Towards Phase-Variable Control of Stair Ascent of Powered Knee-Ankle Prostheses

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I. BACKGROUND

Passive prostheses cannot provide the net positive work required at the knee and ankle for ramp and stair ascent. Previous work in phase-variable based control of powered lower-limb prostheses has demonstrated promising user-synchronized behavior for level and inclined walking [1]. However, differences in thigh kinematic trajectories prevent the use of previous phase variable definitions [2] for stair climbing. To account for this difference we have shifted the gait cycle to begin at the point of maximum hip flexion (MHF) instead of at heel strike and implemented a MHF detection algorithm into our calculation of the phase variable.

II. METHODS

Kinematics from a dataset of ten able-bodied participants ascending stairs with four inclines (20°, 25°, 30°, 35°) served as references for our analysis [3]. The inter-subject mean thigh, knee, and ankle trajectories of the steady-state stride at each stair incline were shifted to start the gait cycle at the point of MHF. Using the shifted thigh angle trajectory shown in Fig 1, phase-variable calculations were performed using a similar approach to [2] with the exception of MHF detection marking the end of the gait cycle instead of heel strike. The knee and ankle trajectories were reparameterized as a function of the phase variable through the creation of time-invariant virtual constraints using Discrete Fourier Transforms [1].

III. RESULTS & DISCUSSION

Fig. 1 shows the phase variable calculated from the inter-subject mean thigh trajectory, as well as a comparison of estimated knee and ankle trajectories to their reference inter-subject mean knee and ankle trajectories, all at a stair incline of 20°. The RMSE between the estimate and reference is 7.06 deg for the knee and 3.52 deg for the ankle. The same process was followed using 25°, 30°, and 35° stair incline data. The knee and ankle RMSEs are respectively 6.78 and 3.68 deg for 25°, 7.44 and 4.20 deg for 30°, and 7.73 and 4.05 deg for 35°. There is a flat period of the phase variable located at the point of minimum hip flexion where the thigh angle changes from decreasing to increasing that impacts the accuracy of our predicted kinematics. Possible solutions include low-pass filtering the phase-variable calculation or using an average of the reference thigh joint velocity from late to terminal stance as the phase variable for this section of the gait cycle. Starting the gait cycle at the point of MHF has removed saturation of the thigh phase variable commonly seen in previous approaches [2]. We believe that adopting this approach for other activities such as level or incline walking will also remove saturation of the phase variable at the end of the gait cycle, making it a standard for similar phase-variable controllers.

IV. CONCLUSION

By shifting the gait cycle to begin at MHF detection, we implemented a phase-variable calculation similar to those used in level and incline walking. Future work will consist of amputee human participant testing of this controller with a powered knee-ankle prosthesis and attempts at a similar control scheme for stair descent.

REFERENCES

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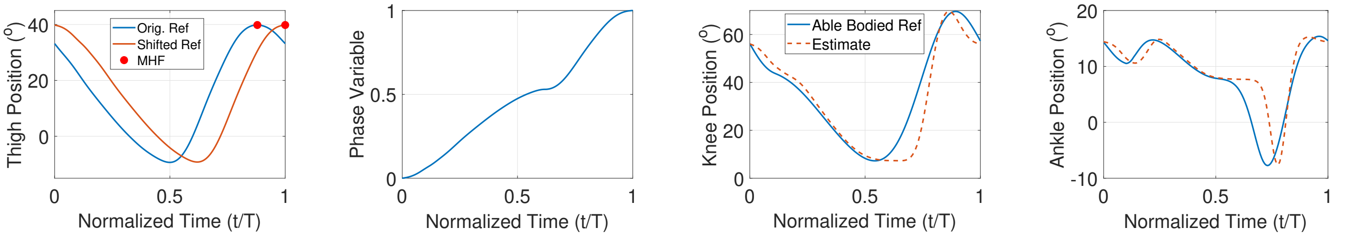

Fig. 1. Original/shifted thigh trajectories, calculated phase variable, and reference/estimated knee and ankle trajectories vs. normalized time for a 20° incline.

This work was funded by the NSF and NIH.

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