Transfemoral Prosthesis Control for Slope Walking with Principal Component Analysis

MECHANICAL ENGINEERING
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INTRODUCTION

Background

- About 185,000 new amputations happen each year in the U.S., and one of every five amputees have transfemoral amputations.

Previous Studies

- Human-inspired control has been implemented in bipedal robots; a human-like gait with guaranteed stability could be generated from human data. However, it cannot be used to generate gaits for different terrains.
- An algorithm using spline-generation was proposed for the different terrains. However, this method is applicable only for the upslope walking.

Objectives

- A unified trajectory generation for the powered transfemoral prostheses need to be considered for both upslope and downslope.

Approach

- Principal Component Analysis (PCA) using human data can take advantage of generating the desired trajectory to perform the slope walking with the prosthesis in real-time.

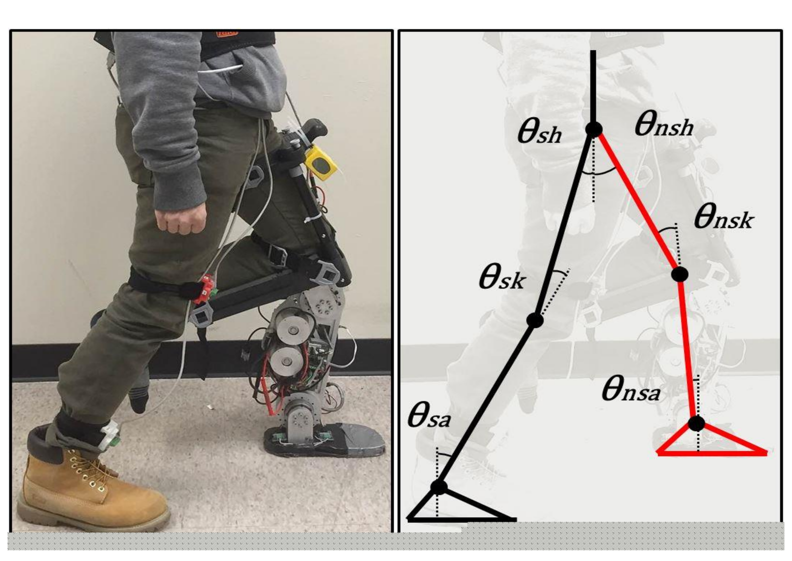

Fig. 1 AMPRO2 and the robotic model

METHODS

Human Strategy for Slope Walking

- During human upslope walking (Fig.2A), as the inclination increases, the knee flexion and ankle dorsiflexion increases.
- During the downslope walking (Fig.2B), the ankle joint angle remains the same as the level walking regardless of the slopes. For the knee joint, as the inclination angle increases, the deviation of the joint angle became significant.

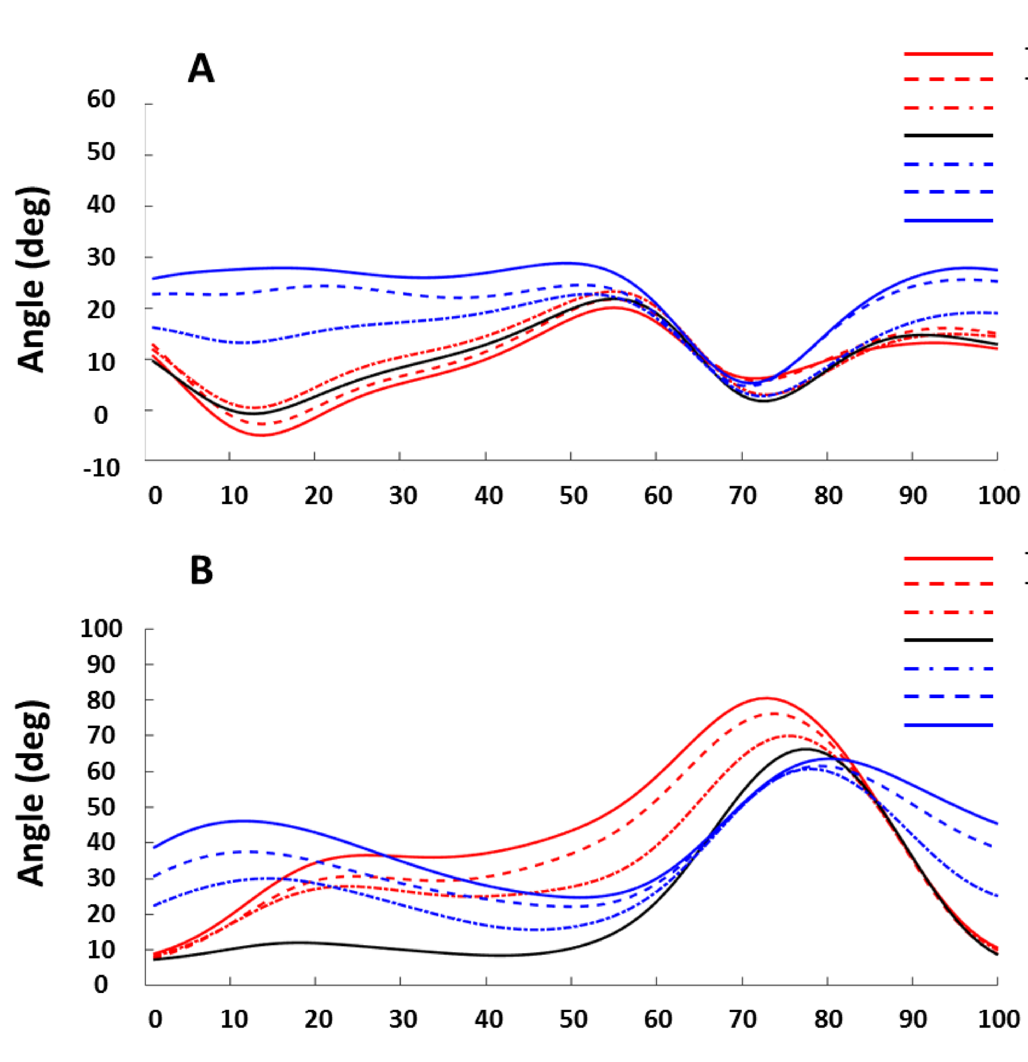

Fig. 2 Human kinematic data showing the effect of the inclination

Trajectory Generation

- For the ankle, it is shown 2 components are dominant with 98.15% correlation; 2 principal components (PCs) are chosen to regenerate the inclined trajectories (Fig.3A,B).
- Appropriate coefficients corresponding to 2 PCs, are calculated from the off-line optimization problem.

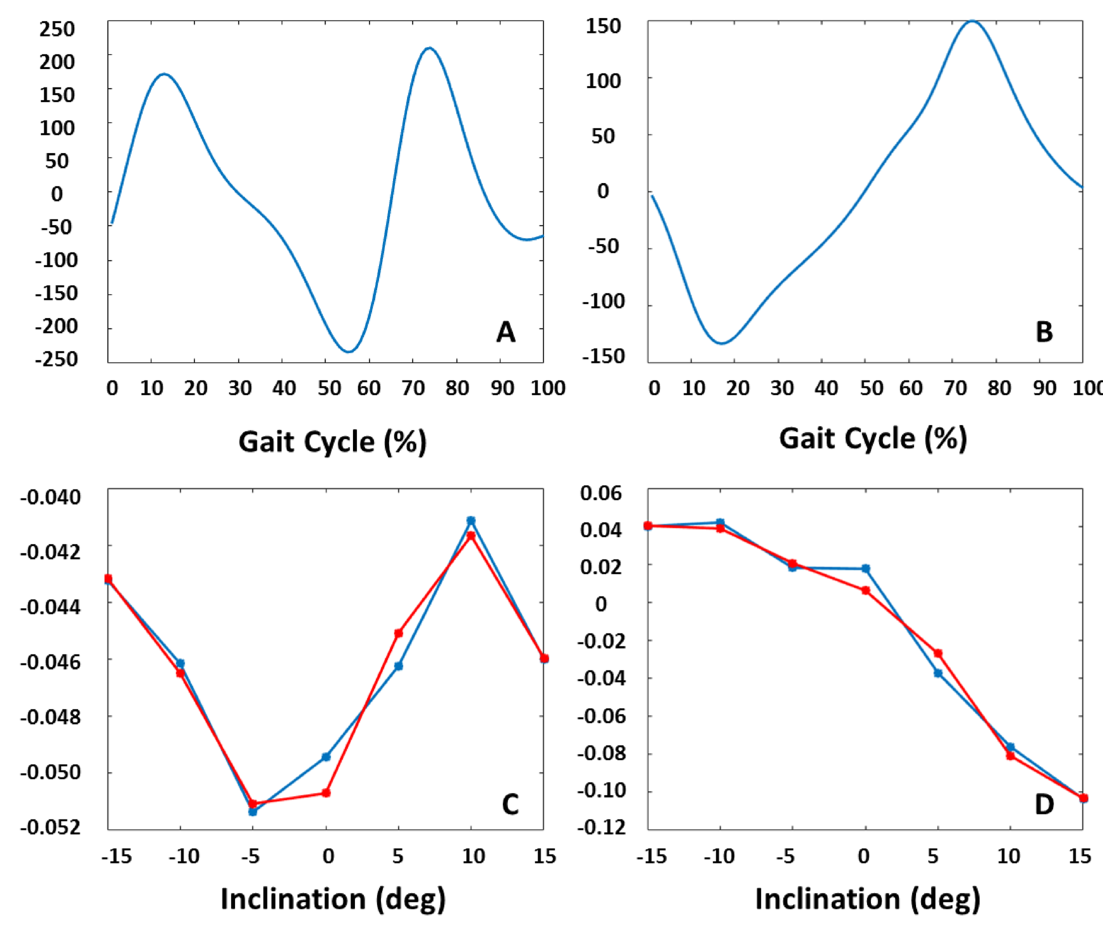

Fig. 3 PCs (A,B) and PCs' coefficients (C,D) of the ankle. Blue: the actual value; red: the optimization result

$$C_i(x,\theta) = \begin{cases} x_{(i,1)} + x_{(i,2)} * \theta + x_{(i,3)} * \theta^2 + x_{(i,4)} * \theta^3 & \theta \geqq 0 \\ x_{(i,5)} + x_{(i,6)} * \theta + x_{(i,7)} * \theta^2 + x_{(i,8)} * \theta^3 & \theta < 0 \end{cases}$$

- For the knee, it is shown 3 components are dominant with 99.91% correlation; 3 PCs are chosen to regenerate the inclined trajectories (Fig.4A,B,C).
- Coefficients of these 3 PCs also can be solved from the optimization problem with cubic polynomials.

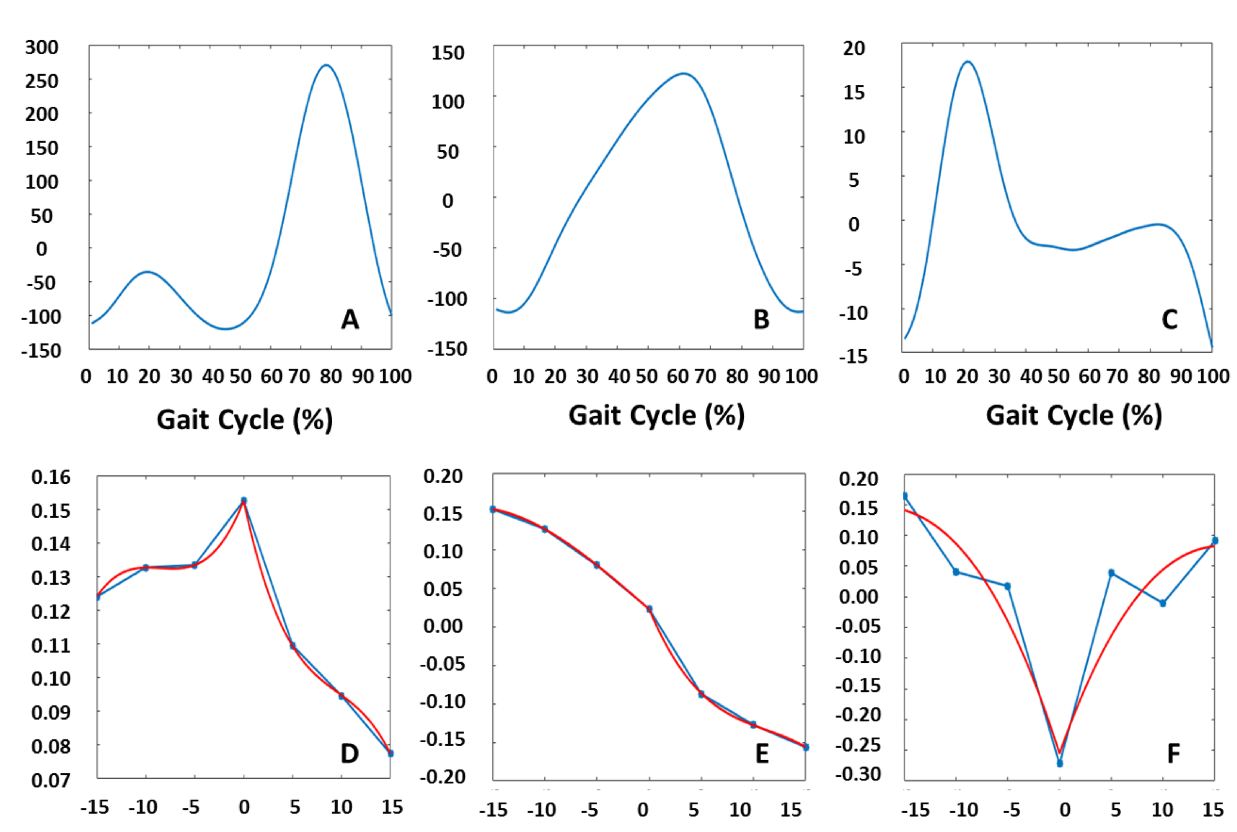

Fig. 4 PCs (A,B,C) and PCs' coefficients (D,E,F) of the knee
Blue: the actual value; red: the optimization result

- De-normalization to regenerate the actual trajectories; mean value can be represented by cubic polynomial functions for both the ankle and knee angles (Fig.5A,B).

$$M(x,\theta) = \begin{cases} x_{(3,1)} + x_{(3,2)} * \theta + x_{(3,3)} * \theta^2 + x_{(3,4)} * \theta^3 & \theta \geqq 0 \\ x_{(3,5)} + x_{(3,6)} * \theta + x_{(3,7)} * \theta^2 + x_{(3,8)} * \theta^3 & \theta < 0 \end{cases}$$

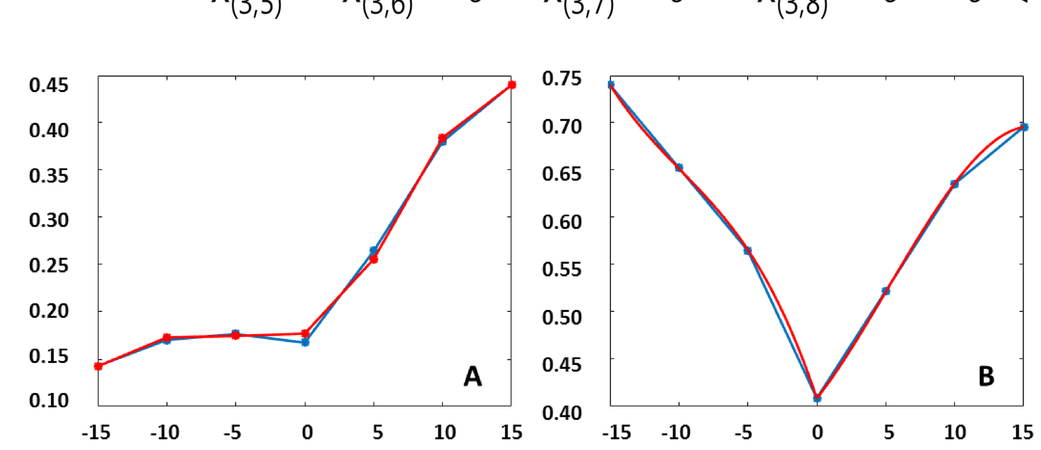

Fig. 5 Mean values to regenerate the actual joint angle trajectories
Blue: the actual value; red: the optimization result
(A: Ankle Joint, B: Knee Joint)

RESULTS

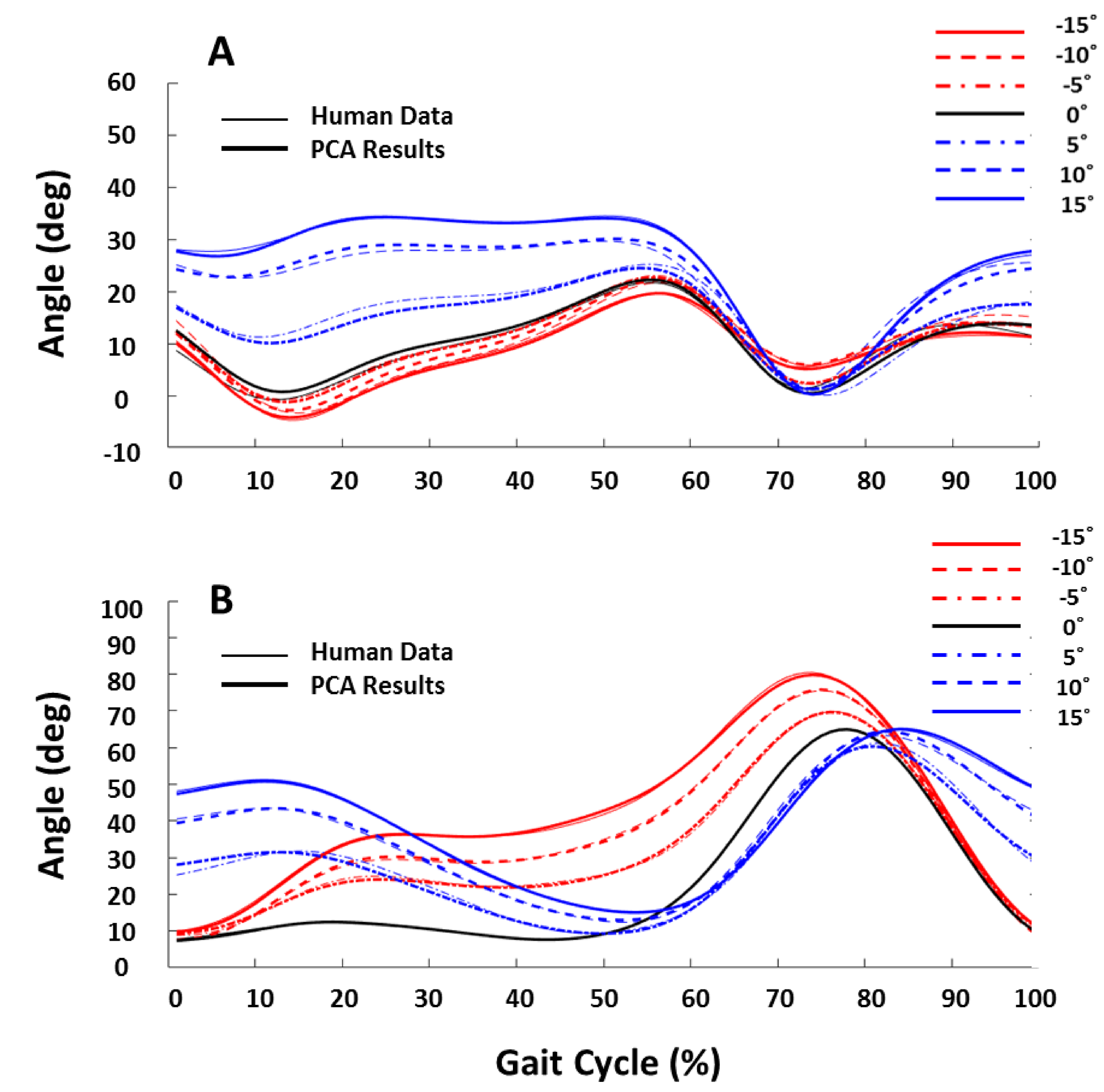

Fig. 6 Regenerated joints trajectories for 7 different slopes (-15˚, -10˚, -5˚, 0˚, 5˚, 10˚, 15˚) with the optimized coefficients and corresponding PCs (A: Ankle Joint , B: Knee Joint)

- For the ankle, Figure 6 shows we could generate the ankle joint trajectories for 7 slopes with 0.9815 correlations with 2 PCs & the optimized coefficients.
- For the knee, the correlation of the regenerated trajectories with the results of PCA was 0.9959.

CONCLUSIONS

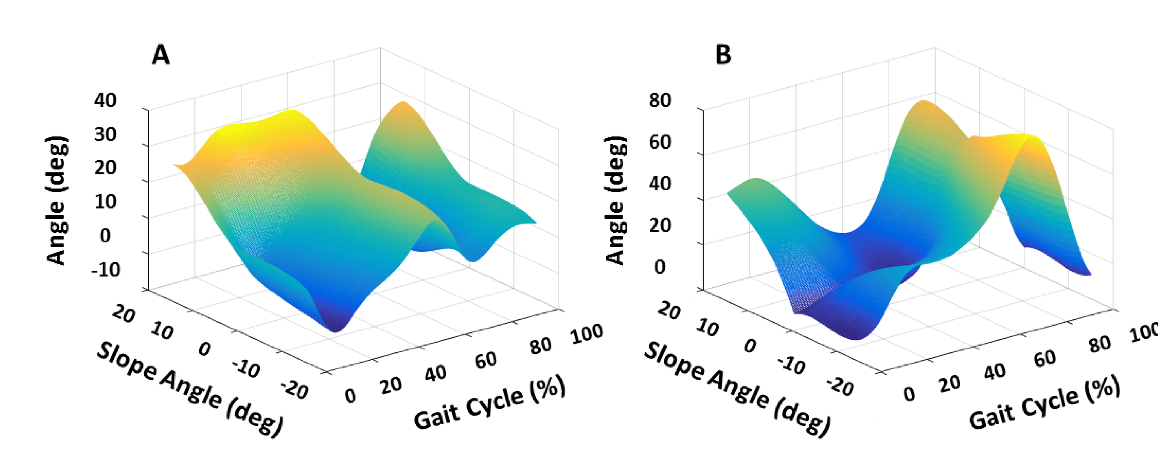

Fig. 7 Kinematic joints trajectories between -15 ˚ and 15 ˚ generated by using PCA (A: Ankle Joint, B: Knee Joint)

- PCA can be used to generate the joint trajectories for various slopes from the linear combination of a small number of components and their coefficients.
- A low gain PD control and the spline generation along with the PCA-based trajectory generation could adapt the control of the prosthesis without any conflicts.

Future works

- We will extend this idea to develop a unifying control algorithm for various slopes with no need to sense the slope angles.
- We will test the algorithm with AMPRO2 on various slopes.

References

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[3] Jonathon S. *CoRR*, abs/1404.1100, 2014.