TRANSFEMORAL PROSTHESIS CONTROL FOR SLOPE WALKING WITH PRINCIPAL COMPONENT ANALYSIS

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INTRODUCTION

A powered transfemoral prosthesis is an assistive device for the amputees who lost their lower limb including the knee that supports their daily locomotion [1]. For the amputee patients, walking on various sloped surfaces are one of the most challenging tasks in their daily lives. However, the existing (both passive and active) prostheses cannot fully accommodate the functions.

Trajectory generation for the powered prosthesis is an important procedure to design an appropriate controller that mimics human walking. Trajectory has to be generated for each gait cycle in real time to produce stable, robust and human-like walking. However, real-time trajectory generation is not a simple task and requires high computational loads, which is usually not tractable for the low profile single board computers. Recently, an algorithm for online trajectory generation for the powered transfermoral prosthesis was proposed using spline-based real time optimization. However, this method is applicable only for the upslope walking [1].

In this study, we generate the desired trajectories for various sloped surfaces with a small set of data using Principal Component Analysis (PCA). PCA lets us reduce a complex data set to a lower dimension [2] to perform the slope walking in different inclination with the prosthesis in real-time. Through PCA, we extract two principal components and their coefficients from the ankle and the knee, respectively. By curve fitting the coefficients of the principal components, we estimate the appropriate coefficients corresponding to the slope angle. In other words, we generate the adequate trajectories from the linear combination of the dominant principal components and their coefficients using only the inclination information. We also utilize a low gain PD controller and the spline generation [1] to adapt the unexpected slope and smoothly blend into the appropriate trajectories corresponding to the new slope.

METHODS

To collect the data for the PCA analysis, we collected human walking data and joint trajectories for the ankle and knee with a motion capture system (Oqus 210c, Qualisys North America, Inc., Highland Park, Illinois, USA). We put 13 reflective markers on the body of the healthy young adult to capture the subject's joint trajectories while walking on a treadmill. The inclination of the treadmill was varied with 7 different inclination angles: -15˚, -10˚, -5˚, 0˚, 5˚, 10˚, and 15˚. We set the limit of the slope angle at ±15˚ since the angles exceeding ±15˚ are rarely encountered in the daily living.

PCA was performed on the joint trajectories to extract the principal components required to reconstruct the various sloped surface trajectories. PCA provided us the most significant principal components that are the most highly correlated to human joint trajectories with a minimum amount of information [2].

It should be noted that the first gait cycle with the heel strike does not have the defined trajectories, which causes discontinuity in trajectory. To resolve this issue, a cubic spline based optimization is used to have smooth transition between each slope [1]. Also, for the slope adaptation during the heel contact, we used a low gain PD controller to avoid the discrete motion due to the new slope [1].

RESULTS AND DISCUSSION

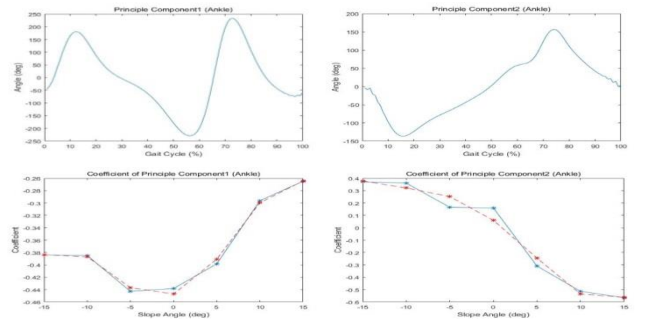

Figure 1. Results of PCA. The principal components (PC) of the knee joint angle (left top: 1st PC, right top: 2nd PC). The coefficients of the principal components (left bottom: 1st PC, right bottom: 2nd PC).

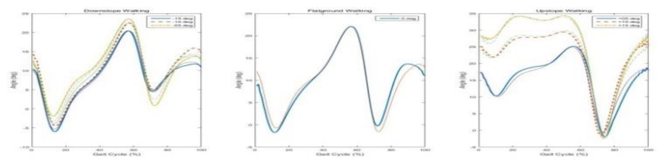

Figure 2. Regenerated Ankle Joint Trajectories with Optimized Coefficients and Corresponding Principal Components. Downslope walking trajectories from -15˚ to -5˚ (left). Flat ground walking (mid). Upslope walking from 5˚ to 15˚ (right).

It was found that the walking pattern for the downslope was different from that of upslope walking. When the subject walked on the downslope surfaces, the ankle joint angle seemed to remain the same as the level walking regardless of the inclination angles. For the knee joint, as the inclination angle increases, the deviation of the joint trajectory became significant. On the other hand, when the subject walked on the upslope surfaces, both the ankle joint and the knee joint angle increase as the inclination angle increases for the range of 0%-40% and 80%-100% of the gait cycle; interestingly, in the mid-range of the gait cycle, they merged to the flat ground walking trajectory [1].

Figure 1, 3 shows the results of PCA from the ankle joint and the knee joint, respectively. We chose two of the most dominant principal components and their coefficients to generate the joint angle pattern. We solved an optimization problem to curve the coefficient plots for calculating the appropriate coefficients corresponding to the slope angle. As Figure 2 shows, with these 2 principal components and the optimized coefficients, we could generate the ankle joint trajectories for 7 slopes with 0.9815 correlations. From Figure 4, the correlation result of the regenerated trajectories with the results of PCA was 0.9959.

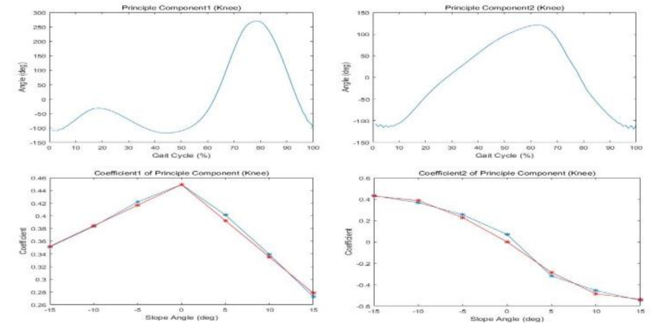

Figure 3. Results of PCA. The principal components (PC) of the knee joint angle (left top: 1st PC, right top: 2nd PC). The coefficients of the principal components (left bottom: 1st PC, right bottom: 2nd PC).

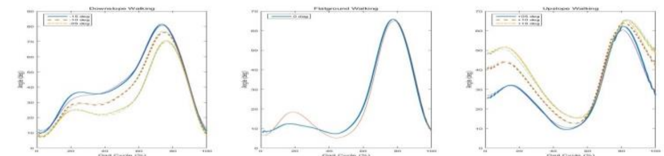

Figure 4. Regenerated Knee Joint Trajectories with Optimized Coefficients and Corresponding Principal Components. Downslope walking trajectories from -15˚ to -5˚ (left). Flat ground walking (mid). Upslope walking from 5˚ to 15˚ (right)

In general, to generate the trajectories for each slope with the increment of 1˚, we need 31 trajectories for the ankle and the knee, respectively. Yet, using PCA, we need 4 trajectories (two principal components for each joint) and the corresponding coefficients with high correlation. It was shown that all sloped trajectories within ±15˚ with the linear combination of these components and coefficients could be reconstructed.

CONCLUSIONS

This research showed that PCA can be used to generate joint trajectories for various slopes from the linear combination of a small number of the 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 transfemoral prosthesis to various slopes without any conflicts [1]. For the future work, we expect to extend this idea to the different situations for the prosthesis control with the unified controller.

REFERENCES

1. Victor P, et al., IEEE/RSJ International Conference on Intelligent Robots and Systems, 2016
2. Jonathon S. *CoRR*, **abs/1404.1100**, 2014