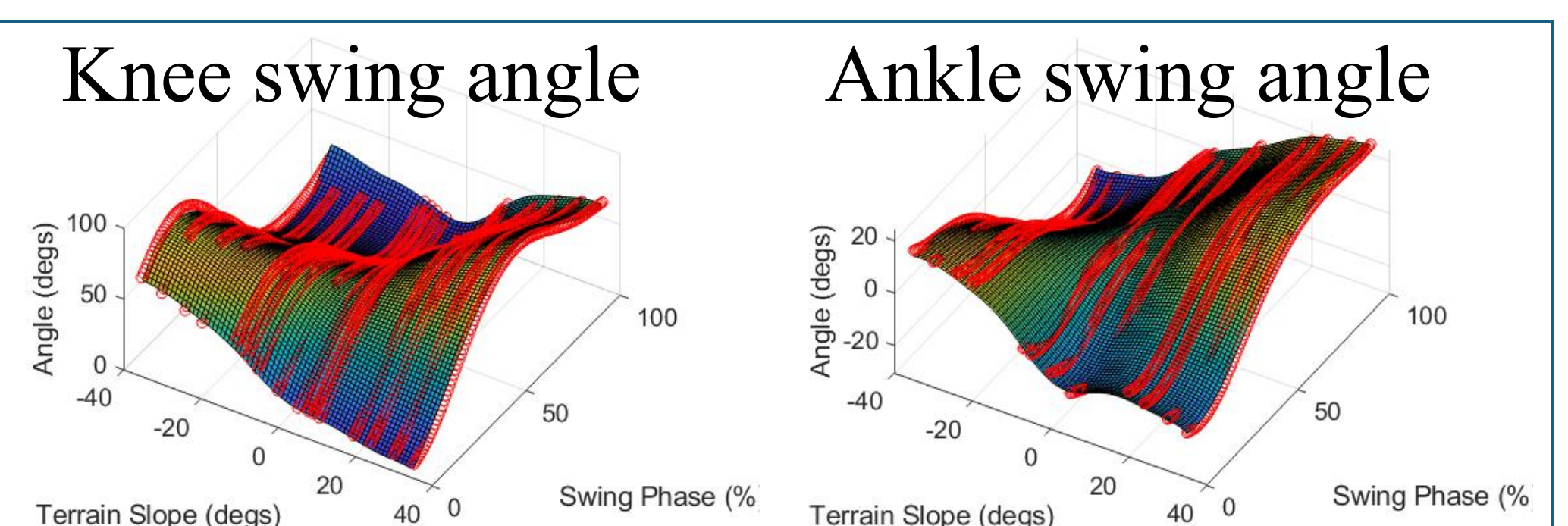
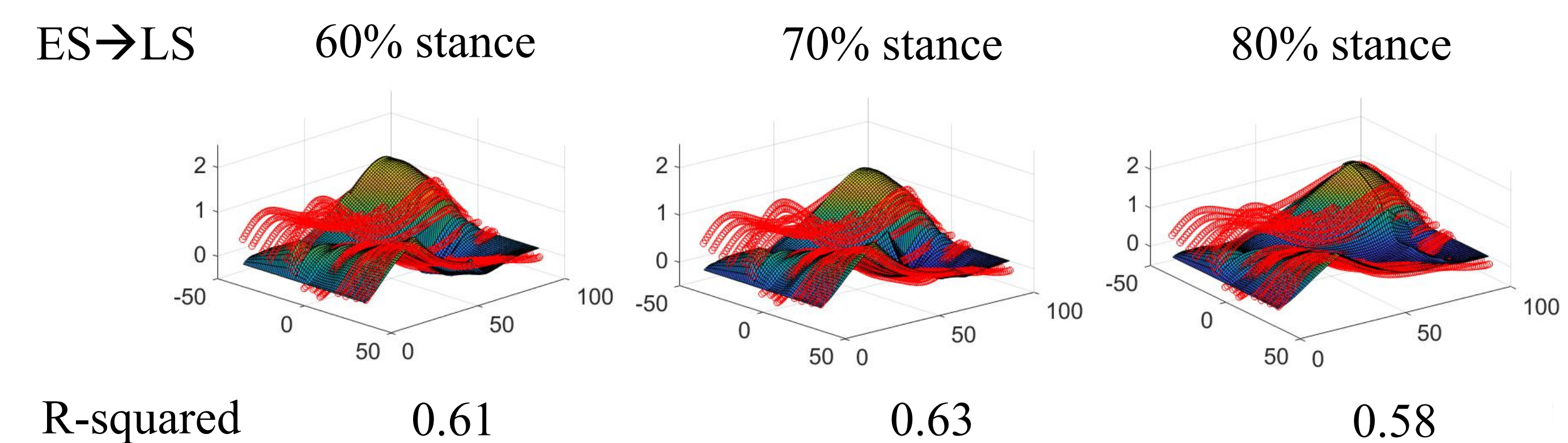


Modeling Results

Knee stance torque



Ankle stance torque



Conclusion & Take-home messages:

Continuous Impedance parameter optimization:

- Human gait biomechanics can be represented in a **continuous domain**.
- Data-driven parameterization can provide a nominal solution **without manual tuning**.

Additional steps:

- Mode-independent **state transition** (e.g., ES→LS) criteria are required.

Acknowledgements

This work was supported by the DoD CDMRP under Award #W81XWH-22-1-1091.

References

- [1] Cortino, 2023 "Data-driven phase-based control of a powered knee-ankle prosthesis for variable-incline stair ascent and descent"
- [2] Best, 2023 "Data-driven variable impedance control of a powered knee-ankle prosthesis for adaptive speed and incline walking"
- [3] Camargo, 2021 "A comprehensive, open-source dataset of lower limb biomechanics in multiple conditions of stairs, ramps, and level-ground ambulation and transitions"