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Upslope Walking with Transfemoral Prosthesis using Optimization based Spline Generation

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Daejeon, Korea 2016

Introduction

- Statistics of Amputation in U.S.A

- There are approximately 185,000 new amputations each year in the United States.
- One out of every five people living with limb loss in the United States has a transfemoral amputation (above the knee)
- Transfemoral amputees behave in a less active life style compared to people with below the knee amputation.

Introduction

- Motivation from the Environment

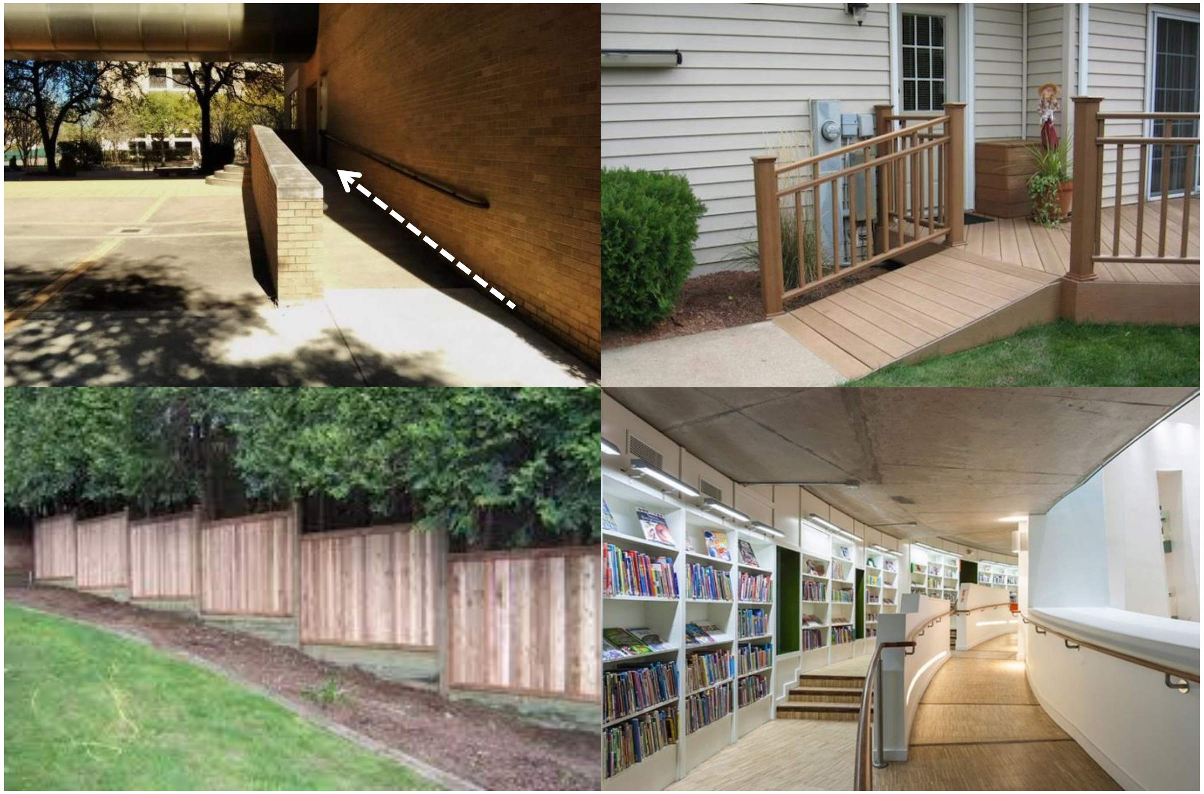

Fig.1 There are lots of ramps around us

Problem Statement

r

- Different trajectories needed for different scenarios

  ex) flat ground walking, upslope walking, etc.

- The possibility of misdetection existed when the prosthesis changes the mode for different scenario

- Additional tuning needed for each users

Objective

- Desired Characteristics of the Controller

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- Perform flat ground and upslope walking with a transfemoral prosthesis
  - Automatically generate walking gaits for different terrain
  - Fast switching algorithms for terrain transitions
  - Avoid tuning processes

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Methods
- Hardware

- AMPRO2 (A&M Prosthesis2)

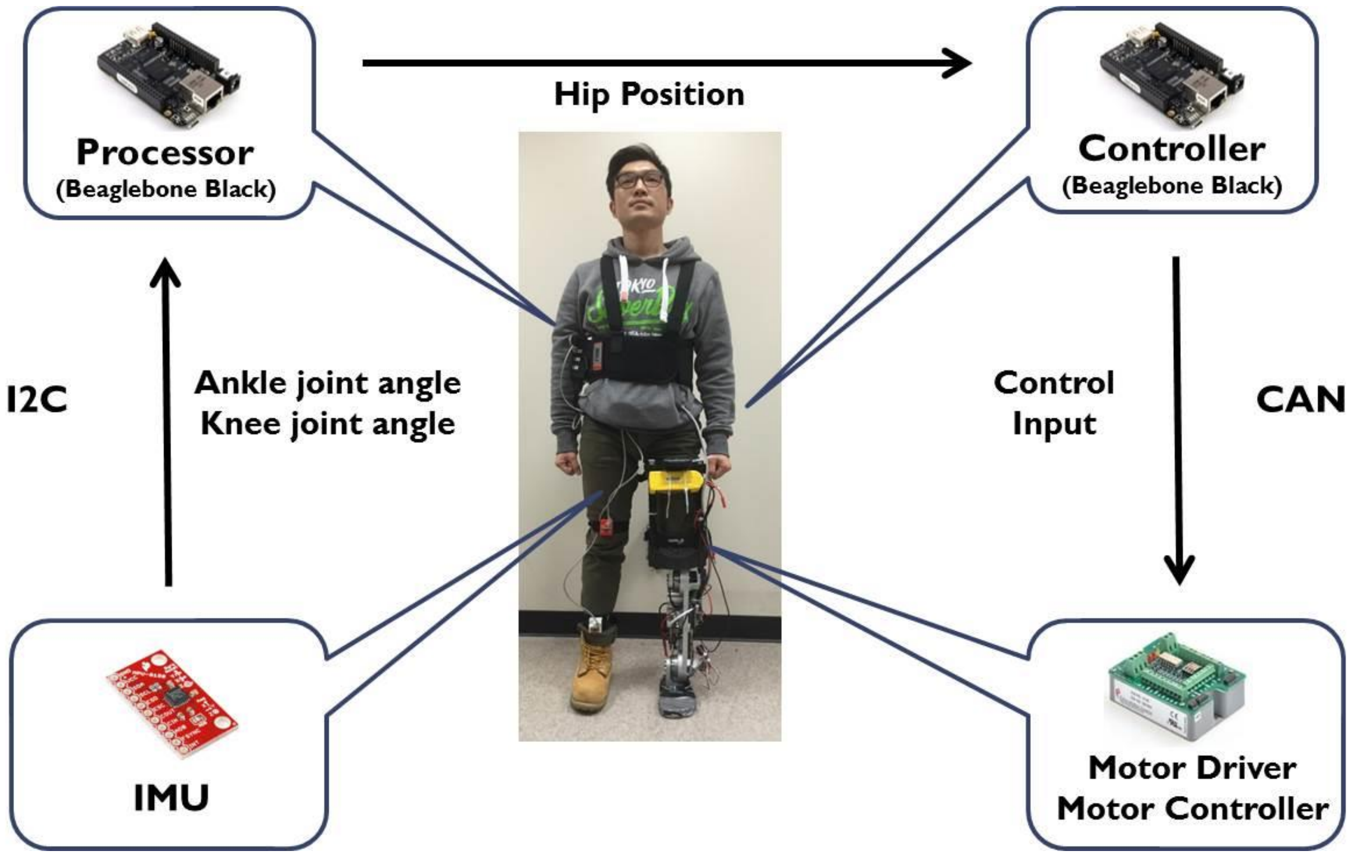

Fig. 2 The entire system flow of AMPRO2

Methods

- Human Walking Data for Upslope Walking

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- As slope increases → Initial & final phase of angles increases
- The upslope trajectories converge to flat ground walking trajectories between 45% and 80% of the gait cycle.

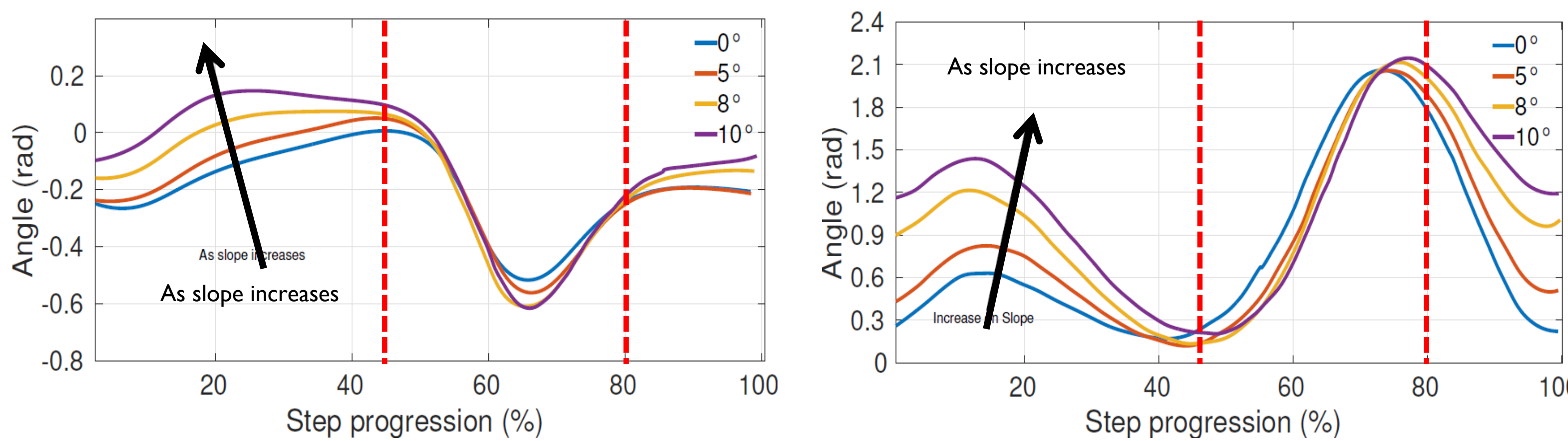

Fig. 3 Joint angle data from motion capture system for different slopes (0°,5°,8° and 10°) (a) Ankle Joint Angle, (b) Knee Joint Angle

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Methods
- Control Strategies

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- Proposed solution
  - Use low gain PD control for terrain adaptation
  - Use splines to blend upslope trajectory into flat ground trajectory
  - Use human-inspired control for flat ground gait generation

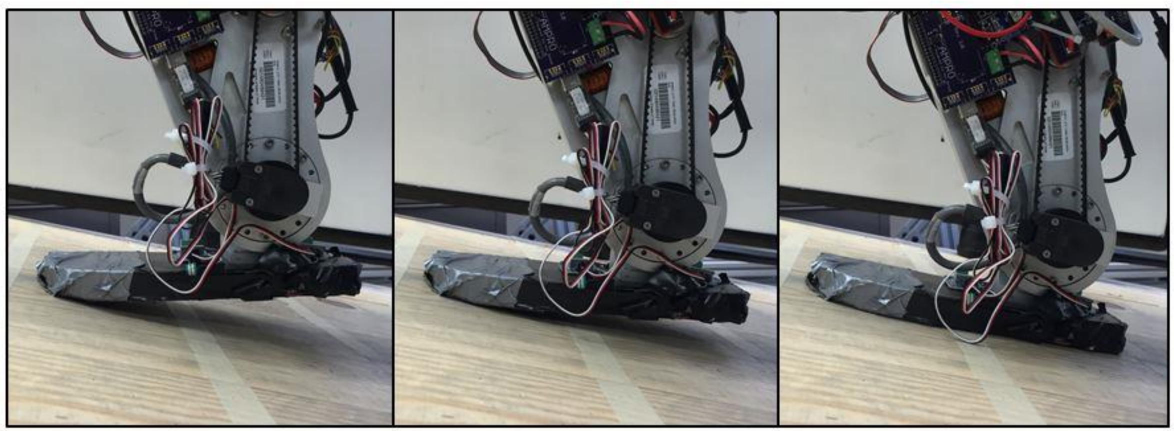


Fig. 4 Transition from flat ground to upslope surface

Methods

- Low Gain PD Control

- Low gain PD control (Blue Region)
  - For the unexpected terrain adaptation
- Heel contact (0 and 100 %)
- Spline generation (Red Region)
  - Starts to blend into the flat ground trajectory

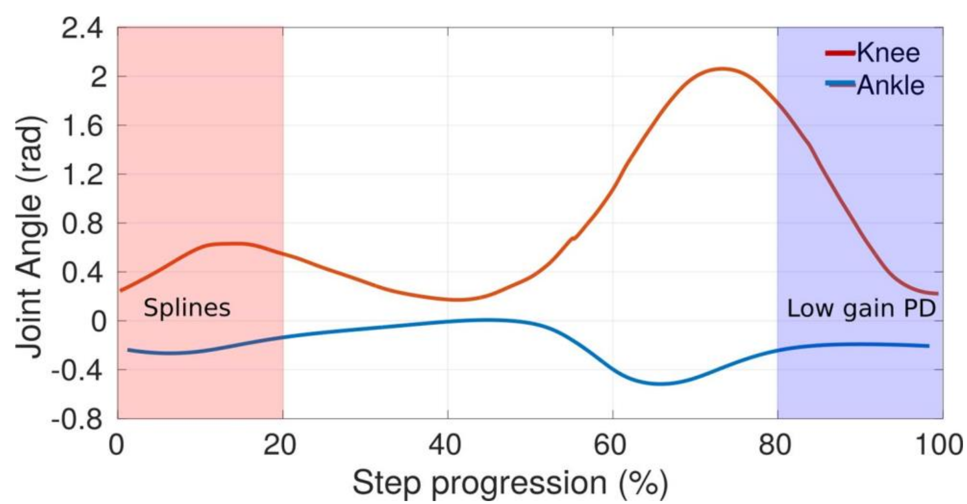


Fig. 5 Ankle, Knee joint angle for one gait cycle of abled subject

Methods
- Spline Generation

- Cubic-splines based convex optimization
  - The end point of C1 = The start point of the generated trajectory
  - Guaranteed continuity in position
  - Guaranteed smoothness in velocity and acceleration

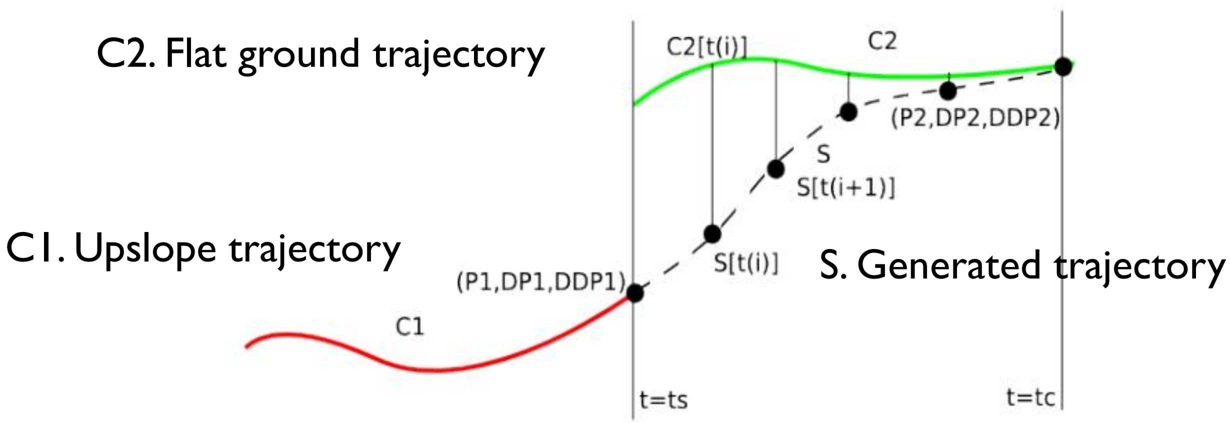
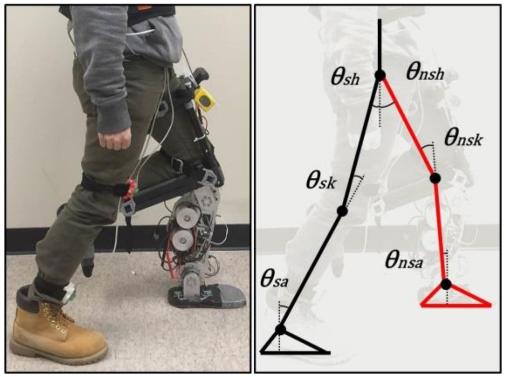


Fig. 6 Two disconnected trajectories C1 and C2 can be connected through a trajectory S.

Methods

- Controller Strategy for Flat Ground Walking



$q = (\theta_{sa}, \theta_{sk}, \theta_{sh}, \theta_{nsh}, \theta_{nsk}, \theta_{nsa})^T$

→ Robot Walking Trajectory

Robot Walking Trajectory

Human Inspired Optimization

- Human data
- Partial Hybrid Zero Dynamics (PHZD)
- Time parameterization

→ Canonical Walking Function

Human-like Walking Trajectory

Methods

- Controller Strategy for Flat Ground Walking

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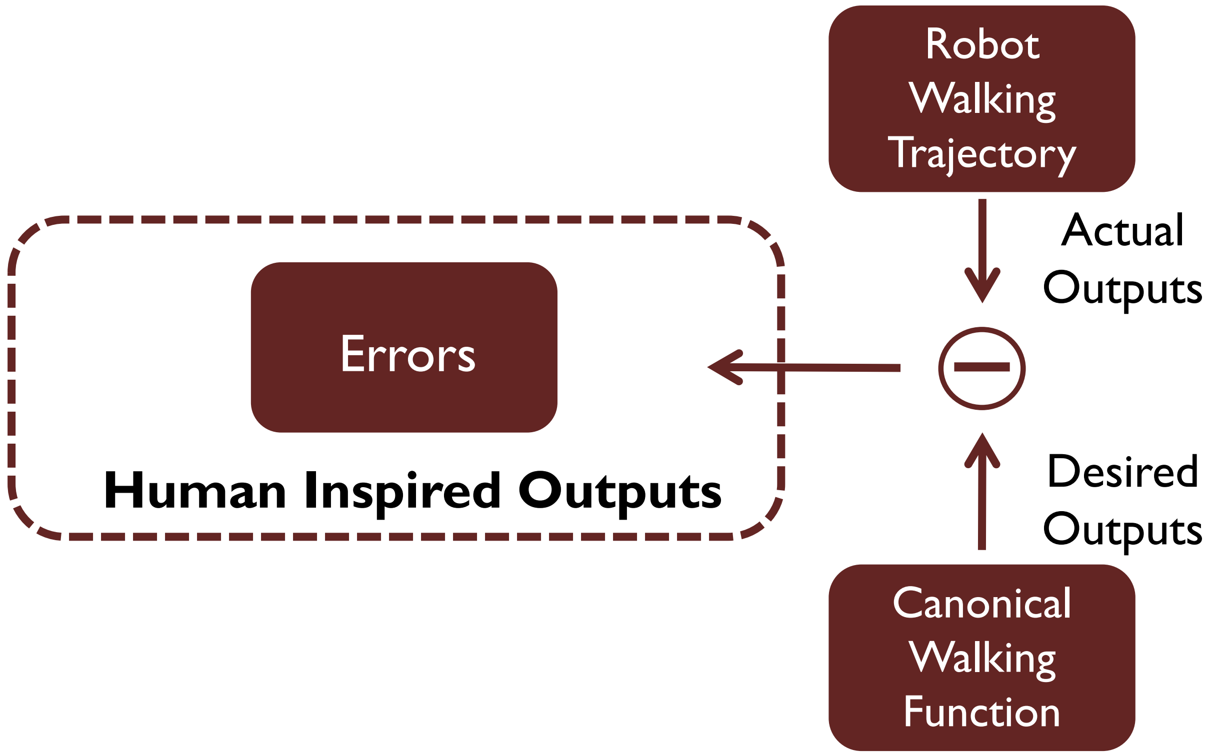

Methods

- Controller Strategy for Flat Ground Walking

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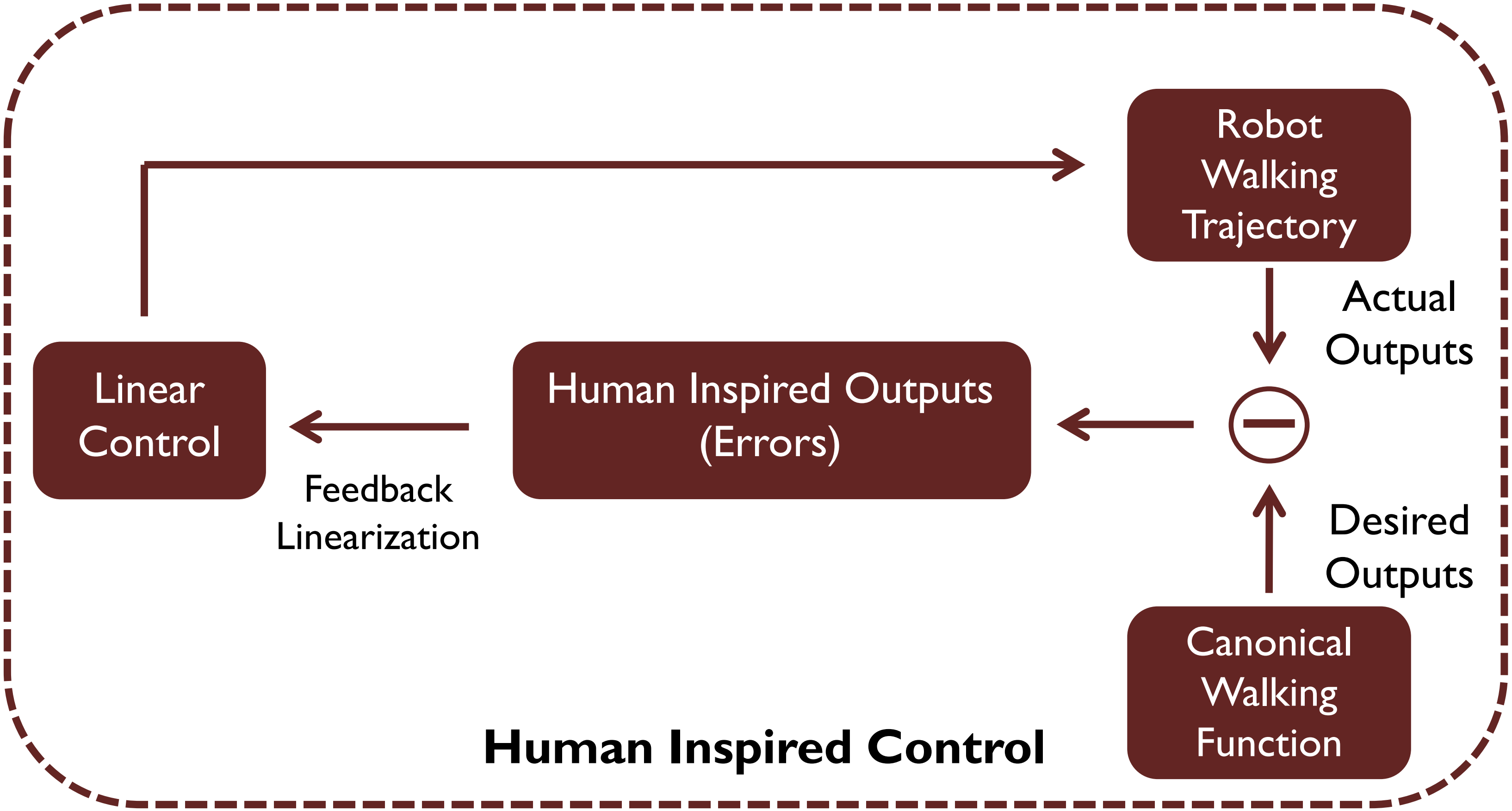


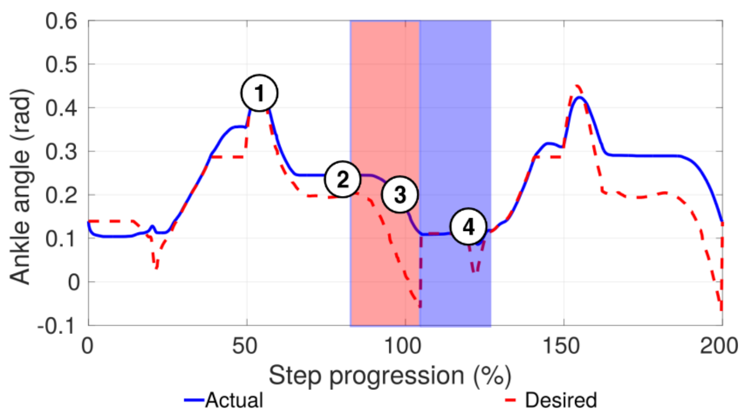
Results

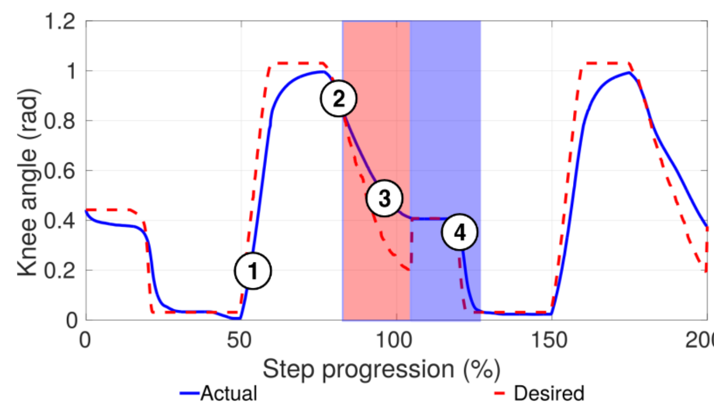
- The Abled Subject Trial

- Test at the indoor & outdoor environments
  - Flat ground & upslope walking with the proposed solution

Results

- The Abled Subject Trial





Conclusion

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Problem Statement (Revisit)

- Different trajectories needed for different scenarios
- The possibility of misdetection existed when the prosthesis changes the mode for different scenario
- Additional tuning needed for each users

Using spline generation and low gain PD control

- Unifying the controller for flat ground & upslope walking
- Fast transition from flat ground to upslope surface
- Eliminating the additional tuning process
- Adapting to the unexpected terrain

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Acknowledgement

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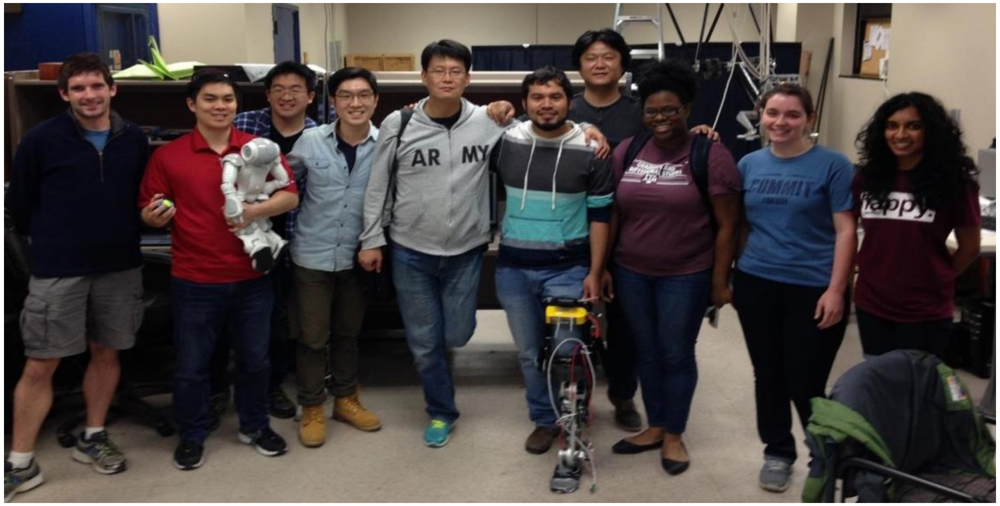
Thank you !



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Back-up slides

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Methods

- Robotic Model Trajectories Generation

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- Robotic Model
  - Anthropomorphic dimensions of the human in the robotic model
  - Choose a co-ordinates

    $q = (\theta_{sa}, \theta_{sk}, \theta_{sh}, \theta_{nsh}, \theta_{nsk}, \theta_{nsa})^T$
  - Equations of motion

    $D(\theta)\ \ddot{\theta} + C(\theta,\dot{\theta})\ \dot{\theta} + G(\theta) = Bu$

    $(\dot{x} = f(x) + g(x) * u)$

    (state vector $x = (q, \dot{q})^T$)

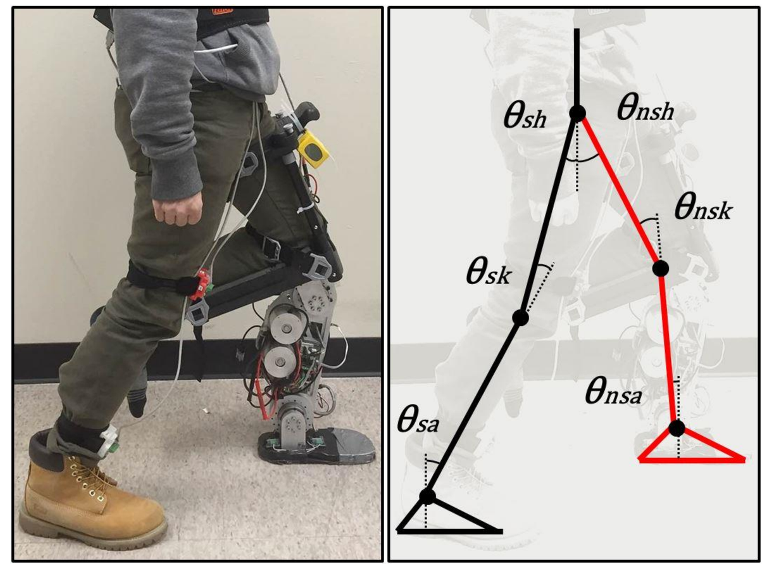

Fig.8 7-links Robotic Model

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Methods

- Human Walking Trajectories Generation

- Human Model

  - Human inspired optimization

$$y_1^d(t,\alpha) = v_{hip}$$
$$y_2^d(t,\alpha) = e^{-\alpha_1 t}(\alpha_2 \cos(\alpha_3 t) + \alpha_4 \sin(\alpha_3 t)) + \alpha_5$$

  - To generate human-like gait functions for flat ground walking
  - Solve the optimization problem between gait function & human data

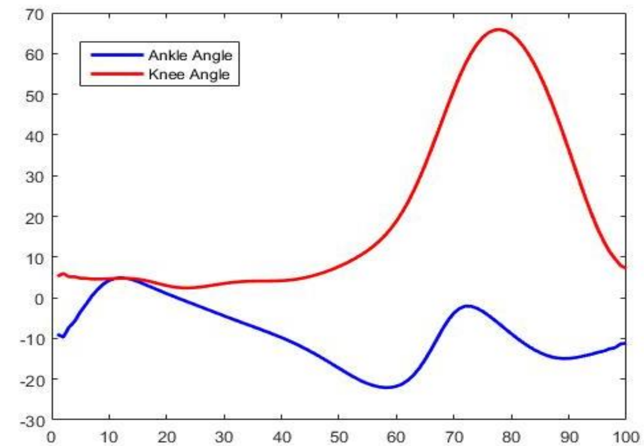

Fig.9 Joint angle of the ankle & knee

Methods

- Human Inspired Control

- Hybrid Zero Dynamics (HZD)

$$Z_\alpha = \{(\theta, \dot{\theta}) : y_1(\theta, \dot{\theta}, \alpha) = 0, y_2(\theta, \alpha) = 0, Lfy_2(\theta, \alpha) = 0\}$$

  - Stay at an exponentially stable periodic orbit

- Partial Hybrid Zero Dynamics (PHZD)

$$PZ_\alpha = \{(\theta, \dot{\theta}) : y_2(\theta, \alpha) = 0, Lfy_2(\theta, \alpha) = 0\}$$

$$\Delta_R(S_R \cap PZ_\alpha) \subset PZ_\alpha$$

  - Relax the invariance of the hip velocity under the heel impact
  - Obtain parameter α^* satisfy hybrid invariance of PZ_α

Methods

- Human Inspired Control

- Phase Variable
  - Eliminate dependence of time (state based)

$$\tau(\theta) = \frac{\delta p_{hip}(\theta) - \delta^{+} p_{hip}}{v_{hip}}$$

where, $\delta p_{hip}(\theta)$ is the linearized hip positon, $\delta^{+} p_{hip}$ the initial hip position and v_{hip} the desired hip velocity

- Human Inspired Outputs

$$y(\theta, \dot{\theta}, \alpha) = \begin{bmatrix} y_1(\theta, \dot{\theta}, \alpha) \\ y_2(\theta, \alpha) \end{bmatrix} = \begin{bmatrix} y^{a}{}_1(\theta, \dot{\theta}) - v_{hip} \\ y^{a}{}_2(\theta) - y^{d}{}_2(\tau(\theta), \alpha) \end{bmatrix}$$

  - Design a controller to drive $y(\theta, \dot{\theta}, \alpha)$ to zero

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Methods

- Control Implementation

- Feedback Linearization
  - Applying the feedback linearization control to the human inspired outputs, the resulting control law is

$$\begin{bmatrix} \dot{y}_1 \\ \ddot{y}_2 \end{bmatrix} = \begin{bmatrix} L_f y_1(\theta, \dot{\theta}) \\ L_f{}^2 y_2(\theta, \dot{\theta}, \alpha) \end{bmatrix} + \begin{bmatrix} L_g y_1(\theta, \dot{\theta}) \\ L_g L_f y_2(\theta, \dot{\theta}, \alpha) \end{bmatrix} \mathrm{u}$$

$$\mathrm{u} = \begin{bmatrix} L_g y_1(\theta, \dot{\theta}) \\ L_g L_f y_2(\theta, \dot{\theta}, \alpha) \end{bmatrix}^{-1} \left(-\begin{bmatrix} L_f y_1(\theta, \dot{\theta}) \\ L_f{}^2 y_2(\theta, \dot{\theta}, \alpha) \end{bmatrix} + \mathrm{v} \right)$$

$$\begin{bmatrix} \dot{y}_1 \\ \ddot{y}_2 \end{bmatrix} = \mathrm{v}$$

Future Works

- Lower Limb Prosthesis

- Find more stable and robust phase variable
- Consider the walking with foot rolling motion which makes more human-like
- Extend to the downslope walking
- Design a new version of lower limb prosthesis with springs

References

[1] Victor Paredes, Woolim Hong, Shawanee Patrick, Huihua Zhao, Dr. Aaron D. Ames and Dr. Pilwon Hur. Upslope Walking with Transfemoral Prosthesis Using Optimization Based Spline Generation, *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*., 2016

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