# Toward Model-Based Intent Detection for Lower-Extremity Exoskeletons

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## Introduction

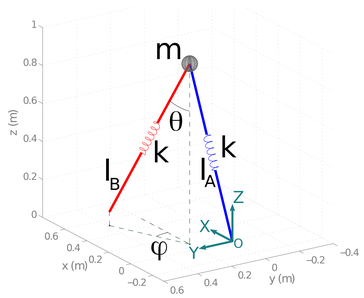
- Robotic exoskeletons can enhance gait rehabilitation for individuals with Spinal Cord Injuries (SCIs)
- Current intent detection methods limit fluent human-robot interaction (HRI)
  - Existing devices use primitive methods for intent detection (e.g., button presses)
- *This work explores a model-based strategy for intent detection using template models of locomotion*

Ekso GT exoskeleton

- Gait library based on template models predicts walking dynamics across a range of speeds
- Interacting Multi-Model (IMM) Estimation used to infer target gait in the library from exoskeleton sensor measurements

## Model & Gait Optimization

- Bipedal Spring-Loaded Inverted Pendulum (B-SLIP)
  - 3D variant enables capturing increased center of mass (CoM) sway at velocities below 1 m/s

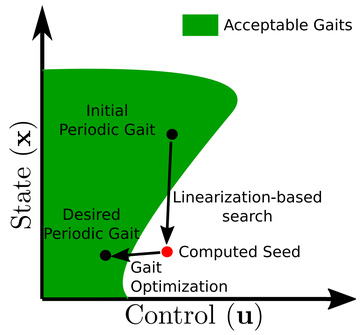



3D B-SLIP Model

- Alternates between double support (DS) and single support (SS) - leg touchdown (TD) and liftoff (LO) mark transitions
- Shooting techniques used to find two-step periodic gaits
- Data-driven foot placement regularization improves convergence
- Model displays increased sensitivity at low speeds

## Optimization of Low-Speed Gaits

- Low-speed gait optimization is sensitive to initial conditions
- Linearized return-map analysis enables predictor-correct scheme to find gait parameters at a lower velocity
- Iterating over desired velocity range yields a gait library



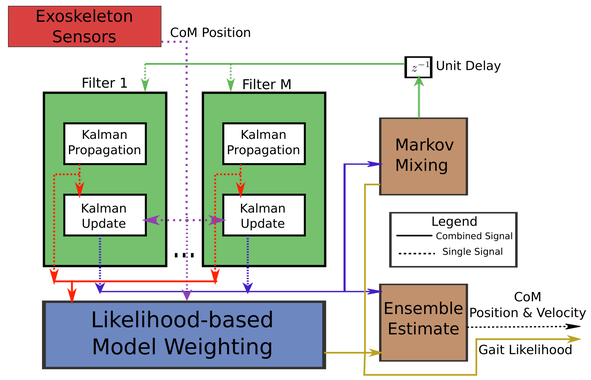

Linearized Seed Search

Return Map:

$$\mathbf{x}_{k+1} = \mathcal{P}(\mathbf{x}_k, \mathbf{u}_k)$$
$$\mathbf{x} = [p_y,\ p_z,\ v_x,\ v_y]^T$$
$$\mathbf{u} = [\varphi,\ \theta,\ k]^T$$

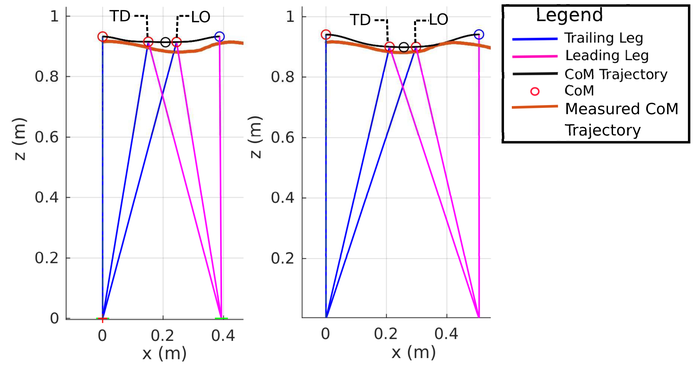
## Multi-Model Estimation

- Bank of parallel Extended Kalman Filters (EKFs) - EKF models are B-SLIP models tuned for library gaits
- Likelihood-based model weights are computed considering
  - Leg length vs. free length (physical likelihood)
  - Measurement residuals (probabilistic likelihood)
- Ensemble estimate from a weighted average of filter estimates
- IMM framework selects the most likely gait from the library



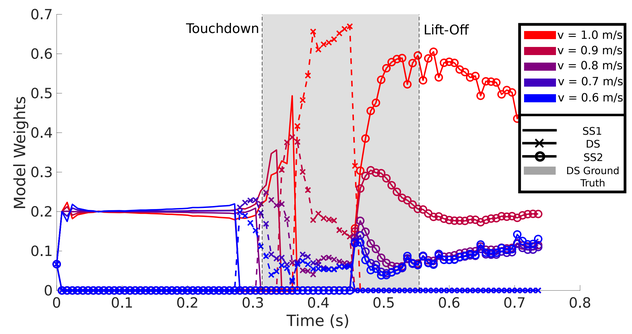

IMM Estimation Framework

## Results




Comparison of gaits at speeds of 0.6 m/s (left) and 1.0 m/s (right)

- Framework tested with exoskeleton sensor data of a subject walking at approx. 0.6 m/s using a walker
- CoM trajectory of an individual walking in an exoskeleton matches more closely with faster gait
- The IMM framework chooses the gait with lowest residual as most likely




Model weights of the IMM when applied to exoskeleton measurements

## Conclusions & Future Work

- Estimator identifies closest matching gait in the library
- Fidelity of library affects estimator performance
- Next steps:
  - Develop a higher fidelity library
  - Incorporate effects of ambulatory devices in the model
  - Augment estimator to accommodate gait asymmetry errors

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